Exploration of the role of visual attention span in reading and spelling in Mandarin-speaking children and adults

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I, Tianyi Wang, confirm that the work presented in my thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

This thesis investigates the role of Visual Attention Span (VAS)—the number of visual elements that can be processed simultaneously—in the development of reading and spelling skills among Mandarin-speaking children and adults. The research is grounded in the Multitrace Memory Model, which distinguishes between global and analytical reading modes, and explores how VAS contributes to literacy acquisition in a logographic language like Chinese. The existing research in VAS has been focused on alphabetic languages including Arabic, Dutch, English, French, German, Greek and Spanish, while few research has explored Chinese. The studies in Chinese also failed to provide a comprehensive picture of the relationship between VAS and Chinese literacy. Thus, this research is to fill in these research gaps.

In the first study oral and silent reading fluency were the outcome measures, involving global and partial report tasks and visual 1-back task as VAS measures. In Study 1a participants were 56 Mandarin-speaking children, and in Study 1b participants were 58 Mandarin-speaking adults. Some literacy-related variables were included with age, such as nonverbal ability, receptive vocabulary, phonological awareness, rapid automatised naming, morphological awareness, verbal and visual short-term memory and single character identification skills. Results of hierarchical regression and structural equation modelings revealed that, after controlling for literacy-related variables, VAS significantly predicted oral sentence reading fluency in children and silent sentence reading fluency in children and adults. Examination of the patterns of performance in the VAS assessments in terms of array positions, as an index of visual attention allocation, revealed similar patterns to those in studies carried out in alphabetic writing systems. The position pattern in the global report

task showed a left-right asymmetry; the position pattern in the partial report task showed a ‘w-shape’; the patterns in visual 1-back accuracy and d prime showed a reverse ‘V’ shape or an inverted ‘U’ shape; the position pattern in visual 1-back correct reaction times showed a ‘v’ shape.

In Study 2 under both the quantitative and qualitative methods, 60-word spelling-to-dictation task was the outcome measure, involving the same VAS tasks and literacy-related assessments as Study 1. Participants were the same as Study 1. Results revealed that VAS (especially global report performance) was a unique predictor of spelling accuracy in both children and adults. Children’s spelling was more influenced by word length (analytical strategy), while adults’ spelling was more influenced by word frequency (global strategy). Compared with poor adult spellers, better adult spellers relied more on global and whole-word processing route. Poor adult spellers showed VAS deficits but not phonological deficits, suggesting a distinct cognitive profile. Previous studies with poor and good adult spellers in alphabetic writing systems revealed that they could be distinguished by letter report performance. Analyses conducted with the data from Study 2b revealed a comparable result.

Child and adult participants who were identified as having poor literacy ability (*n*=9, six children and three adults) took part in Study 3, in which the effectiveness of three types of training was assessed. One was whole-word practice (WWT) involving global orthographic processing, a second was the retention of symbol arrays (V1BT) involving pure visual global processing and attention, and a third was phonologically-focused (NVT) involving pure phonological processing. The outcome variables were reading and VAS performance, plus spelling-to-dictation. Case series analyses and group analyses showed that WWT and V1BT programmes produced significantly better post-test outcomes than NVT in improving reading fluency and VAS performances. Following WWT generalisation of spelling improvement to untrained words was found. All participants improved in at least one of the reading measures at post-test. VAS-based interventions were thus effective across age groups and reading profiles.

The results of the studies are discussed in terms of theories of reading, and their potential implications for education are considered. In terms of theoretical implications, these studies support the independence of VAS from phonological processing, highlight the development of VAS and its increasing role in literacy with age growth, and suggest VAS may function similarly to Orthographic Working Memory (OWM) in spelling. In terms of educational and clinical implications, VAS assessments can aid in identifying dyslexia and dysgraphia in Chinese speakers. VAS-based interventions offer a promising route for remediation of literacy difficulties. Finally, these findings are applicable across languages, especially those with opaque orthographies.

As for conclusions, this thesis provides robust evidence that VAS is a critical cognitive mechanism in reading and spelling development in Mandarin. It challenges the traditional phonological deficit model of dyslexia and offers new directions for assessment and intervention, particularly in non-alphabetic languages. The research bridges cognitive theory and educational practice, emphasising the need for language-specific literacy models and targeted support strategies.

Impact statement

The studies investigated the role of visual attention span (VAS) in reading and spelling in Mandarin-speaking children and adults. The results have important implications for theory and also for the identification of dyslexia and dysgraphia in speakers of Chinese. Until recently research has focused largely on phonological deficits as the main underlying reason for difficulties in acquiring reading and spelling.

The writing system for Chinese is visually complex, with inconsistent associations between syllables and corresponding written characters. It is considered an opaque writing system, relative to the alphabetic writing systems where spelling-sound associations are acquired during the course of learning to read and support skilled reading. It has been argued that learning to read in Chinese depends largely on visual processes. It was therefore hypothesised that the reading of Chinese-speaking children and adults would be heavily influenced by VAS.

The results of two studies revealed that VAS, assessed with a range of measures, was a significant predictor of reading and spelling of Mandarin-speaking children and adults. This was the case, even when a range of important literacy-related variables, such as phonological awareness, were controlled for in the analyses.

In a third study with nine poor readers, two interventions that focused on VAS processes resulted in greater improvement of reading and VAS than a phonological intervention. Analyses of the patterns across arrays in the VAS tasks, as a measure of attention allocation were conducted. The results revealed the effectiveness of VAS training to poor readers with VAS disorder and atypical eye movement patterns of these were also found.

As the first study to provide Chinese case profiles involving VAS, the current research can provide a reference point for further studies investigating dyslexia and dysgraphia in Chinese speakers.

Secondly, participants included children and adults, with multiple tasks for assessing VAS and reading fluency. Several literacy-related variables were also assessed. Findings support the role of VAS in the literacy acquisition of typically developing children and skilled readers. The findings indicate that VAS training may be beneficial for promoting literacy development in children and for improving reading and spelling ability in those with reading and spelling difficulties.

Thirdly, the findings of the research would appear to be applicable to all languages. It has previously been shown that with age, children progress from analytical to whole-word processing strategies for reading and spelling. Thus, whole-word and visual processes will be increasingly pivotal with increase in literacy experience. Although the current research focused on reading and spelling in speakers of Mandarin, the findings from the intervention study should be applicable to other languages, that is, the interventions reported should be effective in improving reading and spelling difficulty.

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Chapter 1: Theoretical model and the Visual Attention Span hypothesis

1.1 Introduction

Ziegler and Goswami (2005) stated that the development of reading depends on phonological awareness (PA), but languages vary in the consistency with which phonology is represented in orthography. This leads to developmental differences in the lexical representations and accompanying differences in developmental reading strategies and the manifestation of dyslexia across orthographies. That is to say, in reading, readers speaking transparent languages (such as Spanish and Greek) mainly use phonological strategy with the phonological deficit as the main reading problem, while readers speaking opaque languages (such as French and English) mainly rely on semantic strategy with the orthographic deficit as the main difficulty. However, with the development of research, researchers found the increasing importance of orthographic processing in literacy acquisition regardless of languages in addition to phonological processing. Share (2025) emphasised a developmental strategy shift from phonological processing to orthographic processing when reading experience growing in alphabetic languages. Concerning the necessity of cultural diversity, it is meaningful to explore processing of languages with different linguistic characteristics from alphabetic languages, such as logographic languages.

As a representative of logographic language, Chinese is totally different from these alphabetic languages (more details in Section 1.3.1.3). For example, there are no letter arrangement in Chinese words and all Chinese words are composed of radicals or strokes. Nearly all Chinese words cannot be processed through the grapheme-phoneme correspondence. In this case, language processing in Chinese is different from that of alphabetic languages. Correspondingly, the manifestation of dyslexia may be also different, mainly showing orthographic deficits rather than phonological deficits. Among these, visual attention span (VAS), the number of visually perceived elements that can be simultaneously processed in one glance, has been recently raised by Bosse et al. (2007) is expected to be a role in orthographic processing in Chinese.

VAS has been reported to associate with both reading and spelling in French (Valdois et al., 2025) and Dutch (Van Den Boer et al., 2015) due to its unique and significant contribution to orthographic acquisition, independent from the phonological processing. Subsequently, dyslexic participants with VAS deficits but intact PA were found, suggesting VAS deficit may be an independent dyslexia subtype. Correspondingly, VAS-related interventions without the involvement of PA were conducted to examine the benefits of VAS to dyslexics or dysgraphics with VAS deficits in single cases or groups, in order to support the independence of VAS deficit as a subtype dyslexia (more details in Chapter 4). However, there are not many studies focusing on VAS in language processing and the corresponding intervention effectiveness in China. Also, there are also other issues. For example, different research groups in Chinese languages used various VAS measures and variables based on different paradigms (more details in Chapter 2). Intervention studies did not just focus on VAS processing but also involve other visual processing to reinforce the training effects (more detailed in Chapter 4). There are no case studies in Chinese participants with VAS deficits.

All of these may cause difficulty to build a clear and solid foundation for the theoretical establishment and clinical application of VAS in Chinese. Thus, aiming to solve these problems, this research as the first study endeavors to provide a clear, detailed and comprehensive investigation of the role of VAS in Chinese, starting from cross-sectional studies to explore the prediction of VAS to Chinese literacy, then to the further intervention studies to examine the clinical intervention effects of VAS in

Chinese children and adult participants with difficulty in VAS and poor reading or spelling, with specific case profiles presented.

The next sections in this chapter review the theoretical background and research evidence regarding the role of VAS in reading and spelling. Section 1.2 provides an overview of the studies that motivated the VAS deficit hypothesis, and outlines the Multitrace Memory model. Research indicating that VAS contributes to reading and spelling in transparent and opaque languages is discussed in Section 1.3, which is relevant to the research studies reported in Chapter 2 and 3. Finally, Section 1.4 briefly summarises the intervention studies about the training effects of different types of VAS-based training programmes on reading improvement across various languages, which is relevant to the intervention study reported in Chapter 4 of the thesis.

1.2 The Multitrace Memory Model and the Visual Attention Span (VAS) hypothesis

According to the Multitrace Memory Model of Ans et al. (1998) there are two reading modes – one involving global processing and one involving analytical processing. The two differ in terms of the size of the visual attentional window from which printed word information is extracted. In global mode, the visual attentional window is wide, and whole words can be processed. In analytical mode, the visual attentional window is narrow, so only parts of a printed word are processed. For expert readers, according to the model, familiar words are processed in global mode. When the input is an unfamiliar word or pseudoword, processing is first initiated in global mode, as usual, but when global processing fails, then the processing shifts to the analytical mode.

Bundesen (1990, 1998) and Bundesen et al. (2005) put forward a theory of visual attention according to which the amount of information processed during a rapid multi-element presentation depends on how well this element was processed when briefly presented in isolation and the quality of the visual attention distributed on the array. Pelli et al. (2006) indicated that very beginning readers performed as well as skilled readers in the single letter identification task, but showed low performance on tasks of multi-letter rapid processing. According to Bundesen's theory, the poor performance of beginning readers in multi-letter processing would reflect a lower capacity than skilled readers to distribute visual attention over the whole letter array, i.e., a smaller VAS, according to Bosse et al. (2007). However, Ziegler et al. (2010) doubted that VAS may involve visual-verbal coding, and the VAS deficit may follow from a deficit in visual to phonological code mapping rather than a visual processing deficit. This was because Ziegler et al. found that their recruited participants (28 French-speaking children aged 8 to 12 years) only showed significant deficits in letter and digit strings, not symbol strings. Two neuroimaging studies using fMRI by Blau et al. (2009) and Blau et al. (2010) also supported the processing of letters and speech sounds may be a proximate cause of dyslexia, for an interrelated network of visual, auditory and brain areas (such as superior temporal sulcus) was found to contribute to the skilled use of letter–speech sound associations necessary for reading. However, Lobier et al. (2011) found that VAS could predict the nonverbal visual processing of typically developing (TD) children (aged 8 to 10 years, French speakers), thus supporting that the VAS impairment was due to visual processing, not verbal processing.

Prior to the Multitrace Memory Model, the Dual-Route (Cascaded) Model and the Parallel Distributed Processing Connectionist Model were also put forward for reading. Coltheart et al. (1993) and Coltheart et al. (2001) raised the Dual-Route (Cascaded) Model to support skilled reading aloud via two routes. One was the lexical route involving reading by accessing a lexicon or memory store of previously seen written words, and the other one was the non-lexical route involving converting written graphemes into spoken phonemes. Phonological information from both the lexical and nonlexical pathways finally converged toward a common component of the model, the phoneme system, which comprises a set of units representing all possible phonemes and their position. The Dual-Route (Cascaded) theory has given rise to many analyses (including analysis of the association of child- and stimuli-related variables, as well as qualitative error analyses) that should be informative for increasing or knowledge of Chinese reading/spelling. Indeed, some of these have already been included in studies of Chinese literacy development, which will be stated in Chapter 3.

On the other hand, Seidenberg and McClelland (1989) raised the Parallel Distributed Processing Connectionist Model composed of three layers of units, an orthographic, a phonological, and a semantic layer, and three sets of hidden units mediating between them. The model postulated a phonological pathway by which the appropriate phonological pattern was computed from the orthographic pattern activated by the input and a semantic pathway allowing a word to be pronounced by means of a computation from orthography to meaning and then from meaning to phonology.

Ans et al. (1998) indicated the two differences between the Dual-Route (Cascaded) Model and the Parallel Distributed Processing Connectionist Model. First, the central regulation of the Dual-Route (Cascaded) Model is that pseudoword reading requires a system of conversion rules but the key feature of the Parallel

Distributed Processing Connectionist Model is that all types of letter strings, including pseudowords, can be read solely based on word knowledge without a separate rule system. A second difference lay in reading procedures. The Parallel Distributed Processing Connectionist Model postulates that the ability to accurately pronounce all kinds of letter strings is supported by a single uniform procedure, whereas the Dual-Route (Cascaded) Model indicated that two separate (lexical and nonlexical) procedures are required.

Compared with the two models, the Multitrace Memory Model shows some similarity and differences. The model does not retain the assumption of the Dual-Route (Cascaded) Model that knowledge about spelling-sound correspondences is represented in terms of orthography-to-phonology conversion rules and that the pronunciation of pseudowords is generated by the application of these rules. Rather, more in accord with the Parallel Distributed Processing Connectionist Model, it assumes that mapping from orthography to phonology only emerges from the integrated activation of previously experienced whole words and word syllabic segments. Moreover, in contrast to the Parallel Distributed Processing Connectionist Model, the Multitrace Memory Model does not postulate that a single uniform procedure is used for generating the pronunciation of both irregular words and pseudowords. Rather, it is assumed here that two types of procedures, a global and an analytic one, are required for processing all kinds of letter strings. Furthermore, although the Multitrace Memory Model also includes two processing modes (global and analytical modes), it does not involve dual routes like the Dual-Route model. The global and analytic reading procedures involve essentially similar computational principles. Second, the two procedures do not work in parallel: Global processing always proceeds first, the analytic procedure being applied only secondarily when global processing has failed. Third, the global and analytic procedures do not only work for a particular kind of letter string (irregular words or pseudowords). Overall, the two processing modes differ only in the kind of visual attentional processing they involve. The Multitrace Memory model emphasised attention distribution, but the Dual-Route Model was not. Finally, in contrast to the two models, Ans et al. (1998) indicated that this Multitrace Memory Model assumes the existence of a phonological pathway fully competent for reading all kinds of letter strings, thus minimising the role of semantics in normal single word reading and consequently in the explanation of surface and phonological dyslexia.

There are some advantages of the Multitrace Memory Model over Dual-Route and Parallel Distributed Processing Connectionist Models.

Firstly, in terms of visual attention focus, the Multitrace Memory Model explicitly incorporates a visual attentional mechanism, which is critical for explaining word length effects in lexical decision tasks, reported by Phénix et al. (2025). In contrast, the Dual-Route focuses primarily on phonological and lexical routes without addressing visual attention, while the Parallel Distributed Processing Connectionist Model’s attention mechanisms are less explicitly defined.

Secondly, the Multitrace Memory Model emphasises orthographic processing as the source of length effects, aligning with behavioral and neuropsychological evidence (e.g., length effects in dyslexics with visual attention deficits, as shown by Ginestet et al., 2019). The Dual-Route Model, by contrast, ties length effects to phonological seriality, which cannot explain length effects in orthographic processing.

The Parallel Distributed Processing Connectionist Model, while parallel, struggles to account for length effects unless augmented with serial orthographic mechanisms, which are not intrinsic to its architecture.

Thirdly, the Multitrace Memory Model successfully explains atypical reading patterns (e.g., dyslexia, letter-by-letter reading) by positing a reduced visual attentional window. The Dual-Route and Parallel Distributed Processing Connectionist Models lack this flexibility, as they focus on phonological or orthographic-phonological interactions rather than visual attention constraints.

The Multitrace Memory Model predicts that a reduction of the visual attentional window will interfere with reading and potentially disturb the processing of any kind of printed letter string. Bosse et al. (2007) claimed that when the visual attentional window is narrow, this restricts the number of written elements that can be simultaneously processed during reading. So, readers who do not have typical visual multi-element simultaneous processing skills were regarded as suffering from restricted VAS (e.g., Awadh et al., 2016; Bosse et al., 2007; Lobier, Zoubrinetzky & Valdois, 2012). Thus, Bosse et al. (2007), Valdois et al. (2003) and Valdois et al. (2008) suggested a VAS deficit was one of the possible causes of reading difficulty in addition to difficulty in phonological processing.

My research highlights the role of visual attention in word recognition (e.g., the influence of attention distribution on letter identification or word length effects), so the Multitrace Memory Model is used as the theoretical framework to explain findings due to its explicit attentional component. The Dual-Route and Parallel Distributed Processing Connectionist Models lack this focus. At the same time, my research also involves analyses of position accuracy across various VAS tasks. Only the Multitrace Memory Model could he helpful to explain results for position accuracy analyses.

Finally, the Multitrace Memory Model emphasises dynamic interactions between layers (e.g., lexical feedback modulating letter perception), which aligns with findings showing top-down influences in word recognition, which are less explicitly modeled in the Dual-Route or Parallel Distributed Processing Connectionist frameworks.

There have been eight behavioural studies that involved investigating VAS deficits. These have used the two main VAS assessments, global and partial report and visual 1-back, in dyslexic children, teenagers and adults in case and group studies across languages (Chinese: Chen et al., 2019; Cheng et al., 2021; French: Bosse et al., 2007; Prado et al., 2007; Valdois et al., 2003; Valdois et al., 2011; German: Banfi et al., 2018; Hebrew: Yeari et al., 2017). In addition to these, there is fMRI evidence examining the role of VAS in reading in TD children, dyslexic children and adult readers (Lobier et al., 2014; Peyrin et al., 2008; Peyrin et al., 2011, 2012; Reilhac et al., 2013; Valdois et al., 2014; Zhao et al., 2022). The independence of VAS and phonological processing has also been investigated (Liu et al., 2022; Peyrin et al., 2012; Valdois et al., 2014; Valdois et al., 2019). These studies are outlined next.

Initial evidence for the VAS deficit hypothesis came from the studies of Valdois et al. (2003) and Bosse et al. (2007). Valdois et al. (2003) reported two French teenagers. One was Nicolas, who had surface dyslexia and dysgraphia but unimpaired phonological awareness and a VAS deficit (assessed as reported below), the other one was, Laurent, who had dyslexia and dysgraphia, poor phonological awareness but no VAS deficit. The contrasting cases supported the independence of phonological processing and VAS.

Valdois et al. (2003) employed global letter report and partial letter report tasks to assess VAS. In the global task, a set of consonant letters was used to produce five-letter arrays. On each trial, participants were presented with an array for 200 milliseconds (ms) and, at the offset, were asked to report as many letters as possible, irrespective of the order in the array. In the partial report task, five-letter strings were created with the same consonant letters as in the global report task. A cue was presented after the presentation of the array so that the report of only one letter was required. The scores were the number of letters accurately reported in the global report and partial report tasks. At the same time, a single letter identification task as a control task was also employed, to identify that any VAS deficit was due to difficulty in processing the multiple items at one glance, rather than being due to a letter processing problem. In the control task, the consonants from the letter report tasks were displayed once at each presentation duration of 33, 50, 67, 84, and 101 ms. A mask was presented at offset for 150 ms. Participants were asked to report each letter. The minimal presentation length of each participant that resulted in at least 80% accurate identification was then used as the identification threshold. The score was the weighted sum of letters accurately identified at each presentation time.

Results showed that Nicolas performed poorly in both global and partial report tasks. For global report he failed to report a complete five-letter string in the 20 trials administered. Scores were reported for chronological age (CA) control children: *m* = 13.7/20, *sd* = 3.3, range: 5–19. Valdois et al. examined accuracy across positions in the letter array and found that Nicolas performed comparably to the CA group in reporting letters in the first and third positions of the five-letter string. However, his accuracy was lower in the second position, and extremely low in the fourth and fifth positions. His performance was even worse than that of Grade 2 or 3 primary school children in the two positions. In addition, most of Nicolas’s responses (18/20) consisted of only three letters, without any attempt to report the last two letters. As for the partial report task, Nicolas's performance was comparable to that of the CA group in the first and third positions, but he had very poor performance for letters in Positions two, four and five. Valdois et al. (2003) hypothesised that the findings indicated a reduction of the visual attentional window through which information from the orthographic input is extracted, and this had resulted in an inability to create word traces and a pattern of surface dyslexia and dysgraphia, namely the VAS deficit hypothesis.

However, this study could not inform as to how common a VAS deficit might be among developmental dyslexics, so Bosse et al. (2007) conducted a group study with French and British dyslexic children and TD readers to show that a VAS deficit, independently from a phonological deficit, is not rare in the dyslexic population.

Bosse et al. used the global report (letters and 5-letter strings) and partial report tasks with French and British dyslexic children aged 10 years in two experiments. In Experiment 1, 68 French-speaking dyslexic children aged 11 and 55 TD and CA control children were assessed in terms of VAS and reading performance; Experiment 2 replicated the procedures of Experiment 1, with 19 ten-year-old English-speaking dyslexic children and 23 CA control children. The results from both experiments showed significant differences between dyslexic children and TD readers in terms of global report with strings (French dyslexics: *m*=5.15, CA *m*=11.9; British dyslexics: *m*=4.3, CA *m*=9.9) and letters (French dyslexics: *m*=73.10, CA *m*=88.8; British dyslexics: *m*=72.9, CA *m*=87.0) and partial report performance (French dyslexics: *m*=38.72, *sd*=7.2; *CA* mean=43.5, *SD*=3.9; British dyslexics: *m*=41.6, *sd*=7.1; CA *m*=45.1, *sd*=3.7). This meant that the French and British dyslexic children were impaired in both the global and partial report tasks.

Bosse et al. (2007) pointed out that the VAS deficit did not result from abnormal decay in iconic memory because the dyslexic participants performed at a similar level on both the global report tasks (was assumed to involve the iconic memory) and partial report tasks (without the reliance of iconic memory), and performance of the two tasks strongly correlated. This finding was contradictory to the previous opinion raised by Averbach and Corriell (1961) and Shih and Sperling (2002) that the global report task should only be affected by the decay of information in iconic memory.

In the same year, Prado et al. (2007) conducted an eye-movement study to explore the eye movements and reading of 14 French-speaking dyslexic children with a restricted VAS and 14 TD readers aged 11 years under the global and partial report tasks. They found that the dyslexic children made many rightward fixations in reading. Compared with dyslexics with VAS disorder, TD readers processed more letters in reading. Correlational analyses also showed that VAS was related to the number of rightward fixations and leftward fixations in reading. Prado et al. thus assumed that the atypical eye movements reflect the VAS disorder.

Since then, researchers in dyslexia have started to shift more attention from PA deficits to VAS deficits.

Valdois et al. (2011) further reported a French-speaking boy aged 9 years, Martial, with mixed dyslexia and surface dysgraphia. Martial had good phonological skills (phoneme awareness and verbal short-term memory) and single letter visual processing ability. In the global report task, Martial could only report a few letters, with better performance in the initial position (left-sided bias). He also performed better when were asked to report a single cued letter within the string in the partial report task and showed a right-sided bias. Martial completed the global report task again but with a new instruction that required him to first report letters that he more easily perceived. The rightward attentional bias was now observed in the global report task. Otherwise, Martial showed preserved single-letter identification skills. His poor multi-letter processing thus seemed to reflect a parallel visual processing disorder that was compatible with either a VAS or a visual short-term memory disorder.

In a study examining VAS in 24 dyslexic and 26 non-dyslexic adults speaking Hebrew, Yeari et al. (2017) reported significant differences in VAS assessed in the global report task between the two groups. However, they found pure dyslexics did not show a VAS deficit because no significant differences in scores for visual multi-element cognition tasks were found between dyslexic and control groups. Yeari et al. attributed it to the specific participant sample and the exclusion of attention disorder for participants in their study. They mentioned various causes underlie developmental dyslexia, and different individuals with dyslexia have different types of deficits, so the results of Yeari et al. did not mean no types of dyslexia were caused by VAS deficits. At the same time, individuals with attention disorders were not considered in previous studies, but Year et al. considered them. So discrepancy occurred.

In more recent investigations, VAS deficits were also reported in Chinese dyslexics. Chen et al. (2019) used the same global report task as Bosse et al. (2007), but with Chinese characters, pronounceable radicals and digits, not alphabetic letters, as materials. They recruited three groups of 10-year-old Cantonese-speaking children, namely dyslexic children, CA control children, and reading level-matched children, with 25 children in each group. More than half of the dyslexic children showed VAS deficits compared with the other two groups: 68% of the dyslexic children revealed VAS deficits in at least one type of material when compared with CA control children; 52% showed VAS deficits when compared with reading level-matched children.

In addition to letter report tasks, the visual 1-back task is the other commonly used VAS paradigm. Unlike the letter report tasks requiring verbal report, the visual 1-back task is a nonverbal technique, which means the influence of verbal output processing is eliminated. More importantly, to rule out a potential visual-verbal coding explanation of letter report performance reported by Ziegler et al. (2010), some researchers employed unfamiliar symbols as materials (e.g., Zhao et al., 2018). It was employed by Lallier et al. (2016) to compare processing in opaque and transparent writing systems in a study with French (opaque)-Basque (transparent) bilingual children and Spanish (transparent)-Basque (transparent) children aged 7 to 11 years. The visual 1-back task requires participants to judge whether a single target was present in a previously displayed five-item string with 200 ms presentation. Responses involve pressing the corresponding computer key. The scores are the number of correct judgements. Lallier et al. (2016) indicated the Spanish-speaking groups showed better Basque pseudoword reading and better phonemic awareness abilities than their French-speaking children, but only in the most difficult conditions of the tasks. However, on the visual 1-back task, the French-Basque bilinguals showed the most efficient visual processing strategies to perform the task. Lallier et al. thus concluded that cross-linguistic interactions influenced the size of both phonological and visual grains adopted in reading. In addition, the results of Lallier et al. indirectly supported that the transparency of languages may affect the VAS performance.

Under the visual -1 back task or the similar task, the studies to investigation dyslexics with VAS deficit were conducted. To explore possible VAS deficits in German-speaking children Banfi et al. (2018) recruited 43 TD children, 26 dyslexic children and 32 children who had an isolated spelling deficit. The authors used a forced-choice task with letters and symbols to test VAS, with a similar procedure to the visual 1-back task, but requiring children to make a verbal response. Banfi et al controlled the eye movements to ensure all children followed the instruction to look at the centred fixation of the screen at the start of each trial. They also demonstrated the patterns in d prime of visual 1-back and revealed a reverse ‘v’ shape for unfamiliar symbols and ‘w’ shape for letters of all children, which was because Grainger et al. (2010) found visual crowding (such as critical spacing) influenced letters much more than symbols. After eye movements collected by an eye-tracking tool (EyeLink 1000) were controlled for, they found there was no main effect of group and no group-related interactions. This indicated that the children with dyslexia and those with isolated spelling deficits did not have a VAS deficit. However, the dyslexic children in the Banfi et al’s study performed worse than the TD readers in the phonological awareness task, thus it could be expected that they would not show a VAS deficit.

Cheng et al. (2021) reported VAS deficits and phonological deficits separately in a group of Chinese dyslexic children aged 8 to 11 years (*n*=45). VAS deficits were only apparent in visual 1-back tasks with characters and digits, and not visual 1-back tasks using symbols and colour dots. This may suggest that VAS deficits were not independent of phonological deficits. However, it should be noted that Cheng et al. did not assess other processes such as visual short-term memory or single character identification that may be related to VAS (Bosse et al., 2007). If dyslexics have difficulties in visual short-term memory or single character processing, their reading difficulties may be caused by these difficulties. Thus, more rigorous assessment is needed.

Other less commonly used paradigms have been used for VAS measurement. A multi-element processing task similar to the partial report task was designed by Hawelka and Wimmer (2005) with German-speaking dyslexic teenagers aged 15 years. Participants were asked to report cued digits in four- and six-digit arrays. The findings revealed independence of VAS and phonological processing deficits. In addition, a nonverbal partial report task without the requirement of verbal report was used by Holmes and Dawson (2014) and Collis et al. (2013) to explore VAS in English-speaking adults with and without dyslexia. In this nonverbal partial report task, participants were asked to remember the initial sequence (five-item strings) and then decide whether the subsequent single letter appeared in the original serial position or elsewhere in the sequence by pressing computer keys. Holmes and Dawson (2014) reported that scores in the partial report task significantly predicted the errors in letter position in words in a lexical decision task in skilled adult readers. Collis et al. (2013) suggested dyslexic adults in their study had a VAS deficit due to difficulty in letter position coding rather than a problem of visual-spatial attention. This was because many errors were found in Positions two and four in the VAS task. At the same time, there was a significant correlation between the position errors and letter transposition errors in reading (e.g., reading ‘salt’ as ‘slat’). In addition, the response pattern of the ‘W-shape’ in the partial report task was also revealed.

In addition to behavioural evidence, findings in neuroscience also supported the VAS deficit hypothesis. Studies have shown involvement of the bilateral superior parietal lobule (SPL) during the simultaneous processing of multiple visual elements in French speakers (Lobier et al., 2014; Lobier, Peyrin et al., 2012; Peyrin et al., 2008; Peyrin et al., 2011, 2012; Reilhac et al., 2013). Parietal activations were consistently found under various VAS tasks, such as the categorisation tasks (Lobier et al., 2014; Peyrin et al., 2011, 2012), verbal report (Peyrin et al., 2008) or string comparison (Reilhac et al., 2013). Moreover, parietal involvement in skilled readers was found to be independent of stimuli in strings (i.e., symbols or alphanumeric characters; Lobier, Peyrin et al., 2012). Findings from fMRI studies of dyslexic readers with VAS deficits revealed reduced SPL activation, with both alphanumeric characters and symbols (Lobier et al., 2014; Peyrin et al., 2008, 2011; Reilhac et al., 2013; Valdois et al., 2014). The findings also suggested that VAS deficit had a relationship with atypical activation of brain regions that related to the dorsal attentional network (Valdois et al., 2022). This interpretation was supported by the study of Zhao et al. (2022) using the visual 1-back task with Chinese-speaking adults aged 22 years. The researchers found that the dorsal attention network (top-down attentional processing) and ventral attention network (bottom-up attentional processing) were significantly activated in the visual 1-back task.

Evidence for the independence of VAS and phonological processing was reported in the fMRI study of Peyrin et al. (2012) investigating two French-speaking dyslexic adults aged 28 years, LL with a phonological disorder but unimpaired VAS, and FG with a VAS deficit but preserved phonological skills. FG showed reduced activity of the SPLs in multi-element processing but normal perisylvian functioning during phonological processing, while LL showed the reverse pattern, namely perisylvian under-activation but preserved SPL functioning.

Case studies with a VAS-impaired dyslexic child, MP aged 9 years (Valdois et al., 2014) and a brain-damaged adult, IG aged 44 years, with bilateral damage of the

SPLs (Valdois et al., 2019) provided further neuroscientific evidence to support the independence of VAS and phonological skills. Valdois et al. (2014) reported that MP exhibited a severe VAS deficit but preserved phonological skills, and this was associated with under-activation of the SPLs at initial testing. After a VAS-focused training programme, MP's letter report performance improved, and bilateral activation of SPLs (BA 7) was found to increase. In the study of Valdois et al. (2019), the adult patient, IG, also revealed a severe VAS deficit in letter report tasks following bilateral damage of the SPLs, but preserved oral language and verbal short-term memory skills.

In an investigation of French-speaking children with and without dyslexia, Liu et al. (2022) obtained results that also indicated independent neural bases corresponding to VAS and phonological processing. This was because, among the three brain hubs they focused on under the MRI technique, one hub, left superior occipital gyrus, could account for VAS deficits but not phonological deficits in dyslexia, but the other two hubs, left middle temporal gyrus and medial orbital superior frontal gyrus, were only associated with phonological processing, not VAS.

Results from these studies supported a specific link between VAS performance and the dorsal attentional network, with SPL being reported by Chica et al. (2013) to be a part of the dorsal attentional network. The specific link existed regardless of which VAS task was used (global and partial report or visual 1-back). Thus, a VAS deficit in dyslexic individuals might reflect abnormal functioning of a brain network dedicated to the simultaneous processing of multielement visual arrays and involved in word-specific orthographic knowledge acquisition.

In summary, behavioural and neuroimaging studies have supported the important influence of VAS in literacy skills, and that VAS deficits can exist independently from phonological deficits (e.g., Bosse et al., 2003; Valdois et al., 2003; Valdois et al., 2011; Valdois et al., 2014; Valdois et al., 2019). VAS deficits have been demonstrated in dyslexics across languages, at least for dyslexic children under both VAS paradigms (letter report and visual 1-back tasks), with verbal materials used so far. Dyslexics with a VAS deficit may have atypical patterns in eye movement (Prado et al., 2007; Valdois et al., 2003; Valdois et al., 2011). In addition, two systematic reviews (Liu et al., 2023; Tang et al., 2023) on VAS and dyslexia reached the consensus that the paradigms, materials and responses used in VAS tasks and writing systems (i.e., opaque or transparent, alphabetic or logographic) can modulate the VAS deficit. VAS deficits were found to be more severe with report tasks with verbal stimuli than n-back tasks with verbal and nonverbal stimuli. Finally, neuroscientific research has indicated a close connection between VAS skills and activation of SPL and a dorsal attentional network (Lobier et al., 2014; Lobier, Peyrin et al., 2012; Peyrin et al., 2008; Peyrin et al., 2011, 2012; Reilhac et al., 2013; Zhao et al., 2022).

The above studies all suggested a key role for VAS in literacy skills. In the next section, studies that explore the role of VAS in literacy skills across languages are discussed.

1.3 The Influence of VAS on reading and spelling across languages

VAS has been found to play an important role in literacy development across languages, including Arabic, Chinese, Dutch, English, French, Greek and Spanish, with more studies conducted on reading than spelling. In this section I first cover the studies exploring the relationship between VAS and reading, and then between VAS and spelling.

1.3.1 Reading

There have been eight cross-sectional studies that report a relationship of VAS and reading across opaque alphabetic languages (Arabic: Awadh et al., 2022; English: Chen et al., 2016; French: Awadh et al., 2016; Bosse et al., 2007; Bosse & Valdois, 2009; Lallier et al., 2014; Lobier et al., 2013) and transparent alphabetic languages (Dutch: Van Den Boer et al., 2015).

In addition, there have been eight studies that have investigated the influence of VAS in Chinese, a logographic writing system, where participants were Mandarin speakers using simplified Chinese characters (Huang et al., 2019; Huang et al., 2021; Zhao et al., 2017; Zhao et al., 2018a, 2018b) or Cantonese-speaking using traditional Chinese characters (Chan & Yeung, 2020; Chen et al., 2019; Cheng et al., 2021). These studies are outlined below following coverage of the studies conducted with alphabetic writing systems.

1.3.1.1 Studies with opaque alphabetic writing systems. As discussed in Section 1.2, the earliest group study investigating the role of VAS in reading in an opaque orthography in children was that of Bosse et al. (2007). The authors investigated the relationship between VAS measured by global and partial report tasks and oral reading performance of French-speaking and English-speaking dyslexic children and TD readers. They found that in addition to phoneme awareness, VAS uniquely explained the variance in reading fluency in regular words, irregular words and pseudo-words after controlling for nonverbal ability, vocabulary and single letter identification skills that were likely to contribute to reading performance.

Bosse and Valdois (2009) then investigated whether VAS and phonological processing were predictors of oral reading accuracy and reading fluency for regular words, irregular words, and pseudo-words in 417 French children in Grades 1, 3 and 5. VAS was assessed by the global and partial letters report tasks, and phonological skills were measured by the phoneme awareness tasks including phoneme segmentation, phoneme deletion and spoonerisms. Results from hierarchical regression revealed that VAS and phonological skills were independent predictors. Importantly, results showed that phonological skills were not a significant predictor of reading fluency in Grade 5 children, but VAS was a significant predictor of reading accuracy and fluency at all levels of all children across grades, supporting the long-term influence of VAS on orthographic knowledge acquisition in French.

Similarly, Lallier et al. (2014) found that VAS measured by global and partial report tasks was significantly associated with oral reading accuracy and fluency with text, regular words, irregular words and pseudo-words in French-Spanish bilingual TD and dyslexic children aged 10 years. Lobier et al. (2013) explored the role of visual processing speed and reading of French children aged 8 and 9 years. Lobier et al. showed that visual processing speed and visual short-term memory predicted VAS, and VAS predicted reading. In addition, visual processing speed predicted reading fluency, but visual short-term memory did not. VAS assessed by the global report task was thus found to be a significant mediator between visual processing speed and oral text reading fluency. Similar results were also found in English.

Exploring 17-year-old English-speaking high school dyslexic students' reading comprehension at easy and difficult levels, Chen et al. (2016) reported that VAS assessed by a global report task was correlated with reading comprehension in long sentences with complex words. Chen et al. found that VAS indirectly explained reading comprehension through pseudo-word reading and word reading skills, which supported the hypothesis that VAS can explain at least part of the dyslexic profile.

In the case of letters, some written languages use visually more complex letters than others; this is particularly true for the Arabic language (Eviatar & Ibrahim, 2014; Verhoeven & Perfetti, 2022). If letter visual complexity impacts letter string processing, then strings of Roman letters should be easier to identify than strings of Arabic letters. This is indeed the case; Arabic skilled readers have lower performance in Arabic-letter-string processing than French or Spanish skilled readers in Roman-letter-string processing, leading to lower VAS in Arabic (Awadh et al., 2016). Assuming that VAS performance is modulated by the visual complexity of characters, any attention-based interpretation of differential performance depending on character type, would require strict matching of alphanumeric and symbol strings in visual complexity, which was not systematically done in previous studies (Banfi et al., 2018; Cheng et al., 2021; Collis et al., 2013).

Recruiting adult speakers of Arabic, French and Spanish, Awadh et al. (2016) explored the relationship between VAS and oral reading fluency with text across the languages. The authors found that compared with French and Spanish readers, Arabic readers' scores in global and partial report tasks were slightly lower, suggesting a more limited VAS of Arabic readers. The VAS position pattern for the global report task showed a left-right asymmetry in all three languages, with a leftward letter advantage in French and Spanish, which was in line with ones from Van Den Boer et al. (2015), but a rightward advantage in Arabic, due to right-to-left reading in Arabic. By contrast, the pattern in the partial report task was symmetric regardless of the language. Awadh et al. (2016) attributed this to the modulation of the retro-cue to attention in working memory. In the partial report task, attention orienting was manipulated by providing a spatial retro cue at the offset of the five-letter string. When the physical stimulus was absent, the target letter indicated by the retro-cue had to be retrieved from memory. The presentation of the retro-cue in partial report may have shifted selective attention on the target letter representation in memory, thus resulting in similar performance whatever the position of the target within the string. Since attention modulation by retro-cues was task-determined, all target letters with the same probability were accurately reported in whatever language.

Lastly, a significant relationship was found between VAS scores and oral text reading fluency for French, but not for Spanish and Arabic. The non-significant association for VAS and reading in Spanish may be due to the high degree of transparency of Spanish. Awadh et al. (2016) suggested that a lack of whole-word reading strategy and the necessity for additional time to process internal morphemes may be the main reasons why VAS was not related to Arabic reading fluency. Word identification in Arabic mainly relies on the processing of root morphemes (comprised of three or four letters) in a word rather than a whole word to convey the core meaning of words (e.g., Boudelaa, 2014). Perea et al. (2010) also supported Arabic readers may not predominantly rely on whole-word processing during reading, but focus on the few letters that carry information on root identity and meaning.

Using the visual 1-back task, Lalier et al. (2018) explored the relationship between VAS (d prime as the indicator) and Arabic text reading of 59 Arabic-speaking children aged 10 years. These children were classified into two groups, namely a group being more proficient in fully vowelised Arabic (VOW) and the other group being more proficient in nonvowelised Arabic (NOVOW). Lallier et al. found that crowding in the VAS task correlated with the reading performance in the NOVOW group only. The authors interpreted this to indicate that VAS is more closely related with reading in readers who rely more on the lexical route (in this case the NOVOW readers). Also, positions of the d prime of the NOVOW group revealed the ‘w’ shape, that is to say, the accuracy of Position 2 and 4 was lower than other positions.

In a later investigation of VAS in 114 Arabic Grade 4 and 5 children, Awadh et al. (2022) found that composite global and partial report scores were a better predictor than phonological awareness of reading fluency for words, pseudo-words and text, as well as text comprehension. Lallier et al. (2018) explained that the discrepancy between the two adult and child studies might be because the VAS-reading relationship varies depending on the Arabic script, which is vowelised for children in early school grades and unvowelised for adults. Meanwhile, the small sample size of Arabic adults (*n*=42) in Awadh et al. (2016) could be a possible reason for the inconsistency in results.

1.3.1.2 Studies with transparent alphabetic languages. VAS has been reported to play a role in oral reading in Dutch-speaking children (Van Den Boer et al., 2015). Van Den Boer et al. (2015) studied Dutch TD children aged 8 to 11 years (117 children in Grade 2, 255 in Grade 4, and 111 in Grade 5). They used the same global report task as Bosse et al. (2007) and Valdois et al. (2003) to assess VAS, with the exception that scores were based on the number of letters correctly pronounced in the correct order. Literacy-related variables were also tested, including nonverbal ability, vocabulary, verbal short-term memory, PA and rapid automatised naming (RAN). Using hierarchical regression analysis and entering nonverbal ability, vocabulary, verbal short-term memory in the first step, PA and RAN in the second step as well as VAS in the third step, they found VAS to be a unique predictor of word reading fluency in Grades 2, 4 and 5 after controlling for nonverbal ability, verbal short-term memory, PA and RAN. The VAS position pattern for the global report task was also investigated, demonstrating a left-right asymmetry and a leftward letter advantage in Dutch. The interaction between grade and reading level was not significant, but they found the performance of poor readers was worse than the performance of average readers.

1.3.1.3 Studies with Chinese readers. Unlike alphabetic writing systems, written Chinese with opaque orthography does not rely on correspondences between graphemes and phonemes but emphasises orthographic processing. Chinese words are comprised of characters, and there are single-character words and multi-character words. Chung and Leung (2008) mentioned Chinese characters involve stroke order, radicals and configuration. Strokes are the basis of radicals in Chinese characters, and the number of strokes in a Chinese character is a measure of its visual complexity. The radicals are configured in a left-to-right structure or a top-to-bottom structure to produce a character. For example, the simplified character 明 (light) is configured by the radicals 日 (sun) and 月 (moon) in a left-to-right structure; the character 否 (not) is formed in a top-to-bottom pattern by two components, 不 (no) and 口 (mouth). Radicals are categorized into two types: semantic radicals, which provide indication about the character's meaning (e.g., the character 妈 (mother) has the semantic radical 女 (female)); and phonetic radicals, which provide clues about the pronunciation of the character (e.g., the phonetic radical 象 (elephant)/xiang4/ in the character 像 (look like)/xiang4/ has the same pronunciation as the character that it forms (Chung & Leung, 2008). However, some compound characters sound completely different from their phonetic radicals (e.g., 煤 (coal)/mei2/ has the phonetic radical 某/mou3/). There are also many compound characters that have semi-irregular sound mappings (e.g., 绯 (rumor)/fei3/ has the phonetic radical 非/fei1/). Such non-correspondence between graphemes and phonemes increases the difficulty of rapidly processing Chinese characters. Moreover, the majority (74%) are two- or multi-character words (ILTR, 1986), and

Chinese possess a great number of homophones and homographs. These factors all increase the difficulty associated with reading and spelling in Chinese. It has been argued that Chinese readers need to allocate visual attention to identify whole characters and subtle stroke differences, and so authors have suggested that VAS may be a critical underlying process for effective Chinese literacy development (e.g., Chen et al., 2019; Cheng et al., 2021; Huang et al., 2019).

In addition, Hong Kong district and Mainland China use different Chinese oral forms (Cantonese in Hong Kong, Mandarin in Mainland China) and written forms (traditional characters in Hong Kong, simplified ones in Mainland China) as scripts (e.g., Wang et al., 2014). In Mainland China, character teaching is accompanied by the Pinyin alphabetic system to help children learn character pronunciation in the early grades of primary school (e.g., Tong et al., 2009).

Zhao et al. (2017) employed the nonverbal visual 1-back task using unfamiliar symbols to explore the association with oral and silent reading of words and sentences. Participants were 60 Mandarin-speaking adults aged 19 to 25 years. Participants used simplified Chinese characters in reading and writing. Correlational and regression analyses indicated that only reaction times (not accuracy) in the visual 1-back task were significantly correlated with and predicted silent sentence reading fluency rather than oral reading, which suggested an association between visual simultaneous processing and reading fluency. Wang et al. (2015) found that silent reading was reported to mainly rely on the global orthographic-to-semantic mapping. In contrast, oral reading fluency has been reported to be involved in orthographic-to-phonological mapping. This may explain the absence of a relationship between VAS and oral reading fluency observed. If this account is broadly correct, then it can be suggested that reading fluency in the silent mode may rely on the global reading procedure whereas reading fluency in the oral mode may rely on the analytic reading procedure.

In a study with children, Zhao et al. (2018a) examined oral word and sentence reading and VAS was assessed with the visual 1-back task with unfamiliar symbols. The children were Mandarin speakers with dyslexia (*n*=57) and without dyslexia (*n*=54) aged 8 to 12 years. All participants used simplified Chinese characters for reading and writing. VAS scores comprised combined z-scores for accuracy, d prime values, and reaction times (RTs). Findings indicated that only the older children, aged 11 to 12, showed lower scores than the controls in the visual 1-back task, showing an increased VAS deficit with development in the dyslexics. Hierarchical regression analyses also showed the significant prediction of VAS skills to oral word reading for older children with dyslexia. The authors suggest that with increasing reading experience, the relationship between VAS and reading skills was also developmentally increasing.

In the same year, Zhao et al. (2018b) assessed the VAS and silent reading of 28 14-year-old Mandarin-speaking teenagers with and without reading fluency difficulty (there were 14 children in each group), again using the visual 1-back task with unfamiliar symbols. The participants used simplified characters in reading and writing. The researchers found that teenagers with reading fluency difficulty showed lower accuracy and d prime values in the visual 1-back task. Results also showed that reaction times in the visual 1-back task were significantly related to silent sentence reading fluency of the TD readers (r = -.81, p < .05), and visual 1-back accuracy was significantly correlated with silent word reading fluency of children with reading fluency difficulty (r = .74, p < .05). Accordingly, Zhao et al. argued that VAS may have an impact on the parallel processing of multiple orthographic units of

Chinese characters, which in turn may affect the efficiency of their sentence comprehension ability in silent reading, which was in line with the above Zhao et al. (2017). Moreover, Zhao et al. (2018b) examined the responses across positions in terms of reaction times, accuracy and d prime values in the visual 1-back task. For d prime values, responses of TD readers exhibited an inverted ‘U’-shaped pattern but those of children with reading fluency difficulty showed a ‘W’-shaped pattern with a rightward bias, which suggested an atypical pattern in children with reading fluency difficulty and a VAS deficit.

This result indicated impaired visual-attentional processing in individuals with a reading fluency problem, which was in line with previous research in alphabetic writing systems (e.g., Lallier et al., 2014; Lobier et al., 2013; Lobier et al., 2014; Lobier, Zoubrinetzky & Valdois, 2012). Reading fluency tests at the word and sentence levels could separately reflect a character-by-character analytical strategy (due to a one-by-one character reading requirement) and a whole-word strategy (due to specific meaning involved in multiple characters rather than one character), respectively. Thus, it could be assumed that children with reading fluency difficulty used the analytical strategy to read due to a restricted VAS, while TD readers are able to use the whole-word strategy to read.

Chen et al. (2019) investigated VAS with the global report task in Cantonese-speaking 10-year-old children in three groups: dyslexic children, CA matched children and reading-level-matched children. Materials in the global report task were Chinese characters, Chinese radicals and digits. In order to examine whether the contribution of VAS to Chinese reading was more than visual orthographic and phonological. Other reading-related cognitive skills such as phonological skills, orthographic skills (visual short-term memory and radical knowledge) and RAN were also assessed. Participants used traditional Chinese characters in reading and writing. Findings showed that for all children, VAS was a significant predictor of oral word reading accuracy at the word level (7%), as well as reading fluency at the word (5%) and text (4%) levels, after controlling for age, nonverbal intelligence, radical knowledge and RAN. They also found RAN was a strong predictor of both word and text reading fluency although not accuracy, which was consistent with previous research to report RAN as the ability to retrieve names of visual materials rapidly reflecting similar ability in fluent word reading in alphabetic and Chinese languages (e.g., Compton et al., 2001; Ho et al., 2002). In the three types of stimuli in the global report task, digits were the easiest to report than Chinese characters or radicals. It was first because children learn to recognise numbers at an early age before they learn to recognise Chinese characters. So, digits are over-learned visual materials for primary school children. Second, the set size was much smaller for digits than for Chinese characters. There were relatively few competitive name candidates in digits so it was faster for children to retrieve the correct name of digits than that of Chinese characters. Due to all materials involving visual-to-phonology code mapping and children's worse performance in characters than radicals and digits, Chen et al. (2019) also assumed the key to the VAS deficit was difficulties in processing visually complex multiple units.

Chen et al. (2019) put forward an explanation for why VAS could predict both reading fluency and accuracy. For reading fluency a VAS deficit may lead to an increase in the number of eye movements during reading and hence result in a more demanding processing load and lower reading rate (e.g., Prado et al., 2007); for accuracy, a VAS deficit may also interfere with orthographic coding and cause confusions between visually similar words (e.g., Casco et al., 1998). Chen et al.

suggested that the reduction of VAS in Chinese dyslexic children might result from different underlying weaknesses, including children's weak orthographic coding, poor organisation and representation of lexical units, and slow processing of visual elements and name retrieval, as indicated in their poor orthographic knowledge and RAN. On the other hand, a restricted VAS may cause low-quality lexical representations, and retrieval of words in the orthographic lexicon may need more time due to the poor activation.

Later, Huang et al. (2019) looked at possible developmental trends in the influence of VAS on reading Chinese in TD Mandarin-speaking readers with mean ages 8, 11 and 14, and adults with a mean age of 23 years. Participants used simplified Chinese characters in reading and writing. VAS was assessed under the visual 1-back task using unfamiliar symbols. Huang et al. found that reaction times in the visual 1-back task were significantly different across age groups and positions, while d prime values of the visual 1-back task were only significantly different in position performance, not in age, which was in line with the findings of Zhao et al. (2018b). For all participants, reaction times in Position 3 (the central position) were significantly shorter than in the fourth and fifth positions, and the reaction times in Positions 1 and 2 were significantly shorter than those in the fifth position (the last position). In addition, an inverse 'u' shape for d prime scores was shown in these readers.

The researchers found that reaction times of the visual 1-back task accounted for 5% of the variance ($p < .05$) in oral-word-reading fluency in the youngest children and 11% of the variance ($p < .05$) in oral-sentence-reading fluency for the 11-year-olds. For the oldest children (14 years old), reaction times accounted for 7% variance in silent sentence reading ($p < .05$). For adults, reaction times were found to be a significant predictor of oral- and silent-sentence-reading fluency (14% and 12%, respectively, $p < .05$).

These findings revealed a developmental transition in the relation between visual 1-back performance and reading, starting from the oral reading mode, moving next to the silent reading mode, and finally settling on a relationship to both oral and silent reading modes for skilled readers. Due to the developmental trend observed, Huang et al. (2019) proposed that oral reading by primary school students mainly involves the activation of phonological representations and the mapping between orthography and phonology. Further, because the mapping to speech sounds is addressed in Chinese reading (i.e., the visual form of a Chinese character corresponds to a syllable), the oral reading procedure might require a narrow VAS window size. In contrast, silent reading involves simultaneous processing of multiple characters to directly map onto the relevant meaning, and may require a wider visual attention span, as Wang et al. (2015) mentioned above. However, the VAS of children aged 8 and 11 is still immature and developing, so it might not satisfy the requirements of the visual attention window for silent reading, possibly resulting in a non-significant relation between VAS and silent reading. With increasing school grades, the VAS window size becomes wider, which could allow for the simultaneous processing of multiple orthographic units. Jasińska and Petitto (2014) also reported that with accumulating reading experience, all of the orthographic, phonological, and semantic representations would be activated both in the oral and the silent reading mode, which was found in Chinese-speaking adults, not children. Thus, the shared cognitive mechanisms of oral and silent reading might be activated together with the increase in reading experiences of adults, and VAS plays a role in such shared mechanisms.

Huang et al. (2021) conducted a study to explore the roles of PA and VAS in reading in Mandarin-speaking children aged 6 and 7 years. They found that phoneme awareness was not a significant predictor of oral word reading fluency, but syllable awareness and VAS were significant predictors. Mediation analysis indicated that syllable awareness partially mediated the relationship between VAS and oral word reading fluency. These children may depend mainly on phonological processing and partially on VAS in reading due to immature VAS. Combining with the results of Huang et al. (2019), it could be hypothesised that younger children mainly used phonological processing in reading, and with age or reading experience, VAS has a much greater role in skilled reading.

Chan and Yeung (2020) compared the influence of verbal (global and partial report) and nonverbal VAS measures (visual 1-back with characters and unfamiliar symbols) in oral word and text reading fluency. They recruited 101 university students who used traditional Chinese characters in reading and writing. Results revealed that VAS was a significant predictor of reading scores. They also reported although all VAS measures were intercorrelated regardless of the nature of stimuli and the reporting method of the task, only scores for global report significantly predicted reading fluency. Non-significant correlations found between the accuracy of visual 1-back tasks (Chinese characters and symbols) and traditional Chinese reading fluency were in line with the above findings for simplified Chinese reading in adults (e.g., Zhao et al., 2017). So, Chen and Yeung (2020) suggested that Chinese reading ability may be more related to verbal VAS. Through comparison with results of previous research in Chinese children (e.g., Chen et al., 2019; Zhao et al., 2018a, 2018b), Chen and Yeung (2020) suggested again that developmental changes might play a role in the relationship between VAS and Chinese reading ability, and it was worth further exploring Chinese adults with VAS deficit and conducting relevant training to increase the size of VAS to examine the causality between VAS and Chinese reading. In addition, they argue that other linguistic measures such as RAN, reading accuracy, and reading comprehension could be assessed in the future.

In the latest relevant studies, Cheng et al. (2021) assessed Mandarin-speaking dyslexic children and TD readers aged from 8 to 11 years. Participants used simplified Chinese characters in reading and writing. The researchers employed visual 1-back tasks with both verbal stimuli (character and digit strings) and nonverbal stimuli (colour dots and symbols). Assessments were also conducted of PA, RAN and verbal short-term memory. Scores in the verbal visual 1-back task explained 19% variance in oral reading accuracy and 8% variance in oral reading fluency, after controlling for age and nonverbal ability. Only performance in the verbal visual 1-back task (character and digit strings) was correlated with all measures including PA, RAN, verbal short-term memory as well as oral word reading accuracy and fluency.

In summary, VAS has been found to play a unique role in reading skills, including oral and silent reading at word and sentence levels, across languages, especially for opaque writing systems (Arabic: Awadh et al., 2022; Chinese: Chan & Yeung, 2020; Cheng et al., 2021; Huang et al., 2019; Zhao et al., 2017; Zhao et al., 2018a, 2018b; English and French: Bosse et al., 2007; Bosse & Valdois, 2009; Chen et al., 2016; Lobier et al., 2013;). Most studies across all languages involved assessments of oral reading fluency, and only three studies from the same research group also involved the investigation of silent reading fluency at the word and sentence levels (Huang et al., 2019; Zhao et al., 2017; Zhao et al., 2018b), in addition to oral reading. There were also two studies covering the significant prediction of VAS to reading comprehension (Arabic: Awadh et al., 2022; English: Chen et al., 2016). Two types of assessment were classified by Chan and Yeung (2020) as verbal (the global and partial report tasks) and nonverbal VAS tasks (the visual 1-back task). The connection between the two types of VAS measures was demonstrated for adult participants but the global report task was found to be the strongest predictor of reading.

So far, there has been little attempt to use unified VAS measures across the studies, but it is clear that the letter report tasks (global and partial report) were widely used as VAS tasks in studies in alphabetic languages, while the visual 1-back task has been more widely employed in Chinese studies. This may be because materials in the global report task in alphabetic languages were letters that are the pronounceable units that combine to make printed words, so comparably, radicals comprising Chinese words should be used in the global report task in the Chinese version. However, unlike letters, most radicals, especially semantic ones, are unpronounceable, so in the global report task in Chinese, single characters have been used as stimuli in the study of Chan and Yeung (2020). In this case, there may exist a discrepancy in scores across languages because the stimuli are more visually complex in Chinese. The scores in the global report task of Bosse et al. (2007) were calculated not only at the letter level but also at the string level, i.e., the number of letters and strings correctly reported. Due to the complexity of Chinese characters, it may be harder for participants to report the correct strings when Chinese characters are used in the global report task, so only the correctly reported number of characters have been scored in the studies using the report task with Chinese speakers. In contrast, the visual 1-back task stimuli have often been unfamiliar symbols, which not only eliminates the language discrepancy reflected in the global report tasks but also circumvents the visual-verbal mapping in the global and partial report tasks.

Different allocation patterns of global report (asymmetry) and partial report tasks (symmetry) may be due to different instructions. Awadh et al. (2016) mentioned above that the retro cue-presented partial report task, unlike the global report task, may shift the selective attention on the target letter representation in memory when the presented stimulus was absent. So attention allocation in this task might not be limited by the positions of letters. By contrast, Bundesen (1990) claimed that global report requires as many letters as possible to be reported, so letters in strings compete for access to a visual short-term memory with limited storage capacities. Each letter has to be allocated attention and even competed weights of attention with other letters.

At the same time, different patterns across positions in the global report task (a left-right asymmetry and leftward advantage) and d prime values of the visual 1-back task (a reverse ‘V’ shape or an inverted ‘U’ shape) may be due to different materials used. Huang et al. (2019) mentioned that when task materials are non-verbal symbols as often used in the visual 1-back task, more attention was weighted in the centre position (position three in the five-item array), so the pattern of d prime values of the visual 1-back task would show a trend with highest scores in the third position of the string and a decrease in performance with increasing eccentricity. By contrast, when materials used are verbal ones, readers would allocate attention to targets from left to right, due to habitual reading direction, so the allocation pattern is asymmetric, as in the global report task reported by Awadh et al. (2016).

In the next section, the existing studies addressing the relationship between VAS and spelling performance are discussed, in separate sections for children and adults.

This is because studies of VAS and spelling followed different research directions - in children these have comprised cross-sectional and longitudinal studies with the aim of identifying developmental trajectories of association of spelling with performance in tasks tapping a range of cognitive processes as well as VAS, such as phonological and rapid naming abilities, visual/orthographic processes. In the case of studies with adults, the avenue of investigation has involved examining the possible causes of weak spelling in participants who have no reported reading difficulties (e.g., Baron et al., 1980; Burden, 1992; Fisher et al., 1985; Holmes & Ng, 1993; Holmes & Quinn, 2009).

1.3.2 Spelling

As noted earlier, many studies have pointed to the contribution of VAS in the development of orthographic representations (e.g., Bosse et al., 2013). Bosse (2015) reviewed the evidence on the processes involved in becoming a skilled reader and speller. The key step of acquiring orthographic knowledge needed for effective reading and spelling was argued to be largely dependent on the ability to distribute visual attention over the whole written word, beyond the contribution of decoding skills, since if an entire letter sequence can be efficiently processed in one glance, its representations can be established or strengthened in the orthographic lexicon. According to this, Van Den Boer et al. (2015) indicated VAS should be critical for literacy acquisition, especially for efficient spelling that requires the use of well-established and detailed orthographic entries. Accordingly, Ginestet et al. (2019) and Valdois et al. (2021) have mentioned that when VAS was restricted, word recognition would also slow down.

Unlike the case for reading, only a small number of studies have focused on spelling and VAS. There have been three recent regression-based studies that investigated the influence of VAS in spelling in TD children in alphabetic orthographies. In addition, one adult study employed the global report task in a study with good and poor adult spellers. These studies are outlined next.

1.3.2.1 Studies of VAS and spelling in children. Van Den Boer et al. (2015) in the study with Dutch-speaking children aged 9 years used the global report task. Verbal short-term memory, RAN and PA were also controlled to explore the unique role of VAS in spelling. The authors found that, along with verbal short-term memory, RAN and PA, VAS reflected by global report performance was a significant predictor of single-word spelling accuracy and orthographic knowledge assessed in a lexical decision task where children were asked to judge whether the presented word is a real word. After controlling for the above predictors, they found that VAS significantly explained 6% of the variance in the children’s spelling-to-dictation scores.

Niolaki et al. (2020), in a study with English-speaking children aged 7 to 10 years, reported that VAS performance in the global letter report task predicted single-word spelling for both younger and older children in the sample, while PA and RAN predicted spelling accuracy for the beginner spellers only. Similar findings were reported by Niolaki et al. (2024). The authors investigated PA and VAS in Greek-speaking children in Grades 1 to 7. They adopted the global report task using Greek letters as materials. In the regression analyses, after controlling for age and single word reading speed, PA was found to predict the spelling accuracy of the beginner spellers (from Grades 1 to 3) while VAS, RAN and PA predicted the spelling accuracy of the more advanced spellers (from Grades 4 to 7). The authors suggested the results reported that with more spelling experience, reliance shifts from phonological processing to visual orthographic processing. These findings again suggested that beginning spellers rely more on phonological processing while advanced spellers rely more on visual-orthographic processing during spelling. Thus, VAS has been shown to have an influence on spelling so far across opaque and transparent writing systems.

1.3.2.2 Studies of VAS and spelling in adults. Only one adult study on spelling has involved the investigation of visual multi-element processing skills. Masterson et al. (2007) carried out a study using the letter report task with English-speaking university students. The adults were divided into good and poor speller groups. The groups did not differ in scores in a reading comprehension test, nor in assessments of phonological ability, involving spoonerisms and speeded naming of pictures and digits. The good spellers outperformed the poor spellers in a lexical decision task, especially in terms of responses to nonwords, and also in a task where participants were asked to report the letters in briefly presented (50 ms) word and nonword letter strings. The poor spellers were significantly less accurate in reporting letters from the nonword strings. There was no group difference for the words. A qualitative analysis of the participants' spelling errors was conducted and revealed that the poor spellers made predominantly word-internal errors, that is, letters in initial and final word positions were relatively accurate.

The authors interpreted the findings as being due to an online processing inadequacy in the poor spellers, which resulted in failure to build robust orthographic representations that could be used for accurate spelling. They referred to previous work by Holmes and Ng (1993) who reported that poor adult spellers were significantly worse than good spellers in detecting stimuli constructed by mis-ordering the middle letters of long words, and studies of Frith (1985) who found that poor spellers were worse than good spellers at detecting silent letters in printed words. Masterson et al. argued that these strands of evidence, together with the poor letter report performance in the poor adult spellers indicated that an underlying cause of poor spelling in adults could be inadequate early-stage processing in printed word recognition, which is in line with the VAS deficit hypothesis that was being put forward on the basis of research with children at the same time. Performance in the letter report task has been interpreted more recently in terms of VAS that is, as reflecting the mechanisms that allow for the simultaneous processing of multiple visual elements (Awadh et al., 2016; Bosse et al., 2007; Ginestet et al., 2020).

In summary, existing research has shown the influence of VAS on children's spelling in both transparent languages (Dutch and Greek) and opaque languages (English), especially for more advanced child spellers who may have levels of literacy approaching those of adults. As for adults, results from the only relevant study indicated that letter report distinguished good and poor spellers. There is no prior research on VAS and spelling with speakers of Chinese. The current research attempted to address this gap in the literature by investigating the relationship between VAS and spelling in Chinese-speaking children and adults. The studies are reported in Chapter 3.

1.4 Intervention for VAS deficits

Arguments have been put forward that intervention studies are important for both theory development and educational practice (e.g., Ans et al., 1998; Castles, 2006; Perry et al., 2010). This is because intervention-based studies are able to provide evidence for causal relationships, by means of examining whether intervention programmes ameliorate the reading difficulty. Such studies have been conducted in group and single case designs, such as the crossover design (Zoubrinetzky et al., 2019), the ABBA design (Jone, 2003), as well as the design with pretest, posttest and follow-up, with a control group or a control training programme (Niolaki & Masterson, 2013; Niolaki et al., 2020; Ren et al., 2023; Roncoli & Masterson, 2016; Valdois et al., 2014; Valdois et al., 2024; Zhao et al., 2019). On the basis of the research indicating that VAS plays an important role in reading and spelling development, intervention studies were conducted as part of the current research, with individuals who had a VAS deficit, in order to provide further supporting evidence for a causal relationship between VAS and literacy skills.

1.5 The present study

With roots in the ancient imperial examination system, the Chinese government has implemented exam-oriented education that means examination and dealing with examination as the purpose and goal of education to screen the abilities through examinations, and then cultivate the selected talents to devote themselves to society. There are three main stages in Chinese public school education system, namely primary school (Grades 1 to 6 with students aged 6 to 13 years), middle school (Grades 1 to 3 with students aged 13 to 16 years) and higher school (Grades 1 to 3 with students aged 16 to 19 years). Students need to pass multiple examinations, especially for middle-term and final-term examinations every year, high-school entrance examination and university entrance examination to upgrade their study levels. Usually, in primary school, there are 50 to 60 students with mixed genders in one class, with one main teacher being responsible for students' discipline and main subject teaching such as English, Chinese and Mathematics, as well as one or two teachers for extra subjects such as arts and physical education. In middle and high school, there are usually 40 to 60 students with mixed genders in one class, with one main teacher being responsible for students' discipline and one main subject teaching, as well as various teachers for extra subjects such as arts and physical education.

In an investigation of the influences of exam-oriented education, Liu (2023) pointed out that exam-focused education is within the area of education that is merit-based. Teachers in China always give the few students who can advance to higher-level schools their full attention, with higher demands and greater consideration. Students with good academic grades sometimes can obtain a privilege from teachers, such as sitting where they like in class, or no homework required.

On the other hand, that is to say, students with lower scores may get less attention and patience from teachers. For example, students with literacy difficulties (such as dyslexia and dysgraphia) are likely to get lower scores than the TD ones, because such students may need a longer time to read exam questions and/or write their answers so that they usually cannot complete the examinations within the time limits and then lose some scores.

So far, relatively few studies have investigated the prediction of VAS to literacy skills in Chinese speakers and it is thus significant to provide comprehensive results about this in Chinese. In the current research, Chinese children and adults were recruited as participants, in order to directly compare the role of VAS in literacy skills and changes of position accuracy of different VAS measures between developing readers and skilled readers, and to see whether the influence of VAS increases over the course of development, as Huang et al. (2019) expected. Prior research in VAS mainly focused on children rather than adults. So relatively, there is not much adult evidence in this field, especially in Chinese. The intervention study involving adults with literacy difficulties could theoretically examine the intervention effects on adults and also enrich the adult profiles in literacy difficulties.

Eight of studies that there are, only two have looked at reading performance in both oral and silent reading modes (Huang et al., 2019; Zhao et al., 2017). In addition, only Huang et al. (2019) included different age groups from children to adults. Only Chan and Yeung (2020) adopted both types of VAS paradigm, namely global and partial report, and visual 1-back. VAS scores in global and partial report tasks were shown by Chan and Yeung (2020) and Chen et al. (2019) to be significant predictors of Chinese oral reading fluency at word and sentence level, but accuracy in the visual 1-back task (Chan & Yeung, 2020) was not. Under the visual 1-back task, Huang et al. (2019) and Huang et al. (2021) indicated that only reaction times, rather than accuracy and d prime values, significantly predicted word and sentence reading fluency in both oral and silent modes. Moreover, different VAS tasks may tap into different cognitive skills. A task analysis of the most commonly used VAS measure, the global and partial report, could suggest that it involves visual perceptual and attentional mechanisms, character/letter recognition and retention, parallel visual processing, access to phonological representations and short-term verbal memory for retention of the response and working memory processes to monitor output (Bosse et al., 2007; Shih & Sperling, 2002). The visual 1-back task as another VAS measure may involve the visual attentional simultaneous processing to process multiple items, and short-term visual memory for retention of the presented stimuli, visual scanning, target identification and visual matching (Zhao et al., 2018a). So, it is worth examining whether VAS assessed in various tasks could still predict the reading skills of children and adults in both oral and silent modes because Liu et al. (2023) and Tang et al. (2023) reported the heterogeneity of VAS paradigms, different participant ages, or different reading tasks used may all cause the inconsistency of results in VAS.

The results of position analyses of the different VAS paradigms were different. Accuracy in the global report task was asymmetric with a leftward letter advantage, while accuracy in the partial report task reported by Awadh et al. (2016) showed a symmetrical pattern. By contrast, Huang et al. (2019) and Zhao et al. (2018b) demonstrated that there was no specific characteristic description of reaction times across positions of the visual 1-back task, while d prime values in the visual 1-back task showed a reverse 'V' shape or an inverted 'U' shape, also shown for accuracy scores. No studies have explored the patterns for global and partial report in Chinese.

Accordingly, in Chapter 2, the relationship between various VAS measures and different reading skills of Chinese speakers was explored, with the position analyses of different VAS paradigms in the end.

In addition, relatively few studies have investigated the influence of VAS on spelling and no previous studies have explored this in Chinese. It was therefore considered important to expand what we know so far about the relationship of VAS to spelling, and to examine the relationship of VAS and spelling in Chinese-speaking participants in Chapter 3.

On the basis of intervention studies, significant improvement in reading and spelling in individuals with VAS deficits has been reported and there is evidence that a VAS deficit may be one of the causes of reading difficulty in Chinese speakers (Ren et al., 2023; Zhao et al., 2019). Chapter 4 reports an intervention study that aimed to investigate the effectiveness of VAS-focused interventions. The results and implications of the studies, as well as limitations and suggestions for future directions for the research are discussed in Chapters 4 and 5.

1.6 General methods for the present study

As mentioned above, this thesis reports three studies involving different research methods. Chapter 2 included Study 1 about reading, whilst quantitative methods were mainly used. Among these, correlation analysis and hierarchical regression were used for first investigating the relationship between VAS and reading in child and adult Chinese speakers, including the VAS paradigms global and partial report, as well as the visual 1-back task. Reading was assessed in different modes - oral and silent reading of words and sentences. Principal component analysis, as a method for reducing a cases-by-variables data table to its essential features (e.g. Greenacre et al., 2022), was adopted for identifying individual VAS variables that are composites of the observed composite variables. Later, structural equation modelling was used for analysing complex relationships between both observed and latent VAS and reading skills. Finally, researchers have conducted position analyses through the ANOVA analyses, line graphs and violin plots with data from VAS tasks, since the patterns have been interpreted as indicating the allocation of attention across letter strings, and in order to compare the differences in responses of dyslexic and non-dyslexic individuals, or reveal a developmental trajectory across age. Responses across positions in the VAS tasks were thus analysed.

Chapter 3 included Study 2 about spelling, whilst both quantitative and qualitative methods were used. As for quantitative analyses, participant-based analyses including correlation and hierarchical regression analyses were used for exploring the relationship between VAS and spelling-to-dictation of children and adults; item-based analyses were conducted through calculating the spelling accuracy per target, and then investigating the relationship between printed word frequency, length and spelling accuracy per target. Correlation and simultaneous multiple regression analyses were used to explore participants' reliance on global or analytical word processing in spelling. Finally, qualitative spelling error analyses were employed to reveal the number and percentage of spelling errors in each error category. So far, this has been the first study to explore the role of VAS in Chinese spelling and also to show potential developmental progression in the role of VAS in spelling between children and adults.

Chapter 4 involved Study 3 about an intervention study with participants identified with reading and or spelling difficulties in the first two studies, with quantitative and qualitative analyses. Two VAS-based and one non-VAS-based training programmes were implemented.

Case series analyses and group analyses were conducted to examine training effects on reading and VAS. As for case series analyses, the effectiveness in VAS and reading of the interventions was evaluated by weighted statistics from Howard et al. (2015), a specialised clinical statistical analysis for small sample sizes, to test whether there is a more significant improvement in the treated stage than the untreated stages, which was further revealed by Venn Diagrams. As for group analyses, mixed ANOVA was used for examining the training effects of classified groups, namely VO (only VAS deficit) group, VPD (VAS and phonological deficit) group, both for children and adults.

The training effects of spelling were then tested by McNemar test, and the qualitative spelling error analyses as used in Study 2.

Finally, comparisons in position accuracy of all VAS measures (global report, partial report, visual 1-back accuracy and visual 1-back correct reaction times) between participants without and with reading difficulty were shown, in order to examine potential differences in attentional allocation.

Chapter 2: Relationship between VAS and reading in Mandarin-speaking children and adults

2.1 Introduction

Evidence reported in Chapter 1 has pointed to a unique predictive role of VAS in the reading of Chinese-speaking children and adults (Chan & Yeung, 2020; Chen et al., 2019; Cheng et al, 2021; Huang et al., 2019; Huang et al., 2021; Zhao et al., 2017; Zhao et al., 2018a, 2018b). However, there are some issues that remain to be addressed in the studies with Chinese speakers. These are outlined below to provide the background for the first study reported in the thesis, on VAS and reading in Mandarin-speaking children and adults. The issues relate to methodological differences across studies that have led to a lack of ability to draw definitive conclusions about the relationship of VAS and reading in Chinese speakers. The methodological differences can be summarised as relating to the tasks used to measure VAS across the studies, the measures of reading and reading-related skills employed, as well as differences in participant characteristics, such as age and reading level. In addition, I argue below that many studies failed to take up the opportunity to examine patterns of performance within the different VAS tasks. This data has been interpreted by Chan and Yeung (2020) as indicating patterns of allocation of visual attention in orthographic processing. The data can therefore provide an important source of information regarding the processes being used in reading by participants of different ages and reading ability levels. The latter issue is taken up in Chapter 4, which addresses VAS and participants with poor reading.

2.1.1 Differences in VAS tasks employed across studies

As discussed in Section 1.3.1, the tasks that have been most commonly used to assess VAS in the past have been global and partial report, and the visual 1-back

(V1b) task. In studies carried out in languages other than Chinese, global and partial report tasks have been used more (Arabic, French and Spanish; Awadh et al., 2016; Arabic: Awadh et al., 2022; English: Bosse et al., 2007; French: Bosse & Valdois, 2009; French and Spanish: Lallier et al., 2014) than the v1b task (French, Spanish, Basque: Lallier et al., 2016). In contrast, the Chinese studies have mostly used the v1b task. The specific reason was discussed in Section 1.3.1. Only Chan and Yeung (2020) adopted both report and v1b tasks. Table 1 provides a summary of the methods used in the VAS studies with Chinese speakers.

Table 1

Summary of Studies Examining the Role of VAS in Reading in Chinese

	Cross-sectional studies with Chinese-speaking children					**Cross-sectional studies with-Chinese-speaking adults**		**Cross-sectional studies with Chinese-speaking children, teenagers and adults**
Studies	1. Zhao et al. (2018a).	2. Zhao et al. (2018b).	3. Chen et al. (2019).	4. Cheng et al. (2021).	5. Huang et al. (2021).	6. Zhao et al. (2017).	7. Chan & Yeung (2020).	8. Huang et al. (2019).
Participants	Mandarin speakers, simplified Chinese Characters (CC) 57 dyslexic children + 54 TD children, Grades 2-6 (8-11 yrs)	Mandarin speakers, simplified CC 14 with reading fluency difficulty (m=14.5 years, sd=0.83) 14 TD children (m=14 years, sd=0.53)	Cantonese speakers, traditional CC 25 dyslexic children (m=10.45 years, sd=0.65) 25 TD (m=10.46 years, sd=0.69) 25 RL controls (m=8.89 years, sd=0.98)	Mandarin speakers, simplified CC 45 dyslexic children (m=10.11 years, sd=0.63) 43 TD children (m=10.15 years , sd=0.58)	Mandarin speakers, simplified CC 65 TD children (m=6.62 years, sd=0.51)	Mandarin speakers, simplified CC 58 undergraduate and graduate students 19-25 years (m=23)	Cantonese speakers, traditional CC 101 university students (m=23.73 years, sd=4.38)	Mandarin speakers, simplified CC 82 low primary (m=8.47, sd=0.85); 77 high primary (m=11.2, sd=0.99); 65 middle school (m=14.31, sd=0.68); 61 undergraduate (m=23.23, sd=1.94)
Tasks	**VAS: composite** V1b (unfamiliar symbols) VAS control: single symbol recognition **Reading:** Oral word and sentence fluency **General language ability**: Character Recognition (writing) **Nonverbal ability**: Raven's SPM **PA:** odd-one-out task **Morphological awareness (MA)**	**VAS: not composite scores** V1b (unfamiliar symbols) VAS control: single symbol recognition **Reading**: Silent word and sentence fluency	**VAS: composite** Global report (characters, radicals, digits) **Reading:** Oral word reading Oral word and sentence fluency **Nonverbal ability:** Raven's SPM **PA:** onset detection, phonological memory **RAN**: digits **Visual orthographic tasks**: Visual memory, Radical knowledge	**VAS: not composite** V1b with characters, digits, colours, symbols **Reading:** Oral word fluency, oral word accuracy **Nonverbal ability:** Raven's SPM **PA:** phoneme, onset, rime deletion, spoonerisms **Verbal short-term memory:** Digit Span from WISC **RAN:** digits, pictures, dice, colours **Dyslexic diagnosis:** Character recognition	**VAS: not composite scores** V1b (unfamiliar symbols) VAS control: single symbol recognition **Reading:** Oral word fluency Nonverbal ability: Raven's SPM **Verbal working memory:** backward digit recall **PA:** syllable, phoneme awareness	**VAS: not composite scores** V1b (unfamiliar symbols) **Reading:** Oral and silent word fluency Oral and silent sentence accuracy and fluency	**VAS: not composite scores** Global, partial report tasks; V1b (characters and unfamiliar symbols) **Reading:** Oral word and sentence fluency	**VAS: not composite scores** V1b (unfamiliar symbols) **Reading:** Oral and silent word fluency Oral and silent sentence accuracy and fluency **General language ability:** Character Recognition **RAN:** digits **Nonverbal ability:** Raven's SPM

It can be seen that five of the six studies with children used the v1b task (Cheng et al., 2021; Huang et al., 2019; Huang et al., 2021; Zhao et al., 2018a, 2018b) and one used the global report task (Chen et al., 2019). Two of the three studies with Chinese-speaking adults used the v1b task (Huang et al., 2019; Zhao et al., 2017), and in the third, Chan and Yeung (2020) used the v1b task as well as global and partial report. Chan and Yeung employed Chinese characters as stimuli in the global and partial report tasks, and conducted one v1b task with Chinese characters and one with unfamiliar symbols. Word and text reading fluency in oral mode were the measures of reading. Results with Cantonese-speaking university students revealed that scores in the VAS measures were significantly inter-correlated, regardless of the nature of stimuli and of the reporting method of the tasks. Awadh et al. (2016) and Valdois (2022) have argued that the more complex orthographic forms are, the greater are demands on visual attentional processes, so we might have expected that a significant association of reading fluency and v1b performance would be found in Chan and Yeung's study which was conducted with traditional Chinese characters (since the participants were from Hong Kong). However, only scores for global report significantly predicted reading fluency. The non-significant correlations found between scores in the v1b task (with both characters and unfamiliar symbols) and reading fluency were in line with the findings previously reported by Zhao et al. (2017) and Huang et al. (2019) for reading fluency with simplified characters in adults (the participants were from mainland China). Cheng et al. (2021) found the prediction of scores in the v1b task with verbal stimuli (characters and digits) to reading fluency of children, not the one of the v1b task with nonverbal stimuli (symbols and colour dots).

However, v1b correct Reaction times (RTs) as another variable of the v1b task were found to significantly predict reading fluency in all studies that included v1b correct RTs (Huang et al., 2019; Huang et al., 2021; Zhao et al., 2017; Zhao et al., 2018a, 2018b). This may be because different VAS tasks involve different cognitive skills, as mentioned in Chapter 1, but these VAS tasks may overlap with parallel simultaneous visual processing and short-term memory storage. The associations of two report tasks with reading are similar because both report tasks involve the visual perception of orthographic lexicons, pronunciation retrieval and access to phonological representations. The observed lack of association of v1b with reading fluency may be because v1b makes more demands on working memory – participants need to retain the array and test target in memory, and scanning and matching of array and targets are also required. In addition, the presentation of the single symbol or character after the array in v1b may result in backward masking because the single stimulus may appear at the same point on the screen as the array was presented, which is unlike the presentation of the underscore cue in partial report. Hermens and Ernst (2008) claimed that visual backward masking would impair the performance of the targets, which may influence their prediction of reading.

In the case of the v1b task, researchers have not consistently used the same behavioural measure. Some studies have employed accuracy (studies 2, 4, 5, 6 and 7 in Table 1), some used d prime (studies 2 and 8), and still some used correct RTs (studies 1, 2, 5, 6 and 8). It may be the case that different cognitive processes are associated with RTs and accuracy/d prime. All studies using the v1b task as a measure of VAS adopted these IVs separately (studies 2, 4, 5, 6, 7 and 8), except for Zhao et al. (2018a), who calculated total scores, which comprised z scores for correct RTs, accuracy, and d prime. The study of Zhao et al. (2018a) was conducted with Mandarin-speaking children with and without dyslexia from Grades 2 to 6 at primary school. Reading measures were oral word and sentence reading. Regression analysis showed that v1b combined scores significantly predicted oral word reading in the older dyslexics and not in the younger dyslexics or the TD readers. Zhao et al. (2018a) claimed that VAS impairment in the dyslexics from high grades may directly exert some influence on Chinese reading (especially at the single-character level), such as on rapid global processing of the visual forms of several Chinese characters in foveal viewing. Zhao et al. (2017) and Zhao et al. (2018a) argued that for older children when reading comes to involve rapid processing of multiple characters and fast visual-semantic mapping, since VAS facilitates this processing, then a deficit in VAS will be apparent at this older age. This concurs with the interpretation of a VAS deficit as one of the underlying causes of dyslexia in alphabetic languages, i.e., Valdois et al. (2012) claimed that VAS relates to global coarse-grain reading processes and visual-phonology processing, and a deficit in VAS thus hinders visual-phonology mapping (this is discussed further in Chapter 4 on participant characteristics).

2.1.2 Difference in outcome measures

The use of different reading tasks may cause discrepant results. As discussed in the previous section, the results of Chan and Yeung (2020) indicated that reading in Chinese may be more related to VAS measured by global and partial report tasks involving oral responses, rather than VAS assessed in v1b tasks. However, the finding may be due to having employed oral, rather than silent reading tasks in that study. Three out of the eight Chinese studies (Huang et al., 2019; Zhao et al., 2017; Zhao et al., 2018b) involved silent reading tasks. Huang et al. (2019) and Zhao et al.

(2017) reported a significant association between reading fluency and VAS measured by v1b, with correct RTs in the v1b task showing a stronger association with reading fluency than accuracy. Zhao et al. (2018b) similarly found the predictor of v1b correct RTs to the silent reading accuracy. Among all Chinese studies, only Huang et al. (2019) used both oral and silent reading tasks, at both word and sentence levels, and found a significant prediction of v1b to both oral and silent reading, and across age groups. However, due to the single VAS paradigm used by Huang et al. (2019), we still do not have a full picture of how all VAS measures are associated with reading in Chinese.

2.1.3 Analysis of accuracy across positions/VAS as a measure of allocation of attention

A third issue with the extant studies is that not all of them reported the response patterns across array positions in the VAS tasks. As was discussed in Section 1.3.1, Lallier et al. (2016) indicated the pattern of correct responses across array positions has been interpreted as indicative of the allocation of attention across written letter strings. Valdois et al. (2003) claimed that this has been considered particularly informative in terms of comparison of patterns between TD and dyslexic readers. There is some evidence in support of different patterns across the different VAS tasks for typically developing readers. Awadh et al. (2016) and Van Den Boer et al. (2015) showed that the pattern in the global report task has been observed to show a left-right asymmetry and a leftward letter advantage. Awadh et al. (2016) showed that the pattern in the partial report task has been found to demonstrate a symmetry regardless of languages, and Collis et al. (2013) even showed this to be a ‘W-shape’. By contrast, the pattern for d prime values in the v1b task has been revealed to be a reverse ‘V’ shape reported by Huang et al. (2019) or an inverted ‘U’ shape reported by Zhao et al. (2018b).

Among the studies on VAS in Chinese readers, only Huang et al. (2019) and Zhao et al. (2018b) reported v1b accuracy, d prime scores and RTs across positions. There are no Chinese studies reporting accuracy across positions in global and partial report tasks. Chan and Yeung (2020) compared the relationship between different VAS tasks and oral reading fluency, but they did not compare the response patterns in the different VAS tasks. Thus, there is scant information on potential patterns of attention allocation with different VAS paradigms.

2.1.4 Difference in participant characteristics across studies

Fourthly, the majority of studies focused on single age groups, therefore it was not possible to observe any potential development trends in the relationship of VAS and reading. As can be seen in Table 1, of the eight studies on VAS in Chinese speakers, four involved child participants (Chen et al., 2019; Cheng et al., 2021; Huang et al., 2021; Zhao et al., 2018a), one involved teenagers (Zhao et al., 2018b), two involved adults (Chan & Yeung, 2020; Zhao et al., 2017) and only one included both children and adults (Huang et al., 2019). Huang et al. (2019) and Huang et al. (2021) discussed that developmental changes might play a role in the relationships between VAS and Chinese reading ability. As discussed in Section 1.3.1, one reason for proposing an increase in the influence of VAS with reading experience in Chinese is that, across the course of reading instruction, the utilisation of alphabetic Pinyin gradually diminishes and orthographic lexicons were forced to be mapped from visual to speech directly without the reliance of Pinyin system. Thus, during this process, the impact of VAS on reading is likely to change. However, so far, only Huang et al. (2019) have conducted a study aimed at investigating a developmental trend in the relationship between VAS and reading fluency. The researchers reported that VAS in adults predicted sentence reading fluency and not word reading fluency, while for children, VAS predicted word reading fluency. Since this is the only study on VAS and reading across age groups in Chinese it would seem that potential developmental change including adult groups in the relationship is worth investigating further.

Although the existing Chinese studies explored the Chinese language, they investigated readers speaking different dialects (Cantonese- and Mandarin-speaking) and writing forms (traditional and simplified Chinese characters). Traditional Chinese characters are higher in visual complexity than simplified Chinese characters, as noted in Section 1.3.1. However, there were no significant differences in results about the unique contribution of VAS to reading, and all these Chinese studies found a significant association between VAS and reading fluency. Chen et al. (2019) and Chan and Yeung (2020) respectively focused on Cantonese-speaking children and adults using traditional Chinese characters. Zhao et al. (2017) and Zhao et al. (2018a, 2018b), Huang et al. (2019), Huang et al. (2021) and Cheng et al. (2021) focused on Mandarin-speaking children and adults using simplified Chinese characters. The only difference was that the pinyin system was in place for children using simplified Chinese characters during early literacy learning, not for children using traditional Chinese characters. Yeung et al. (2013) reported that RAN and MA (morphological awareness) were significant longitudinal predictors of Chinese word reading of Cantonese-speaking children in Grades 1 to 4. There is nearly not much influence of phonological processing on the reading of children using traditional Chinese characters. So, it might be assumed that compared with children using simplified Chinese characters, for reading, children using traditional Chinese characters may benefit from VAS at younger ages.

Finally, other variables previously found to significantly influence reading ability (age, nonverbal ability, vocabulary, PA, RAN, MA, phonological memory or single character identification) have been included in the existing VAS studies in Chinese children and adults (only without MA for adults). However, no study has investigated all these variables together with VAS in a single study.

2.1.5 The present study

The research reported in this chapter aimed to address the above issues to provide greater clarity on the relationship of VAS and reading in Chinese. The first study (Study 1a) was conducted with children and the second (Study 1b) with adults. The patterns of responses in the different VAS tasks of children and adults were examined in Study 1c. The findings of Huang et al. (2019) and Zhao et al. (2018a) indicate that VAS comes to have a more important role with an increase in reading experience. Thus, it was predicted that VAS would be more closely associated with reading in the adult participants. Results of Huang et al. (2019) and Zhao et al. (2017) suggest the relationship should be stronger for reading fluency in silent rather than oral mode. Study 1a and Study 1b included measures of vocabulary, visual and verbal memory, PA, RAN and character identification These literacy-related variables, together with age and nonverbal ability, were included in Study 1a, and all variables except for MA were included in Study 1b (specific reasons were mentioned in Study 1b).

This will be the first research to incorporate such a comprehensive set of measures. It was predicted that all of the variables would be significantly associated with reading. The first aim was to investigate whether VAS would have an influence on reading over and above the influence of these important variables. The second aim was to examine which of the various measures of VAS would play a stronger role in reading in which kind of modes. The third aim was to investigate whether VAS was associated with any of the reading-related measures, as outlined in the next section. The final aim was to examine the response position patterns from the different VAS tasks. It was thought that the findings would offer comprehensive information about the cognitive processes associated with reading through the exploration of the relationship among VAS, other important variables and reading. This knowledge would then provide a basis for investigating potential underlying causes of dyslexia, addressed in Chapter 4.

2.2 Study 1a: Relationship between VAS and reading in Mandarin-speaking children

This study involved Mandarin-speaking children who were aged 10 to 12 years. The target age range was chosen as it covers the age range of children in previous studies examining the relationship of VAS and reading acquisition (Awadh et al., 2022; Bosse et al., 2007; Bosse & Valdois, 2009; Van Den Boer et al., 2015). In addition, results of the study with Chinese speaking children of Zhao et al. (2018a) indicated that VAS might be more critical for literacy in Chinese students in higher school grades (Grades 5 and 6, aged 11 to 12 years) than in lower grades, since a significant deficit in VAS was detected in dyslexic children from Grades 5 to 6 but not in those from Grades 2 to 4. Furthermore, with increasing age, Shen and Bear (2000) claimed that Mandarin-speaking children rely less on the Pinyin alphabetic teaching system, probably starting from 10 years old when children are in Grade 5. Thus, we targeted Mandarin-speaking children aged 10 to 12 years.

Other literacy-related variables and reading

Some other important reading-related variables have been reported to be significantly associated with children's reading, including PA, RAN, MA, vocabulary, verbal and visual short-term memory and character identification. Cheng et al. (2021) and Huang et al. (2021) showed there were strong associations between PA and oral word reading fluency, since this has been reported for Chinese children aged 7 to 12 years. Results indicated the significant association between RAN and oral word and sentence reading in 10-year-old Chinese children (Chen et al., 2019; Cheng et al., 2021; Huang et al., 2021), between verbal short-term memory and oral word reading fluency in children aged 8 to 11 years (Cheng et al., 2021) as well as between vocabulary and character identification skills and reading ability in 10-year-old Chinese children (Zhao et al., 2018b). Previous results of Huang et al. (2019) and Zhao et al. (2018a) also respectively revealed a strong influence of RAN on adults' silent sentence reading fluency and a strong effect of MA on oral word reading for 11- to 12-year-old Chinese dyslexics. The function of visual memory in Chinese reading was mentioned. Yang et al. (2013) reported that young Chinese readers may just simply recognise a graphemic form as a visual image, so visual memory could help them store the shape of characters. Dall et al. (2021) mentioned processing in Chinese characters also modulate attentional components like visual short-term memory capacity and processing speed. Thus, a measure of visual short-term memory was also included in the present study to re-explore the relationship between Chinese reading and these literacy-related variables.

Potential associations of VAS and other literacy-related variables

VAS tasks may have potential associations with different cognitive skills. As discussed in Section 1.5, the two report tasks may involve access to phonological representations, character/letter recognition and retention, and parallel simultaneous processing, reported by Bosse et al. (2007) and Shih and Sperling (2002). Significant correlations between RAN and VAS (assessed by the global and partial report tasks) were found by Bosse et al. (2007), Bosse and Valdois (2009) and Van Den Boer et al. (2015). PA and VAS were found not to be correlated in the studies of Bosse et al. (2007), Bosse and Valdois (2009) and Chen et al. (2019). Although verbal short-term memory was ever reported to be involved in the global and partial report tasks (Bosse et al., 2007; Bosse & Valdois, 2009; Van Den Boer et al., 2015), the evidence of Lobier, Zoubrinetzky and Valdois (2012) indicated that the two report tasks were still visual not verbal tasks. First, it has been shown by Scarborough (1972) that performance in the global report task is barely affected by a concurrent verbal short-term memory task. Second, Wolford (1975) demonstrated the patterns of errors produced in the whole report task reflect visual rather than verbal confusions. Third, in partial report, a single letter has to be reported, so it is unlikely that phonological short-term memory is a major factor, as confirmed by Dixon and Shedden (1993) who showed that partial report is only minimally affected by articulatory suppression. Bosse and Valdois (2009) and Niolaki and Masterson (2013) supported that VAS may contribute to information storage in visual short-term memory, thus influencing single-word reading and whole-word orthographic acquisition. However, it should be noted that no studies in Chinese and alphabetic languages directly explored the association between visual short-term memory and VAS, except Chen et al. (2019), but Chen et al. did not find any correlation between visual memory and VAS. This may be because the correlation analysis included dyslexic children and TD children together, so the result may be affected by combining the data.

On the other hand, the v1b task may involve visual attentional simultaneous processing and short-term visual memory for retention of unfamiliar symbols, as mentioned by Zhao et al. (2018a). So far, no studies have explored these literacy-related variables and performance in relation to the v1b task, but it could still be expected to see the associations between the v1b tasks and literacy-related variables, such as visual memory and RAN.

Overall, it was worth exploring the inter-relationship between VAS and the reading-related variables (PA, RAN, verbal and visual memory) in order to increase understanding of what VAS involves. It was predicted that RAN and visual memory might be particularly strongly associated with VAS performance.

Correlations between different VAS tasks

As for different VAS tasks, significant correlations between the global report and partial report have been reported for 10-to-12-year-old children (Awadh et al., 2022; Bosse et al., 2007; Bosse & Valdois, 2009). Huang et al. (2019) showed that a significant association between v1b accuracy and d prime was also found in 10-to-12-year-old children, but the correlations between v1b rt and v1b accuracy/d prime were not found in 10-to-12-year-old children. No study with children has investigated the relation between performance in the report tasks and the v1b task. So, this study also investigates potential relationships in performance in the different VAS tasks.

2.2.1 Research questions

The research questions for Study 1a were:

1. Does VAS predict reading fluency in 10- to 12-year-old Mandarin-speaking children over and above the influence of other literacy-related variables (vocabulary, PA, RAN, MA, verbal and visual memory and character identification)?

   If so, which reading modes show the strongest influence of VAS?

   And which VAS task shows the strongest association with reading?
2. What is the association of VAS with other literacy-related variables?
3. What is the association of VAS tasks from different VAS paradigms?

With regard to RQ1, the prediction was that VAS would be a unique predictor of reading fluency for these children after controlling for other important literacy-related variables. It was further predicted that global and partial report performance may show a stronger influence on oral reading, as found in Study 4 in Table 1, Cheng et al. (2021). V1b scores would show a stronger influence on silent reading, as found in

Study 8, Huang et al. (2019). Finally, the strongest influence of VAS should be observed for oral sentence reading fluency, as found in Study 8, Huang et al. (2019).

With regard to RQ2, the prediction was that VAS may be significantly associated with RAN, verbal memory, and visual memory, but not associated with PA, as reported by Bosse et al. (2007) and Bosse and Valdois (2009).

With regard to RQ3, the prediction was that global and partial report scores would be significantly correlated with each other, as reported by Bosse et al. (2007) and Bosse and Valdois (2009). D prime and accuracy in the v1b task would also be significantly associated, as reported in Study 8, Huang et al. (2019). Finally, V1b correct RTs would not be associated with v1b accuracy or d prime, as mentioned in Study 8, Huang et al. (2019).

2.2.2 Method

2.2.2.1 Participants. Participants included 56 children (25 girls) aged 10 to 12 years (*m*= 10.65, *sd* = 0.63). They were all native speakers of Mandarin. The children were recruited at a primary school in northeastern mainland China with a low-to-middle SES background (on the basis of school district). The children were all in Grade 5. None of children had had cognitive or language assessments for suspected dyslexia. None of the children had any learning difficulty or sensory impairment according to school records. All of the children had normal or corrected to normal vision. Based on the G-power analysis, there should have been at least 55 children, so the sample size of 56 children was sufficient for this study.

Ethical approval for the current study was acquired from the UCL, Institute of Education ethical review panel. Written informed consent to participate in the research was obtained from the children, the children's parents/guardians, the children's teachers themselves before testing began. The author's DBS certificate was provided.

2.2.2.2 Materials. The assessments in Study 1a include tasks of nonverbal ability, global and partial report, v1b, vocabulary, verbal and visual short-term memory, PA, RAN, MA, character identification, as well as word and sentence reading fluency in oral and silent modes.

Nonverbal ability. Nonverbal reasoning ability was tested by Raven's Standard Progressive Matrices (Raven et al., 1996). Raven's SPM is a widely used measure of general cognitive ability (Raven, 1989). Zhang and Wang (1989) established the normative data for the Chinese city version of Raven's SPM, which was adapted for all age groups from 5 to 70 years.

VAS global report. The global report task was first used by Bosse et al. (2007) and was adapted for Chinese-speaking participants by Chan and Yeung (2020) using 10 traditional single characters each with eight strokes (the reliability was reported to be 0.83 for adults in that study). For the present study, the characters from Chan and Yeung were employed but in simplified form, because the recruited participants were Mandarin speakers. The task used 10 Chinese characters. All the characters were pronounceable (门 /men2/ [door]; 雨 /yu3/ [rain]; 并 /bing4/ [and]; 东 /dong1/ [east]; 表 /biao3/ [watch]; 非 /fei1/ [no]; 事 /shi4/ [thing]; 兔 /tu4/ [rabbit]; 京 /jing1/ [Beijing]; 金 /jin1/ [gold]). Before the task, the participants were asked to name the stimuli to make sure they know them. The characters were common ones, usually learned by children in Grade 1.

The simplified characters were assessed for familiarity in a pilot study with five 10- to 12-year-old children who were randomly selected from another class at the participants' school. The characters were all found to be familiar to the children. Cronbach's alpha was calculated as 0.95 on the basis of data from the current study.

The procedure for the task was the same as that in the study of Chan and Yeung. Trials involved the presentation of 20 six-character arrays. Each array did not produce semantic meanings. Each trial began with a central fixation point (for 1000 ms) followed by a blank screen (50 ms) and then a centrally displayed array for 200 ms. Children were required to orally report the characters in the array, irrespective of position after they disappeared. The measure employed in the analyses was the total number of characters correct (the maximum score on this test was 120).

VAS partial report. The partial report task was also developed by Bosse et al. (2007), and for assessing Chinese participants was adapted by Chan and Yeung (2020) (reliability was reported to be 0.79). For our study, Cronbach's alpha was 0.95 for children on the basis of data from this study. Stimuli were the same 10 characters as for the global report task. The six-character arrays consist of different combinations of these characters, without repetition within a string, and the arrays were not repeated. Each array did not produce semantic meanings as well. Each character appears six times in the same position and serves as the target character once at each position. A total of 36 trials were administered, preceded by two practice trials. In this task, an underline cue appeared after the offset of the array. Participants were asked to report the target character prompted by the underline cue. The experimenter recorded the reported character and proceeded to the next trial by pressing a button without giving feedback. The score was the sum of correctly reported target characters (the maximum score on this test was 36)

VAS v1b. The v1b task developed by Zhao et al. (2018a) was used in the present study (reliability was reported to be 0.81 for 10-12-year-old children). Cronbach's alpha was 0.6 on the basis of data from the current study. The stimuli were 15 unfamiliar geometric symbols. A list of 80 five-symbol arrays was created. No string included the same symbol twice. Participants were asked to press the *j* key as quickly and accurately as possible when the target figure was present in the preceding array (200 ms) before 500 ms fixation, and they were asked to press the *f* key when it was absent. The target symbol was replaced by a blank screen (100 ms) after the response. The blank screen lasted for 1000 ms between successive trials. The test trials were preceded by 10 practice trials. Correct RTs, accuracy (80 as the maximum) and D prime values were recorded. All children's d prime values were randomly assigned into four sections and the four sections were shown not to be significantly different (please see Appendix A), suggesting no attention distraction of children in the v1b task.

Vocabulary. The receptive vocabulary task of Gong and Guo (1984) was adopted. The Peabody Picture Vocabulary Test – Chinese edition (PPVT-C) was based on the Peabody Picture Vocabulary Test developed by Dunn and Dunn (1997). Cronbach's alpha was 0.82 on the basis of data from the current study. The experimenter states a word, and children need to point to the corresponding picture out of four choices. The task ends when children make more than five errors in a set of eight words. Performance was recorded in terms of raw scores (i.e., ceiling item – total errors). The maximum score on this test was 120.

Verbal short-term memory. Verbal short-term memory was assessed using the Digit Span Forward and Backward subtests of the Chinese Wechsler Intelligence Scale for Children (C-WISC; Gong & Cai, 1993). The highest number of digits correctly repeated by children was their score (Cronbach's alpha was 0.67 for children on the basis of data from this study). The maximum score on this test was 12.

Visual short-term memory. Visual simultaneous and sequential memory tasks developed by Hulme (1981) were used (Cronbach's alpha was 0.67 for children on the basis of data from this study). Arabic characters (unfamiliar symbols for the participants) were the stimuli. There were 12 trials for each task. Two, three, or four characters were presented simultaneously or sequentially twice on the computer screen, for two seconds per character. The participants were then required to select the characters that were shown, in the correct order, from a test array of the characters that were presented, intermixed with two distractor characters. The test array was presented following a retention interval of one second for the first six trials and 10 seconds for the following six trials. Participants provided their responses by saying aloud the number tags under the relevant characters in the test array. The maximum score was 12 for each task.

Phonological awareness (PA). The phoneme deletion task from Song et al. (2020) was used (Cronbach's alpha was 0.85 on the basis of data from this study). The phoneme deletion task was adopted to assess phonological awareness. Participants were presented with one-, two-, or three-syllable items spoken by the tester, and were asked to say aloud the syllable without the initial, middle, or final phoneme (for example, 'please tell me what /po1/ would be without the initial '/p/', correct answer /o1/; what /guan3/ would be without the middle '/u/', correct answer /gan3/; what /huang2/ would be without the last /g/, correct answer /huan2/'). There were 26 items for the main task and eight practice items. Correct responses were given one point.

Rapid automatised naming (RAN). The RAN digit and picture tasks were from the Phonological Assessment Battery (Frederickson et al., 1997). The picture task used line drawings of five common objects: a table, a door, a ball, a hat and a box. The digit naming task used digits 1 to 9. In each case, participants were shown a visual display of randomly presented items and asked to name them in sequence as quickly as they could. The response time to complete naming the pictures/digits was recorded. Cronbach's alpha was 0.72 for the recruited children on the basis of data from this study.

Morphological awareness (MA). The compounding production task developed by Liu and McBride-Chang (2010) was used for this study with six practice items and 31 test items. Cronbach's alphas were reported by Liu and McBride-Chang to be between 0.74 and 0.79 for children aged 9 years. Children were asked to generate a novel word that could best reflect the meaning provided by the question (for example, 'What should we call a monster that eats iron?', '我们把专门吃铁块的怪兽叫做什么?'. Correct answer: 'iron-eating monster', '吃铁怪'). Children's responses were scored according to the criteria in the study of Liu and McBride-Chang. The scoring criteria were as follows:

a. Correct and succinct structure; all critical morphemes (or semantically similar morphemes); expressing the complete meaning - 4 points;

b. Correct but redundant or incomplete structure; uses more or fewer morphemes (but not simple repetition); incomplete meaning - 3 points;

c. Correct but redundant or incomplete structure; uses some unrelated morphemes (or just simply repeats the morphemes in the question); related meaning - 2 points;

d. Incorrect (e.g., reversed) structure; uses some critical morphemes or similar morphemes; related meaning - 1 point;

e. Incorrect structure; uses unrelated morphemes; express unrelated meaning - 0 point;

The maximum possible correct score on this test was 124 (four points × 31 items). Cronbach's alpha was 0.75 based on the scores in the present study.

Single-character identification. A letter identification task was employed by Bosse et al. (2007). In the character identification task here, the stimuli were the 10 Chinese characters used in the VAS report task. In the Bosse et al. (2007) study, at the offset of the letter, a mask was displayed for 150 ms, but considering the complexity of the Chinese characters and the participants' ages, a mask was not used for children in this study. The Cronbach's alpha was 0.74 for children on the basis of data from this study. The characters were presented individually in random order for a total of five times each. The presentations had different durations (33, 50, 67, 84, and 101 ms), so each character appeared once at each presentation duration (again in random order). Before the test trials, the participants were given ten practice trials, two for each presentation duration, with feedback. Children were asked to name each character after its presentation. The score was calculated based on the formula from Antzaka et al. (2018), that is, accuracy at 33 ms x 5 + accuracy at 50 ms x 4 + accuracy at 67 ms x 3 + accuracy at 84 ms x 2 + accuracy at 101 ms.

Oral word and sentence reading fluency. The Chinese word reading task developed by Chan and Yeung (2020) was adopted in this study. In the study of Chan and Yeung (2020), the lower-bound reliability of this task is calculated (word fluency, r_{lower} = 0.66). In this study, the Cronbach's alpha for children was 0.70 on the basis of data from this study. For the oral word reading task, a list consisting of 120 two-character high-frequency Chinese words was used, and for the oral sentence reading task, a narrative essay with five paragraphs was used. All tasks were administered online. The participants were asked to read aloud as many words or sentences as accurately as possible within 45 seconds. The experimenter timed 45s and recorded errors. The fluency score is the sum of items correctly pronounced within 45 seconds (word fluency: max = 120, sentence fluency: max=420). If participants finished reading materials for each task within 45 seconds, their final scores were calculated based on the number of correctly read words/finishing time * 60.

***Silent word and sentence reading fluency*.** The silent word task developed by Zhao et al. (2017) was used to assess silent word fluency. Participants were asked to silently read Chinese single-character words as quickly and accurately as possible within 1 minute while crossing out the noncharacters. At the end of this test, participants were asked to mark the last item they read. The score was computed as the number of items read minus the number of errors, in which errors included non-identified noncharacters and incorrectly-marked real characters. There were 402 real-word items with 14 non-word items. The score was the number of words read in one minute (words/min).

This silent sentence task developed by Zhao et al. (2017) was used. Four sentences were presented in the practice session and 50 in the main test. The sentences are about simple facts, and the length of each sentence varies from seven to 22 characters (e.g., 一个星期有七天 'There are seven days in a week'). Half of the sentences were true, and half were false.

Participants are asked to silently read the sentence as accurately and quickly as possible, and to press the space bar when finished. The interval between the beginning of the sentence presentation and the time of pressing the space bar was recorded. Reading fluency for each sentence was calculated based on the relative ratio of the number of characters in the sentence to the time taken to read the sentence. After pressing the space bar, participants were asked to press a key according to whether the sentence made sense or not (*f* key for false and *j* key for true). The accuracy of the veracity judgments was also recorded. Cronbach's alpha for children was reported to be 0.74 on the basis of data from this study.

2.2.2.3 Procedure. The data were collected over the autumn school term in 2021. Two class teachers helped to administer the Raven's SPM test with group testing (lasting c. 30 mins). One week later, children were assessed individually. The assessments were carried out in the school IT room, and Lenovo computers with 21.5-inch screens and a display resolution of 1920x1080 were used. Before the assessments began, children were seated by their class teacher at a distance of approximately 50 cm from the computer screen. The computer microphone was checked, and the shared screen was used (by the researcher) to introduce the tasks.

For the tasks that required children to respond to stimuli presented on the computer screen (VAS tasks, reading tasks, visual memory and RAN), the researcher informed the child of the instructions and once it was clear that the child understood the task, and any practice trials were completed, the shared screen was turned off, in order not to provide distraction. As for the other tasks that did not require children to respond to stimuli on the screen (verbal short-term memory and PA), the shared screen was turned off after the introduction of the trials. Rest breaks were given between the tasks.

2.2.2.4 Data analyses. The analyses involved correlation, principal component analysis, hierarchical regression and structural equation modelling to explore the relationship between reading and VAS assessed with character report and v1b tasks. Relationships of the reading measures with the range of literacy-related variables were explored with correlation analysis and scores for selected variables were included in early steps in the regression analysis, with VAS in the final steps, in order to see whether the effect of VAS would still be significant if influential variables were controlled for. Principal component analysis was used to simplify the complex dataset of various VAS tasks. Structural equation modelling was conducted in order to examine the relationships of observed variables including VAS and reading fluency, and to explore the possible existing latent variables.

2.2.3 Results

The first section presents the descriptive statistics for all the variables and then results for analyses examining potential associations of PA, RAN, MA, character identification, verbal and visual short-term memory, vocabulary and VAS with the children's reading fluency are presented. Table 2 provides a summary of the children's scores in the reading and literacy related measures, while Table 3 provides a summary of scores in the VAS assessments.

Table 2

Descriptive Statistics for Age and Literacy-Related Measures in Study 1a

	Mean (SD)	Range
Age	10.65 (0.63)	8.90-12.80
Nonverbal Abil. (/60)	29.71 (5.14)	12-41
Vocabulary (120)	98.46 (7.46)	86-114
PA (/26)	18.87 (4.86)	8-26
RAN picture (seconds)	88.48 (20.81)	60.21-153.69
RAN digits (seconds)	36.68 (7.89)	21.41-57.30
MA (/124)	90.51 (12.27)	55-115
VerbalFor STM (/13)	8.22 (1.55)	5-13
VerbalBack STM (/12)	5.37 (2.72)	2-12
VisualSimul STM (/12)	9.19 (1.74)	3-12
VisualSeq STM (/12)	9.28 (2.24)	3-12
Oral word fluency	69.25 (17.01)	6-98
Oral sentence fluency	162.98 (49.88)	7-284
Silent word fluency	277.43 (84.40)	123-483.20
Silent sentence fluency	254.56 (91.17)	106.14-552.12
Char. Ident. (/150)	108.63 (15.38)	39-132

Note:. Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN: rapid automatised naming, RAN picture: RAN picture task, RAN digits: RAN digits task, MA: morphological awareness, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification.

Table 3

Descriptive Statistics for VAS Measures in Study 1a

Variables	Mean (SD)	Range
Global report (/120)	66.19 (12.65)	37-91
Partial report (/36)	22.22 (5.85)	7-36
V1b accuracy (/80)	46.15 (7.05)	30-61
V1b d prime	0.44 (0.53)	-1.06-1.75
V1b correct RTs (seconds)	3.33 (0.36)	2.56-4.27

Note:. V1b accuracy: visual 1-back accuracy, V1b d prime: visual 1-back d prime, V1b correct RTs: visual 1-back correct reaction times.

Pearson's correlation analysis revealed the correlations between all the variables in Study 1a. Children’s verbal short-term digit forward memory and digit backward memory were significantly correlated, and visual simultaneous short-term memory and sequential memory were significantly correlated. RAN picture and RAN digits were significantly correlated.

In addition, children’s global report and partial report were significantly correlated, and v1b accuracy and d prime were also significantly correlated. Partial report was significantly associated with v1b accuracy. However, v1b accuracy was not correlated with v1b correct RTs. RAN picture and digits were significantly correlated with global report. These significant correlations are highlighted in red in Table 4.

Table 4

Pearson's Correlation Variables in Study 1a

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Nonverbal Abli.	-																
2	Age	-.06	-															
3	Vocabulary	.31*	.07	-														
4	PA	.14	.01	.10	-													
5	RAN picture	-.01	-.05	-.21	-.30*	-												
6	RAN digits	.11	-.04	.01	-.10	.58***	-											
7	MA	.38**	-.25+	.22	.25+	-.03	-.07	-										
8	VerbalFor STM	.13	.18	.05	.18	-.09	-.06	.21	-									
9	VerbalBack STM	.11	.08	.15	.50***	-.30*	-.10	.24+	.37**	-								
10	VisualSimul STM	.41**	-.04	.25+	.24+	.00	-.04	.31*	.10	-.12	-							
11	VisualSeq STM	.41**	.02	.35*	.50***	-.27*	-.04	.38**	.26+	.38**	.31*	-						
12	Chat. Ident.	.13	-.06	-.10	.06	-.06	-.12	.16	.10	.02	.12	.08	-					
13	Global	-.13	-.02	.17	.05	-.45**	-.45**	.14	.03	.01	-.04	.14	-.14	-				
14	Partial	-.04	-.08	.05	.08	-.11	-.07	-.01	-.11	-.19	.04	.04	.10	.52***	-			
15	V1b accuracy	.15	-.11	.20	.10	.00	.19	-.03	-.24+	-.05	.25+	.19	-.14	.06	.27*	-		
16	V1b d prime	.11	-.16	.17	.09	-.01	.22	.04	-.15	.03	.17	.18	-.17	.04	.22	.94***	-	
17	V1b correct RTs	-.12	.15	-.06	-.07	.25+	.20	.02	.12	.05	-.10	-.07	-.07	.07	.22	.15	.19	-

Note:. Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN: rapid automatised naming, RAN picture: RAN picture task, RAN digits: RAN digits task, MA: morphological awareness, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification, Global: global report; Partial: partial report; V1b accuracy: visual 1-back accuracy; V1b d prime: visual 1-back d prime; V1b correct RTs: visual 1-back correct reaction times.

$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

Principal component analysis with an oblique rotation was used to explore the factor structure in the VAS measures in Table 5. Due to the high correlation between v1b accuracy and d prime in Table 4 (also found by Huang et al., 2019), only v1b accuracy remained to enter the later analysis. The bold loadings in each component might share similarities. Results showed that the global and partial report tasks (Factor 1) shared similarities, and v1b accuracy and correct RTs (Factor 2) shared similarities, respectively.

Table 5

Principal Component Analysis with an Oblique Rotation of VAS Variables in Study 1a (pattern matrix)

	KMO=0.51, Bartlett: *p*=.001	
	Factor 1	Factor 2
Global report	**0.93**	-0.17
Partial report	**0.79**	0.26
V1b accuracy	0.03	**0.75**
V1b correct RTs	-0.03	**0.75**
% of Variance	42.46	25.54

Note:. Variables with high loadings (over 0.3) are in bold. Results for this analysis under the varimax rotation were similar to this one.

Considering the significant correlations between the two verbal short-term memory tasks, also between the two visual short-term memory tasks and between the two RAN tasks, composite scores for verbal short-term memory, visual short-term memory and RAN were calculated by summing the z scores, and they were used in later analyses. This was because, Serlin and Mailloux (1999) claimed that, with normally distributed data, composite variables could provide the greatest increase in power when the original variables have similar associations with the outcome variable.

As for VAS tasks, composite scores were also considered for the later analyses. For global and partial report, a significant correlation was found, and the principal component analysis also revealed similarities between the two tasks. As for the v1b task, the principal component analysis showed similarities between v1b accuracy and v1b correct RT, although no significant correlations were found between v1b accuracy and correct RTs.

Thus, composite scores of the global and partial report tasks were calculated under the formula of Awadh et al. (2022): VAS report composite scores = (Global Score + 2 × Partial Score) × 100/2 × 80. Accuracy and correct reaction times from the v1b task could also be combined together, as Zhao et al. (2018a), but due to the reversed calculation methods between v1b accuracy and correct RTs, v1b errors rather than accuracy were used to combine with correct RTs by adding the z scores of v1b errors and correct RTs, thus producing v1b composite z scores.

Results of normality tests showed that nonverbal ability, visual short-term memory composite z scores, oral word reading fluency, oral sentence reading fluency, silent word reading fluency, single character identification, VAS report composite scores, and V1b composite scores were normally distributed, so other variables (age, verbal short-term memory composite z scores, PA, and silent sentence reading fluency) were transformed: scores for silent sentence reading fluency were transformed using log transformation, while scores for the other variables were transformed using inverse-normal transformation raised by Templeton (2011) because after using log transformation, scores for these variables were still not normally distributed.

Since there was a relatively narrow age range in the participants in this study, we did not expect that chronological age would have a major influence on the results. Indeed, age was not significantly associated with the variables in the simple correlation analysis. Consequently, chronological age was not included in the subsequent analyses.

Pearson's correlation and partial correlation analyses controlling for nonverbal ability showed the results reported in Table 6. Pearson's and partial correlation analyses showed that children's VAS report composite scores were significantly correlated with oral word and sentence reading fluency, and their V1b composite scores were significantly correlated with silent sentence reading fluency. In addition, with both Pearson's and partial correlation analyses, children's RAN composite z scores were significantly associated with oral word and sentence reading fluency, and character identification skills were correlated with silent word reading fluency.

Pearson's correlation analysis also revealed significant correlations between PA and oral sentence reading fluency ($p<.05$), between MA and children's oral sentence reading fluency ($p<.01$) and silent sentence reading fluency ($p<.05$), as well as between vocabulary and oral sentence reading fluency ($p<.05$). The significant correlations between reading and VAS composite scores are highlighted in red in Table 6.

On the basis of the results of the correlation analyses, the variables vocabulary, PA, RAN, MA, character identification and VAS, together with nonverbal ability were considered for inclusion as predictors of the reading measures in the regression analyses that are reported next.

Table 6

Pearson's Correlation (above the diagonal) and Partial Correlation (below the diagonal) Controlling for Nonverbal Ability, with Literacy-related Variables, Reading Measures, and VAS Task Performance in Study 1a

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Nonverbal Abli.	-	-.06	.31*	.14	.02	.38**	.23+	.40**	.02	.17	.22	.23+	.13	-.13	-.04	.15	.11	-.12	-.02	-.25+
2	Age	-	-	.07	.01	.01	-.25	.09	.08	.02	-.01	.02	.04	-.06	-.02	-.08	-.11	-.16	.15	-.16	.17
3	Vocabulary	-	.36*	-	.01	-.17	.22	.02	.39**	.21	.31*	.03	.16	-.10	.17	.05	.20	.18	-.06	.25+	-.22
4	PA	-	.08	-.03	-	-.29*	.25+	.32*	.29*	.33*	.29*	-.02	.08	.06	.05	.08	.10	.09	-.07	.14	-.15
5	RAN comp	-	-.19	-.16	-.29+	-	-.08	-.07	-.11	-.77***	-.71***	-.04	-.27+	-.03	-.58***	-.15	.12	.08	.30*	-.50***	.20
6	MA	-	-.13	.07	.14	.09	-	.19	.35*	.22	.43**	.06	.31*	.16	.14	-.01	-.03	.04	.02	.15	.03
7	Verbal STM comp	-	.01	-.09	.32+	-.03	.12	-	.22	-.01	.04	.10	-.01	.04	-.07	-.11	-.08	.00	.10	-.09	.17
8	Visual STM comp	-	.20	.25	.11	-.11	.25	.08	-	.18	.23+	.11	.06	.16	.02	.16	.08	.02	-.11	.24+	-.20
9	Owf	-	.17	.13	.25	-.75***	-.04	-.11	.21	-	.87***	.25+	.41**	.18	.53***	.14	-.12	-.17	-.25+	.48***	-.15
10	Osf	-	.12	.25	.21	-.71***	.18	-.03	.24	.82***	-	.21	.51***	.14	.63***	.23+	-.06	-.03	-.11	.57***	-.10
11	Swf	-	.04	-.09	-.04	-.09	-.03	.02	.10	.16	.06	-	.11	.38**	-.08	-.18	-.14	-.12	-.06	-.14	-.03
12	Ssf	-	-.15	.19	.00	-.27+	.24	-.19	-.04	.46**	.47**	-.02	-	-.05	.33*	.03	.14	.14	-.32*	.20	-.40**
13	Chat. Ident	-	.04	-.13	-.02	-.09	.08	.04	.09	.19	.13	.40*	.07	-	-.14	.10	-.14	-.17	-.07	-.01	.04
14	Global	-	.15	.22	.05	-.51**	-.01	-.02	-.02	.53**	.63***	-.04	.36*	-.18	-	.52***	.06	.04	.07	.88***	.01
15	Partial	-	-.08	.09	-.00	-.19	-.17	-.26	.04	.21	.31+	-.10	.14	.01	.47**	-	.27*	.22	.22	.84***	-.03
16	V1b accuracy	-	-.22	.13	-.05	.13	.00	-.09	-.16	-.11	-.07	-.18	.17	-.28+	-.05	.07	-	.94***	.15	.11	-.57***
17	V1b d prime	-	-.31+	.07	-.05	.08	.08	-.02	-.19	-.12	-.02	-.13	.11	-.21	-.07	.05	.96***	-	.19	.06	-.50***
18	V1b correct RTs	-	.06	-.04	-.07	.25	.19	.12	-.11	-.21	.01	.01	-.28+	-.05	.15	.12	.08	.14	-	.09	.70***
19	VAS report comp	-	.06	.19	.03	-.43**	-.09	-.15	.01	.45**	.57***	-.08	.31+	-.11	.89***	.82***	.00	-.02	.16	-	.01
20	V1b comp	-	.18	-.14	-.05	.20	.15	.21	-.05	-.18	-.02	.05	-.38*	.13	.16	.07	-.49**	-.43**	.80***	.14	-

Note:. Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN comp: rapid automatised naming composite z scores, Verbal STM comp: verbal short-term memory composite z scores, Visual STM comp: visual short-term memory composite z scores, Owf: oral word reading fluency, Osf: oral sentence reading fluency, Swf: silent word reading fluency, Ssf: silent sentence reading fluency, Chat. Ident.: character identification, Global: global report; Partial: partial report; V1b accuracy: visual 1-back accuracy; V1b d prime: visual 1-back d prime; V1b correct RTs: visual 1-back correct reaction times, VAS report comp: composite scores of the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.

$^{+}$ p<.1, *p<.05; **p<.01; ***p<.001

Regression analyses

Hierarchical regression analysis was carried out with oral and silent reading fluency (Table 7) as the dependent variables for children. Hair et al. (2014) suggested that the recommended the minimum size for conducting multivariate analyses is ten times the number of research instruments. In light of the sample size in the current study, in the regression analysis exploring the predictors of the reading measures, the six independent variables including nonverbal ability, PA, RAN, MA, character identification skills and VAS, that were most strongly associated with children's reading fluency (please refer to Table 6) were entered into the regression. The results of the hierarchical regression analysis including vocabulary as an additional predictor are shown in the Appendix B.

In Step 1, nonverbal ability was entered, and in Step 2, PA, RAN composite scores, MA and character identification were entered. At Step 3, VAS report composite scores were entered in the regression analysis with oral reading fluency as a dependent variable due to significant correlations between VAS report composite score and oral word and sentence reading fluency. V1b composite scores were entered in the regression analysis with silent reading fluency as a dependent variable, because of significant correlations between v1b composite scores and silent sentence reading fluency. Results are reported in Table 7.

Table 7

Hierarchical Regression Analyses with Oral Reading Fluency as the Dependent Variables in Study 1a

		Oral word reading fluency						Oral sentence reading fluency					
Step		ΔR^2	ΔF	β	t	Tol	VIF	ΔR^2	ΔF	β	t	Tol	VIF
1	Nonverbal Abil.	0.00	0.04	-0.03	-0.21	1.00	1.00	0.02	0.86	0.14	0.93	1.00	1.00
2		0.44***	7.51					0.29**	4.02				
	PA			0.09	0.70	0.91	1.10			0.04	0.27	0.91	1.10
	RAN comp			-0.62***	-4.86	0.91	1.10			-0.49**	-3.45	0.91	1.10
	MA			-0.04	-0.31	0.87	1.15			0.24	1.65	0.87	1.15
	Char. Ident			0.10	0.79	0.96	1.04			-0.01	-0.05	0.96	1.04
3	VAS report comp	0.05+	3.45	0.23+	1.86	0.90	1.11	0.17**	12.12	0.43**	3.48	0.90	1.11
		Silent word reading fluency						Silent sentence reading fluency					
Step		ΔR^2	ΔF	β	t	Tol	VIF	ΔR^2	ΔF	β	t	Tol	VIF
1	Nonverbal Abil.	0.06	2.82	0.25	1.68	1.00	1.00	0.03	1.52	0.18	1.23	1.00	1.00
2		0.15	1.87					0.13	1.58				
	PA			-0.03	-0.21	0.87	1.14			-0.13	-0.83	0.90	1.11
	RAN comp			0.00	0.00	0.85	1.17			-0.20	-1.33	0.91	1.10
	MA			-0.07	-0.41	0.79	1.26			0.33*	2.11	0.84	1.19
	Char. Ident			0.39*	2.67	0.95	1.05			-0.12	-0.83	0.96	1.05
3	V1b comp	0.00	0.01	-0.01	-0.09	0.91	1.10	0.13*	7.04	-0.38*	-2.65	0.89	1.13

Note:. Nonverbal Abil.: nonverbal ability, PA: phonological awareness, RAN comp: RAN composite z scores, MA: morphological awareness, Char. Ident.: character identification, VAS report comp: composite scores in the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.
$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

For oral reading fluency, at Step 2, RAN composite scores significantly predicted word and sentence fluency. At Step 3, VAS report composite scores uniquely predicted sentence fluency (*p*<.05).

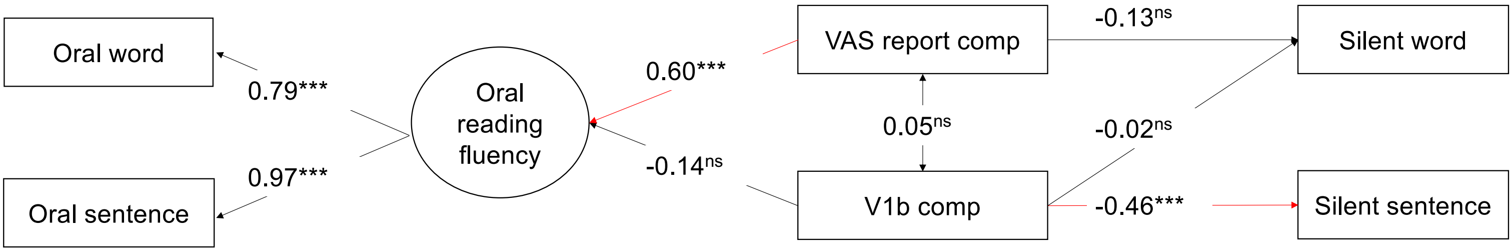
For silent reading fluency, at Step 2, character identification was the only predictor of word fluency, while MA was the only predictor of sentence fluency. At Step 3, V1b composite scores significantly explained 13% of the variance in sentence fluency (*p*<.05).

Structural equation modelling

Structural equation modelling was used to examine the relationship between VAS measures and reading fluency in oral and silent modes (Figure 1).

Figure 1

Structural Equation Modelling of VAS and Oral and Silent Reading Fluency in Study 1a



Note:. Oral word: oral word reading fluency, Oral sentence: oral sentence reading fluency, Silent word: silent word reading fluency, Silent sentence: silent sentence reading fluency, VAS report comp: composite scores in the global and partial report tasks, V1b comp: v1b composite z scores of errors and correct reaction times. The red line means a significant prediction.
$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

Figure 1 shows the model with maximum likelihood as the estimation method, which demonstrated a good fit to the data [x^2 (3, *n* = 56) = 2.83, *p* = 0.42; *CFI* = 1.00; *RMSEA* = 0.00; *SRMR* = 0.02]. This model showed one latent factor made up of oral word and sentence reading fluency. Children's VAS report composite scores and V1b composite scores were not intercorrelated. VAS report composite scores predicted oral reading fluency, whereas V1b composite scores predicted silent sentence reading fluency.

2.2.4 Discussion of 1a

Study 1a investigated the relationship between VAS and Mandarin-speaking children's reading performance. VAS was assessed with two paradigms - global and partial report, and v1b. Results revealed that reading fluency was significantly associated with VAS scores.

RQ1 was "Does VAS predict reading fluency in 10- to 12-year-old Mandarin-speaking children over and above the influence of other literacy-related variables (vocabulary, PA, RAN, MA, verbal and visual memory and character identification)? If so, which reading modes show the strongest influence of VAS? And which VAS task shows the strongest association with reading?”

The findings revealed that VAS report scores uniquely predicted oral sentence reading fluency, and v1b composite scores predicted silent sentence reading fluency after controlling for nonverbal ability, PA, RAN, MA and character identification. The strongest influence of VAS was found for oral sentence reading fluency (17%).

RAN was also found to be a robust predictor of children’s oral reading fluency, which is in accord with existing research (e.g., Chen et al., 2019; Huang et al., 2019; Van Den Boer et al., 2015). This is because RAN shares many processes with reading aloud. For silent reading fluency, results of the regression analyses indicated that character identification and MA were significant predictors of word and sentence reading fluency. Giazitzidou and Padeliadu (2022) and Giazitzidou et al. (2024) indicated the MA was found to significantly predict silent reading fluency of Greek-speaking children after controlling for nonverbal ability, vocabulary and PA. They explained it may be because in the silent reading task, participants may first identify their familiar morphemes in each word based on their semantic memory, and then based on this information, they may recognise and retrieve faster the lexical representation. So, MA involving word meanings could be beneficial for participants to rapidly understand and judge whether the sentences make sense in the silent sentence reading task.

There is a consensus that PA is important for learning to read in alphabetic languages (e.g., Anthony & Francis, 2005) due to the existence of grapheme-phoneme correspondences. In Chinese, although there are no grapheme-phoneme correspondences, it has also been found that PA skills facilitate early character identification, likely through clear and consistent mapping of phonemes to characters, especially for younger children (e.g., children aged 8 to 9 in the study of Cheng et al., 2021, children aged 6 to 7 years in the study of Huang et al., 2021). However, it should be noted in Study 1a that PA scores were only significantly associated with those for oral reading in the simple correlation analysis, and after controlling for nonverbal ability, there was no significant association between PA and any reading measure. This finding is not in line with results for many studies of reading in Chinese speaking children (Cheng et al., 2021; Huang et al., 2021) and in alphabetic languages (e.g., Awadh et al., 2022; Van Den Boer et al., 2015). However, the result from the current study was in accord with that of Chen et al. (2019). Chen et al. reported that PA was not significantly associated with 10-12-year-old children's oral word and sentence reading fluency. Researchers including Yeung et al. (2011) and Yeung et al. (2013) suggested that older children may rely more on orthographic processing for reading and younger children aged phonological processing. This change in literacy strategy has also been proposed for spelling development, as we see in the next chapter.

Most importantly, after controlling for nonverbal ability, PA, RAN, MA and character identification, the regression analyses still showed the predictive power of VAS report scores to children's oral sentence reading (17%, p<.01). These findings are in line with those of Chen et al. (2019) and Huang et al. (2019). The two studies reported the unique role of VAS in oral sentence reading fluency after controlling for nonverbal ability and RAN. The results from Study 1a support the unique prediction of VAS to children's oral reading fluency. Chen et al. (2019) and Huang et al. (2019) suggest that this is because well developed VAS enables the parallel processing of multiple orthographic units (Chinese characters), thus affecting the efficiency of processing sentences.

By contrast, v1b composite scores significantly explained 13% of the variance in silent sentence reading fluency (p<.05). This finding supports the unique role of VAS in children's silent reading fluency, which is not in line with the results of Huang et al. (2019) who found a unique prediction of VAS (correct RTs) to 10- to 12-year-old children's oral sentence reading fluency, not silent sentence reading fluency. The discrepancy in results might be because, firstly, compared with Huang et al. (2019), who controlled for age, nonverbal ability and language skills, more related variables were controlled for in the regression analyses in the present study. Secondly, the composite scores of the v1b tasks were used in this study rather than a single (correct RT) variable used by Huang et al. (2019).

In addition, the analyses revealed that VAS report scores predicted children's oral reading fluency at sentence level, whereas v1b scores just predicted their silent sentence reading fluency. This may be because the global and partial report tasks involved not only visual-phonology mapping to characters but also oral report, which overlaps with the processing involved in oral reading, as argued by Chen et al. (2019). By contrast, the processes involved in the v1b task may be more in line with skills used in silent reading. The silent sentence reading task requires a larger visual attentional window than the silent word task. So, the prediction of the v1b scores to silent sentence reading fluency but not to silent word reading fluency could be expected.

The structural equation model with a good model fit demonstrated the relationship between VAS under different tasks and children's reading fluency in oral and silent modes. Children's oral reading fluency as a latent factor was made up of oral word and sentence reading fluency, but silent reading fluency failed to comprise silent word and sentence reading fluency as another latent factor. This may suggest that children have more reading experience and familiarity with oral reading rather than silent reading.

Regarding RQ2 ‘What is the association of VAS with other literacy-related variables’, the findings were partially in line with the hypothesis that results showed no correlation between VAS and PA and significant associations between VAS and RAN. However, significant correlations between VAS and verbal and visual memory were not observed.

VAS and PA were not significantly associated, which supports the independence of VAS and phonological skills, as previously noted by, for example, Valdois et al. (2003) and Bosse et al. (2007). In terms of VAS and RAN, correlational analyses revealed significant associations between the two, which was in line with the findings of Van Den Boer et al. (2015). This indicates that they share underlying processes, including the processing of (familiar) visual stimuli, access to lexical representations and corresponding verbal labels, together with the production of phonological forms (Chen et al., 2019; Moll et al., 2009; Nielsen & Juul, 2016; Stainthorp et al., 2010; Van Den Boer et al., 2014; Ziegler et al., 2010) On the other hand, considering potential non-overlapping aspects of the VAS and RAN measures, the additional feature required in tasks used to assess VAS is the requirement to process the stimuli in parallel. VAS had a more significant association with sentence reading and RAN played a more important role in word reading, likely because sentence reading draws more strongly on visual parallel processing than word reading.

In terms of VAS and verbal memory, no relationship between VAS and verbal short-term memory was found, which was in line with Cheng et al. (2021). Cheng et al. showed VAS assessed in the v1b task with unfamiliar symbols was not correlated with verbal memory. Lobier, Zoubrinetzky and Valdois (2012) also claimed that although VAS assessed in the global report task included verbal responses and stimuli (Ziegler et al., 2010), VAS was still visual, not verbal tasks. Verbal memory in the global task was only used in the retention of visual items that were identified by participants before the oral report, thus not being involved too much.

In terms of VAS and visual memory, no correlation between VAS and visual short-term memory was found, which was in accord with the findings of Chen et al. (2019). Chen et al.'s results revealed that visual memory storage is different from visual simultaneous processing. However, this does not mean there is no relationship between VAS and visual memory. The sample size may not have been large enough to find a correlation between VAS and visual memory in Study 1a. More participants may be needed in the future to explore this in detail. The alternative explanation may be, as Huang et al. (2019) argued, that children's VAS and visual memory are still developing, so it is reasonable not to see a relationship between the two variables. Thus, it could be expected the relationship between VAS and visual memory in the following adults 'study.

Regarding RQ3 "What is the association of VAS tasks from different VAS paradigms", the results were in line with the hypothesis that global and partial report scores were significantly correlated with each other and d prime and accuracy in the v1b task were also significantly associated. V1b correct RTs were not associated with v1b accuracy or d prime. In addition to these, a new finding was that partial report was found to be significantly associated with v1b accuracy.

Significant correlations between global and partial report were found in children's groups, which was in line with the existing research (such as Bosse et al., 2007 for

French and English children aged 9 to 11 years; Bosse et al., 2009 for French children aged 6 to 11 years). V1b accuracy was also highly correlated with d prime, which was in line with Huang et al. (2019) who claimed d prime and accuracy overlapped with each other to a great extent.

However, in Study 1a, v1b accuracy and partial report were found to be significantly associated. I previously hypothesised there was no correlation between the two different paradigms. The structural equation model also showed children's VAS report scores and v1b scores were not intercorrelated, which indicates that the processes involved in the two VAS paradigms do not overlap to a great extent. This may be because children have not yet developed mature VAS, as reported by Huang et al. (2019). The other possibility is that the v1b task makes demands on resources that are not present in the report tasks due to use of unfamiliar symbols, which made it difficult for them to achieve high sensitivity in this task, as found by Zhao et al. (2018a). So far, no children's studies have reported such a correlation. The finding in Study 1a supported the connection between the partial report and v1b accuracy.

Overall, regarding the research questions, VAS played a unique role in Mandarin-speaking children's reading fluency (17%, $p<.01$) after controlling for nonverbal ability, PA, RAN, MA and character identification skills. VAS report scores in global and partial report significantly predicted children's oral reading fluency, mainly in oral sentence reading, in addition to RAN. V1b scores significantly predicted children's silent sentence reading fluency (13%, $p<.05$), in addition to MA. The strongest influence of VAS was observed for oral sentence reading fluency. The findings are discussed in relation to those of the adult participants in Study 1b at the end of the chapter.

2.3 Study 1b: Relationship between VAS and reading in Mandarin-speaking adults

This study aims to investigate the relationship between VAS and reading fluency of Mandarin-speaking adults. So far, only four studies have explored VAS and reading of adults, one that has included Arabic-, French- and Spanish speakers (Awadh et al., 2016) and three that have involved Chinese speakers (Chan & Yeung, 2020; Huang et al., 2019; Zhao et al., 2017). These studies focused on exploring the relationship between VAS and reading fluency and VAS tasks themselves rather than the relationship between VAS and other literacy-related variables. However, in order to conduct a comparison with the results for children in Study 1a, the relationships between VAS and the same literacy-related variables, with the exception of MA were explored in Study 1b. This is because MA was usually shown to be a predictor of reading fluency in younger children but not in adults. MA has always been reported to be an important longitudinal factor in Chinese early literacy acquisition, including reading and spelling of Mandarin-speaking and Cantonese-speaking children (Mandarin-speaking children aged 7 to 10 years from Li et al., 2020; Mandarin-speaking children aged 4 to 11 years from Pan et al., 2016; Cantonese-speaking children aged 5 to 7 years from Tong et al., 2009; Cantonese-speaking children aged 7 to 11 years from Yeung et al., 2013).

As discussed in Section 1.5, VAS is likely to involve parallel processing, visual attention allocation and working memory. At the same time, no correlations between PA, verbal memory and VAS were found. So, I might expect to find in Study 1b with adults, significant associations between VAS, RAN and visual short-term memory.

In addition, significant correlations among global report, partial report and v1b accuracy of adults were reported in Chan and Yeung (2000). However, Huang et al.

(2019) found correlations between v1b correct RTs and v1b accuracy/d prime were not found in adults. So, this study also investigated the potential associations among the report and v1b tasks.

2.3.1 Research questions

The three research questions were also the same as the Study 1a:

With regard to RQ1 and RQ2, the predictions were the same as the Study 1a

Different from the children study, the prediction to RQ3 in adult study was that nearly all VAS variables were significantly correlated with each other, except for v1b correct RTs and v1b accuracy/d prime, as reported in Studies 7 and 8, Chan and Yeung (2020) and Huang et al. (2019) respectively.

2.3.2 Method

2.3.2.1 Participants. Participants included 58 adults (28 female) aged from 19 to 51 years (*m*=27.85, *sd*=7.19) through simple random sampling. They are all native speakers of Chinese (Mandarin) and use simplified Chinese characters under diverse SES and education background. Most of the adult participants (*n*=46) had a university degree and these adults have relatively high-level English skills, especially for reading and writing because they were required to pass the College English Test Band 4 (an official test involving English listening, reading and writing) according to the regulations of higher education in China. The rest of the participants (*n*=12) had graduated from junior colleges. All of the adults had normal or corrected to normal vision. One male adult and one female adult have been diagnosed as dyslexics in UK and Singapore as teenage and adult respectively, but they had not received any subsequent intervention. The other adults did not participate in any assessment of literacy and cognition for dyslexia and dysgraphia. Based on the G-power analysis, there should have been at least 55 adults, so the sample size of 58 adults was sufficient for this study.

Ethical approval for the current study was acquired from the authors' university ethical review board. Written informed consent to participate in the research was obtained from adult participants themselves before testing began. DBS certificate was also provided.

2.3.2.2 Materials*. Nonverbal ability.* The assessment was the Raven's SPM task, as used in Study 1a. The Cronbach's alpha was 0.92 for adults based on scores from this study.

***VAS global report task**.* This was the same as the one used in Study 1a - adapted for Chinese-speaking adult participants by Chan and Yeung (2020) using 10 traditional single characters (the reliability was reported to be 0.83 for adults in that study). The Cronbach's alpha was 0.94 for adults based on scores from this study.

VAS partial report task. This was the same as the one used in Study 1a. The Cronbach's alpha was 0.81 for adults based on scores from this study.

VAS v1b task. This one was the same as the one used in Study 1a. The Cronbach's alpha was 0.67 for adults based on scores from this study. All adults' d prime values were randomly assigned into four sections and the four sections were shown not to be significantly different (please see Appendix A), suggesting no attention distraction of adults in the v1b task.

Vocabulary. This was the same as the one used in Study 1a. The Cronbach's alpha was 0.69 for adults based on scores from this study.

Verbal short-term memory. Verbal short-term memory was assessed using the Digit Span Forward and Backward subtest of the Chinese Wechsler Intelligence Scale for adults (Revision of Wechsler Adult Intelligence Scale in China, WAIS-RC; Gong, 1983). The highest number of digits correctly repeated by adults was their score (Cronbach's alpha was 0.72 for the Digit Span Forward task; Cronbach's alpha was 0.80 for the Digit Span Backward task based on scores from this study). The maximum score on this test was 13.

Visual short-term memory. This was the same as the task used in Study 1a. Cronbach's alpha was 0.58 for the visual simultaneous memory task, and Cronbach's alpha was 0.55 for the visual sequential memory task based on scores from this study.

Phonological awareness (PA). The phoneme deletion task for adults from Hamilton (2007) was used. Cronbach's alpha was 0.68 based on scores from this study. Participants were presented with one, two, or three Chinese syllable items spoken by the tester, and were asked to say aloud the syllable without the initial, middle, or final phoneme (for example, 'please tell me what/guang1/would be without the first sound.' The correct answer was '/uang1/'). The task for adults comprised 33 items for the main task and three practice items. Correct responses were given one point.

Rapid automatised naming (RAN). This was the same as the RAN task used in Study 1a. Cronbach's alpha was 0.87 for adults based on scores from this study.

Single-character identification. This task was similar to the one used in Study 1a, but at the offset of the letter, a mask was displayed for 150 ms for adults. The mask was introduced as otherwise scores would be at ceiling in the task. The version of the task with a mask was as it had been used in the study with adults of Awadh et al. (2016). The Cronbach's alpha was 0.85 for adults based on scores from this study.

Oral word and sentence reading fluency. This was the same as the task used in Study 1a. Cronbach's alpha was respectively 0.67 for adults based on scores from this study.

Silent word and sentence reading fluency**.** This was the same as the task used in Study 1a. The Cronbach's alpha was 0.68 for adults based on scores from this study.

2.3.2.3 Procedure. The data were collected from June to December 2022 and all tasks were administered individually online by the researcher, with sessions on four separate days for each participant. Participants used their laptops (including 23 laptops with Mac systems and 35 laptops with Windows systems) with 60 Hz to 75 Hz refresh rate during the assessments.

The global and partial report tasks were assessed first and then the v1b task (lasting c. 15-20 minutes in total). The nonverbal ability task (usually lasting 35 to 45 minutes) was administered in the second session. At the third session, vocabulary was assessed (usually lasting 25 minutes). In the fourth section, oral reading, PA, RAN and verbal short-term memory were administered (lasting c. 25-35 minutes in total). Finally, visual short-term memory, silent reading fluency and character identification tasks were conducted (lasting c. 30-40 minutes in total).

2.3.2.4 Data analyses. The analyses involved the same data analyses as the Study 1a including correlation, principal component analysis, hierarchical regression and structural equation modelling. In addition, independent t-tests were conducted to compare the scores of children from Study 1a and adults for purposes of examining developmental progression in the variables.

2.3.3 Results

The first section presents the descriptive statistics for all the variables and then results for analyses examining potential associations of age, nonverbal ability, vocabulary, PA, RAN, character identification, verbal and visual short-term memory and VAS with reading fluency are presented.

Table 8 provides a summary of the adult participants' scores in all the literacy-related measures as well as the results of t-tests comparing scores with those from the children Study 1a.

Table 8

Descriptive Statistics for All Literacy-Related Measures in Study 1b and Comparison with Results for Children from Study 1a

	Adults		Children		
Variables	Mean (SD)	Range	Mean (SD)	T-test	*P*
Age	27.85 (7.19)	19.08-51	10.65 (0.63)	$t(57.91) = -18.15$	.000
Nonverbal Abil. (/60)	44.3 (8.01)	19-59	29.71 (5.14)	$t(95.68)=-11.54$	.000
Vocabulary (120)	112.41 (4.06)	100-118	98.46 (7.46)	$t(84.29)=-12.33$	.000
PA (/33)	28.38 (2.64)	21-33	18.87 (4.86)	$t(83.21)=-12.75$	.000
RAN picture (seconds)	68.40 (12.19)	50.70-98.81	88.48 (20.81)	$t(84.28)=6.17$	.000
RAN digits (seconds)	26.09 (6.24)	14.93-55.74	36.68 (7.89)	$t(100.90)=7.84$	.000
VerbalFor STM (/13)	10.04 (1.17)	8-12	8.22 (1.55)	$t(107)=-6.91$	.000
VerbalBack STM (/13)	7.24 (1.95)	2-12	5.37 (2.72)	$t(99.46)=-4.20$	.000
VisualSimul STM (/12)	10.43 (1.69)	5-12	9.19 (1.74)	$t(111)=-4.01$	.000
VisualSeq STM (/12)	10.48 (1.58)	5-12	9.28 (2.24)	$t(94.76)=-3.27$	.001
Oral word fluency	98.74 (16.40)	58-135	69.25 (17.01)	$t(112)=-10.25$	.000
Oral sentence fluency	296.98 (84.69)	155-651.72	162.98 (49.88)	$t(92.88)=-10.34$	.000
Silent word fluency	451.93 (238.50)	145-1269.47	277.43 (84.40)	$t(71.96)=-5.23$	.000
Silent sentence fluency	357.94 (124.12)	135.05-608.97	254.56 (91.17)	$t(102.82)=-5.05$	.000
Char. Ident. (/150)	103.07 (22.76)	29-134	108.63 (15.38)	$t(98.50)=1.52$	.131

Note:. Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN: rapid automatised naming, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification. Maximum scores for PA task were 26 for children and 33 for adults. Maximum scores for each verbal memory test were 12 for children and 13 for adults.

Inspection of Table 8 reveals that there were significant differences in all reading-related variables between children and adults, except for scores in the character identification task. This is likely due to the use of a post-presentation mask in the character identification task for adults but not children. Table 9 provides a summary of the adults' scores in the VAS assessments and the results of t-tests comparing scores with those from the Study 1a.

Table 9

Descriptive Statistics for VAS Measure in Study 1b and Comparison with Results for Children from Study 1a

	Adults		Children		
Variables	Mean (SD)	Range	Mean (SD)	T-test	*P*
Global report (/120)	80.69 (13.77)	46-110	66.19 (12.65)	$t(110) = -5.79$	.000
Partial report (/36)	24.10 (5.92)	9-35	22.22 (5.85)	$t(110) = -1.69$	.094
V1b accuracy (/80)	50.33 (7.35)	36-63	46.15 (7.05)	$t(112) = -3.24$	.002
V1b d prime	0.79 (0.59)	-0.49-2.89	0.44 (0.53)	$t(110) = 4.04$	.000
V1b correct RTs (seconds)	3.01 (0.47)	1.95-4.38	3.33 (0.36)	$t(109) = -3.23$	.002

Note:. V1b accuracy: visual 1-back accuracy, V1b d prime: visual 1-back d prime, V1b correct RTs: visual 1-back correct reaction times.

In Table 9, there were significant differences in all VAS tasks between children and adults, except the partial report.

Pearson's correlation analysis showed the correlations between all VAS variables and other related variables reported in Table 10. Digits forward and digits backward scores were significantly correlated, and visual simultaneous memory and sequential memory were significantly correlated. RAN picture and RAN digits were also significantly correlated.

In addition, global report and partial report were significantly correlated, and V1b accuracy and d prime scores were also significantly correlated. Partial report scores were found to be significantly associated with those for visual simultaneous memory, v1b accuracy and d prime. V1b accuracy was also correlated with v1b correct RTs. Visual sequential short-term memory was correlated with the partial report, and scores for the two RAN tasks were significantly associated with those from the global report task. These significant correlations are highlighted in red in the table.

Table 10

Pearson's Correlation with VAS and Other Important Variables in Study 1b

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Nonverbal Abli.	-															
2	Age	.08	-														
3	Vocabulary	.40**	.09	-													
4	PA	-.26+	.04	.01	-												
5	RAN picture	-.19	.08	-.14	.03	-											
6	RAN digits	.17	.21	-.20	-.21	.36**	-										
7	VerbalFor STM	.05	-.06	.30*	.33*	-.26+	-.32*	-									
8	VerbalBack STM	.23+	.07	.25+	.12	-.00	-.17	.29*	-								
9	VisualSimul STM	.24+	-.24+	.23+	-.17	-.10	-.07	-.12	.28*	-							
10	VisualSeq STM	.10	-.06	.28*	.08	-.21	-.13	-.01	.25+	.62***	-						
11	Chat. Ident.	-.09	-.38**	-.15	-.13	-.03	-.01	-.02	-.09	.04	-.09	-					
12	Global	-.09	-.31*	.15	.10	-.33*	-.35**	.24+	.33*	.19	.12	.31*	-				
13	Partial	.16	-.27*	.16	-.00	-.16	-.05	.16	.22	.31*	.14	.17	.49***	-			
14	V1b accuracy	.43**	-.04	.19	-.02	-.11	.01	.04	.05	.16	.09	-.05	.17	.32*	-		
15	V1b d prime	.44**	.02	.21	-.07	-.06	.03	-.03	.05	.13	.06	-.07	.17	.33*	.92***	-	
16	V1b correct RTs	.16	.23+	.25+	-.01	.13	.16	-.07	-.09	-.14	-.06	.04	-.08	-.07	.27*	.24+	-

Note:. Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN: rapid automatised naming, RAN picture: RAN picture task, RAN digits: RAN digits task, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification, Global: global report; Partial: partial report; V1b accuracy: visual 1-back accuracy; V1b d prime: visual 1-back d prime; V1b correct RTs: visual 1-back correct reaction times.

$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

Principal component analysis with an oblique rotation was used to explore the factor structure in all VAS measures. Results are presented in Table 11. The bold loadings in each component might share similarities. Results showed that the global report task, partial report tasks and v1b accuracy (Factor 1) shared similarities, whereas v1b accuracy and correct RTs (Factor 2) shared similarities.

Table 11

Principal Component Analysis with an Oblique Rotation of VAS Variables in Study 1b

	KMO=0.51, Bartlett: *p*=.000	
	Factor 1	Factor 2
Global report	**0.81**	-0.10
Partial report	**0.84**	0.09
V1b accuracy	**0.33**	**0.75**
V1b correct RTs	-0.25	**0.84**
% of Variance	39.43	30.77

Note:. Variables with high loadings (over 0.3) are in bold. Results for this analysis under the varimax rotation were similar to this one.

As in Study 1a, correlations were examined in order to reduce variables where possible. There were significant correlations between scores in the two verbal short-term memory tasks, the two visual short-term memory tasks and between the two RAN tasks. Thus, the respective composite scores of verbal short-term memory, visual short-term memory and RAN were calculated by summing standardised scores for each variable, and these were used in the later analyses.

For the VAS tasks, the respective composite scores of the two VAS paradigms were also considered for the later analyses, namely VAS report composite scores and v1b composite z scores.

Results of normality tests showed that scores for nonverbal ability, verbal short-term memory composite scores, PA, oral word fluency, silent sentence fluency, VAS report composite scores and character identification were normally distributed. Scores for other variables (age, visual short-term composite scores, RAN composite z scores, oral sentence fluency, silent word fluency and v1b combined scores) were transformed using the inverse-normal transformation (Templeton, 2011) because after using the conventional log transformation, scores for these variables were still not normally distributed.

Pearson's correlation and partial correlation analyses controlling for nonverbal ability revealed the results reported in Table 12. Under both sets of correlation analyses, VAS report composite scores were significantly correlated with silent word reading fluency, while V1b composite scores were significantly correlated with silent sentence reading fluency. In addition, RAN was significantly associated with oral word reading fluency in Pearson’s and partial correlation analyses. PA and RAN were not significantly associated with scores for any VAS task.

Pearson’s correlation analysis also revealed significant correlations between chronological age and sentence reading fluency in oral (p<.05) and silent (p<.01) modes, and between age and the two sets of VAS composite scores. VAS report composite scores were also found to be significantly correlated with V1b composite scores (p<.05). The partial correlation also showed a significant correlation between character identification and oral word reading fluency (p<.05). The significant correlations between reading and VAS composite scores and between two the VAS composite scores are highlighted in red in Table 12.

The variables age, RAN and character identification were included together with nonverbal ability as predictors in the following regression analyses.

Table 12

Pearson's Correlation (above the diagonal) and Partial Correlation (below the diagonal, after controlling for age and nonverbal ability) of VAS, Other Cognitive Variables and Reading Fluency in Study 1b

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Age	-	.08	.09	.04	.22	.02	-.09	-.12	.32*	-.26+	.44**	-.38**	-.31*	-.27*	-.04	.02	.23	-.27*	.27*
2	Nonverbal Abil.	-	-	.40**	-.26+	.04	.19	.18	.03	.25+	.06	.13	-.09	-.09	.16	.43**	.44**	.16	.02	-.15
3	Vocabulary	-	-	-	.01	-.18	.33*	.27*	.17	.11	.15	.08	-.15	.15	.16	.19	.21	.25+	.10	.11
4	PA	-	-	.08	-	-.14	.31*	.02	.10	-.04	.19	-.08	-.13	.10	-.00	-.02	-.07	-.01	.08	-.02
5	RAN comp	-	-	-.14	-.13	-	-.09	-.10	-.69***	-.27*	-.21	-.36**	-.04	-.36**	-.09	-.08	-.03	.16	-.25+	.21
6	Verbal STM comp	-	-	.24	.35*	-.06	-	.08	.23+	.03	.06	.12	-.09	.31*	.23+	.07	.04	-.06	.30*	-.06
7	Visual STM comp	-	-	.08	.16	-.10	-.08	-	.06	.22	.10	.23+	.02	.12	.28*	.18	.13	-.08	.12	-.24+
8	Owf	-	-	.14	.08	-.62***	.07	-.01	-	.39**	.09	.32*	-.14	.30*	-.01	.06	.04	-.26*	.18	-.21
9	Osf	-	-	.00	.02	-.21	-.15	.14	.36*	-	.35**	.19	.16	.12	.16	.12	.01	.08	.13	-.08
10	Swf	-	-	.20	.18	-.30+	.09	.14	.22	.32*	-	.13	.25+	.27*	.37**	.08	.02	.04	.30*	-.08
11	Ssf	-	-	-.16	-.07	-.14	.03	.14	.14	-.14	-.01	-	.19	.31*	.33*	.16	.12	-.38**	.29*	-.43**
12	Chat. Ident	-	-	-.14	-.18	.18	-.10	.01	-.35*	-.04	.14	-.03	-	.31*	.17	-.05	-.07	.04	.11	.13
13	Global	-	-	.11	.07	-.09	.26+	-.02	-.04	-.05	.31*	-.03	.20	-	.49***	.17	.17	-.08	.86***	-.15
14	Partial	-	-	-.03	.02	.14	.07	.16	-.37*	-.06	.30+	.09	.02	.21	-	.32*	.33*	-.07	.79***	-.29*
15	V1b accuracy	-	-	-.05	.10	-.01	-.02	.10	-.05	-.00	-.09	.07	.02	.18	.35*	-	.92***	.27*	.28*	-.63***
16	V1b d prime	-	-	.01	.09	.04	-.06	.04	-.13	-.04	-.12	.02	.02	.15	.41**	.95***	-	.24	.30*	-.55***
17	V1b correct RTs	-	-	.26	-.04	.02	-.04	-.10	-.19	.06	-.12	-.42**	.18	.18	.02	.31*	.39*	-	-.10	-.50***
18	VAS report comp	-	-	.05	.06	.02	.22	.08	-.24	-.07	.39*	.03	.15	.81***	.74***	.33*	.34*	.13	-	-.31*
19	V1b comp	-	-	.24	-.10	.10	-.05	-.24	-.12	.03	-.06	-.39*	.15	-.01	-.31*	-.60***	-.49**	.53***	-.19	-

Note:. Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN comp: rapid automatised naming composite z scores, Verbal STM comp: verbal short-term memory composite z scores, Visual STM comp: visual short-term memory composite z scores, Owf: oral word reading fluency, Osf: oral sentence reading fluency, Swf: silent word reading fluency, Ssf: silent sentence reading fluency, Chat. Ident.: character identification, Global: global report; Partial: partial report; V1b accuracy: visual 1-back accuracy; V1b d prime: visual 1-back d prime; V1b correct RTs: visual 1-back correct reaction times, VAS report comp: composite scores of the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.

$^{+}$ $p<.1$, *$p<.05$; **$p<.01$; ***$p<.001$

Regression analyses

Hierarchical regression analysis was carried out with oral and silent reading fluency as the dependent variables. Results are reported in Table 13. According to our sample size, in the regression analysis to explore the predictors of the reading measures, the five independent variables (age, nonverbal ability, RAN composite z scores, character identification skills and VAS) that were most significantly correlated with the participants' reading fluency were entered into the regression.

In Step 1, age and nonverbal ability were entered, and in Step 2, RAN composite scores and character identification were entered. At Step 3, VAS report composite scores were entered in the regression analysis with oral reading fluency and silent word reading fluency as dependent variables. V1b composite scores were only entered in the regression analysis with silent sentence reading fluency as the dependent variable. Results are reported in Table 13.

Table 13

Hierarchical Regression Analyses with Oral and Silent Reading Fluency as the Dependent Variables in Study 1b

		Oral word reading fluency						**Oral sentence reading fluency**					
Step		ΔR^2	ΔF	β	t	Tol	VIF	ΔR^2	ΔF	β	t	Tol	VIF
1		0.02	0.57					0.15*	3.98				
	Age			-0.12	-0.84	0.98	1.02			-0.37*	-2.68	0.97	1.04
	Nonverbal Abil.			-0.08	-0.52	0.98	1.02			0.19	1.37	0.97	1.04
2		0.49***	22.78					0.05	1.24				
	RAN comp			-0.67***	-6.32	0.96	1.05			-0.21	-1.54	0.96	1.04
	Chat. Ident			-0.21+	-1.82	0.84	1.19			0.07	0.44	0.81	1.24
3	VAS report comp	0.01	0.63	-0.09	-0.79	0.82	1.22	0.02	1.09	-0.16	-1.05	0.82	1.22
		Silent word reading fluency						**Silent sentence reading fluency**					
Step		ΔR^2	ΔF	β	t	Tol	VIF	ΔR^2	ΔF	β	t	Tol	VIF
1		0.08	1.92					0.17*	4.71				
	Age			-0.26+	-1.86	0.98	1.02			-0.38**	-2.87	0.99	1.01
	Nonverbal Abil.			0.12	0.87	0.98	1.02			0.11	0.81	0.99	1.01
2		0.02	0.42					0.07	1.92				
	RAN comp			-0.11	-0.72	0.96	1.05			-0.27+	-1.96	0.93	1.07
	Char. Ident			0.10	0.61	0.84	1.19			0.04	0.30	0.83	1.21
3	VAS report comp	0.03	1.51	0.06	0.40	0.82	1.22						
3	V1b comp							0.09*	5.66	-0.31*	-2.38	0.89	1.12

Note:. Nonverbal Abil.: nonverbal ability, Chat. Ident.: character identification, RAN comp: rapid automatised naming composite scores (z), VAS report comp: composite scores of the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.
$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

For oral reading fluency, at Step 1, age was the only predictor, and at Step 2, RAN composite z scores were significant predictors (*p*<.001). At Step 3, VAS report composite scores were not significant predictors.

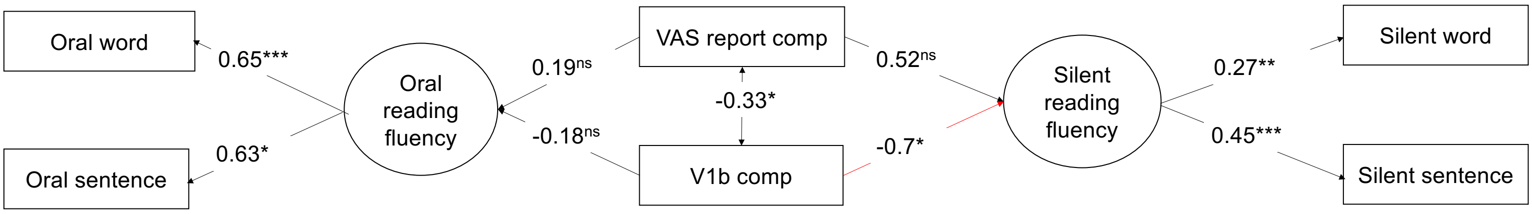
For silent reading fluency, at Step 1, age was a significant predictor. At Step 3, V1b composite scores as unique predictors significantly explained 9% of the variance (*p*<.05).

Structural equation modelling

Structural equation modelling was used to test the relationship between VAS measures and reading fluency in oral and silent modes. The results are summarized in Figure 2.

Figure 2

Structural Equation Modelling of VAS and Oral and Silent Reading Fluency Measures in Study 1b



Note:. Oral word: oral word reading fluency, Oral sentence: oral sentence reading fluency, Silent word: silent word reading fluency, Silent sentence: silent sentence reading fluency, VAS report comp: composite scores of the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times. The red line means the significant prediction.

$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

Inspection of Figure 2 reveals the model with diagonally weighted least squares as the estimation method, which demonstrated a good fit to the data [x^2 (5, *n* = 58) = 6.02, *p* = 0.30; *CFI* = 0.98; *RMSEA* = 0.06; *SRMR* = 0.07]. This model showed two latent factors: one made up of oral word reading fluency and oral sentence reading fluency and the other made up of silent word reading fluency and silent sentence reading fluency. VAS report composite scores failed to predict oral reading fluency whereas V1b composite scores predicted silent reading fluency. VAS report composite scores and V1b composite scores were significantly associated.

2.3.4 Discussion of 1b

Compared with scores of children and adults, it could be found that adults' scores for all literacy-related variables were significantly higher than children's, except for the character identification. This may be because a mask in this character identification task was used for adults rather than for children. Moreover, there were significant differences in nearly all VAS tasks between children and adults, except for the partial report, meaning children and adults had analytical processing skills at similar levels, but adults' VAS performed better. Pearson's correlation also showed a significant correlation between adults' VAS report scores and v1b scores, not for children in Study 1a. These all suggested the developmental trend of VAS.

Regarding RQ1 "Does VAS predict reading fluency of Mandarin-speaking adults over and above the influence of other literacy-related variables? If so, which reading modes show the strongest influence of VAS? And which VAS task shows the strongest association with reading?" the prediction was that VAS would have a unique prediction for reading fluency after controlling for other important variables. Global and partial report may show a stronger influence on oral reading. The v1b showed a stronger influence on silent reading. The strongest influence of VAS would be observed for silent sentence reading fluency.

Results from Study 1b were in line with these hypotheses, except that all VAS tasks, even including global and partial report tasks, just showed a strong correlation with silent reading rather than oral reading. The hierarchical regression analyses showed that VAS failed to predict any adults' oral reading fluency. RAN was an extremely significant predictor of adults' oral word reading fluency after controlling for age and nonverbal ability, which was in line with Study 1a. The result re-suggested the importance of RAN in oral word reading. With the increase in vocabulary and reading experience, adults could retrieve the pronunciation of the words through partial cues of words rather than the whole words (e.g., Greenberg et al., 2002). Even if some adults did not have large VAS to read, they still could identify the words due to their familiarity with the partial cues of words. Accordingly, the automatic retrieval speed becomes more critical for adults in word reading fluency.

By contrast, for silent reading fluency, correlational analyses showed that scores in whichever VAS paradigms were only significantly correlated with adults' silent reading fluency rather than oral reading fluency. This may be because compared with oral reading, adults may be involved in more silent reading during daily life. Van Den Boer et al. (2014) mentioned that silent reading fluency was the more common mode of reading for proficient readers because the focus shifts rapidly from initial instruction in oral decoding toward independent silent reading in school.

More importantly, after controlling for age, nonverbal ability, RAN and character identification, V1b composite z scores were still found to play a unique predictive role in adults' silent sentence reading fluency, which was in line with Huang et al. (2019) and Zhao et al. (2019). The two studies reported the unique prediction of v1b correct RTs to silent sentence reading fluency of Mandarin-speaking adults. This was because VAS could influence the parallel processing of multiple orthographic units, thus facilitating the processing efficiency in the silent sentence reading task, as reported by Zhao et al. (2017).

It should be noted that only v1b scores were found to show the predictive power of adults' silent sentence reading fluency, although VAS report scores were significantly correlated with silent word and sentence reading fluency in Pearson's correlation. After controlling for age, nonverbal ability, RAN and character identification skill, the prediction of VAS report scores was not significant. Silent reading was implicated with the parallel processing of multiple orthographic units as mentioned by Van Den Boer et al. (2014), which might be reflected in the global report task involving global mode processing, rather than the partial report task involving the analytical mode processing. Thus, after combining the scores in the global and partial report, the influence of VAS report composite scores on silent reading may be weakened, which could partially explain why adults' VAS report composite scores were significantly correlated with their silent reading fluency (silent word and sentence reading in Pearson's correlation, and silent word reading in Partial correlation) but failed to predict their silent reading fluency in the regression analyses.

The final structural equation model with a good model fit demonstrated the relationship between VAS (VAS report scores and v1b scores) and adults' reading fluency in oral and silent modes. Adults' oral reading fluency as a latent factor was made up of oral word and sentence reading fluency, and their silent reading fluency was comprised of silent word and sentence reading fluency as another latent factor. This meant adults had enough reading experience in both oral and silent reading. Jasińska and Petitto (2014) found that all of the orthographic, phonological, and semantic representations would be activated in the oral as well as the silent reading mode in adults due to their growing reading experience. Neuroimaging findings support the above inference. For example, Wang et al. (2015) indicated that both silent reading and oral reading in adults activate brain regions involved in visual-to-semantic mapping (e.g., left middle temporal gyrus) and brain areas responsible for orthographic-to-phonological mapping (e.g., left inferior frontal gyrus, left inferior parietal lobule).

Findings also indicated that age was a predictor of adults' oral sentence reading fluency. Results of hierarchical regression analyses revealed that age was a predictor of silent sentence reading fluency for adults. This has not been found in any Chinese adult studies in terms of VAS because the existing two Chinese adult studies of Chan and Yeung (2020) and Huang et al. (2019) recruited undergraduates as participants aged within a small range. The recruited adults' ages in Study 1b ranged from 19 to 51 years: 45 adults aged 19 to 30, seven adults aged from 30 to 40, and six adults aged over 40, so the wider age range may be easier to produce more reliable results. Ageing was also reported by Paterson et al. (2020) to affect eye movements in reading due to changes in visual, attentional and cognitive abilities that occur naturally in older adults.

Regarding RQ2 "What is the association of VAS with other literacy-related variables for Mandarin-speaking adults?" the prediction was that VAS may be significantly associated with RAN and visual memory.

The findings in Study 1b were in line with the hypothesis, indicating that the global report was found to be significantly correlated with RAN digit and picture tasks, and the partial report was correlated with visual simultaneous short-term memory. Results in terms of the relationship between VAS, RAN and PA were in line with Study 1a, suggesting the overlapping processing between VAS and RAN, as well as the independence between VAS and PA, as supported by Bosse et al. (2007) and Bosse and Valdois (2009). Different from Study 1a, adults' visual simultaneous memory was found to be correlated with partial report, which was consistent with the assumption of Bosse et al. (2007) that the letters in multi-letter array compete for access to visual short-term memory (parallel competitive processing) according to Bundesen's theory of visual attention (TVA theory: Bundesen, 1990, 1998).

However, after using the combing scores, the above correlations were not significant, particularly under the partial correlation. This may be caused by the influence of age and the utilisation of the composite scores. Song et al. (2013) has mentioned that some of the composite variables would explain less variability than do the original variables

Regarding RQ3 “What is the association between VAS tasks from different VAS paradigms for Mandarin-speaking adults?”, the prediction was nearly all VAS variables were significantly correlated with each other, except for v1b correct RTs and v1b accuracy/d prime.

The results were not fully in line with these hypotheses, for a correlation between v1b correct RTs and v1b accuracy was also found. Correlational analysis showed that global and partial report was significantly correlated, which was in line with Awadh et al. (2022), Bosse et al. (2007) and Bosse and Valdois (2009). V1b accuracy and partial report were correlated with each other, which was in line with Chan and Yeung (2020). In addition, v1b accuracy and correct RTs of adults were significantly correlated, which was first found and was not consistent with Huang et al. (2019). Huang et al. did not find such a correlation between v1b accuracy and correct RTs of adults. This may be because our recruited adults had a higher d prime (0.79) than adults (0.68) in Huang et al. which meant our recruited adults had a higher sensitivity to the v1b task and may have a better performance of the v1b task than adults in Huang et al. So, it could be expected the correlation between v1b accuracy and correct RTs.

However, only the partial report not the global report was associated with v1b accuracy, which was not consistent with Chan and Yeung (2020). This may be because the v1b task with unfamiliar symbols was used. Even if Chan and Yeung found a correlation between the global and partial report and v1b accuracy (using symbols), the significance and coefficients were still not high (*r*=0.22 between global report and v1b accuracy, *r*=0.21 between partial report and v1b accuracy, *p*<.05). When unfamiliar symbols were used, only VAS skill involving the parallel processing was tapped into the global and partial report and the v1b task. So, the correlation between the v1b task using unfamiliar symbols and the two report tasks was not as significant as the correlation between the two report tasks and the v1b task (using characters as materials) because the v1b task may lack assistance from orthographic processing of characters when symbols were used. In this case, participants could not read these symbols as characters by retrieving characters from long-term memory and had to use their pure visual skills to identify symbols and then judge whether the target was presented. Accordingly, the association between their v1b accuracy and the partial report could be expected. The alternative reason was that the sample size in Study 1b was not as large as the one used by Chan and Yeung (2020) (recruiting 101 adults), so more sample size could be considered in the future research.

Furthermore, the principal component analysis showed loadings of global report, partial report and v1b accuracy, which was different from the results in Study 1a. In the v1b task, Zhao et al. (2018a) have mentioned that compared with correct RTs, v1b accuracy might be more suitable for reflecting the capacity of the VAS, because the correct RTs might consist of the processes of visually coding the target figure, the search and retrieval from the relevant resources in short-term memory, decision making, selections between different keys, pressing the corresponding keys, etc. Some of the components in the selective RTs may significantly develop with age, such as visual coding, key-pressing, and decision-making (e.g., Eenshuistra et al.,

2004) which could have covered up the developmental pattern in VAS. Thus, this may mean that compared with children, adults' VAS were already developed and more mature to be reflected in different VAS paradigms. The later structural equation model also revealed VAS report scores and v1b scores were intercorrelated, supporting the overlapped skills in terms of VAS under two different paradigms.

Overall, regarding to the research questions, VAS played a unique role in Mandarin-speaking adults' reading fluency. Only v1b scores uniquely predicted adults' silent sentence reading fluency after controlling for age, nonverbal ability, RAN and character identification skills. The strongest influence of VAS would be observed for silent sentence reading fluency (9%, $p<.05$).

2.4 Study 1c: Investigation of VAS patterns: global and partial report tasks and the visual 1-back (v1b) task

As discussed in Section 1.3.1, the pattern in the global report task has been reported to show a left-right asymmetry and a leftward letter advantage in children (Dutch: Van Den Boer et al., 2015) and adults (French and Spanish: Awadh et al. 2016), which were attributed to reading direction from left to right when the task involved the identification of all of the letters within string. On the other hand, the pattern in the partial report task has been found to demonstrate symmetry regardless of language, reported by Awadh et al. (2016), revealing a 'w-shape' illustrated by Collis et al. (2013). As mentioned in Section 1.3.1, Awadh et al. (2016) claimed that the possible explanation was the manipulation of the retro-cue that would trigger participants to retrieve the targets from memory without the influence of target positions. However, these studies did not focus on the developmental trend of VAS from children to adults, so did not compare different patterns of children and adults in terms of age and position accuracy. As for the v1b task mentioned in Section 1.2, one German study by Banfi et al. (2018) reported the patterns in d prime of v1b revealed a reverse 'v' shape for unfamiliar symbols and 'w' shape for letters of all children because of more influence of visual crowding on letters than on symbols.

As for report tasks, no studies in Chinese reported the patterns in the two report tasks. However, considering the reading direction from left to right in Chinese, the pattern of global report would be similar to the above mentioned ones in French, Dutch and Spanish, namely a left-right asymmetry and a leftward letter. Similarly, Awadh et al. (2016) have mentioned the pattern of partial report was not affected by language, so such a pattern in Chinese could also be expected to be similar to the ones in French, Dutch, Spanish and Arabic, namely a symmetry one.

As for the v1b task, two Chinese studies reported the pattern of this task (Study 8 in Table 1, Huang et al., 2019; Study 2, Zhao et al., 2018b). For both children and adults, the pattern for d prime values was demonstrated by Banfi et al. (2018) and Huang et al. (2019) to be a reverse ‘V’ shape, or by Zhao et al. (2018b) to be an inverted ‘U’ shape of TD readers, especially for unfamiliar symbols as materials. Huang et al. and Zhao et al. explained that this may be because these TD readers using the whole-word strategy, in which the target would not be influenced by the adjacent stimuli in strings. For d prime values, the main effect of position was significant, which was found by Banfi et al. (2018), Huang et al. (2019) and Zhao et al. (2018b), but the effect of age was not, which was reported by Huang et al. (2019). At the same time, Zhao et al. (2018a) (Study 1 in Table 1) indicated that v1b accuracy was also an important variable that refers to the capacity of VAS, and v1b accuracy was widely mentioned in VAS studies in Chinese (Chan & Yeung, 2020; Cheng et al., 2021; Zhao et al., 2017; Zhao et al., 2018b) but no studies have reported the pattern for this variable. Huang et al. (2019) mentioned that v1b accuracy was also highly correlated with d prime. So, it may be expected that the pattern of v1b accuracy was similar to that of the v1b d prime. In contrast, Huang et al. (2019) demonstrated that there were no specific characteristics of the pattern for correct RTs, but the main effects of position and age were significant. Huang et al. did not provide a reason for such a pattern without obvious characteristics, but this may indirectly support the equal reaction times of targets and attention allocation of each position.

Based on the relevant literature, the research questions are:

2.4.1 Research questions

1. What is the pattern of responses across array positions in the global report task, the partial report task, v1b accuracy, v1b d prime and v1b correct RTs?
2. Does the participants' age influence the patterns in the different VAS tasks?

With regard to RQ1, the prediction was that the pattern in the global report task may show a left-right asymmetry and a leftward letter advantage, as reported by Awadh et al. (2016). The pattern in the partial report task may show a symmetrical trend, even being a 'w-shape', as illustrated by Awadh et al. (2016) and Collis et al. (2013). The pattern in v1b accuracy and d prime may both show a reverse 'V' shape or an inverted 'U' shape because of its high correlation found in Study 1a and 1b (Banfi et al., 2018; Study 8 in Table 1, Huang et al., 2019; Study 2, Zhao et al., 2018b). The pattern in v1b correct RTs may demonstrate no specific characteristics, as Study 8, Huang et al. (2019) and Study 2, Zhao et al. (2018b).

With regard to RQ2, the patterns of the two report tasks may be influenced by participants' age (children and adults) and position, as reported by Van Den Boer et al. (2015). The patterns of v1b accuracy and d prime were affected by position rather than participants' age as Study 8, Huang et al. (2019). The pattern of v1b correct RTs was influenced by age and position, as Study 8, Huang et al. (2019).

2.4.2 Method

Participants. Participants were those who took part in Study 1a and 1b.

Materials. VAS tasks were the same as those in Study 1a and 1b.

Data analyses. Mixed-measures ANOVAs were used to analyse the response pattern across positions of each VAS task in terms of participants (children and adults) and position. When the interaction effect was found, the simple main effect analysis was considered to be used.

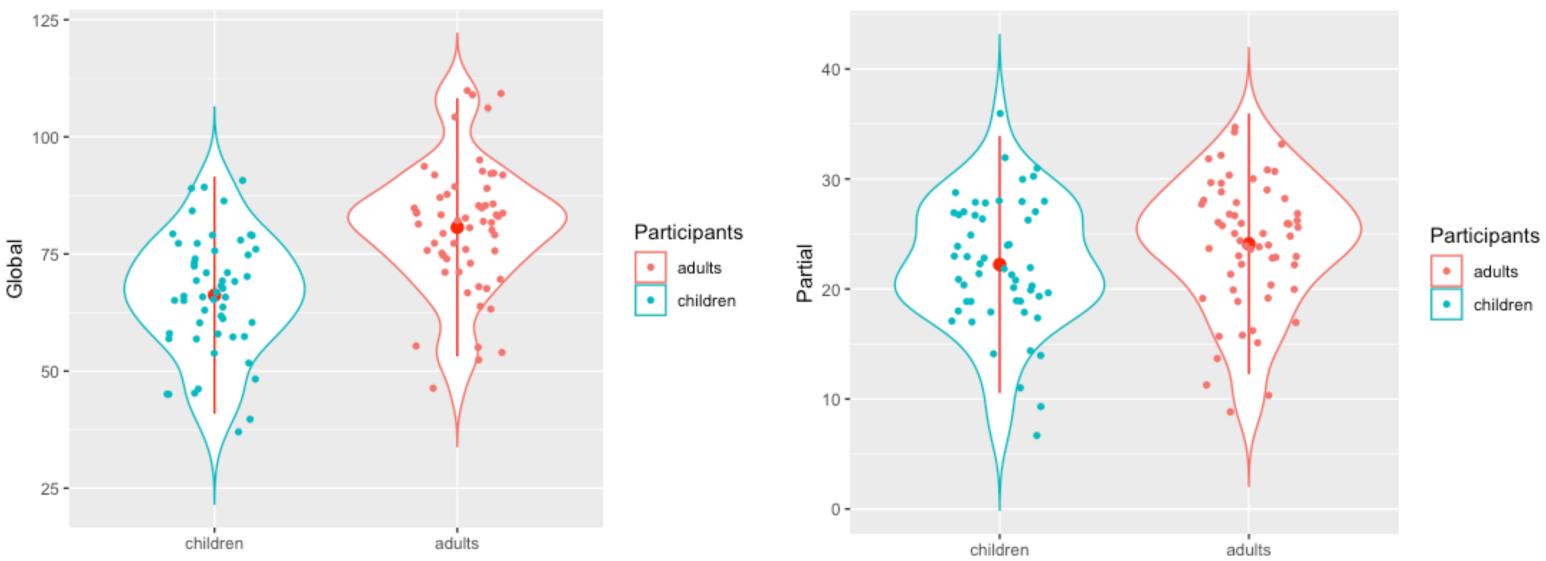
2.4.3 Results

Global and partial report tasks

Scores in global and partial report tasks of children and adults are presented in violin plots in Figure 3. Based on the density curves, Figure 3 shows that adults have better performance than children in the global report task and the partial report task, in particular in the global report task.

Figure 3

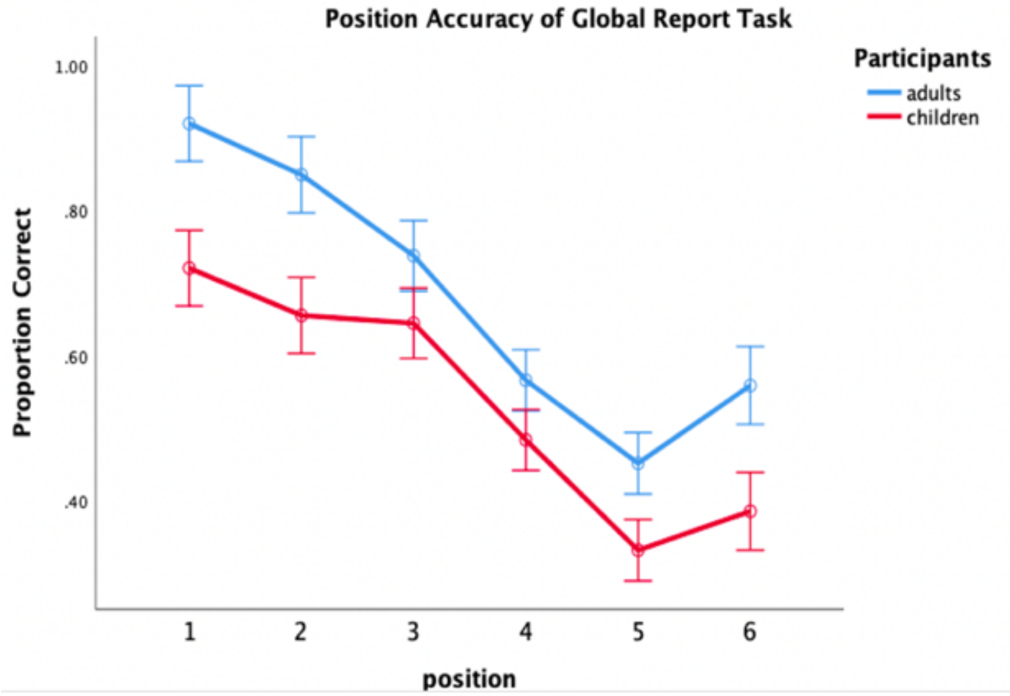
Score Distributions in the Global Report (Left) and Partial Report (Right) Tasks Children (Green) and Adults (Red)

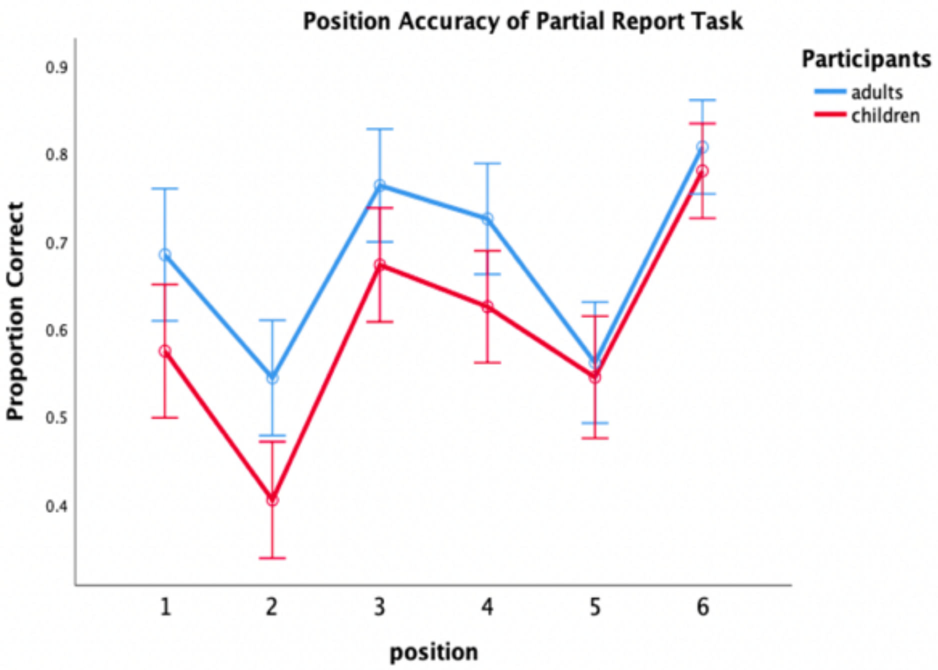


Mixed measures ANOVAs were used to explore the scores according to array position for each VAS task for the children's and adults' data. Plots of accuracy according to position in the global report and partial report tasks are shown in Figure 4.

Figure 4

Accuracy across Array Positions in the Global Report (Top) and Partial Report (Bottom) Tasks of Children (Red) and Adults (Blue)





For the global report task, the figure reveals a downward trend in accuracy of children and adults from Position 1 to Position 5, and a slight recovery from Position 5 to 6. The main effect of group was significant, *F* (1,110) = 40.44, *p*<.001. Adults' accuracy at each position was higher than children's accuracy. The main effect of position was also significant, *F* (2.74, 301.32) = 138.36, *p*<.001. Pairwise comparisons showed accuracy between all positions was significantly different, except for between the fourth and sixth positions. The interaction effect (position x group) was significant, *F* (2.74, 301.32) = 3.20, *p* = .03. Due to the founded interaction between positions and groups, a further simple main effect analysis was used. Results showed significant differences in the group (children and adults) were found in all positions (Position 1, *p*=.00; Position 2, *p*=.00; Position 3, *p*=.012; Position 4, *p*=.019; Position 5, *p*=.001; Position 6, *p*=.00).

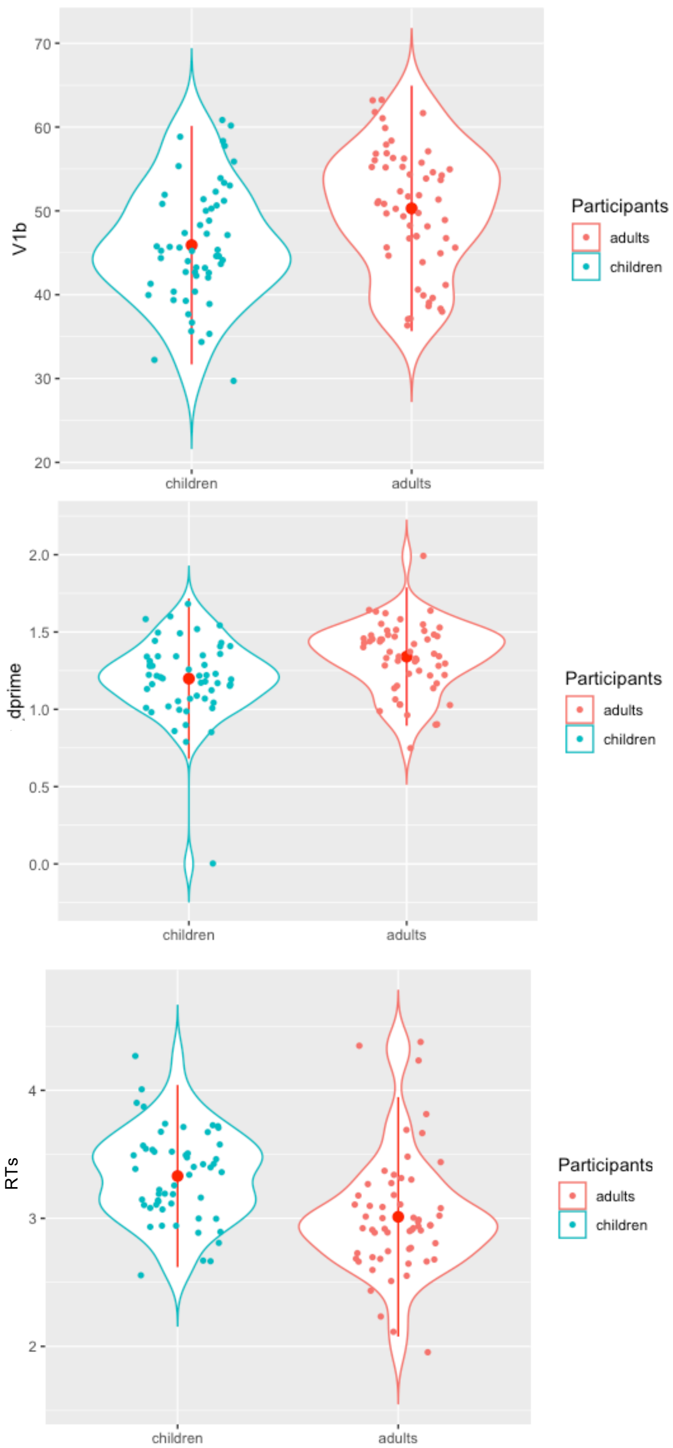
Accuracy in the partial report task showed a 'w-shape' trend for both children and adults. The main effect of group was significant, *F* (1,111) = 6.47, *p* <.05, and the main effect of position was also significant, *F* (5, 555) = 36.63, *p* <.001. Pairwise comparisons indicated significant differences in accuracy between Position 2 and Positions 1, 3, 4, and 6, as well as between Position 5 and Positions 3, 4, and 6, but accuracy between Position 2 and Position 5 was not significantly different. Adults' accuracy in the partial report task across each position was higher than children's accuracy, especially from Positions 1 to 4. However, the interaction effect (position x group) was not significant, *F* (5, 555) = 1.62, *p* = 0.15.

V1b task

V1b accuracy, d-prime value and correct RTs are visualised in violin plots in Figure 5. Based on the density curves, adults performed better in v1b accuracy, d-prime value and correct RTs than children. D prime was transformed to improve the distribution and homogeneity of variance by moving all scores within the positive range (by adding the absolute value of the smallest score to all the data) and then applying a square root transformation, as in the study of Antzaka et al. (2018).

Figure 5

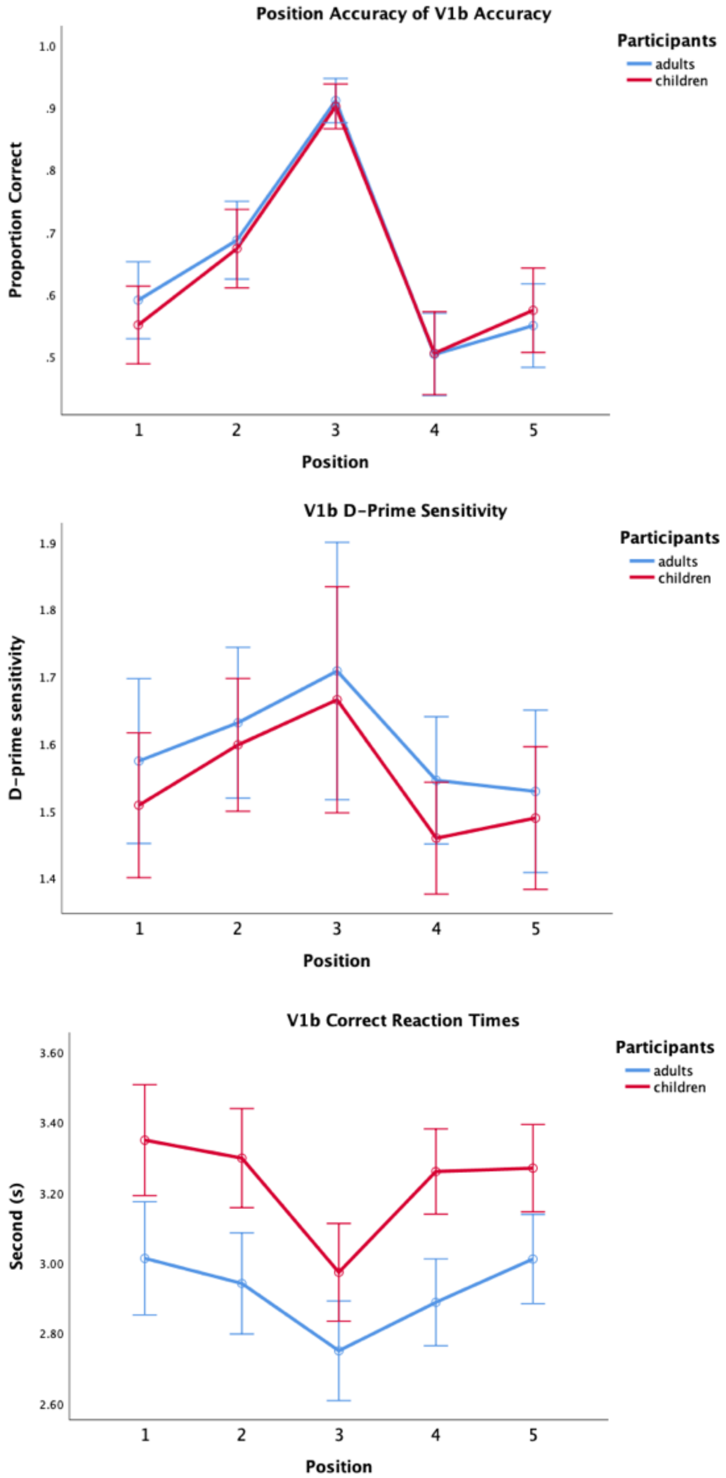
Comparison of Score Distributions in VAS V1b Accuracy (Top), D-Prime Values (Middle) and Correct Reaction Times (Bottom) for Children (Green) and Adults (Red)



Plots of v1b accuracy, d prime and correct RTs across each position of the v1b task are shown in Figure 6.

Figure 6

V1b Accuracy (Top), D-Prime Value (Middle) and Correct Reaction Times (Bottom) across Each Position of Children (Red) and Adults (Blue)



For v1b accuracy and d-prime sensitivity, an inverted ‘v’ shape is revealed in Figure 6. For accuracy, the main effect of group was not significant, F (1,105) = 0.1, p=0.75 while the effect of position was significant, F (3.66,384.70) = 62, p<.001. Accuracy between Position 3 and other positions was significantly different, but differences were not significant between Positions 1, 4 and 5. The interaction effect (position x group) was not significant, F (3.66, 384.70) = 0.34, p = 0.84.

For d prime values, the main effect of group was not significant, F (1, 37) = 0.74, p=0.39, but position was significant, F (2.99, 110.77) = 5.28, p<.001. V1b d prime between Position 3 and Position 4 was significantly different, and differences were also significant between Positions 1, 2, 4 and 5. The interaction effect (position x group) was not significant, F (2.99, 110.77) = 0.10, p = 0.96.

For v1b correct RTs a ‘v’ shape was revealed. The main effect of group was significant, F (1, 98) =18.54, p<.001. Position was also significant, F (3.32, 325.69) = 10.96, p<.001. Pairwise comparison indicated that only RTs at Position 3 were significantly different from those at other positions. The interaction effect (position x group) was not significant, F (3.23, 325.69) = 0.73, p = 0.55.

2.4.4 Discussion of 1c

Study 1c investigated Mandarin-speaking children’s and adults’ response distribution across positions for accuracy in the global and partial report tasks, and in the v1b task accuracy, d-prime sensitivity, and correct RTs.

Regarding RQ1 “What is the pattern of responses across array positions in the global report task, the partial report task, v1b accuracy, v1b d prime and v1b correct RTs?”, the prediction was that the pattern in the global report task may show a left-right asymmetry and a leftward letter advantage. The pattern in the partial report task may show a symmetrical trend, even being a ‘w-shape’. The pattern in v1b accuracy and d prime may both show a reverse ‘V’ shape or an inverted ‘U’ shape, and the pattern in v1b correct RTs may demonstrate no specific characteristics. Study 1c showed that the patterns in the global report task and v1b accuracy and d prime were consistent with the expectations. However, the pattern in the partial report task showed a ‘w’ shape, but not full symmetry. The pattern in v1b correct RTs showed a ‘v’ shape rather than without any particular characteristics.

As for global report, accuracy across positions of children and adults all decreased from left to right, accuracy of Position 1 being the greatest and of Position 5 being the worst. This was generally in line with trends found by Valdois et al. (2003) for French teenagers aged 13 to 14 years in Grade 7, Niolaki and Masterson (2013) for Greek children aged 12 to 13 years, Valdois et al. (2014) for French-Spanish bilingual children aged 9 years, and Van Den Boer et al. (2015) for Dutch children in Grade 2 (7 to 8 years old) and 5 (10 to 12 years old). This finding reflected the attention allocation decreasing from left to right during the orthographic processing because of the left-to-right reading direction, as mentioned by Awadh et al. (2016). It was also possible that Huang et al. (2019) showed that participants developed an expectation to direct their attention to the left side of the visual field prior to the presentation of the string, which might result from their left-to-right orientation during daily reading experience. However, accuracy of Position 6 (the last position) was higher than Position 5, which was in line with the trend of Valdois et al. (2003) but different from that of Van Den Boer et al. (2015) who reported the pattern of the global report was similar to Valdois et al. (2003), but performance on the final positions was on average somewhat lower. Van Den Boer et al. (2015) explained that such difference may be due to participants’ younger ages and the strict scoring method including the position of letters being also considered in addition to the accuracy of letter identification. At the same time, Van Den Boer also mentioned the performance in global report of the above-average readers was omitted. Moreover, the results of the simple main effect analysis revealed that different performances in children and adults affected the accuracy across all positions in the global report task. This could support adults' larger visual attentional window. Higher familiarity with orthographic representations of adults with more reading experience than children may also help adults retrieve the pronunciations of stimuli more precisely.

In addition, accuracy across positions in partial report task showed a 'w' shape, meaning that accuracy of Positions 1, 3, and 6 (the last position) was (even significantly) higher than that of Positions 2 and 5 to some extent. This finding was in line with results from Collis et al. (2013). However, the pattern found in Study 1c was asymmetry, which was not consistent with most studies in alphabetic languages (Awadh et al., 2016; Niolaki & Masterson, 2013; Valdois et al., 2003; Valdois et al., 2014) that the pattern in partial report was symmetry and attention allocation across each position was equal, without significant differences in accuracy across positions. Such discrepancy may be ascribed to visual crowding as reported by Banfi et al. (2018) particularly influencing Positions 2 and 5. Single whole characters rather than a single letter as stimuli used that were different from alphabetic languages required more advanced visual analytical processing because of the higher visual complexity of Chinese characters. More importantly, it should be noted the longer length of position arrays was adopted in the current study, that is, six positions rather than five positions as previous studies (Awadh et al., 2016; Niolaki & Masterson, 2013; Valdois et al., 2003; Valdois et al., 2014) in alphabetic languages were set, requiring a relatively larger visual attentional window. Position 3 was not at the centre position, and participants had to allocate attention to Positions 3 and 4, so the pattern was not symmetry like previous studies.

Moreover, accuracy and d prime across positions in the v1b task using unfamiliar symbols showed a reversed ‘v’ shape or the inverted ‘u’ shape with the highest accuracy of Position 3, reflecting attention allocation to symbol processing decreasing from the centre to the sides. This finding was generally in line with the findings of Zhao et al. (2017) for Mandarin-speaking teenagers aged 14 years, Huang et al. (2019) for Chinese-speaking participants aged from 8 to 24 years and Banfi et al. (2018) for German children aged 9 to 10 years. The only difference was that the children’s d prime of Position 5 (the last position in the v1b task) was slightly higher (although not significantly) than the accuracy of Position 4, which could not exclude the slight influence of visual crowding of Position 4 and the small visual attention window of children. The reversed ‘v’ shape or inverted U shape of the attention distribution pattern for children and adults in the current study supported a large VAS, in which the targets would be less affected by adjacent stimuli in the string. Zhao et al. (2017) suggested that these participants use a whole strategy for their daily reading because utilisation of a lexical whole-word strategy requires a larger size of visual units. Lallier et al. (2014) also supported that the whole-word strategy would diminish the interference from surrounding stimuli, which would cause the absence of the W-shaped pattern.

Furthermore, correct RTs revealed a ‘v’ shape, meaning the shortest RTs in Position 3, which was not in line with the pattern shape reported by the study of Huang et al. (2019). The ‘v’ shape in this present experiment looked much sharper than that of Huang et al. (2019), and only RTs of Position 3 were significantly lower than that of other positions. According to the correlational results of Study 1b, v1b accuracy and d prime were positively correlated with correct RTs, meaning the shorter RTs, the lower accuracy and d prime. However, V1b accuracy and d prime in Position 3 were highest, but correct RTs in Position 3 were shortest. More attention allocation was assigned to other positions than the centre position, so the RTs of Position 3 were the quickest ones. This may suggest the global processing of multiple symbol items. VAS was good enough to process not only the centre position but also other neighbouring positions. Unlike Huang et al. (2019), the correct RTs of Positions 1 and 2 were not significantly different from that of Position 5 in Study 1c. This could be because participants were unfamiliar with symbols, so they equally allocated more visual attention to other positions except for the centred Position 3.

Regarding RQ2 “Does the participants’ age influence the patterns in the different VAS tasks?”, the patterns of the two report tasks may be influenced by participants’ age (children and adults) and position. The patterns of v1b accuracy and d prime were affected by position rather than participants’ age, and the pattern of v1b correct RTs was influenced by age and position.

The findings were partially consistent with the hypothesis. Results of the ANOVA test showed that position and participants’ age may affect the pattern of nearly all VAS variables, except for the v1b accuracy, consistent with findings in the study of Van Den Boer et al. (2015) and Huang et al. (2019). Van Den Boer et al. showed the older children had better global report performance than younger children. Huang et al. reported the v1b correct RTs were influenced by age and position, but v1b d prime was only influenced by positions.

Patterns of the two report tasks were affected by participants’ age and positions, which respectively implied the developmental VAS and the attention allocation during the global and analytical processing. The pattern of v1b correct RTs was influenced by age, which was in line with Zhao et al. (2018a) who reported that the correct RTs might significantly develop with age, such as visual coding, key-pressing and decision-making. The pattern of v1b correct RTs was also influenced by position, which may reflect the different processing speeds of different positions.

However, adults' v1b d prime was not significantly higher than children's, which was not fully in accord with results from Huang et al. (2019). Huang et al. found that although there was no significant main effect of ages (covering ages from 8 to 23 years) for d prime, the undergraduates' v1b d prime was still significantly higher than the children aged 10 to 12. Adult participants' age has a large range, not just including young adults, which might explain the discrepancy. It was witnessed that a slightly higher v1b d prime in Position 3 of adults than children was still shown in Figure 6, so more young adults could be recruited to see whether there were consistent findings that were found.

Overall, regarding the research questions, for children and adults, patterns in global report revealed left-to-right asymmetry and patterns in partial report revealed 'W-shape', not full symmetry. V1b accuracy and d prime across positions showed a reversed 'v' shape or an inverted 'u' shape when unfamiliar symbols were used and correct RTs revealed a 'v' shape. Except for v1b accuracy and d prime, patterns in other VAS variables may be influenced by position and participants' age groups.

2.5 General Discussion

To the author's knowledge, this was the first research to cover two patterns of VAS measures (global and partial report tasks, as well as the v1b task) and assessments of reading fluency in oral and silent modes, with a focus on both children and adults. Results revealed that VAS played a unique role in Chinese reading fluency after controlling for other important variables. For the children in the present study VAS report composite scores of significantly predicted oral sentence reading fluency after controlling for nonverbal ability, PA, RAN, MA and character identification skills. For the adults, V1b composite scores significantly predicted silent sentence reading fluency after controlling for age, nonverbal ability, RAN and character identification skill.

Regarding the research question about VAS and other literacy-related variables, RAN was significantly correlated with children's and adults' global report. Visual short-term memory was found to be correlated with adults' partial report. No VAS measures were significantly associated with PA.

Regarding the research question about relationships between various VAS variables, stronger associations between adults' VAS scores were found than between children's. Adults' VAS skills seemed to be greater than children's, which suggested that adults's VAS may be more mature than children.

Regarding the question about position patterns, children and adults showed similar patterns. Scores in the global report and partial report tasks and the v1b task presented different patterns. The global report revealed a decreasing trend from left to right, while VAS partial report revealed a 'w' shape, indicating relatively higher scores in Positions 1, 3 and 6. V1b accuracy showed a reversed 'v' shape with the highest accuracy at Position 3, reflecting attention allocation decreasing from the centre. Correct RTs of the v1b task showed a 'v' shape, with the shortest RTs in the centre position.

Differences in relationships between VAS and reading of Mandarin-speaking children and adults

One of the main differences was that adults' all VAS scores were only associated with silent reading tasks. By contrast, children's VAS in global and partial report task was correlated with oral reading and children's VAS in the v1b task was correlated with silent reading. This could be attributed to different reading fluency modes. Zhao et al. (2017) explained that reading fluency in the silent mode may rely on the global reading procedure while reading fluency in the oral mode may rely on the analytic reading procedure. The second explanation was the developmental trend of VAS with age increasing. Huang et al. (2019) indicated that VAS broadens with age and is wider for higher graders, as supported by Bosse and Valdois (2009). Accordingly, adults have a larger visual attention window. In contrast, children's visual attentional window was not large enough, so they had to rely more on analytical skills than global reading procedures to process words.

Differences in the development of VAS of Mandarin-speaking children and adults

The second main difference was that compared with children, adults' VAS variables under different paradigms reflected developed VAS. This meant that adults had a similar level of analytical processing skills as the children but better global processing skills, supporting the developmental trend of VAS with age developing. For future study it will be informative to have younger children to see if there is no or little effect of VAS when (presumably) at a stage when analytic reading processes are mainly used (Huang et al., 2019). Such findings would provide evidence and reference for Mandarin-speaking children and adults with dyslexia (Chapter 4).

In conclusion, this chapter mainly explored the relationship between VAS assessed in various tasks and reading fluency in oral and silent modes of Mandarin-speaking children and adults. Unique roles of VAS in reading fluency were found in both children and adults. Under different reading fluency modes, predictions of VAS assessed in various VAS tasks were also different. The development of VAS between children and adults was also shown, for participants' age and position may influence the position accuracy of nearly all VAS variables.

Chapter 3: Relationship between VAS and spelling of Mandarin-speaking children and adults

3.1 Introduction

In reviewing the literature on VAS and reading and spelling in Chapter 1 it was noted that role of VAS in the spelling of Chinese speakers has not yet been investigated. The studies on VAS and its relationship to single word spelling in alphabetic languages are reviewed below in order to provide the background for the studies reported in this chapter on VAS and spelling in Mandarin-speaking children and adults. The previous studies on spelling and VAS in children have involved regression-based analyses looking at child- and adult-related variables, such as vocabulary, verbal short-term memory, and PA, as in the reading studies reviewed in the previous chapter. The review below extends to the study of adults who differ in spelling ability, and single case studies of children and adults with impaired spelling ability that have used a dual route spelling theoretical framework. The analyses used in this line of research, looking at the types of errors made in spelling and the effect of stimulus-based variables on spelling accuracy were incorporated in the current studies. This is because the dual route framework has been adapted to explain spelling in Chinese speakers (Mo, 2020), focusing especially on the orthographic working memory component, as outlined below.

3.1.1 VAS and single word spelling in children and adults

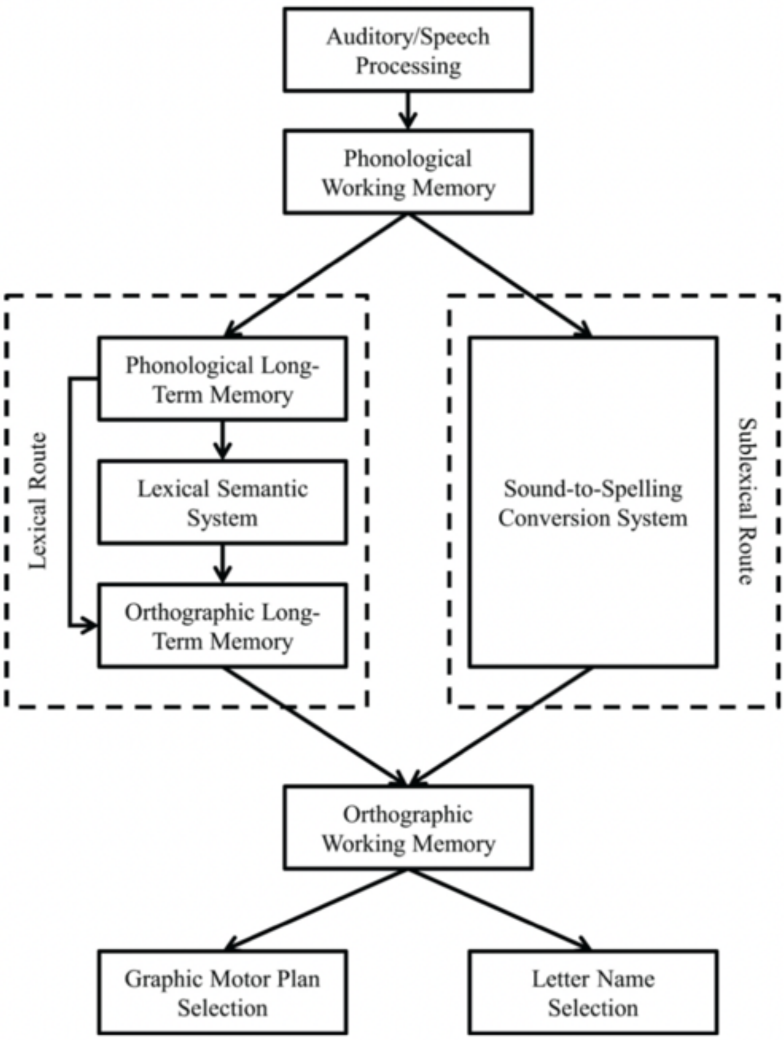
As discussed in Chapter 1 Section 1.3.2, studies in alphabetic writing systems have indicated a significant role for VAS in children's single word spelling. Van Den Boer et al. et al. (2015) in a study with Dutch-speaking children aged 9 to 10 years reported that VAS uniquely predicted spelling accuracy, after controlling for nonverbal ability, verbal short-term memory, PA and RAN. Niolaki et al. (2020)

assessed English-speaking children aged 9 years and reported the same result, after controlling for age, nonverbal ability, PA, RAN, and visual short-term memory. The same was reported for Greek-speaking children in Grades 4 to 7 (mean age 10 years), after controlling for age and reading speed (Niolaki et al., 2024). In terms of adult single word spelling, Masterson et al. (2007) reported that letter report performance distinguished good and poor adult spellers who did not differ in terms of reading or phonological ability. In that study a VAS framework was not used, and the letter report performance was interpreted, along with performance in other printed word tasks such as lexical decision, in terms of an online orthographic processing deficit, that is, a weakness in the lexical route of dual route spelling models.

According to dual route theories of spelling, phonological (phoneme-to-grapheme) processes are used to spell regular words and unfamiliar words effectively, while whole-word lexical processes are employed for irregularly spelled words (e.g., Barry, 1994; Hepner et al., 2017; Kreiner & Gough, 1990). Printed word frequency would have an influence on lexical processing since the strength of entries in the orthographic lexicon is influenced by the number of times the child or adult has been exposed to the printed words and has the opportunity to write them (Barry, 1994; Spencer, 2007). On the other hand, word length would influence the written production of words relying on sublexical processes, since parsing, conversion from phonemes to graphemes, and assembly in a short-term graphemic output buffer are involved (Valle-Arroyo, 1990). The framework is depicted in Figure 7. The dual route theory of spelling has been used to interpret spelling deficits revealed in single case studies with children and adults.

Figure 7

Cognitive Process of Spelling (Hepner et al., 2017)



Roncoli and Masterson (2016) used the dual route framework and developed the orthographic processing weakness explanation of poor spelling as articulated by Holmes and colleagues and Masterson et al. (2007) in a single case study with a 10-year-old boy, Alan. Assessments revealed that Alan had advanced reading skills but very poor spelling. Global report performance, when compared to that of CA controls, was significantly impaired. In addition, Alan showed a pronounced effect of word length on spelling accuracy, and his errors involved transposition, substitution, omission and addition of letters. The authors noted that the effect of word length and the types of spelling errors observed were previously reported for adult aphasic patients with acquired graphemic buffer disorder (e.g., Caramazza et al., 1987; Schiller et al., 2001) and in Hebrew speakers with developmental spelling difficulty (Yachini & Friedmann, 2010). Barisic et al. (2017) have subsequently reported the case of LS, a 10-year-old boy with graphemic buffer disorder, investigating in detail the factors that influenced LS's spelling accuracy.

These studies of acquired and developmental graphemic buffer disorder involved analysis of the spelling difficulties in terms of dual route theories rather than using the framework of the Multitrace Memory model of Ans et al. (1998). As noted in Section 1.2, the latter emphasises allocation of attention (Awadh et al., 2016; Bosse et al., 2007; Ginestet et al., 2020), while the former does not. According to the dual route models the graphemic buffer (or 'orthographic working memory' (OWM), Costa et al., 2011), temporarily holds output from either the lexical or sublexical spelling procedures in abstract format while the motor planning and production processes required for generating the spelling response are carried out. Caramazza et al. (1986) proposed the graphemic buffer as a working memory system since it is at a stage in the process of spelling where multi-grapheme representations are being converted into individual forms for output. The studies of patients with a graphemic buffer deficit indicated that the location of the OWM must be post-lexical since spelling errors were observed with both familiar words and nonwords and were independent of the modality of input (spelling to dictation, written picture naming, spontaneous writing, etc.). The characteristic 'letter' errors (transpositions, substitutions, omissions, deletions and additions) as well as word length effects on accuracy were interpreted as reflecting the role of OWM in keeping written units active.

Numerous studies of acquired OWM deficit have been published (e.g., Caramazza & Miceli, 1990; Costa et al., 2011, Krajenbrink et al., 2021, Sage & Ellis, 2004; Tainturier & Caramazza, 1996), but, as noted above, studies reporting developmental cases have been relatively rare (Barisic et al., 2017; Masterson & Roncoli, 2016; Yachini & Friedmann, 2010). In the present study it was decided to employ analyses that have been habitually used in the studies of OWM and spelling – investigation of the types of errors made, as well as the variables (in addition to VAS) that affect spelling accuracy. This approach is discussed further, after the following section that outlines an adaptation of the dual route theory of spelling for Chinese speakers.

3.1.2 Dual route theory of spelling adapted for spelling in Chinese

Research conducted over the last twenty years has examined the processes children use in writing Chinese characters. Using qualitative analysis of errors, Shen and Bear (2000) gathered errors made by children from Grades 1 to 6 in writing simplified Chinese characters in a spelling-to-dictation task. The authors reported a decreasing rate of phonologically-based errors and an increasing number of orthographic and meaning-related errors across school grades (although phonological errors remained the largest category even for older children). The authors interpreted their results to mean that orthographic and meaning-based spelling strategies were used more as grade level increased, while a phonological strategy was dominant in lower grades. Since then, spelling error analyses in the spelling-to-dictation task have been used in research on Chinese spelling. Tong et al. (2009) conducted a one-year longitudinal study with Cantonese-speaking children spelling traditional characters. The children were six years old at Time 1 and were tested a year later at Time 2. Although they were young, the children had 2.5 to 3.5

years of literacy instruction by the time they took part in the study. Errors were classified as in the study of Shen and Bear (2000). The authors found that at Time 1, 97% of the children's errors were in the orthographic and meaning-related categories, and this was similar at Time 2 (95% of errors). The results from both timepoints supported the involvement of lexical processes in spelling because of the preponderance of meaning-based and orthographic errors. Yeung et al. (2013) conducted subsequent research investigating spelling to dictation of traditional Chinese characters in Hong Kong Grades 1 to 4 children (aged 6 to 10 years). The researchers reported that, across grades, the largest error category was orthographic errors. The discrepancy across the studies in terms of the predominant error category being orthographic in the studies of Tong et al. (2009) and Yeung et al. (2013) and phonological in the study of Shen and Bear (2000), may be due to the use of transparent Pinyin for teaching simplified characters in the early school years, which applied only to the study of Shen and Bear. Learning to read and spell traditional characters involves rote learning through visual inspection and copying, practices which are likely to encourage the use of lexical-orthographic processes from an early stage.

In addition to the spelling-to-dictation task, McBride-Chang et al. (2011) and Wang et al. (2014) used the delayed copying task to assess the visual orthographic skills of Chinese children. Visual orthographic skills refer to the ability to process visual representations and knowledge of internal structures, positions and functions of Chinese characters. In delayed copying, participants are required to write down as much as they can remember of an unfamiliar but real Chinese character which has been briefly presented. McBride-Chang et al. (2011) investigated the prediction of delayed copying skills in 7-to-10-year-old Chinese children with and without dyslexia and found that copying skills could uniquely explain 6% and 3% of the variance in Chinese word reading and spelling-to-dictation of these children after controlling for age, nonverbal ability, MA and RAN. Wang et al. (2014) explored the influence of delayed copying skills on the spelling-to-dictation performance of Chinese kindergarteners. They found that delayed copying scores explained a significant 5% of the variance in Chinese word spelling after controlling for age, grade and nonverbal ability. Later, in one-year longitudinal studies examining predictors of writing in Chinese kindergarteners, Wang et al. (2015) and Ye et al. (2021) reported that delayed copying was a unique predictor of the spelling-to-dictation task at the first assessment after controlling for some variables, such as age, gender, nonverbal ability, vocabulary knowledge and reading skills. Thus, the importance of delayed copying to Chinese spelling was supported.

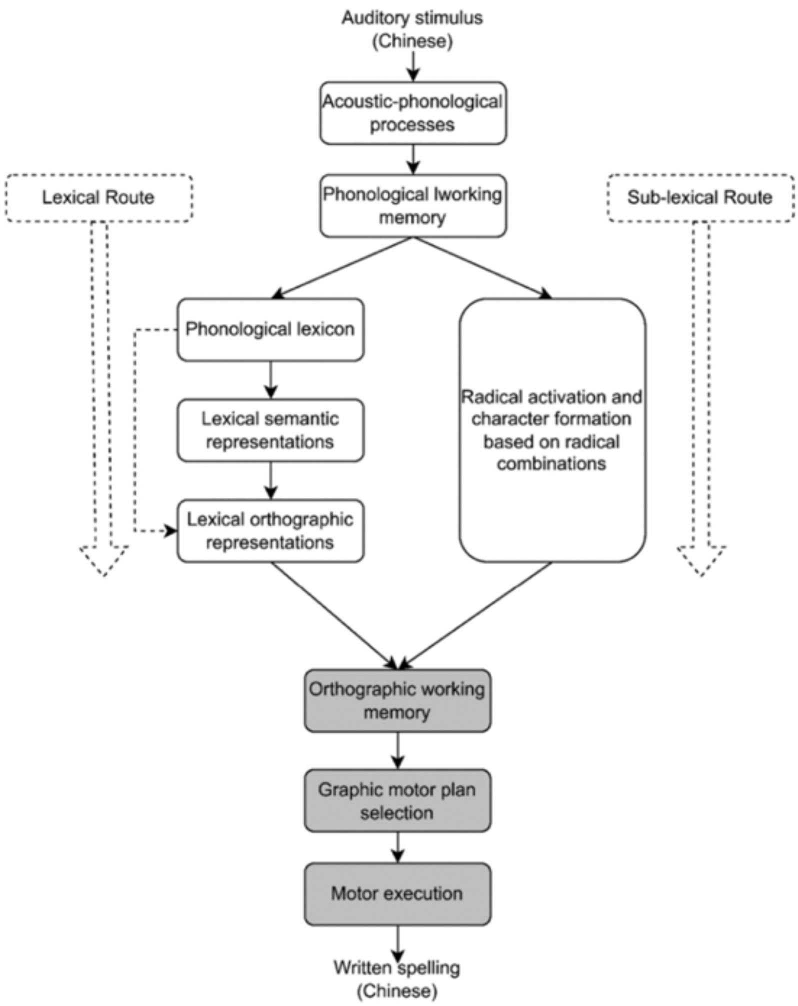
The delayed copying task was later used to examine spelling in Chinese adults with dysgraphia. These studies have also involved qualitative analysis of the types of spelling errors made. In this study, Law and Leung (2000) reported a case study of a Cantonese-speaking dysgraphic adult in a delayed copying task. Law and Leung first created a term called 'logographemes' that were the smallest units in a character that are spatially separated and cannot be further disassembled into other logographemes. Relationship between logographemes and strokes are that logographemes are the combinations of strokes. For example, '吐' has two logographemes, namely '口' and '土', but '口' cannot be split into four strokes including '一' and '丨'. Law and Leung found this dyslexic adult made many spelling errors in logographmes in the delayed copying task. The spelling errors made by this adult involved substitution, deletion, insertion, and transposition of logographemes. This result may suggest that it may be more precise to determine the psycholinguistic factors of Chinese characters based on logographemes than strokes. Han et al. (2007) also used a delayed spelling task to investigate spelling in a Mandarin-speaking dysgraphic adult, WLZ. The dominant spelling errors made by WLZ were substitution of logographemes followed by deletion of logographemes. Moreover, WLZ's spelling accuracy was only significantly influenced by the number of logographemes, which supported logographemes as the basic units in writing Chinese characters. The authors also suggested that WLZ had a deficit of OWM which manifested in difficulty in organising the position of strokes and radicals before written characters were produced, due to his errors in substitution, deletion, insertion, and transposition.

On the basis of the evidence from the children reviewed above, and the adults with acquired spelling disorder, using the delayed copying task, Mo (2023) proposed an adaptation of the model of (English) spelling of McCloskey and Rapp (2017) for Chinese spelling and emphasised the role of OWM where characters and their relative positions are retained temporarily, while the graphic motor plan and motor processes are executed for final production. According to the model (please see Figure 8), in the case of familiar words, the phonological long-term memory store is addressed, an activated representation will then in turn activate a representation in the semantic store, and then a lexical orthographic representations, or else progress directly to lexical orthographic representations.

On the other hand, when spelling unfamiliar words, the sublexical mechanism is based on radical-character correspondences, since characters are the smallest pronounceable units. Although characters form the components of multi-character compounds, which are the most common type of words (80%) in text, they can also be words in their own right, so as sublexical units they comprise semantic and phonetic radical information, as well as radical position regularity information (for example, the phonetic radical appears on the right in the majority of single words). A speller can therefore use radical knowledge to attempt to write down an unfamiliar dictated word. However, as discussed above, information conveyed by radicals is not very reliable; thus, the spelling attempt merely relying on radical knowledge may not often be correct. Overall, in the adapted model the two processing routes are global lexical processing (lexical-semantic store to lexical orthographic representations) and sublexical analytical processing, which involves radical-character correspondences without the involvement of phonemes.

Figure 8

Model of Single Word Spelling in Chinese (Mo, 2023, Adapted from McCloskey & Rapp, 2017)



As noted above, the adaptation of the dual route theory for Chinese spellers was motivated by research in recent years investigating the development of spelling ability in children learning Mandarin and Cantonese, and studies of adult dysgraphic patients. Studies on the acquisition of spelling in Chinese are reviewed next in the introduction to Study 2a.

Different spelling error patterns have been reported to be a reflection of subcomponents of OWM that can be impaired separately (Krajenbrink et al., 2021)(e.g., letter identity and sequencing of strokes). As discussed above, OWM is thought to be responsible for temporarily storing details of orthographic representations, which may involve simultaneous processing at the multi-element level. Early Chinese character instruction, as noted in Chapter 1, involves daily copying practice with fixed order of strokes, which must recruit motor-kinesthetic memory and multi-element processing skills, which means that these skills are repeatedly highlighted. This emphasis on visual retention of written forms is important, given the complexity of Chinese characters, and the lack of reliable phonological support for reading. Thus the processes involved in OWM and VAS, whether they are completely or partially overlapping, would seem to be crucial for spelling in Chinese relative to their involvement in alphabetic languages.

3.1.3 The present study

The research reported in this chapter aimed to examine the influence of VAS in spelling in Chinese. The first study (Study 2a) was conducted with children and the second (Study 2b) was conducted with adults. Considering the development of VAS as discussed in Section 1.3.1, Huang et al. (2019) suggested that VAS may play a more important role in reading in adults than children. Given that spelling and reading draw on many of the same cognitive processes, VAS may have a stronger influence on spelling for adults than children.

Studies 2a and 2b included spelling-to-dictation, VAS assessed with the global report task, the partial report task and the v1b task, and child- and adult-related variables that have been found to be associated with spelling in past research. These are discussed in more detail in the next section. Finally, qualitative analyses of the spelling errors made by the children and adults were conducted.

This will be the first study to explore the relationship between VAS and spelling-to-dictation in Chinese. The first aim was to see whether VAS would affect spelling over and above the influence of other variables known to be associated with spelling. The second aim was to examine which of the various measures of VAS would be most strongly associated with spelling. The third aim was to see whether there might be a stronger influence of VAS in spelling in the adults versus the children. The final aim was to explore whether poor spelling in adults might be associated with poor performance in VAS and whether this would also be associated with a pronounced influence of word length in the item-based analyses of spelling accuracy, as well as with a preponderance of transposition errors in spelling.

3.2 Study 2a: The relationship between VAS and spelling in Mandarin-speaking children

3.2.1 Research questions

The research questions were as follows:

1. Does VAS significantly predict spelling-to-dictation in 10- to 12-year-old Mandarin-speaking children over and above the influence of other related variables (vocabulary, PA, RAN, MA, verbal and visual memory and character identification)? And which VAS task would show the strongest association with spelling?
2. Would the item-related variables word frequency and word length be associated with spelling accuracy? And would word frequency be more strongly related with spelling accuracy than word length?
3. What are the main spelling strategies of children?

Regarding RQ1, the prediction was that VAS as assessed in global report and partial report tasks would uniquely predict the children's spelling accuracy, as reported by Van de Boer et al. (2015), Niolaki et al. (2020) and Niolaki et al. (2024). Regarding RQ2, the prediction was that word frequency and word length would be significant predictors of spelling accuracy, but that word frequency would be an especially important predictor, given the difference in findings of studies across languages with different levels of opacity (Niolaki et al., 2024; Niolaki & Masterson, 2012; Wong, 2017). Regarding to RQ3, Mandarin speaking children may rely more on whole word lexical processes for spelling (cf. results reported by Shen and Bear, 2000; Tong et al., 2009 and Yeung et al. (2013).

3.2.2 Method

Participants. The children were those who took part in Study 1a (please find details of the sample in the *Participants* section of Study 1a).

Materials. The results for all tasks used in the analyses were those conducted in Study 1a, except for the spelling-to-dictation task described next.

Spelling-to-dictation. Spelling was assessed using the 60-item list from Masterson et al. (2008) and translated into Mandarin by Wong (2017). The words were originally selected to be familiar concepts to children aged from 6 to 7 years and above, and to children from diverse language and cultural backgrounds. They also comprised a range of familiarity levels, in order to avoid ceiling or floor effects in terms of accuracy in the spelling to dictation task. The translated list of items comprises 41 single character words, 18 two-character words and one three-character word. Chinese printed word frequency values for the 60 words were obtained from the database of words in children's books compiled by Li et al. (2023, CCLOWW database). The mean zipf frequency[1] for the words was calculated as *m*=4.42 (*sd*=0.90). In addition, five Chinese teachers, one teaching Grade 4, two for Grade 5, and two for Grade 6, were asked to rate how familiar they thought the words were to children aged 10 to 12 years. To obtain the ratings a five-point Likert scale (with 1 representing 'highly unfamiliar' and 5 representing 'highly familiar') was used. The mean familiarity rating for the words was 4.76 (*sd*=0.5).

The association of the teachers' familiarity ratings and the zipf frequency values from Li et al. (2023) was investigated, as well as the association of these two

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[1] Zipf frequency is a standardized frequency measure, calculated as log10 (Freq. million) + 3. Compared with raw frequency values, the advantages of zipf frequency are as follows: its interpretation does not depend on the size of the corpus; it permits the computation of frequency for words not observed in a corpus; it can also correct for the number of types in the corpus (Korochkina et al., 2024).

variables with zipf frequencies for the English translations of the 60 words (taken from the CYP-LEX database, Korochkina et al., 2024, for English children's books). Pearson's correlations revealed a significant association between the Chinese frequency values and the teacher ratings, $r= .60$, $p<.001$, as well as between the teacher ratings and the English frequency values, $r= .52$, $p<.001$, and the Chinese and English frequency values, $r= .58$, $p<.001$. The word list and obtained values for frequency and familiarity can be found in the Appendix C.

In administering the spelling to dictation task, the words were presented in two sets of 30 items with a short break between the sets. The words were randomly allocated to the sets and a single fixed order was used for testing. Each target word was read aloud once, followed by a sentence containing the item, and the children were asked to write down the target item. The maximum correct score was 60. Cronbach's alpha was calculated as 0.88, based on the scores from the participants in the current study.

Procedure. The procedure for data collection for all measures apart from spelling to dictation was as described in Study 1a. The data were collected in September 2021. Two trained class teachers helped to collect the spelling data. Group testing for spelling-to-dictation (lasting c. 15 minutes) was carried out in the classroom, with a 10-minute break between the two word 30-word sets.

Data analyses. The participant-based analyses involved correlation and hierarchical regression to explore the relationship between spelling and VAS assessed with character report and v1b tasks. The relationship of spelling with the literacy-related variables was explored with correlation analysis and scores for selected variables were included in early steps in the regression analysis, with VAS in the final steps, in order to see whether the effect of VAS would still be significant if influential variables were controlled for. The item-based analyses involved correlation and simultaneous regression analyses to investigate the relationship between word length and word frequency and spelling accuracy. Word length and frequency were entered the simultaneous regression as independent variables. Finally, the qualitative spelling errors analyses were conducted to see the spelling strategies children used.

3.2.3 Results

The descriptive statistics are reported in Study 1a in the previous chapter, except for spelling accuracy. The mean spelling accuracy for the children in the sample was 44.74 (*sd*=7.18), and the range of scores was from 30 to 60. The results of exploratory data analyses (EDA) revealed that scores for spelling accuracy were normally distributed.

Pearson's correlation and partial correlation analyses controlling for nonverbal ability were conducted to explore the relationship between the variables and spelling accuracy. The results are reported in Table 14.

Table 14

Pearson's Correlation (above the diagonal) and Partial Correlation (below the diagonal, after controlling for Nonverbal Ability) with VAS and Other Important Variables in Study 2a

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Spelling accuracy	-	.38**	.07	-.19	.13	.46**	-.46**	-.36**	.38**	.14	.40**	.00	.33*	.31*	.43**	.19	.00	-.01	-.12	.42**	-.09
2	Owf	.42**	-	.02	.02	.21	.33*	-.66***	-.61***	.22	.01	.05	.36**	.22	.18	.53***	.14	-.12	-.17	-.25+	.48***	-.15
3	Nonverbal Abli.	-	-	-	-.06	.31*	.14	-.01	.11	.38**	.13	.11	.41**	.41**	.13	-.13	-.04	.15	.11	-.12	-.02	-.25+
4	Age	-.13	.20	-	-	.07	.01	-.05	-.04	-.25+	.18	.08	-.04	.02	-.06	-.02	-.08	-.11	-.16	.15	-.16	.17
5	Vocabulary	.07	.13	-	.31*	-	.10	-.21	.01	.22	.05	.15	.25+	.35*	-.10	.17	.05	.20	.18	-.06	.25+	-.22
6	PA	.52**	.27+	-	-.00	.02	-	-.30*	-.10	.25+	.18	.50***	.24+	.50***	.06	.05	.08	.10	.09	-.07	.14	-.15
7	RAN picture	-.41**	-.66***	-	-.13	-.20	-.30+	-	.58***	-.03	-.09	-.30*	.00	-.27*	-.06	-.45**	-.11	.00	-.01	.25+	-.35*	.24+
8	RAN digits	-.25	-.57***	-	-.26	.02	-.11	.62***	-	-.07	-.06	-.10	-.04	-.04	-.12	-.45**	-.07	.19	.22	.20	-.38**	.04
9	MA	.32*	-.09	-	-.14	.07	.12	.11	.08	-	.21	.24+	.31*	.38**	.16	.14	-.01	-.03	.04	.02	.15	.03
10	VerbalFor STM	.18	-.04	-	.23	.02	.11	-.04	-.06	.11	-	.37**	.10	.26+	.10	.03	-.11	-.24+	-.15	.12	-.01	.26+
11	VerbalBack STM	.45**	-.12	-	-.00	.03	.56***	-.12	-.08	.21	.35*	-	-.12	.38**	.02	.01	-.19	-.05	.03	.05	-.07	.10
12	VisualSimul STM	-.03	.22	-	.10	.02	-.00	-.11	-.18	.06	.09	-.17	-	.31*	.12	-.04	.04	.25+	.17	-.10	.10	-.31*
13	VisualSeq STM	.31*	.24	-	.04	.26	.41**	-.16	-.04	.21	.26	.26	.14	-	.08	.14	.04	.19	.18	-.07	.19	-.23
14	Chat. Ident.	.46**	.29+	-	-.11	-.05	.01	-.23	-.21	.12	.09	.17	.02	.11	-	-.14	.10	-.14	-.17	-.07	-.01	.04
15	Global	.32*	.46**	-	.15	.23	.09	-.37*	-.38*	-.03	.13	-.10	.14	.12	.05	-	.52***	.06	.04	.07	.88***	.01
16	Partial	.23	.18	-	-.11	.10	.13	-.25	-.17	-.15	-.08	-.16	.06	.08	.30+	.48**	-	.27*	.22	.22	.84***	-.03
17	V1b accuracy	.02	-.11	-	-.26	.16	.02	.03	.10	-.02	-.21	-.06	.11	.08	-.06	-.06	.13	-	.94***	.15	.11	-.57***
18	V1b d prime	.03	-.15	-	-.36*	.11	.01	.07	.13	.07	-.15	-.06	.02	.04	-.04	-.08	.11	.95***	-	.19	.06	-.50***
19	V1b correct RTs	-.06	-.33*	-	.20	-.11	-.05	.22	.17	.17	.26	.19	-.19	.05	.18	-.02	-.06	-.03	.02	-	.09	.70***

20	VAS report comp	.33*	.39*	-	.04	.19	.13	-.37*	-.33*	-.10	.04	-.15	.12	.12	.19	.89**	.83**	.03	.01	-.04	-	.01
21	V1b comp	-.05	-.23	-	.31+	-.22	-.07	.19	.11	.13	.32*	.22	-.27+	-.04	.17	.03	-.13	-.60***	-.54***	.78***	-.05	-

Note:. Owf: oral word reading fluency; Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN picture: RAN pictures task, RAN digits: RAN digits task, MA: morphological awareness, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification, Global: global report, Partial: partial report, V1b correct RTs: visual 1-back correct reaction times, VAS report comp: composite scores of the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.

$^{+}$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001.

Inspection of Table 14 reveals that spelling accuracy was significantly associated with scores for oral word reading fluency, PA, RAN pictures, MA, digit backwards, visual sequential short-term memory, character identification, global report and VAS composite scores, in both Pearson's and partial correlation. Neither of the v1b measures was significantly associated with spelling scores. Due to the lack of significant correlation between partial report and spelling accuracy, only the global report task scores were used for later analyses. The significant correlations between reading measures and VAS are highlighted in red in the table.

These variables - PA, RAN pictures, MA, digit backwards, visual sequential short-term memory, character identification, and global report, together with nonverbal ability, were included as predictors in the following analyses.

Regression analyses

Hierarchical regression analysis was carried out with accuracy in the spelling-to-dictation task as the dependent variable. Hair et al. (2014) suggested that the recommended minimum datapoints is ten times the number of research instruments. Thus, according to our sample size (*n*=56), the six independent variables that were most strongly associated with reading measures in the correlation analyses (nonverbal ability, PA, RAN pictures, MA, character identification and global report) were entered in the regression. The results including verbal and visual memory in the hierarchical regression analysis are not presented here but can be found in the Appendix D. In Step 1, nonverbal ability was entered, and in Step 2, PA, RAN pictures, MA, and character identification were entered. At the final step, scores for the global report task were entered. Results are reported in Table 15.

Table 15

Hierarchical Regression Analyses with Spelling Accuracy as the Dependent Variable in Study 2a

		Spelling accuracy					
Step		ΔR^2	ΔF	β	t	Tol	VIF
1	Nonverbal Abil.	0.01	0.30	0.08	0.55	1.00	1.00
2		0.54***	11.65				
	PA			0.37**	3.25	0.88	1.13
	RAN pictures			-0.30*	-2.66	0.91	1.10
	MA			0.31*	2.63	0.84	1.19
	Char. Ident.			0.34*	3.05	0.93	1.07
3	Global	0.05*	4.51	0.25*	2.12	0.76	1.31

Note:. Nonverbal Abil.: nonverbal ability, PA: phonological awareness, RAN picture: RAN picture task, MA: morphological awareness, Char. Ident.: character identification, Global: global report
$^{+}$ *p*<.01, **p*<.05; ***p*<.01; ****p*<.001.

Results showed that PA, RAN pictures, MA, and character identification were all significant predictors of spelling accuracy. After controlling for nonverbal ability and the above variables, global report still significantly explained 5% of the variance in spelling accuracy (*p*<.05).

Item-based analyses

As noted in the Introduction to this chapter, the sublexical processing in Chinese outlined by Mo (2023) is different from that in alphabetic languages, as outlined by Hepner et al. (2019) and others, because of a lack of grapheme-phoneme correspondences. In Chinese the sublexical route involves radical combinations with analytical processing. So, printed word frequency in Chinese spelling was suggested to be associated with lexical processing, while word length was suggested to be associated with sublexical/analytical processing. Word length here was the number of logographemes calculated based on *Chinese character component standard of GB 13000.1 character set for information processing* (1998).

Spelling accuracy was calculated across participants for each item in the spelling-to-dictation task to conduct the item-based analyses. The results of EDA revealed that the scores for word length and spelling accuracy violated the assumption of normality. These variables were transformed using log transform. Zipf. Frequency as standardised scores were used. Pearson's correlation was used to explore the correlation between word frequency, length and spelling scores. Results are presented in Table 16.

Table 16

Pearson's Correlation with Word Frequency, Word Length and Spelling Accuracy per Item

		1	2	3
1	Frequency	-		
2	Word Length	-.42**	-	
3	Spelling accuracy	.35**	-.54***	-

Note:. *p<.05; **p<.01; ***p<.001.

Results in Table 16 showed that spelling accuracy was significantly associated with word frequency and length, with a stronger association with word length.

Simultaneous multiple regression analysis was conducted with word frequency and length as independent variables and spelling accuracy as the dependent variable. Results are shown in Table 17. The results indicated that only word length was a significant predictor of the children's spelling accuracy.

Table 17

Simultaneous Multiple Regression Analyses with Spelling Accuracy as the Dependent Variable in Study 2a

	Spelling accuracy			Tol	VIF
	B	β	*t*		
Frequency	0.06	0.16	1.27	0.82	1.22
Word Length	-0.89	-0.47***	-3.88	0.82	1.22

Note:. *p<.05; **p<.01; ***p<.001.

Qualitative spelling error analyses

Following Shen and Bear's (2000) qualitative analysis of spelling errors, we adopted the categories phonological errors, orthographic errors, meaning-related errors, and no responses. Phonological errors included *pinyin substitution*, *homophone* and *semi-homophone substitutions*; orthographic errors included *change in configuration, character substitution similar in shape, addition or deletion of strokes, partial character* and *invention of an unconventional character.* Among the orthographic errors, *change in configuration, character substitution similar in shape, and addition or deletion of strokes* respectively corresponded to errors in transposition, substitution, addition and deletion. Meaning-related errors included *synonym substitution* and *substitution of meaning-related characters.*

Examples of each spelling error category were as follows:

Phonological errors: *pinyin substitution* (e.g., 字 (word)/zi4/ spelled with its pinyin /zi4/); *homophone* and *semi-homophone* substitutions (e.g., 议(discuss)/yi4/ in the target item 议会(council)/yi4 hui4/ written with other characters 意 (meaning)/yi4/ or 衣 (clothes)/yi1/ with similar pronunciations as the target).

Orthographic errors: *partial character* (e.g., the character 飓 in target 飓风 (hurricane)/ju4 feng1/ was written as 风); *invention of an unconventional character* (strokes, radicals, etc. irrelevant to the target); t*ransposition* (e.g., 地 (place)/di4/ was written as 也土); *deletion* (e.g., 日 (day)/ri2/ was written as 口); *addition* (e.g., 猴 (monkey)/hou2/ was written as  with a short slash added in the left semantic radical); *substitution* (*real word*: e.g., 河 (river)/he2/ was written as 苛 (severe)/ke1/ with a similar shape as the target; *nonword*: e.g., 鼻 (nose) /bi2/ was written as 

The difference between *deletion* and *partial character* categories lay in how large the missing part of the target was. *Deletion* errors involved missing strokes *as the smallest units,* while *partial character* errors involved the deletion of logographemes.

Meaning-related errors: *synonym substitution* (e.g., the character 寺 (temple)/si4/ was written 庙 (temple) /miao4/) and *substitution of meaning-related characters* (e.g., the character 航 (sail)/hang2/ was written 船 (boat)/chuan2/).

The actual spelling errors of the children can be found in Appendix E.

Category in Study 1a

Table 18

Percentage (and Number) of Spelling Errors in Words of Different Frequency in Each Error

	Low-frequency words	Middle-frequency words	High-frequency words
Total number of errors	496	258	124
Phonologically based errors	55.24 (274)	31.01 (80)	25 (31)
Pinyin substitution	30.04 (149)	22.48 (58)	8.87 (11)
Homophone and Semi-homophone substitution	25.20 (125)	8.53 (22)	16.13 (20)
Orthographic errors	19.76 (98)	44.57 (115)	50 (62)
Partial character	1.41 (7)	0.39 (1)	0.81 (1)
Invention of an unconventional character	1.41 (7)	2.33 (6)	3.23 (4)
Transposition	0.60 (3)	1.55 (4)	3.23 (4)
Deletion	8.06 (40)	15.12 (39)	26.61 (33)
Addition	3.02 (15)	16.67 (43)	9.68 (12)
Substitution (real words)	3.02 (15)	3.49 (9)	4.84 (6)
Substitution (nonword)	2.22 (11)	5.04 (13)	1.61 (2)
Meaning-related errors	0.81 (4)	1.55 (4)	0.81 (1)
Synonym substitution	0 (0)	0.78 (2)	0 (0)
Substitution of meaning-similar character	0.81 (4)	0.78 (2)	0.81 (1)
No responses	24.19 (120)	22.87 (59)	24.19 (30)

Table 18 indicates the spelling errors for words of different frequency. There was the greatest number of spelling errors with low-frequency words. Children made more phonologically-based errors and no responses with low-frequency words. By contrast, children made more orthographic errors with words of middle and high frequency, and transposition, deletion, etc. errors accounted for a relatively greater proportion of the orthographic errors.

3.2.4 Discussion of 2a

Study 2a examined the relationship between VAS and Mandarin-speaking children's spelling-to-dictation performance. Results revealed that global report performance was significantly associated with the children's spelling accuracy. A unique prediction of global report was found after controlling for nonverbal ability, PA, RAN, MA and character identification in the regression analyses.

Regarding RQ1 "Does VAS significantly predict spelling-to-dictation in 10- to 12-year-old Mandarin-speaking children over and above the influence of other related variables?" the prediction was that VAS assessed with global and partial report and v1b tasks would uniquely predict the children's spelling accuracy. Results from Study 2a were partially in line with the hypothesis because VAS assessed in partial report and the v1b task was not found to predict children's spelling but the global report was. This point will be discussed later.

PA, RAN, MA and character identification were found to significantly predict children's spelling. Significant associations of PA, RAN and MA with spelling accuracy are consistent with findings from studies of spelling development in alphabetic writing systems (e.g., Casalis et al., 2011; Görgen et al., 2021; Niolaki et al., 2020; Van Den Boer et al., 2015). In regression analyses, PA, RAN, MA and character recognition scores together explained 55% of the variance in spelling accuracy. As noted in the Introduction, PA and RAN have previously been reported to significantly predict spelling accuracy in Mandarin-speaking children (e.g., Li et al., 2020; Yeung et al., 2011). This could be because effective PA skills facilitate early character identification through clear and consistent mapping of phonemes to characters (e.g., Yeung et al., 2013); RAN skills may facilitate extraction of orthographic patterns and pronunciation retrieval from memory (e.g., Yeung et al., 2011); MA might be of benefit in deconstructing Chinese complex words such as compound words through distinguishing and organising the morphemes, which may be helpful for producing accurate spellings (Li et al., 2020).

Some researchers have pointed to the fact that the association between phonological processing ability and spelling for Chinese-speaking children may be due to learning English from the third grade of school. Huang and Hanley (1995) proposed that Chinese children's PA performance was influenced by having learned the alphabetic writing system of English. In addition, as noted in the Introduction, the children in this study had learned the transparent Pinyin system in the early stages of being introduced to characters, and this may have facilitated the development of PA and its association with literacy skills. Strong predictions of PA found in the present study also suggested the importance of phonological processing.

Individual character identification skill was also found to predict spelling accuracy. Liu et al. (2015) and Liu et al. (2016) conducted studies with 9-year-old Hong Kong Chinese children assessing character reading and spelling accuracy. They found that character reading and spelling were both predicted by performance in a visual search task involving the detection of targets in a matrix of targets and distractors. Liu et al. argued that Chinese spelling requires storage and retrieval of detailed orthographic information, and this information is easily extracted and stored during reading in children who have good visual discrimination and attention abilities.

In the regression analysis VAS assessed in the global report task remained a significant predictor of spelling accuracy when entered after scores for PA, RAN, MA and character identification were entered, which is in line with the existing studies on VAS and children's spelling. Van Den Boer et al. (2015), Niolaki et al. (2020) and Niolaki et al. (2024) also reported that VAS (assessed with the global report task in their studies), was a significant predictor of spelling ability in Dutch-, English- and Greek-speaking children, respectively, after controlling for at least PA and RAN. This finding in the present study extends the association to Mandarin-speaking children aged 10-to-12 years.

However, no correlations between the partial report task and spelling accuracy were found. This may be because as mentioned in Chapter 2 the attention allocation in partial report was equal to each position but the attention allocation to different characters or radicals during the spelling processing may be different due to different familiarity.

No v1b variables were associated with children's spelling. It may be because the spelling to dictation word task was used. Compared with reading in Chinese, spelling in Chinese is considered to be a more cognitively demanding task because processing the exact spatial positioning of strokes in complex configurations is required (Liu et al., 2016). Spelling production wuld depend on the quality of representations in the orthographic lexicon and the intact function of VAS. Correspondingly, as a pure visual processing task, the v1b task may be less involved in the spelling process.

Regarding RQ2 "Would the item-related variables word frequency and word length be associated with spelling accuracy? And would word frequency be more strongly related with spelling accuracy than word length?" the prediction was that word frequency might be a stronger predictor of spelling accuracy than word length. The results of the item-based analyses were not in line with the hypothesis. Word frequency and word length were significantly associated with spelling, which was in line with the finding of Wong (2017). Word length was more strongly associated with spelling. The finding suggests that children relied more on analytical than lexical processing for spelling.

As discussed in Chapter 1, the Multitrace Memory Model of Ans et al. (1998), argues for global processing requiring large VAS and analytical processing requiring small VAS. Combined with the results in Study 1a, these findings indicate the VAS of the children was not large. However, this result was not in line with Niolaki et al. (2024) who reported that word frequency predicted the spelling-to-dictation of older Greek-speaking children aged 10 to 13 years. Compared with Greek, Chinese places greater demands on visual processing during early literacy acquisition, and children need to process details of characters, so it should perhaps explain that word length rather than word frequency was a significant predictor of spelling accuracy.

Regarding RQ3 ”What are the main spelling strategies of children?”, the prediction was that Mandarin speaking children may rely more on whole word lexical processes for spelling. Results were partially in line with the prediction.

The qualitative analysis of spelling errors showed that there were more phonological errors than orthographic errors for low-frequency words but more orthographic errors than phonological errors for mid- and high-frequency words. The results for mid- and high-frequency words are in line with those of Tong et al. (2009) and Yeung et al. (2013), suggesting more reliance on orthographic processing in Chinese-speaking children. The results for low-frequency words are in line with those of Shen and Bear (2000). This may suggest that the words in Shen and Bear were difficult to spell words and so it is likely they were of low frequency - thus when the children are unable to draw on lexical entries they report to phonological strategies (use of pinyin and use of characters for similar-sounding items). Phonological errors have been interpreted as reliance on phonological processing for spelling - so for the lower frequency words the children are relying on pinyin knowledge and substitution of other words with similar sound - these two constitute phonological processing. It could be concluded that the Mandarin-speaking children relied on phonological strategy in low-frequency words and orthographic strategy in middle-frequency and high-frequency words.

In summary, the results indicated that VAS assessed with global report uniquely predicted Mandarin-speaking children's spelling after controlling for PA, RAN, MA and character identification.

3.3 Study 2b: Relationship between VAS and spelling of Mandarin-speaking adults

As mentioned in Chapter 1, so far, there have been no studies directly exploring the relationship between VAS and adults' spelling. However, letter report tasks have previously been used as measures of the efficiency of orthographic processing to distinguish good and poor spelling performance in adults by Ginestet et al. (2020) and Masterson et al. (2007).

Adult spellers with unexpected spelling difficulty

An early indication of the research with good and poor adult spellers was that poor spelling was due to weak phonological processing abilities (e.g., Burden 1992; Burt & Shrubsole, 2000), in line with previous research with children (e.g., Bruck & Waters, 1988), and with dyslexic children and adults (e.g., Campbell & Butterworth, 1985). For example, Burden (1992) reported poor adult spellers also with poor nonword reading skills. However, later studies showed that good and poor spellers but with equated reading ability failed to support phonological weakness as a universal explanation for poor spelling in adults (e.g., Holmes & Quinn, 2009; Masterson et al., 2007).

Inefficient orthographic processing has been investigated as a cause of poor spelling since the investigations of Frith (1980; 1985). Frith's (1980; 1985) found that good adolescent readers who were unexpectedly poor spellers were worse than good spellers at detecting instances of silent *e* in a letter-cancellation task. Frith suggested that the results were due to a reliance on partial cues in reading of poor spellers, thus leading to the establishment of incomplete orthographic representations. Holmes and colleagues extended the work of Frith and proposed that poor spelling was due to difficulty in identifying and parsing orthographic input.

Holmes and Ng (1993) assessed good and poor adult spellers in lexical decision tasks and found that what discriminated between the groups was lexical decision for long idiosyncratic words and long non-words with mis-ordered internal letters - the poorer spellers were less accurate and were slower. The researchers outlined the early cessation of processing hypothesis that poor spellers, in reading, terminate processing before carrying out a complete analysis of the printed word, and this leads to failure to establish detailed representations that can be used for accurate spelling.

Holmes and Castles (2001) found that unexpectedly poor adult spellers produced similar misspellings as good spellers, indicating good knowledge of grapheme-phoneme correspondences. However, the poor spellers were slower than the good spellers at making lexical decisions on regularly and irregularly spelled printed words and were slower and made more errors when matching pairs of common regularly spelled words, presented either intact (e.g., *bathroom–bathroom*) or with a pair of medial letters misordered (errors in transposition, e.g., *platform–plaftorm*). Similarly, findings of Holmes et al. (2008) supported the idea that unexpectedly poor spellers were poorer at orthographic processing, for in a lexical decision task, unexpectedly poor spellers were significantly slower and more error-prone than better spellers when classifying both regularly and irregularly spelled words, as well as when detecting letter transpositions in long misordered words with regular spellings (e.g., *turlte, pilrgim*). Similar to spelling errors in transposition, errors in substitution, addition, deletion, and omission in words, were regarded as difficulties in OWM or the grapheme buffer area, as mentioned above. Thus, such types of spelling errors found in poor adult spellers may suggest deficits in OWM.

Masterson et al. (2007) also found that English-speaking adults who were good readers but who differed in spelling ability were not differentiated by performance in tasks of phonological ability (spoonerisms and speeded naming of pictures and digits). The groups did differ, however, in reporting letters from briefly presented nonword letter strings. In addition, qualitative analysis of the participants' spelling errors revealed the preservation of letters in initial and final word positions for the poor spellers. Similar to the incomplete processing hypothesis (Holmes & Ng, 1993), the authors suggested that poor spellers make an incomplete analysis of printed stimuli, which leads to a failure to retain detailed orthographic representations that can be used for accurate spelling.

Performance in the letter report task has been interpreted more recently in terms of VAS, that is, as outlined in the previous chapters, in terms of reflecting the mechanisms that allow for the simultaneous processing of multiple visual elements (Awadh et al., 2016; Bosse et al., 2007; Ginestet et al., 2020). This efficient processing of multiple orthographic elements is considered to facilitate the establishment of lexical-orthographic entries (Bosse et al., 2015; Valdois et al., 2014). Support for this view was obtained in an investigation of novel word learning using eye movement measures in French-speaking adults by Ginestet et al. (2020). They reported that adults with higher VAS assessed by global and partial report tasks were able to process more novel words in a single fixation after five encounters with the stimuli. They also found that participants with higher letter report scores outperformed those with lower report scores in a spelling assessment.

The present study was carried out to examine whether VAS would be a significant predictor of spelling in Mandarin-speaking adults. It was predicted that since Mandarin has an opaque orthography and an instruction system is used that emphasises orthographic processing (see Section 1.3.1 in Chapter 1) then VAS would have an influence on spelling in the adults in the present study just as it had been found to with the 10- to 12-year-old child participants in Study 2a.

3.3.1 Research questions

VAS tasks were employed in Study 2b to investigate the relationship between VAS and other literacy-related variables and spelling accuracy in adult Mandarin speakers. In addition scores from the assessments were used to explore potential underlying cognitive weaknesses in adult poor spellers who were good readers through participant-basedbased analyses, item-based analyses, as well as qualitative spelling error analyses.

The first research question was similar to Study 2a to investigate the unique prediction of VAS under measures to spelling-to-dictation of adults.

The second research question: Is the spelling performance of poor spellers with good reading ability due to weak skills in phonological processing?

With regard to RQ1, the prediction was that VAS assessed in global report might predict spelling accuracy in Mandarin-speaking adults after controlling for other literacy-related variables, as in the study of Masterson et al. (2007).

With regard to RQ2, poor spelling in Chinese adult spellers may be due to weak VAS or other orthographic processing skills, rather than due to a phonological deficit (as reported by Holmes et al., 2008; Holmes & Ng, 1993; Holmes & Castles, 2001; Masterson et al., 2007).

3.3.2 Method

Participants. The adults were those who took part in Study 1b (please find details of the sample in the *Participants* section of Study 1b).

Spelling-to-dictation. As in Study 2a, the 60-word spelling list created by Masterson et al. (2008), translated into Mandarin by Wong (2017), was used to assess spelling. Printed word frequency values for adults for the words were obtained from SUBTLEX-CH (Cai & Brysbaert, 2010), a database of Chinese characters for adults. Zipf frequency for the 60 words was calculated as *m*=4.54 (*sd*=0.82). Values were calculated for the length of each word in terms of number of logographemes (*m*=3.78, *sd*=1.70).

Cronbach's alpha was calculated as 0.72, based on the scores from the participants in the current study.

Procedures*.* The data collection was as described in Study 1b and the data were collected in December 2022.The spelling-to-dictation task (lasting c. 10 minutes) was conducted in the third session of testing and involved an audio presentation of the 60 words and their associated sentences. For the spelling to dictation task, the researcher played the audio to the participants, and the participants wrote their responses. At the end of the task participants sent a photo of their script to the researcher via email. Participants used their own laptops (including 23 laptops with Mac system and 35 laptops with Windows system) with 60 Hz to 75 Hz refresh rate during the assessments.

Data analyses. Data analyses were the same as in Study 1b including the participant-based, item-based and qualitative spelling error analyses. The only difference was that after the participant-based analyses focusing on all adults, participants were then classified into better and poor spellers based on the median score for the spelling assessment for the latter two analyses to examine whether the poor orthographic processing could differentiate spelling performance of poor and better adult spellers. Independent t-tests were also used to compare the scores of the speller groups.

3.3.3 Results

The first section gives the results of analyses examining potential associations of VAS and spelling accuracy of the adults. The results of EDA revealed that the scores for adults' spelling accuracy were normally distributed. The mean of the spelling accuracy was 54.97 (*sd*=3.18), with the range from 45 to 60. Pearson's correlation and Partial correlation analyses controlling for age and nonverbal ability were conducted to explore the relationship between the variables. The results are reported in Table 19.

Table 19

Pearson's Correlation (above the diagonal) and Partial Correlation (below the diagonal, after controlling for Age and Nonverbal Ability) with VAS and Other Important Variables in Study 2b

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Spelling accuracy	-	.16	.00	-.21	.21	.12	-.06	-.23+	.08	.32*	.33**	.30*	.09	.45***	.29*	.24+	.24+	-.07	-.45**	-.23+
2	Owf	-.03	-	.03	-.12	.17	.10	-.54	-.72***	.32*	.10	.13	.08	-.14	.30*	-.01	.06	.04	-.26*	.18	-.21
3	Nonverbal Abli.	-	-	-	.08	.40**	-.26+	-.19	.17	.05	.23+	.24+	.10	-.09	-.09	.16	.43**	44**	.16	.02	-.15
4	Age	-	-	-	-	.09	.04	.08	.21	-.06	.07	-.24+	-.06	-.38**	-.31*	-.27*	-.04	.02	.23+	-.27*	.27*
5	Vocabulary	.11	.10	-	-	-	.01	-.14	-.20	.30*	.25+	.23+	.28*	-.15	.15	.16	.19	.21	.24+	.10	.11
6	PA	.21	.08	-	-	-.08	-	.03	-.21	.33*	.12	-.17	.08	-.13	.10	-.00	-.02	-.07	-.01	.08	-.02
7	RAN picture	-.01	-.50**	-	-	-.03	.07	-	.36**	-.26+	-.00	-.10	-.21	-.03	-.33*	-.16	-.11	-.06	.13	-.27*	.22
8	RAN digits	-.16	-.69***	-	-	-.30+	-.17	.34*	-	-.32*	-.17	-.07	-.13	-.01	-.35**	-.05	.01	.03	.16	-.25+	.13
9	VerbalFor STM	-.01	.15	-	-	.23	.31*	-.11	-.27+	-	.29*	-.12	-.01	-.02	.24+	.16	.04	-.03	-.07	.18	-.05
10	VerbalBack STM	.30+	-.03	-	-	.14	.26	.07	-.20	.29	-	.28*	.25+	-.09	.33*	.22	.05	.05	-.09	.36**	-.07
11	VisualSimul STM	.28+	-.03	-	-	-.09	-.06	-.11	.04	-.35*	.11	-	.62***	.04	.19	.31*	.16	.13	-.14	.15	.24+
12	VisualSeq STM	.17	-.01	-	-	.06	.17	-.27+	-.12	-.08	.22	.64***	-	-.09	.12	.14	.09	.06	-.06	.10	-.15
13	Chat. Ident.	.04	-.26+	-	-	-.09	-.17	.05	.08	-.14	-.00	.03	--.02	-	.31*	.17	-.05	-.07	.04	.11	.13
14	Global	.42**	.10	-	-	.06	.08	-.18	-.19	.04	44**	.16	.14	.14	-	.49***	.17	.17	-.08	.86***	-.15
15	Partial	.18	-.33*	-	-	-.09	-.00	.11	.11	-.07	.17	.18	.06	-.05	.15	-	.32*	.33*	-.07	.80***	-.29*
16	V1b accuracy	.13	-.06	-	-	-.16	-.00	.02	.10	-.02	-.01	.12	-.10	.06	.22	.35*	-	.92***	.27*	.28*	-.63***
17	V1b d prime	.11	-.14	-	-	-.14	-.03	.08	.18	-.02	-.09	.11	-.15	.02	.12	.86*	.95***	-	.24+	.30*	-.55***
18	V1b correct RTs	-.03	-.20	-	-	.21	-.13	.18	.09	-.07	-.07	-.14	-.09	.11	.09	-.09	.21	.26+	-	-.10	.50***
19	VAS report comp	.40*	-.15	-	-	-.02	.05	-.05	-.06	-.01	.41**	.22	.14	.07	.78***	74***	.37*	.33*	.00	-	-.31*
20	V1b comp	-.17	-.08	-	-	.27+	-.08	.19	.02	-.07	-.09	-.24	-.07	.02	-.14	-.40*	-.67***	-.60***	.54***	-.35*	-

Note:. Owf: oral word reading fluency; Nonverbal Abil.: Nonverbal ability, PA: phonological awareness, RAN picture: RAN picture task, RAN digits: RAN digits task, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification, Global: global report, Partial: partial report, V1b correct RTs: visual 1-back correct reaction times, VAS report comp: composite scores of the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.
$^{+}$ p<.1, *p<.05; **p<.01; ***p<.001

The analyses showed that global report and VAS report composite scores were significantly correlated with spelling scores. Pearson's correlation showed that spelling significantly correlated with backward digit span, both visual short-term memory tasks, as well as global and partial report. The significant correlations between reading and VAS are highlighted in red.

Although the correlation between VAS report composite scores and spelling accuracy was significant, only global report was significantly correlated with spelling accuracy under both correlational analyses. So only global report was used for the later analyses. The assessment of character identification was also employed, with the intention that this would be controlled in the analyses, so that the remaining variance in VAS scores could be attributed to participants' ability to simultaneously process the multi-element array. So, the variables digit backwards, visual short-term memory composite scores, character identification and global report scores, together with age and nonverbal ability, were included as predictors in the following analyses.

Hierarchical regression analysis was carried out with spelling accuracy as the dependent variable. In Step 1, age and nonverbal ability were entered, and in Step 2, digits backwards, visual short-term memory composite scores and character identification were entered. At the final step, scores for the global report task were entered. Results are reported in Table 20.

Table 20

Hierarchical Regression Analyses with Spelling Accuracy as the Dependent Variable in Study 2b

		Spelling accuracy					
Step		ΔR^2	ΔF	β	t	Tol	VIF
1		0.02	0.47				
	Age			-0.14	-0.95	0.96	1.04
	Nonverbal Abil.			0.00	0.00	0.96	1.04
2		0.18*	3.42				
	VerbalBack STM			0.30*	2.14	0.91	1.10
	Visual STM comp			0.24+	1.77	0.93	1.07
	Char. Ident.			0.13	0.87	0.80	1.26
3	Global report	0.09*	5.86	0.38*	2.42	0.64	1.57

Note:. Nonverbal Abil.: nonverbal ability, VerbalBack STM: verbal digit backward short-term memory, Visual STM comp: visual short-term memory composite z scores, Char. Ident.: character identification, Global: global report task
$^{+}$ *p*<.01, **p*<.05; ***p*<.01; ****p*<.001.

Results of the hierarchical regression analysis revealed that VAS report scores significantly explained 9% of the variance in spelling accuracy after controlling for age, nonverbal ability, backward digit span, visual short-term memory and character identification.

Comparison of poor and better spellers

The aim of the analyses reported in this section was to conduct item-based analyses and qualitative analysis of errors that were employed in previous studies of English-speaking better and poor adult spellers to see whether findings might be similar for Mandarin speakers.

Following the analyses looking at the effect on spelling accuracy of VAS and participant-based variables nonverbal ability, PA, RAN, reading fluency, character identification, visual STM, and backward digit span, as reported in the previous section, the adult participants were divided into two spelling ability groups on the basis of the median score of the group for spelling accuracy. The results for the two groups in the participant-related variables were then compared to identify potential weaknesses in the different cognitive associates of spelling in the poor speller group. Following this, analyses of the effect of the item-related variables (word frequency and word length) were conducted. Finally, qualitative analysis of the spelling errors of the two groups was carried out.

Table 21 shows mean values for age, nonverbal ability, vocabulary, reading fluency, and spelling accuracy for the better and poor spellers. Potential differences in the measures were examined using independent groups t-tests. The only significant difference was in spelling accuracy scores (highlighted), with the poor spellers scoring significantly worse than the better spellers, as expected.

Table 21

Descriptive Statistics for Age, Nonverbal Ability, Vocabulary, Reading Fluency, Spelling Accuracy of Poor and Better Adult Spellers

	Poor spellers (*n*=27)		Better spellers (*n*=31)		T	*p*
Variables	Mean (SD)	Range	Mean (SD)	Range		
Age	29.35 (7.44)	20-48.06	26.54 (6.81)	19.08-51	*t*(56)=-1.50	.14
Nonverbal ability (/60)	45.76 (7.34)	24-59	43.94 (7.31)	26-58	*t*(54)=-0.93	.36
Vocabulary (/120)	111.63 (4.51)	100-116	113.10 (3.56)	105-118	*t*(56)=1.38	.17
Reading fluency	96.28 (18.19)	58-135	100.89 (14.62)	73-125.58	*t*(56)=1.07	.29
Spelling accuracy (/60)	52.33 (2.70)	45-55	57.26 (1.13)	56-60	*t*(33.76)=8.83	.00

Table 22 shows mean values for PA, RAN, verbal and visual short-term memory, character identification and VAS report tasks for the two spelling groups. Results of independent groups t-tests revealed a significant group difference only for global report scores, with the poor spellers obtaining lower scores than the better spellers.

Table 22

Descriptive Statistics for Phonological Awareness, Rapid Automatised Naming, Verbal and Visual Memory, Character Identification and VAS Report Tasks of Poor and Better Adult Spellers in Study 2b

	Poor spellers (*n*=27)		Better spellers (*n*=31)		T	*p*
Variables	Mean (SD)	Range	Mean (SD)	Range		
PA (/33)	28.11 (4.73)	16-33	28.68 (3.26)	21-33	*t*(45.22)=0.52	.60
RAN digits (seconds)	27.33 (7.65)	14.93-55.74	25.01 (4.56)	19.68-38.83	*t*(56)=-1.42	.16
RAN pictures (seconds)	70.05 (12.91)	50.70-98.81	67 (11.63)	50.95-96.01	*t*(56)=-0.95	.35
VerbalFor STM (/12)	9.93 (1.11)	8-12	10.14 (1.24)	8-12	*t*(53)=0.68	.50
VerbalBack STM (/10)	6.85 (2.48)	2-12	7.58 (1.29)	5-10	*t*(37.83)=1.38	.18
VisualSimul STM (/12)	10.19 (1.59)	5-12	10.65 (1.76)	6-12	*t*(56)=1.04	.30
VisualSeq STM (/12)	10.22 (1.65)	6-12	10.71 (1.51)	5-12	*t*(56)=1.18	.25
Char. Ident. (/150)	105.44 (21.27)	37-132	103.55 (20.42)	48-134	*t*(54)=-0.34	.74
Global (/120)	76.48 (11.44)	46-92	84.35 (14.74)	54-110	*t*(56)=2.25	.03
Partial (/36)	22.56 (5.74)	10-32	25.45 (5.84)	9-35	*t*(56)=1.90	.06

Note:. PA: phonological awareness, RAN: rapid automatised naming, RAN picture: RAN picture task, RAN digits: RAN digits task, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification, Global: global report, Partial: partial report.

Item-based analyses

Spelling accuracy was calculated across participants for each item in the spelling task. Results of EDA revealed that spelling accuracy and word length (the number of logographemes) violated the assumption of normality, therefore the two variables were subjected to log transformation. Pearson's correlation was used to explore the association of word frequency, word length and spelling accuracy scores. Results of the analyses are presented in Table 23.

Table 23

Pearson's Correlation with Printed Word Frequency, Word Length and Spelling Accuracy for Poor Spellers (below the diagonal) and Better Spellers (above the diagonal) in Study 2b

		1	2	3
1	Frequency	-	-.42**	.39**
2	Word Length	-.42**	-	-.33*
3	Spelling accuracy	.52***	-.49***	-

Note:. *p<.05; **p<.01; ***p<.001.

The results indicated that the spelling accuracy of poor and better spellers was significantly correlated with word frequency and length, in particular for word frequency.

Two separate simultaneous multiple regression analyses were employed to look for potential effects of word frequency and word length on spelling accuracy (the dependent variable in each analysis) for the better and poor spellers. The results are presented in Table 24.

Table 24

Simultaneous Multiple Regression Analyses with Spelling Accuracy as the Dependent Variable and Item-Related Variables as the Predictors for the Poor and Better Spellers in Study 2b

	Poor spellers			Better spellers			Tol	VIF
	B	*β*	*t*	B	*β*	*t*		
Frequency	0.03	0.38**	3.20	0.01	0.31*	2.32	0.82	1.22
Word Length	-0.10	-0.33**	-2.80	-0.04	-0.20	-1.50	0.82	1.22

Note:. *p<.05; **p<.01; ***p<.001.

The analyses revealed that word frequency and word length were significant predictors of spelling accuracy for the poor spellers, while only word frequency was a significant predictor of spelling accuracy for the better spellers.

Qualitative analysis of spelling errors

Categories of spelling errors were the same as in Study 2a. The mean percentage and number of errors for each spelling error type for poor and better spellers are presented in Table 25. The scores of children from Study 2a are also reported in the table for comparison. Figure 9 depicts the data in visual form. The actual spelling errors of adults were attached in Appendix F.

Table 25

Percentage (and Number) of Spelling Errors in Each Error Category of Children, Poor Adult Spellers and Better Adult Spellers

Error category	All children (n=56)	Poor spellers (n=27)	Better spellers (n=31)
Low-frequency words	496	151	35
Phonologically based errors	55.24 (274)	9.27 (14)	17.14 (6)
Pinyin substitution	30.04 (149)	0.66 (1)	0 (0)
Homophone and Semi-homophone substitution	25.20 (125)	8.61 (13)	17.14 (6)
Orthographic errors	19.76 (98)	44.37 (67)	62.86 (22)

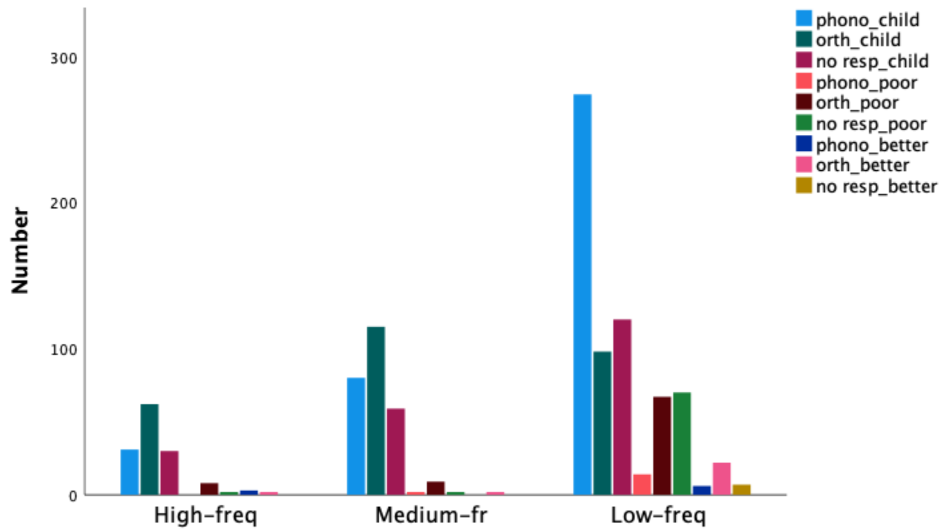
Partial character	1.41 (7)	2.65 (4)	5.71 (2)
Invention of an unconventional character	1.41 (7)	1.32 (2)	0 (0)
Transposition	0.60 (3)	1.32 (2)	5.71 (2)
Deletion	8.06 (40)	22.52 (34)	20 (7)
Addition	3.02 (15)	13.25 (20)	31.43 (11)
Substitution (real words)	3.02 (15)	1.32 (2)	0 (0)
Substitution (nonword)	2.22 (11)	1.99 (3)	0 (0)
Meaning-related errors	0.81 (4)	0 (0)	0 (0)
Synonym substitution	0 (0)	0 (0)	0 (0)
Substitution of meaning-similar character	0.81 (4)	0 (0)	0 (0)
No responses	24.19 (120)	46.36 (70)	20 (7)
Middle-frequency words	258	13	2
Phonologically based errors	31.01 (80)	15.38 (2)	0 (0)
Pinyin substitution	22.48 (58)	0 (0)	0 (0)
Homophone and Semi-homophone substitution	8.53 (22)	15.38 (2)	0 (0)
Orthographic errors	44.57 (115)	69.23 (9)	100 (2)
Partial character	0.39 (1)	15.38 (2)	0 (0)
Invention of an unconventional character	2.33 (6)	0 (0)	0 (0)
Transposition	1.55 (4)	7.69 (1)	0 (0)
Deletion	15.12 (39)	30.77 (4)	50 (1)
Addition	16.67 (43)	0 (0)	50 (1)
Substitution (real words)	3.49 (9)	0 (0)	0 (0)
Substitution (nonword)	5.04 (13)	15.38 (2)	0 (0)
Meaning-related errors	1.55 (4)	0 (0)	0 (0)
Synonym substitution	0.78 (2)	0 (0)	0 (0)
Substitution of meaning-similar character	0.78 (2)	0 (0)	0 (0)
No responses	22.87 (59)	15.38 (2)	0 (0)
High-frequency words	124	10	5
Phonologically based errors	25 (31)	0 (0)	60 (3)
Pinyin substitution	8.87 (11)	0 (0)	0 (0)
Homophone and Semi-homophone substitution	16.13 (20)	0 (0)	60 (3)
Orthographic errors	50 (62)	80 (8)	40 (2)
Partial character	0.81 (1)	0 (0)	0 (0)
Invention of an unconventional character	3.23 (4)	0 (0)	0 (0)
Transposition	3.23 (4)	0 (0)	0 (0)
Deletion	26.61 (33)	40 (4)	40 (2)
Addition	9.68 (12)	20 (2)	0 (0)
Substitution (real words)	4.84 (6)	0 (0)	0 (0)
Substitution (nonword)	1.61 (2)	20 (2)	0 (0)
Meaning-related errors	0.81 (1)	0 (0)	0 (0)
Synonym substitution	0 (0)	0 (0)	0 (0)
Substitution of meaning-similar character	0.81 (1)	0 (0)	0 (0)
No responses	24.19 (30)	20 (2)	0 (0)

In terms of spelling errors in all words, adults made fewer phonologically-based errors than orthographic errors, whereas children made more phonologically-based errors than orthographic errors in low-frequency words.

The largest percentage of orthographic errors in the three groups was different. Children and poor adult spellers made more errors in *deletion*, while better adult spellers made more errors in *addition*, especially for words with low-frequency and middle-frequency.

Figure 9

Categories of Spelling Errors of Words of Different Frequency for Children, Poor Adult Spellers and Better Adult Spellers



3.3.4 Discussion of 2b

This research was the first study to explore spelling-to-dictation in adult Chinese speakers. The first aim was to investigate the influence of VAS on spelling.

Regarding RQ1 about the independent and significant prediction of VAS to spelling performance, results from Study 2b were in line with the expectation and similar to results in Study 2a. VAS assessed in the global report task uniquely predicted spelling accuracy after controlling for age, nonverbal ability, verbal and visual short-term memory, and character identification. The amount of variance predicted was 9% ($p<.05$). This finding supports the view that VAS influences the establishment of lexical-orthographic representations (Bosse et al., 2013; Ginestet et al., 2020; Steinhiber et al., 2023). That is to say, the effective acquisition of orthographic knowledge in Chinese depends on the ability to distribute visual attention over the whole written word, since if an entire letter sequence can be efficiently processed, its representation can be established in the orthographic lexicon.

Regarding RQ2 “Is the spelling performance of poor spellers with good reading ability due to weak skills in phonological processing?”, the prediction was that global report scores may distinguish the spelling performance of Chinese better and poorer adult spellers, rather than phonological ability.

Results from Study 2b were in line with the hypothesis. Global report scores differentiated better and poor spellers, and this finding was in line with those of Ginestet et al. (2020) and Masterson et al. (2007) who reported an association of letter report performance with spelling ability in adults with no reported reading difficulties. In the current study, it was observed that phonological processing did not differentiate the spelling ability groups, but that VAS global report scores did. This was in accord with the work of Frith (1980), Holmes and Ng (1993) and Hanley et al. (1992), who posited inefficient orthographic processing as an underlying cause of poor spelling. Thus, as Bosse et al. (2015) and Ginestet et al. (2020) argued, VAS may affect the establishment of lexical-orthographic representations.

As for the item-based analyses, the findings revealed that word length and word frequency predicted the spelling accuracy of the poorer spellers while only word frequency predicted the spelling accuracy of the better spellers. This suggested that poor spellers may rely on both analytical and lexical whole-word processing, while better spellers may rely predominantly on lexical whole-word processing.

As for the spelling error analyses, all adults made fewer phonological errors than the children. Poor adult spellers made more *deletion* errors and no-response errors with low-frequency words, while better adult spellers made a larger percentage of *addition* errors. This may indicate unlike better spellers, the poor spellers are unable to draw on fully specified orthographic representations.

3.4 General discussion

This is the first study to examine how different VAS measures (global and partial report tasks, as well as the v1b task) relate to spelling accuracy in Mandarin-speaking children and adults. While performance on the global report task was a significant predictor of spelling in both groups, adults may rely more on VAS not phonological processing than children.

Participant-based analyses

Different from children, adults' spelling was not significantly correlated with PA and verbal short-term memory. These results were in line with suggestions from the previous studies of Tong et al. (2009) and Yeung et al. (2013) that there is a shift from phonological to more orthographic processes with age increasing.

Item-based analysis

Combining item-based analysis results from Study 2a and 2b, it can be shown that only word length significantly predicted children's spelling accuracy; word length and frequency predicted the spelling accuracy of the poor adult spellers; but only word frequency predicted the spelling of the better adult spellers. These findings suggest a developmental shift in Chinese character processing, from analytical processing in younger spellers to increasing lexical reliance with reading experience (Su & Samuels, 2010). Su and Samuels examined response latencies in written word recognition of Taiwanese children in Grades 2, 4 and 6, and adults with traditional Chinese characters. Results showed that response latencies increased with the number of strokes in characters for Grade 2 children, but no effect for fourth graders, sixth graders, or university students. These findings suggested that beginning Chinese readers process characters in an analytic way, but that the decoding process changes gradually from analytic to whole words as literacy skills develop.

Qualitative spelling error analyses

The analysis of spelling errors revealed that children made many phonologically-based errors. In contrast, adults made more orthographically-related errors. For low-frequency words, children and poor adult spellers made more *deletion* errors than *addition* ones, while better adult spellers made more *addition* than *deletion* errors, suggesting that they had more complete orthographic representations, despite the low exposure of these words. An inference from this is and that the better spellers had more efficient VAS skills that had been responsible for the establishment of the orthographic representations (according to the arguments of Bosse et al, 2015 and Ginestet et al., 2020).

VAS and OWM

VAS appears to serve a similar function to the orthographic working memory (OWM) in spelling, which is understood as a limited capacity system, responsible for the retention of identity and order information over a short period of time (e.g., Costa et al., 2011; Hepner et al., 2017). Valdois et al. (2025) conducted a VAS-focused training study with children from the beginning to the end of Grade 1 and found an improvement in spelling after the intervention. They suggested that efficient VAS allows for the simultaneous allocation of attention across many letters, enhancing letter identity encoding for novel words, thus boosting word identification in reading.

As for spelling, good VAS skills may be expected to lead to more efficient establishment of detailed orthographic representations, and these are used for spelling (as well as reading). Ginestet et al. (2020) provided evidence to support this argument. Ginestet et al. investigated VAS (using composite scores of global and partial report) of French-speaking adults without dyslexia and dysgraphia. They found that participants with a higher VAS had higher accuracy in orthographic decisions and shorter processing times. They thus assumed that processing time for bottom-up information extraction seemed to be modulated by VAS.

Bi et al. (2009) and Han et al. (2007) reported that two Chinese-speaking dysgraphic adults made the same type of spelling errors, involving substitution, transposition, addition, and deletion. These findings suggested the Chinese participants’ spelling difficulty was possibly due to poor simultaneous multi-element processing, that is to a weakness in allocating attention to orthographic details, such as the order, identity and arrangement of radicals or stokes. Errors in deletion, addition, transposition and substitution were observed in the children in the present study, and these have been interpreted in the past as reflecting the capacity of OWM (Barisic et al., 2017; Holmes & Castles, 2001; Holmes et al., 2008; Roncoli & Masterson, 2016). These results suggest that VAS may play a similar role as OWM.

In conclusion, the findings demonstrate that VAS, as measured by the global report task, plays a unique role in Chinese spelling across children and adults, even after controlling for key literacy-related variables. In adults, VAS appears to be a stronger predictor of spelling ability, and effectively differentiates between poor and better spellers. In terms of implications for instruction of the findings, one reason for poor spelling among Chinese adults may be a weakness of VAS, which if detected early, may lead educators to consider VAS-targeted interventions. Previous training studies focusing on a VAS deficit have proved to be effective in improving reading skills in participants with reading difficulties (e.g., Niolaki et al., 2020; Niolaki & Masterson, 2013; Valdois et al, 2014; Zhao et al., 2019). The findings of the current study indicate that VAS-focused intervention may also be effective in the case of VAS-related spelling deficits. The next chapter focuses on intervention studies.

4: Investigating the effectiveness of VAS-focused interventions in Mandarin-speaking children and adults

4.1 Introduction

In line with prior studies in VAS and literacy skill in Chapter 1, the results of studies 1 and 2 reported in the previous two chapters revealed that VAS was a significant predictor of reading and spelling in the Mandarin-speaking children and adults assessed in the current research.

The current chapter outlines Study 3, which involved interventions conducted with poor readers and spellers who were identified in the first study. Researchers (e.g., Nickels et al., 2010) have argued that intervention studies should be viewed as a powerful methodology for developing and evaluating cognitive theories, for the intervention studies can investigate the causation-association problem and the generalisation of treatment effects could also be expected (e.g., Nickels et al., 2015).

It has been argued that group studies enable generalisation of findings and ensure a high level of reliability (e.g., Margevičiūtė, 2012). On the other hand, authors have pointed out that in situations where relatively little current knowledge exists, single case or case series studies can provide a stronger methodological approach for advancing theories of cognitive processes (e.g., Caramazza, 1986; Franklin et al., 2002; Howard, 1986; Shallice, 1979). This is because, when constructs are not well understood, in group studies we may be unwittingly combining results from participants with disparate cognitive strengths/weaknesses, and so the group result may not be representative of any one participant. Proponents of single case studies argue that the detailed observations that they involve provide rich data relating to associations, and over multiple replications and extension studies with carefully controlled manipulations, they provide powerful evidence for theoretical advancement. The area of visual attentional processes in reading and spelling can be considered a relatively sparse research landscape, thus it was considered appropriate to conduct single case and case series analyses for Study 3.

In what follows, I discuss previous VAS-focused intervention studies, with group intervention studies covered first and then case studies. Table 26 provides a summary of the studies. Following this, the current study looking at the effectiveness of VAS-focused interventions is described.

Table 26

VAS-Focused Intervention Studies

Research	Type of intervention	Intervention duration	Participant age	VAS assessments	Presenting difficulty	Results after VAS training
Group studies involving VAS interventions						
1. Zoubrinetzky et al. (2019)	VAS: Visual categorisation task (increasing string length) - MAEVA© programme PA - RapDys© software	6 weeks (75 mins a week, 15 mins a day)	French-speaking children (mean=10:07, SD=16 months)	Letter report (global & partial report)	Dyslexia	Improvement in VAS; Improvement in irregular word reading and text reading fluency and accuracy; *no delayed post-test
2. Zhao et al. (2019)	VAS: Visual-processing training in visual short-term memory, visual search and digit cancelling	4 weeks (1 - 1.5 hour a week)	Chinese-speaking children (mean=10.06)	Visual 1-back task	Dyslexia with and without a VAS deficit	Improvement in VAS; Improvement in silent sentence reading accuracy; *long-term effectiveness
3. Ren et al. (2023)	VAS: Visual attention training (visual short-term memory, rapid visual discrimination, visual search etc.) Control intervention: non-attentional training (nonverbal reasoning and creativity tasks)	6 weeks (12 training sessions, 2 sessions per week)	Chinese-speaking children aged 8 to 12 years (Grade 3 to 6)	CombiTVA paradigm (similar to v1b task but with a post mask, and the stimuli presented in a circle)	Dyslexia	Improvement in visual processing speed and efficiency of attentional control; Marginally significant improvement in silent sentence reading accuracy; *long-term effectiveness
4. Valdois et al. (2025)	VAS: a game software named EVASION Control intervention: grapheme-phoneme association training; 'business-as-usual' teaching)	10 weeks (about 10 hours)	French-speaking children aged 6-7 years at Grade 1	Letter report (global & partial report)	Typically developing readers without any difficulties	Improvement in reading fluency; Improvement in VAS, especially in children with low VAS skills;
Case studies involving VAS interventions						
5. Niolaki & Masterson (2013)	Global report training	9 weeks (10 mins a day)	RF (12;08) Greek speaking monolingual	Letter report (global & partial report)	Slow word reading; Poor spelling of irregular words; Poor global report (normal partial report)	Improvement in global report; Significant improvement of word reading and speed/fluency; *long-term effectiveness
6. Jones (2013)	VAS: Whole-word training Control intervention: PA training	6 hours	MS (10;94) English speaker	Letter report (global & partial report)	Surface dyslexia; VAS deficit	Improvement in reading regular words, irregular words and nonwords
7. Valdois et al. (2014)	Visual-processing training (visual search, visual matching and visual parsing)	6 weeks (2 hours a week, 20 mins a day)	MP(9;3) French-Spanish bilingual	Letter report (global & partial report)	Slow reading speed; <u>French</u>-Poor in global and partial report; <u>Spanish</u>-Poor in global report (moderate-partial report)	Improvement in VAS; Improvement in word and text reading speed/fluency - more in French; *long-term effectiveness
8. Roncoli & Masterson (2016)	VAS: Whole-word training Sublexical intervention: PA training	4 weeks (1 hour a week)	Alan (10;04) English speaker	Letter report (global & partial report)	Poor spelling of regular and irregular words; Poor global report (arrays and letters)	Improvement in spelling accuracy; *long-term effectiveness
9. Niolaki et al. (2020)	Global report training	9 weeks (10 mins a day)	TN (9;11) Greek speaker	Letter report (global & partial report)	Slow word, nonword and text reading; Poor spelling of irregular words; Lack of semantic priming; Poor in global report task (normal-partial report)	Improvement in global report (arrays and letters); Improvement in word reading speed/fluency; *long-term effectiveness

4.1.1 Group studies involving VAS interventions

To date, four studies have examined the effect of VAS-based interventions on literacy outcomes in groups of children. Two of these were with French speakers (Valdois et al., 2025; Zoubrinetzky et al., 2019) and two were conducted with speakers of Chinese (Ren et al., 2023; Zhao et al., 2019). Zoubrinetzky et al. (2019) carried out their study with French speaking dyslexic children aged 10 years, and investigated whether two types of training, one targeting VAS and one targeting phonological processes, could improve reading performance. The RapDys© progamme was used for the phonological training and involved practice with phoneme identification and discrimination. The alternative intervention, using the MAEVA© programme, involved visual categorisation training, which was assumed to target VAS.

The MAEVA© programme was based on visual categorisation tasks as used in the neuroimaging study of Lobier et al. (2014) mentioned in Chapter 1, who tested dyslexic adults and skilled readers with fMRI. In the MAEVA© programme the training involved increasing numbers of simultaneously presented items. The stimuli involved five families: lowercase letters, pseudo letters, numbers, Japanese Hiragana characters and unfamiliar shapes. Before the training, participants had five minutes to familiarise themselves with the character families. Thereafter, they saw a string of stimuli, and were required to click on the appropriate family labels. Three parameters were manipulated across trials: the number of stimuli in the string (from two to seven), presentation duration (420 to 120 msecs) and task difficulty. The difficulty of each trial was calibrated to depend on the children's previous responses. The study involved a crossover design with six weeks for each training.

Zoubrinetzky et al. found a significant improvement in VAS global and partial report scores and in irregular word reading after training with the programme. Phoneme discrimination and nonword reading were also assessed and following training with the RapDys© software improvement in both outcome tasks was observed. Phoneme awareness and regular word reading were found to show significant improvement after both MAEVA© and RapDys© training. Zoubrinetzky et al. concluded that the training programs had specific effects on the different reading subskills, supporting the notion of the independence of PA and VAS deficits in developmental dyslexia, although Zoubrinetzky et al. also found that VAS and PA training showed similar contribution to improvement in phoneme awareness.

Zoubrinetzky et al. suggested that training with a tailored and specific training duration for each child may be needed, and also that long-term effectiveness of the training needed to be assessed. They also noted that it would be informative to target specific training according to whether participants had VAS or phonological deficits. The current study incorporated delayed post-intervention assessment to look at the long-term effectiveness of intervention, and also evaluated VAS-targeted and non-VAS targeted training in participants with specific VAS or phonological deficits.

The two VAS-based intervention group studies with Chinese speakers emphasised attention processes, rather than simultaneous visual processing. Zhao et al. (2019) and Ren et al. (2023) designed interventions involving top-down and bottom-up attentional processes, because they believed that both types of attentional process should contribute to VAS, according to the visual attention theory of Bundesen (1990). The training in the study of Zhao et al. involved a line estimation task, which was assumed to train visual short-term memory to address bottom-up attention processes, as well as visual search and digit cancelling tasks, which were assumed to target top-down attentional modulation and control. Finally, Zhao et al. argued that that eye movements might influence performance in VAS tasks and so the training involved visual tracking tasks to train eye movement control.

VAS was assessed with a v1b task with unfamiliar symbols as stimuli. Ten VAS-impaired dyslexic children and 10 non-VAS-impaired dyslexic children aged 9 to 10 years took part in the training during 10 sessions (two or three sessions per week, 30 minutes per session, four to five weeks in total). TD children were also included as the control group. Zhao et al. found that the training was only effective for VAS-impaired dyslexic children, in terms of improvement in VAS scores, and also in silent sentence reading accuracy.

Ren et al. (2023) adopted similar training tasks in a study with dyslexic undifferentiated children from Grades 3 to 6. Bottom-up attentional processes were assumed to involve visual short-term memory and perceptual processing speed, and top-down processes were assumed to consist of attentional weight and inhibitory control. The dyslexic children were allocated to three training groups – one received bottom-up attentional training, one top-down attentional training and the third group received non-attentional training (nonverbal reasoning and creativity tasks). The bottom-up training involved visual short-term memory, rapid visual discrimination and a task like the v1b task but with symbols presented in a circle rather than horizontally with two array conditions (six-target and two-target arrays). The top-down training involved the v1b-like task but with two targets and four distractors, a spatial cueing task where a picture cue was presented in the same or different orientation to a target presented subsequently in an array (participants judged the orientation of the target), and a visual search task (searching for a target picture among distractors).

The three types of intervention were conducted over 12 training sessions (two sessions per week), of 25 minutes each. Ren et al. used the CombiTVA programme from Habekost (2015) to assess VAS. This was similar to the v1b task but with a post mask, and the stimuli were presented in a circle rather than a horizontal array. There were several indicators reflected in the CombiTVA programme including visual short-term memory storage capacity, visual processing speed, spatial bias of attentional weight and efficiency of attentional control. Results after training revealed that the bottom-up intervention resulted in improvement in the VAS subcomponents including visual processing speed and efficiency of attentional control, and a marginally significant improvement in silent sentence reading accuracy was also observed. On the other hand the top-down training did not result in improvement in any VAS subcomponent, although significant improvement in silent character reading was observed. Improvements were generally maintained three months after the intervention.

Ren et al. suggested that it might have been the case that benefits of the top-down training could have been detected with a different VAS task (perhaps tapping attentional shifting and orientation). In addition, they noted that the majority of the dyslexic children demonstrated VAS deficits and especially in the subcomponent of visual processing speed assessed in the CombiTVA programme, therefore, since evidence showed that improvements following intervention are observed in areas of weakness rather than strength (e.g., Gustafson et al., 2007), it is perhaps inevitable - that the bottom-up training resulted in significant improvement in VAS skills. Finally, the authors questioned whether different measures may have been more sensitive to improvement in the different VAS subcomponents.

Several issues need to be noted with the studies of Zoubrinetzky et al. (2019), Zhao et al. (2019) and Ren et al. (2023). Zoubrinetzky et al. adopted lowercase letters and pseudo letters as materials in the VAS training, which involved the linguistic factors so the training improvement may be partially attributed to the mapping between visual to phonological codes. Due to the numerous training tasks that were employed in Zhao et al.'s intervention, it is not possible to know which component produced the change in VAS. Most of the training tasks involved more focus on attentional processes rather than on simultaneous visual processing skills. For example, Zhao et al. mentioned that the line estimation task did not trigger multiple visual processing. The training effects in reading may have been due to improvement in attentional control rather than pure visual simultaneous multi-element processing. Ren et al. (2023) used a visual attention measure (CombiTVA programme) rather than a traditional VAS-focused assessment. Habekost (2015) reported the CombiTVA progrmme was designed based on the theory of visual attention of Bundesen (1990) involving visual processing speed, storage capacity of visual short-term memory, perceptual threshold, efficiency of top–down selectivity, and spatial bias of attentional weighting. So, the skills assessed in the CombiTVA programme may not fully represent VAS.

In the most recent group intervention study, Valdois et al. (2025) used a game software, EVASION, to investigate potential effects on the reading and spelling of 453 French-speaking TD children in Grade 1. EVASION includes four minigames that require participants to speedily detect target strings among distractors. The runner game involves catching target letter strings while avoiding distractors, the letter tower game involves opening the doors with target strings one by one, the ghost forest game involves clicking on ghosts that could form the target string when they join hands, and the castle game involves moving targets to a castle as quickly as possible. Children had to select the targets while inhibiting responses to distractors and also to ignore some unrelated events that could occur while playing.

Children were divided into three groups with one group taking the EVASION training, one a grapheme-phoneme training (GraphoGame), and one group receiving ‘business-as-usual’ teaching, which involved grapheme-phoneme mapping and development in phonological awareness. After 10 weeks (also 10 hours) of training, the results showed that the EVASION trained group improved significantly more than the other groups in word reading fluency and spelling, as well as in VAS as assessed by global and partial report. This was especially the case for children with low VAS skills at the outset of the study.

Limitations of the study were noted by Valdois et al. One was that although they had intended training to be of 10 hours in duration, the effective training time with EVASION was only six hours, thus possibly weakening the intervention effects. In addition, the authors noted that training time for all children was fixed not tailored, so it was likely that training effects for some children may not have been detected or were weak, when they could have been more pronounced with longer training time. Thus, case studies with individuals, rather than a one-size-fits-all approach may result in more evidence for the effectiveness of VAS-focused interventions.

4.1.2 Case studies involving VAS interventions

In addition to group studies, single case studies of children with a VAS deficit have been conducted to investigate the effects of VAS-based interventions. These have been conducted with speakers of French, Spanish, Greek and English (Jones, 2013; Niolaki et al., 2020; Niolaki & Masterson, 2013; Roncoli & Masterson, 2016; Valdois et al., 2014).

In the study of Valdois et al. (2014), a bilingual French-Spanish dyslexic girl aged 9 years old is reported. MP was found to have a VAS deficit that was more pronounced in French than Spanish when assessed with letter report tasks, but there was no evidence of any weakness in phonological skills. MP undertook a six-week VAS-based training that involved repeated engagement in a set of visual processing tasks that were assumed to tap aspects of VAS. They included visual search, visual matching and visual parsing. Visual search training is assumed to involve both sequential and simultaneous visual perceptual attention (Huang & Pashler, 2005; Laller et al., 2013; Liesefeld & Müller, 2020) because it involves simultaneous screening along a line of targets, engaging controlled attention to detail and fast scanning, or saccades[2]. It has been argued by Reihac et al. (2013) that visual matching may expand VAS because being required to quickly determine whether two presented strings are identical can force participants to focus their visual attention by avoiding additional ocular saccades and by constraining parallel processing of strings. Zoubrinetzky et al. (2014) argued that training visual parsing improves VAS through quickly detecting target strings that are embedded among items of the same category.

MP was required to respond in the training tasks as quickly as possible. Valdois et al. reported that, following the intervention, there was significant improvement in MP's score for global report and in reading speed for single words and text. Comparison of results for Spanish and French revealed that Spanish was less affected by the intervention, although reading in Spanish was still found to show some (non-significant) improvement.

[2] Saccades refer to rapid movements of the eyes that abruptly change the point of fixation.

Whole word training has been found to be an effective technique in intervention studies for reading and spelling difficulties (e.g., Behrmann, 1987; Broom & Doctor, 1995; Brunsdon et al., 2005; Kohnen et al., 2010; Rowse & Wilshire, 2007; Weekes & Coltheart, 1996). Whole-word training involves repeated presentation of target words for reading or spelling practice. The latter is often referred to as the 'Look-cover-write-check' technique that has been widely used for instruction and remediation purposes in classrooms with English-speaking children (e.g., Cooke, 1997; Montgomery, 2012; Reason & Boote, 2013). This training usually involves visual mnemonic flashcards with target words, with the participant being asked to write the word after the flashcard has been removed. The assumption is that, with repeated exposure, an entry for the target word would be established in the orthographic lexicon, or else the quality of an existing entry would be improved, so that fast automatic access to units for reading or spelling wou be possible.

There have been two intervention studies that have used whole word training with children with VAS deficits and related literacy problems (Jones, 2013; Roncoli & Masterson, 2016). Jones (2013) compared phonological training and whole-word training (using flashcards, as well as degraded presentation of printed words) with the aim of improving the reading of two surface-dyslexic English-speaking children aged 11 years, MS and HG. Assessment revealed that HG had phonological deficits and good VAS, while MS had poor scores in both global and partial report tasks but good phonological skills. The programme lasted six hours in total for each intervention and significant improvement was observed in reading, however Jones found no significant difference in improvement with the two types of training, and improvement in reading of regular words, irregular words and nonwords was observed following both interventions. Moreover, although VAS improvement was found after this training, it was not significant. As for this point, Jones argued that the intervention aim was not to extend VAS but to increase the quality of lexical representations, so increasing the visual attentional window was not at the core of the training. However, I believe a potential reason for the result was the training design. Training for MS included four blocks: block 1 VAS training, block 2 PA training, block 3 PA training and block 4 VAS training. There was no wash-out period to eliminate the effects of the previous intervention and the two types of intervention may have mutual influence, so there was no significant differences in improvement in reading after VAS and non-VAS training.

Roncoli and Masterson (2016) compared the effect of a phonological intervention and whole-word spelling training in a study with a 10-year-old boy, Alan, who had dysgraphia and a selective VAS global report deficit, but unimpaired phonological ability and visual memory. As noted in Chapter 3, Roncoli and Masterson reported that, as well as the VAS deficit, Alan showed characteristics of graphemic buffer disorder, that is, a pronounced effect of word length on spelling accuracy, and the errors Alan made involved transposition, insertion, deletion and substitution of letters. As discussed in Chapter 3 this profile has been called graphemic buffer disorder in studies with adults with acquired aphasia.

In a previous intervention study with an adult dysgraphic patient with graphemic buffer disorder, Sage and Ellis (2006) found that untreated words that were orthographic neighbours of the treated words were improved following whole word spelling intervention. They suggested that an increase in activation in a target’s neighbour in the lexicon (due to the intervention) allowed the target to receive support within the graphemic buffer, due to cascading activation from the orthographic lexicon. Untreated words that were not orthographic neighbours of the treated words did not show improvement. Kohnen et al. (2008) found similar results to those of Sage and Ellis in an intervention study using the whole word training technique with a child with mixed dysgraphia. In light of these findings, Roncoli and Masterson (2016) argued that whole word training could be appropriate in Alan's case as it had been previously found to be effective for cases with a similar profile of graphemic buffer deficit (e.g., Aliminosa et al., 1993; Rapp & Kane, 2002; Sage & Ellis, 2006), and also the technique was widely used in Alan's educational context.

The authors found that following the phonological intervention there was no improvement in Alan's spelling, however after the whole-word training there was a highly significant improvement in spelling accuracy for the trained words, which was found to persist with delayed post-intervention testing. The authors also observed a small increase in accuracy for the untrained words. Although VAS was not re-tested by Roncoli and Masterson after training, a significant improvement in spelling was found, which suggested the possibility that whole word training may result in improvement of the functioning of the graphemic buffer. Repeated activation would result in a long-term increase in connection strength of the links between the lexicon and the letters at the grapheme level for a particular representation (Kohnen et al., 2008). Stronger connections increase the chance of a correct response. It was noted in Chapter 3 that the graphemic buffer has been referred to in recent years as orthographic working memory (OWM), for example in the models of Hepner (2017, Figure 7 in Chapter 3) and in the adaptation of dual route models of spelling to a model for spelling in Chinese (Mo, 2023, Figure 8 in Chapter 3). It was noted that these models have resulted in a great deal of research into literacy processes, both with regard to intervention studies for reading and spelling difficulties and with regard to, for example, error analysis and the effect of psycholinguistic variables in TD children and skilled readers and spellers. It was suggested in Chapter 1 that these analyses would be employed in the current research, alongside those that have emerged from research into VAS. The analyses of the single cases outlined in the present chapter draw on this cross-field approach.

We turn now from single case studies that have involved whole-word training to a final group of studies that involved training aimed at increasing the capacity of the visual attentional window through practice in reporting arrays of increasing size. Niolaki and Masterson (2013) conducted a study using this type of training technique with a 12-year-old Greek-speaking boy, RF. As discussed in Chapter 1 and Chapter 3, for historical reasons Greek does not have irregular words for reading, as grapheme-phoneme correspondences are transparent and consistent, however there are irregular words for spelling since some phonemes have alternative spellings. Niolaki and Masterson reported that RF was very poor at spelling irregular words, and he was also slow and inaccurate in reading words. His errors in spelling irregular words were phonologically appropriate, and phonological abilities were unimpaired. RF’s performance in global report was very poor (TD children from RF’s school acted as a comparison group in the assessments), although partial report performance was not impaired. The dissociation of global and partial report performance has been reported in several other cases of children with a VAS deficit (e.g., Valdois et al, 2011).

RF took part in a nine-week training program that involved reporting letter arrays that increased in size over the course of training, in response to observed accuracy levels. Materials were three sets of arrays, 195 two- to four-letter arrays in Set 1, 195 three- to five-letter arrays in Set 2 and 104 four- and five-letter arrays in Set 3. The intervention was found to be effective in terms of observed improvement in global report, as well as reading accuracy and latency. The improvement in word-reading accuracy and latency was found to be sustained at follow-up testing four months and eight months after the intervention.

Niolaki et al. (2020) conducted another single case VAS intervention study with a 9-year-old monolingual Greek-speaking girl, TN, with a global letter report deficit but no weakness in phonological abilities. The same intervention procedure was adopted as had been used with RF. Before the intervention TN exhibited good reading accuracy but slow reading fluency with words and non-words. Similar to RF, after the intervention, TN showed improvement in global report, as well as in reading latency for both real words and nonwords. TN also showed a strong improvement in text reading fluency.

The implication of the results was that improvement in VAS was responsible for an increase in reading fluency, as in previous studies with other interventions. However, Niolaki et al. (2020) pointed out that the training may have caused a switch to the use of larger phonological units in the early stages of processing, or else have resulted in faster sublexical processing because of the involvement of oral report. Thus, there remain alternative explanations for improvement in such training that still need to be resolved.

In summary, the effectiveness of VAS-based interventions has been found in group and case studies across languages. Inspection of Table 25 reveals that training duration across the studies was between 4 to 10 weeks (and about one hour a week). Researchers designed various interventions based on their interpretation of VAS. Different methods were used to investigate the influence of training on reading or spelling improvement. Six studies used a design involving pretest, posttest and follow-up, with a control group or a control training programme. Valdois et al. (2025)

included TD children with one experimental group for VAS training and two control groups for phonological training. One study used the crossover design in comparing the effects of VAS and phonological training for the same participants (one group of dyslexic children, Zoubrinetzky et al., 2019). One study by Jones (2013) used an ABBA design to train a child with a VAS-based intervention and a phonological intervention. Across studies, some training programmes were fixed software or games, so that participants could complete them by themselves or follow the experimenters' instructions (Ren et al., 2023; Valdois et al., 2014; Valdois et al., 2025; Zhao et al., 2019; Zoubrinetzky et al., 2019). Some interventions involved oral report and/or spelling, requiring interactive communication (Jones, 2013; Niolaki et al., 2020; Niolaki & Masterson, 2013; Roncoli & Masterson, 2016). Regardless of the way tasks were conducted, significant intervention effects were found. However, there remain some issues to address.

Authors have focused on processes of attention allocation (Ren et al., 2023; Zhao et al., 2019), multiple-element simultaneous processing (Niolaki & Masterson, 2013; Niolaki et al., 2020; Valdois et al., 2014; Zoubrinetzky et al., 2019), both visual attention and multi-character simultaneous processing (Valdois et al., 2025), and increasing short-term storage (Jones, 2013; Roncoli & Masterson, 2016). Moreover, some intervention studies involving multiple types of training (Ren et al., 2023; Valdois et al., 2014; Valdois et al., 2025; Zhao et al., 2019) appear to involve more processes than the ones thought to underly VAS, for example, visual search, involving top-down controlled attention, visual matching, involving visual identification, decision making and executive function skills. In the case where multiple training tasks were used, it is not clear which skills were tapped, and which ones resulted in improvement. It therefore seemed important to use individual VAS-focused tasks in the present study.

Furthermore, previous studies focused on children aged 7 to 12 years, not other age groups. Participants from other age groups could be considered. Nearly all intervention studies focused on dyslexics and their improvement in reading. Only Roncoli and Masterson (2016) focused on improving the spelling of a child, Alan, with both dyslexia and dysgraphia. Alan was reported to suffer from a deficit of OWM, and his performance in global report was found to be poor. Thus, OWM and VAS were considered the same thing, for the results in Study 2 supported this argument. Study 2 also suggested that the occurrence of the great number of OWM *deletion* errors may mean the poor VAS because the limited visual attentional window failed to acquire all details of orthographic presentations. It was thus considered informative to explore whether the participants with spelling difficulty may have a VAS deficit and in this case whether the VAS training could benefit their spelling performance.

4.2 The present study

Prior research such as Bosse et al. (2007), Chen et al. (2019), Cheng et al. (2021) and Valdois et al. (2003) has already found VAS deficits as one of the main causes of dyslexia across French, English and Chinese etc. Accordingly, it would be good to see whether the VAS-based interventions could exactly ameliorate the reading difficulties of poor readers due to VAS impairment, and whether the VAS-based interventions could significantly improve VAS rather than PA according to independence between both, which was supported by behavioural evidence of Bosse et al. (2007) and Valdois et al. (2014) as well as neurological evidence of Peyrin et al. (2012) and Valdois et al. (2019) etc.

The following considerations were taken into account in light of the concerns discussed above in relation to interventions for VAS deficits.

First, I discussed above that some intervention studies (Jones, 2013; Niolaki & Masterson, 2013; Niolaki et al., 2020; Ren et al., 2023; Roncoli & Masterson, 2016; Valdois et al., 2014; Valdois et al., 2025; Zhao et al., 2019; Zoubrinetzky et al., 2019). Among these, Valdois et al. (2014), Ren et al. (2023) and Zhao et al. (2019) included a range of types of training, and it was not possible to ascertain which aspect(s) of the training had been effective. It was therefore decided to include single types of intervention, and where the training seems to have a clear focus.

It was decided to include an intervention that focused on increasing the size of the attentional window (Niolaki & Masterson 2013; Niolaki et al., 2020) since this has been found to be effective in two previous studies, where improvement in reading accuracy and speed (TN's spelling was not impaired in Niolaki et al. (2020)) were observed. These two studies were carried out with speakers of Greek. Valdois et al. (2014), as noted in the above literature review, carried out a VAS-targeted intervention with a bilingual French-Spanish speaking child and found greater improvement in reading for opaque French than transparent Spanish. The authors suggested that interventions focusing on VAS could be more effective for opaque orthographies than transparent ones (such as Greek), since reading in the latter type of writing system relies more on smaller orthographic units. It is therefore impressive that the intervention employed with Greek-speaking RF and TN was associated with improvement in reading. It was considered that, since the present study was carried out in opaque Mandarin, then a VAS-related intervention that has been shown to be effective with a transparent script may have a good prospect of being effective.

At the same time, as Chapter 1 (Section 1.3.1.3) highlighted by Chen et al. (2019) and Huang et al. (2019), Chinese readers rely heavily on VAS for orthographic processing. It was expected to see literacy improvement after the VAS-based training, but Chapter 1 (Section 1.5) noted that there has been a lack of Chinese VAS intervention case studies. So, it would be necessary to conduct case study analyses to fill in this gap.

V1b task performance has been found to be consistently associated with reading across studies in Chinese (especially in terms of reading fluency), (see Chapter 1, Section 2.1 in Chapter 2) and this was confirmed in the current research, as reported in Study 1a and 1b. Therefore, according to the Multitrace memory modal, the wider visual attention window could improve the reading efficiency of Chinese characters. V1b task was employed in a form of training in this intervention study where symbol target arrays were increased across the training period, on the assumption that the capacity of the attentional window would be increased.

However, there is an issue that Niolaki and Masterson (2013) raised in relation to improvement in reading associated with intervention focused on increasing the capacity of the attentional window. This is that it is unclear what the mechanism responsible for improvement was – it could be that the attentional window indeed increased in capacity, or else it could be, for example, because analytical reading procedures (speed of identification of sublexical orthographic units and their associated phonology and semantics) were somehow made more efficient during the intervention.

It was therefore decided to employ a second VAS-focused intervention so that results could be contrasted across the two types with the aim that insight might be obtained regarding mechanisms of improvement. Following Valdois et al.’s (2014) evidence that VAS-focused training improves dorsal attention network activation (Section 1.4), we considered the whole-word training as the second intervention to strengthen whole-character processing, aligning with the Multitrace Model's global mode (Section 1.2). The whole word training involved the participant reproducing the written form of presented training words after a delay. As noted earlier, this type of training has been found to result in improvement in reading as well as spelling, which can be considered an educationally-relevant reason for employing the technique. An additional advantage of this type of intervention is that generalisation to untrained words has been reported in several studies (e.g., Niolaki & Masterson 2013; Rowse & Wilshire, 2007). The rationale behind this type of intervention is that the training increases inspection of detail in the target at the time of presentation, and/or that retention of the target stimuli is improved, and this leads to the formation of new orthographic units, or the strengthening of existing ones.

Thus, the assumption is that the v1b training with increasing array size would result in improvement in VAS. Research in McBride-Chang et al. (2011) and Wang et al. (2014) mentioned in Chapter 3 has indicated that the copying technique involved in whole-word training is an effective means of strengthening Chinese orthographic representations through the process of deconstructing and recomposing Chinese character subcomponents. This is thought to facilitate learners' awareness of Chinese characters' internal structures, leading to higher-quality lexical representations (e.g., Guan et al., 2011; Tan et al., 2005). Using the framework of Sage and Ellis (2006), outlined above, the whole word training may lead to improvement in performance in VAS tasks due to top-down feedback from the orthographic lexicon to OWM/VAS, or else to an increase in the capacity of OWM/VAS.

If the increase-in-array-size training is more effective then this could indicate that the individual's VAS deficit was due to restricted visual attentional window, according to the Multitrace model framework. If the whole-word training is more effective this could indicate that the deficit was due to weak top-down support from the orthographic lexicon. If the whole-word approach is effective then we might expect to see an accompanying generalization effect to untrained words, as observed in previous studies with this technique.

In addition to the two VAS-based interventions, a non-VAS intervention was also employed in order to see whether VAS and reading benefited more from VAS-focused intervention than non-VAS training. A phonological training was used including tone awareness, vowel and consonant awareness, phoneme segmentation and matching. Zoubrinetzky et al. (2019) reported that both the phonological and VAS interventions significantly improved oral word reading fluency. So even if VAS was not observed to improve following the non-VAS training, an improvement in reading to some extent might still be expected.

Finally, as discussed in Chapter 1, people with a VAS deficit may have atypical patterns in eye movement (Prado et al., 2007; Valdois et al., 2003; Valdois et al., 2011; Zhao et al., 2019). So, compared with participants without reading difficulty, different patterns of responses in VAS tasks of participants with reading difficulty could be expected.

4.3 Research questions

The research questions were as follows:

1. Would the three interventions be effective in bringing about improvement in reading fluency in Mandarin-speaking children and adults with difficulties in VAS, and reading or spelling?

2. Would the two VAS-based interventions be effective in bringing about improvement in VAS in the Mandarin-speaking children and adults with difficulties in VAS, and reading or spelling?

3. If the whole-word training was found to be effective in terms of improvement in reading and spelling, would the effects generalise to untrained words?

4. What is the poor readers’ pattern of responses across array positions in the global report task, the partial report task, v1b accuracy and v1b correct RTs?

With regard to RQ1, the prediction was that the three interventions would be associated with significant improvement of reading fluency of children and adults who took part in this study, as reported by Zoubrinetzky et al. (2019). With regard to RQ2, the prediction was that the two VAS-based interventions would be associated with significant improvement of VAS, but the non-VAS-based intervention would not be, as reported by Ren et al. (2023), Valdois et al. (2025) and Zoubrinetzky et al. (2019). With regard to RQ3, the prediction was that generalisation effects to untrained words could be found after the whole-word training, as reported by Roncoli and Masterson (2016). With regard to RQ4, the prediction was that compared with participants without reading difficulty, poor readers with poor VAS may show lower performance across positions in nearly all VAS tasks. Also, patterns of responses of the poor readers in VAS should be different from the ones of readers without reading difficulties.

4.4 Method

4.4.1 Participants

Participants were identified on the basis of the data from Study 1 and having consented to participate in this intervention study. All children and adults who took part had normal or corrected to normal vision and were without attention deficits. The children and adults had to have:

a. within average scores for nonverbal ability, vocabulary and arithmetic skills;
b. at least one of the reading skills (oral or/and silent reading fluency in word or/and sentence level) below 1*sd* of all participants in their group (child or adult);
c. at least one VAS measure (global report, partial report, v1b accuracy or/and v1b correct RT) below 1*sd* of all participants in their group;

Nine participants, including six children (one boy and five girls) aged 10 years, and three adults (two males and one female) aged from 27 to 41 years, were identified as having difficulties in VAS, reading or spelling. Six screened children from the same class are all Mandarin speakers using simplified Chinese characters, with middle-to-low SES background. They have not been tested in cognition and literacy skills before, so without any literacy training before. All children attended all following three training and all posttests, except for Child 5 SHANXT (please see Table 27) who was absent in the posttest after her second training. Among three screened adults, Adult 1 and Adult 2 have been diagnosed as dyslexics respectively in UK and Singapore, but still without any further training. Adult 3 was screened from the recruited adult participants in Study 1b according to the above screening criteria.

Among these participants from Tables 27 to 30, three children (Child 4, 5 and 6) and two adults (Adult 2 and 3) had low PA (below 1*sd* of the mean scores of PA of all participants in their respective group), and these five participants were later categorised as having both VAS and PA deficits (VPD). By contrast, the rest of three children and one adult did not have PA deficits, and were categorised as having only VAS deficits (VO).

In terms of 1*sd* from the group, three of the six children were found to only have difficulty in oral word reading fluency (Child 2, 5 and 6), one had only difficulty in silent sentence reading fluency (Child 1). Two children had difficulties in both oral word and silent sentence reading fluency (Child 3 and 4). In terms of spelling, three of the six children were found to have difficulty with spelling (Child 4, 5 and 6). Among the adults, only one had difficulty in oral word reading fluency (Adult 1), and the other two adults had difficulty in both oral word and silent sentence reading fluency, and spelling difficulty. Most participants were found to have difficulty in oral word reading fluency and silent sentence reading fluency. So, these two reading tasks were used as the main post-test measures after interventions.

The comparison groups for children and adults (children and adults with normal reading and spelling) for each case were chosen based on their comparable ages and the results of the reading and spelling study.

4.4.1.1 Profile of children. Results of the participants of comparable age to each screened child from the above reading study were used to analyse potential deficits in nonverbal ability, arithmetic, verbal and visual short-term memory, vocabulary, PA, RAN, character identification, VAS, reading and spelling.

Table 27 reveals the scores of background assessments for each child case and the corresponding chronological age comparison groups. All child participants were 10 years old, so they had the same comparison group. Scores outside 1*sd* of the comparison group are highlighted in red.

Table 27

Scores in Background Assessments for Each Child Participant and the Comparison Groups (n=7, standard deviations are in parentheses)

Children	Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	Comparison group
Age	11.8	10.4	9.9	10.8	10.2	11.4	10.43 (0.30)
Nonverbal ability (/60)	26	31	32	26	28	33	30.57 (3.88)
RAN picture (seconds)	70.67	84.31	109	121.78	84.45	90.79	84.91 (22.41)
RAN digits (seconds)	37.94	36.6	50.71	41.39	31.83	49.01	38.76 (12.51)
Vocabulary (/120)	96	99	95	101	95	103	103 (8.16)
VerbalFor STM (/13)	12	7	7	8	6	8	8.43 (1.27)
VerbalBack STM (/12)	8	8	12	4	4	3	6 (3.87)
VisualSimul STM (/12)	10	10	6	9	3	9	9.29 (1.50)
VisualSeq STM (/12)	12	10	11	5	10	8	9.86 (2.27)
Char. Ident. (/150)	114	112	122	114	112	91	104.43 (13.48)

Note:. RAN: rapid automatised naming, RAN picture: RAN picture task, RAN digits: RAN digits task, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification.

Before interventions, all participants took part in the baseline test. The scores of the baseline test are shown in Table 28. Scores outside 1*sd* of the comparison group are highlighted in red.

Table 28

Scores in the Baseline Test Assessments for Child Participants and Comparison Groups (standard deviations are in parentheses)

Children	Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	Comparison group
Of (/120)	82	64	50	62	63	56	83.14 (10.52)
Sf	184.39	293.06	175.27	169.33	276.72	272.28	332.03 (82.67)
Spelling (/60)	51	51	53	35	41	32	48 (6.03)
Global (/120)	69	55	48	50	68	51	74.15 (11.59)
Partial (/36)	28	16	13	16	14	11	22.86 (5.43)
V1b accuracy (/80)	48	47.5	49	38	35	52	50.86 (4.8)
V1b RTs (seconds)	3.51	3.36	3.84	3.95	3.13	3.43	3.01 (0.25)
PA (/26)	25	23	22	16	12	16	22.36 (3.56)

Note:. Of: oral word reading fluency, Sf: silent sentence reading fluency, Global: global report, Partial: partial report, V1b accuracy: visual 1-back accuracy, V1b RTs: visual 1-back correct reaction times, PA: phonological awareness.

4.4.1.2 Profile of adults. Results of the participants of comparable age to each screened adult from the above reading study were used to analyse potential deficits in nonverbal ability, arithmetic, verbal and visual short-term memory, vocabulary, PA, RAN, character identification, VAS, reading and spelling. The comparison groups for each adult were different according to the different ages of the adults.

Table 29 reveals the scores of background assessments for each adult case and the corresponding chronological age comparison groups. Scores lower than 1*sd* of ones of the comparison groups were highlighted in red.

Table 29

Scores in Background Assessments for Each Screened Adult Participant and the Comparison Groups (n=7 for each group, standard deviations are in parentheses)

Adults	Adult 1 HL	Comparison group	Adult 2 LM	Comparison group	Adult 3 ZJF	Comparison group
Age	41.07	39.47 (6.17)	34	33.91 (4.15)	27.05	27.92 (2.80)
Nonverbal ability (/60)	48	43.57 (6.35)	59	39.86 (15.39)	48	38.14 (16.50)
RAN p (seconds)	63.11	69.94 (11.62)	85.45	68.57 (12.51)	81.36	69.64 (13.06)
RAN d (seconds)	29.58	23.14 (4.32)	33.91	23.05 (4.73)	28	22.93 (2.86)
Vocabulary (/120)	115	113 (3.21)	116	110.86 (5.64)	108	111.14 (6.39)
VerbalFor STM (/12)	8	10.57 (1.13)	10	10.71 (1.11)	9	10.29 (0.95)
VerbalBack STM (/10)	9	7.57 (1.51)	5	7.71 (2.14)	8	7.29 (1.7)
VisualSimul STM (/12)	11	9.29 (2.36)	10	9 (2.94)	9	10 (3.11)
VisualSeq STM (/12)	10	10.43 (2.51)	9	9.71 (2.81)	9	10 (2.83)
Char. Ident. (/150)	93	86.43 (20.44)	84	100.14 (17.34)	37	100.71 (15.26)

Note:. Arithmetic (after all ints.): arithmetic scores after all interventions, RAN: rapid automatised naming, RAN picture: RAN picture task, RAN digits: RAN digits task, VerbalFor STM: verbal digit forward short-term memory, VerbalBack STM: verbal digit backward short-term memory, VisualSimul STM: visual simultaneous short-term memory, VisualSeq STM: visual sequential short-term memory, Chat. Ident.: character identification.

Before interventions, all participants took part in the baseline test. The scores of the baseline test are shown in Table 30. Scores lower than 1*sd* of ones of the comparison groups were highlighted in red.

Table 30

Scores in the Baseline Test Assessments for Each Adult Participant and The Comparison Groups (standard deviations are in parentheses)

Adults	Adult 1		Adult 2		Adult 3	
	HL	Comparison group	LM	Comparison group	ZJF	Comparison group
Of (/120)	90	107.22 (11.10)	77	104.14 (14.04)	86	106.43 (9.54)
Sf	326.90	320.98 (140.34)	179.64	296.93 (40.48)	262.21	394.80 (74.27)
Spelling (/60)	53	54 (3.74)	45	53 (5.23)	47	56.57 (4.79)
Global (/120)	74	76.79 (13.24)	54	79.93 (11.81)	49	85.86 (14.13)
Partial (/36)	26	23.36 (7.38)	19	25.71 (6.07)	11	26.71 (5.5)
V1b accuracy (/80)	50	52.21 (6.74)	48	51.94 (8.23)	48	51 (10.66)
V1b RTs (seconds)	3.4	2.99 (0.17)	3.33	3 (0.16)	3.43	2.78 (0.22)
PA (/33)	31	29.29 (2.56)	26	30.79 (1.78)	20	29.64 (3.91)

Note:. Of: oral word reading fluency, Sf: silent sentence reading fluency, Global: global report, Partial: partial report, V1b accuracy: visual 1-back accuracy, V1b RTs: visual 1-back correct reaction times, PA: phonological awareness.

4.4.2 Research design

The study involved a case series design. The focus was to compare the effectiveness of two VAS-based interventions – a whole-word training (WWT) and a visual 1-back training (V1BT), and a non-VAS training (NVT). A 3 x 3 Latin square design was used for administration of the training types for counterbalancing purposes. The study involved three intervention phases separated by two washout phases, five post-test assessments and a delayed follow-up assessment (please see Figure 10).

Figure 10

The Phases of the Intervention Study

Baseline			*Intervention Phrases 1-3*			*Delayed Post-Test Assessment*
A1 (one week)	**WWT (six weeks). A2**	**Wash out (three weeks). A3.**	**V1BT (six weeks). A4**	**Wash out (three weeks). A5**	**NVT (six weeks). A6**	**Follow up (two months). A7**
A1 (one week)	**V1BT (six weeks). A2**	**Wash out (three weeks). A3.**	**NVT (six weeks). A4**	**Wash out (three weeks). A5**	**WWT (six weeks). A6**	**Follow up (two months). A7**
A1 (one week)	**NVT (six weeks). A2**	**Wash out (three weeks). A3.**	**WWT (six weeks). A4**	**Wash out (three weeks). A5**	**V1BT (six weeks). A6**	**Follow up (two months). A7**

A: assessment

4.4.3 Materials

Assessments used in this study covered VAS (global and partial report and visual 1-back tasks), PA and reading fluency in oral and silent modes, which were the measures used in Study 1. Arithmetic tasks (Children: C-WISC; Gong & Cai, 1993; Adults: WAIS-RC; Gong, 1983) was administered prior to training and at the end of the study to investigate whether any improvements observed as a result of training were restricted to reading and VAS.

V1BT- visual 1-back training (approx. 10-20 minutes x five days a week, six weeks). This training involved repeated practice with trials similar to those in the visual 1-back paradigm used to measure VAS with 0.81 reliability reported by Zhao et al. (2018). The only difference was that, rather than having arrays of fixed length (five elements), the number of elements in the array varied from two to seven. The stimuli for the arrays consisted of 15 unfamiliar symbols with five strokes each. A list of 80 arrays with varying number of symbols was created using the 15 figures. No array included the same figure twice. They were presented in white on a grey screen with PsychoPy software, with the same procedures as the v1b task.

The test trials were preceded by 10 practice trials. Reaction time and accuracy for the key press responses were recorded.

WWT- whole-word training (approx. 1.5 hours a week, six weeks). Baseline measures of spelling were collected using a list of characters from the 60-word Mandarin spelling to dictation task (MSTDT) (Masterson et al., 2008) described above in Study 2. However, the 60 words were too easy for adults and adults without spelling difficulty, so additional resource for spelling-to-dictation was also used, including *The scale and assessment of vocabulary for primary school (in Chinese)* (Wang & Tao, 1996), and *Dictionary of Modern Chinese Frequency (in Chinese)*

(1986). Considering participants' ages and character difficulty, the misspelt characters were extracted (202 misspelt characters for Child 1, 219 misspelt characters for Child 2, 242 misspelt characters for Child 3, 287 misspelt characters for Child 4, 287 misspelt characters for Child 5, 280 misspelt characters for Child 6, 210 misspelt characters for Adult 1, 332 misspelt characters for Adult 2 and 306 misspelt characters for Adult 3). The misspelt characters were randomly allocated to two sets, a trained and an untrained set. The two sets were matched for printed word frequency and word length for each participant. About 20 to 40 characters for children and adults were trained each week.

In the training session, a 500 ms fixation was first presented at the centre of the computer screen, and then there was a 100 ms blank. After that, participants were shown a character for 200 ms, followed by a blank screen. Participants were asked to write down the character from the trained set on the tablet/phone/laptop/computer. If participants gave the wrong answer, the researcher would show them the character again till they correctly wrote the character. If their spelling was correct, they then moved on to the next character.

NVT (non-VAS training)-phonological training (approx. 1.5 hours a week, six weeks). Due to a lack of published phonological training schemes in the Chinese language, the programme used was adapted from that of Zhou (2018). It involved a detailed and systematic training with five aspects - tone awareness, vowel and consonant awareness, phoneme awareness and matching.

The tone awareness part included an introduction to the definition and types of tones, and examples to enhance the participants' understanding of different tones. In the set, the researcher read out three items, one of which was distinct from the other two in terms of tone, and asked the participants to identify the item with a different tone from the other two. For example, the researcher read out /yu2/, /du3/, /tu2/, and asked participants to identify the item with a different tone from the other two. The correct answer was /du3/. Each set had five practice trials and 30 to 40 trials for training.

The vowel and consonant awareness part included an introduction to the definition and types of vowels and consonants, using examples. In the first set of tasks, the researcher read aloud the items with vowels and consonant, asking participants to orally report the corresponding vowels and consonants in the sound. For example, the researcher read out /lai2/, and asked participants to orally report the corresponding vowels and consonants in the sound. The correct answer was the consonant /l/ and the vowel /ai/. In the second set of tasks, the researcher read out three items, each item containing the syllable sounds with the same tone but different vowels or consonants and asked the participants to report the common vowels or consonants in all three items. For example, the researcher read out /ha1/, /hei1/, /hu1/, and asked participants to report the common vowels or consonants in all three items. The correct answer was the consonant /h/. Each set had five practice trials and 30 to 40 trials for training. In the third set of tasks, 20 sets of materials were presented, each consisting of words with different pronunciations. The research read out the words and the participants were asked to orally report the tone, vowels and consonants in the word. For example, the researcher read out /huan2/, and asked participants to report the common vowels or consonants in all three items. The correct answers were /h/ as the consonant, /u/ and /an/ as the vowels, with the second tone.

The phoneme awareness part consisted two sections namely phoneme deletion and phoneme segmentation. The phoneme awareness intervention included an introduction to syllables and phonemes and the use of demonstration and imitation. In the phoneme deletion task, the researcher read aloud a pronunciation of a character and removed a phoneme from the middle or final and asked the participant to pronounce the remaining syllable(s). For example, the researcher read aloud /jian1/ and removed the /a/ in the middle and asked for participants' answers to pronounce the remaining syllables. The correct answer was /jin1/. In the phoneme segmentation task, the researcher read aloud a pronunciation of a character and then asked the participants to pronounce every syllable in the word. For example, the researcher read aloud /mu3/ and asked for participants to pronounce every syllable in the character. The correct answers were /m/ and /u/.

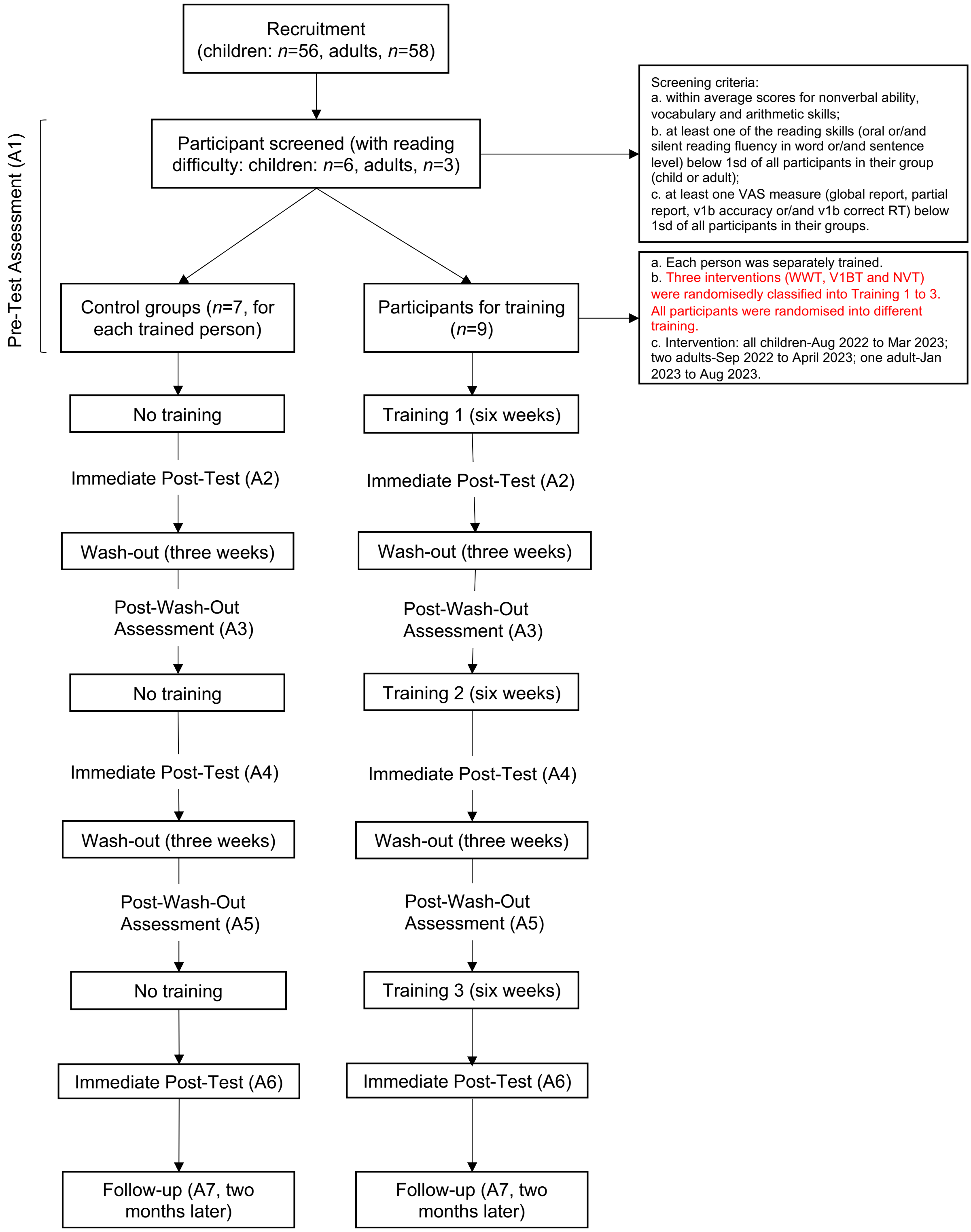
The final task was aimed at improving participants' accuracy in retrieving Chinese words using phonology. The researcher read out a sound but without an exact tone and asked participants to produce homophones or semi homophones based on the syllable pronunciations. For example, the researcher read aloud 'qin' and asked for some words with the same or similar pronunciations as the 'qin'. The accepted answers were 亲 /qin1/,沁 /qin4/, 勤 /qin2/ and 寝 /qin3/.

4.4.4 Procedures

In Figure 10, the pre-test assessment (A1) was conducted first with reading fluency in oral word and silent sentence reading, spelling-to-dictation, PA and VAS. Immediate post-test assessments (A2, A4, A6) were conducted at the end of each of the three training phases. Each wash-out period lasted three weeks. Two post-test assessments (A3, A5) were conducted at the end of the two wash-out periods. One delayed post-test assessment was conducted after two months (A7). The overall study lasted approximately eight months but there were some differences across participants in the duration of the whole study. Interventions for children were conducted within eight to nine months under the assistance of the class teachers and support of their parents from August 2022 to March 2023, and they finished the final assessment in May 2023. Two of the adults took part from September 2022 to April 2023 and finished the final follow-up assessment in June 2023. One adult took part late from January 2023 to August 2023 and finished the final assessment in October 2023 due to health problems. Please see the flowchart for the intervention procedures (Figure 11).

Figure 11

Flowchart for Intervention Procedures



Children and adults used different online platforms to conduct the interventions. Most child participants used school computers (Lenovo computers with 21.5-inch screens and a display resolution of 1920 x 1080) or their tablets (9.7-inch iPads with a display resolution of 2048 x 1536). The three adults used their own computers, including two laptops with a Mac system and one laptop with a Windows system) with 60 Hz to 75 Hz refresh rate.

The WWT and NVT needed the researcher's guidance and involved one-to-one interaction, while the V1BT could be conducted by the participants themselves on the computer. Some children's families did not have computers, so a phone version of the V1BT online link created by Palvovia via PsychoPy software was additionally created and children could self-administer using the touch screen under their parents' supervision. As for WWT, the online notetaking function was turned on in advance. The researcher then shared the laptop screen to show the characters to participants and participants handwrote the characters on their phone or screens after a delay.

All participants were randomly assigned to the training orders before analyses of specific deficits. Please see more details about the intervention phase in the Appendix G.

4.4.5 Data analyses

As for RQ1 and RQ2 relating to the intervention effects to reading fluency and VAS, the analyses involved case series analyses, group analyses and intervention effect analyses to explore the effectiveness of the three types of training on reading fluency and VAS. Case series analyses included weighted statistics to examine whether there were significantly greater changes during intervention phases than other phases (baseline, wash-out and follow-up) for each participant. Mixed ANOVAs were then used for the group analyses to examine whether the three interventions were associated with differences in reading fluency and VAS in terms of Participant group (children and adults) and Deficits (VO-only VAS deficits and VPD- both VAS and PA deficits). Finally, Venn diagrams were used to illustrate the outcome of interventions per participant.

For RQ3 relating to a possible generalisation effect of spelling improvement after WWT, the analyses involved the McNemar test to compare participants' spelling accuracy at pre-test with post-WWT spelling accuracy and qualitative spelling error analyses to show changes in spelling errors before and after WWT.

For RQ4 relating to position responses of VAS tasks, mixed ANOVAs were used to examine potential differences in position accuracy in the VAS tasks between the participants and readers without reading difficulty.

4.5 Results

This section separately reports children and adults, including case series analyses of intervention effects. After that, group analyses and intervention effect analyses of training effects were shown. Spelling with WWT was shown finally.

4.5.1 Case series analyses

Children

WEST-ROC (Weighted Statistics of Rate Of Change-Comparing the amount of change in the treated and untreated periods, Howard et al., 2015) was used to test whether there was significantly greater improvement of participants who took part on Study 3 in reading performance and VAS during the treated phase (WWT, V1BT and NVT) than the untreated phase (baselines and washout periods). All participants who took part on Study 3 were classified into two groups (only with VAS deficits-VO group, and with both VAS and phonological deficits-VPD group) by deficits they had. Three Participants (Child 1, Child 2 and Child 3) were found to only suffer from VAS deficits (VO group), and three (Child 4, Child 5 and Child 6) were found to suffer from both VAS and phonological deficits (VPD group). Under this analysis, results for children were calculated.

Reading

One child, Child 5 SHANXT, had not attended two post-tests of all computer tasks (including silent reading tasks) after her second intervention (NVT) and the second wash-out period, so results in her silent sentence reading fluency were left blank. Results of the case series analyses for reading fluency are presented in Table 31.

Table 31

Weighted Statistics for Oral and Silent Reading Fluency Measures of Children

		Children						**Number showing improvement**
		VO			**VPD**			
WWT		Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	
Of	t	4.63**	-2.38	0.88	3.50**	0.63	1.13	2
Sf	t	0.31	0.07	0.18	5.34**	N/A	1.43	1
		VO			**VPD**			
V1BT		Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	
Of	t	1.41	1.92	3.59**	-2.31	2.69*	-1.92	2
Sf	t	1.08	6.98***	0.92	1.37	0.48	1.30	1
		VO			**VPD**			
NVT		Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	
Of	t	-3.40	-0.93	2.16*	-1.85	1.85	2.47*	2
Sf	t	-0.57	1.51	0.49	-3.63	N/A	1.99	0

Note:.Of: oral word reading fluency; Sf: silent sentence reading fluency; VO: participants who only suffer from VAS deficits; VPD: participants who suffer from both PA and VAS deficits.
*$p<.05$; **$p<.01$; ***$p<.001$

Results revealed that separately after WWT or the V1BT, two of the six children showed a significant improvement in oral word reading fluency, and one of the six children revealed a significant improvement in silent sentence reading fluency. No children's silent sentence reading fluency was improved during the NVT.

During interventions, reading fluency in several cases was shown to have a significant decrease. There was a significant decrease in oral word reading fluency after WWT (Child 2), V1BT (Child 4) and NVT (Child 1). It should be noted that only during the NVT, there was a significant decrease in silent sentence reading fluency (Child 4).

In summary, each child had significant improvement in at least one reading fluency measure during at least one training. The WWT and V1BT resulted in improvement in oral and silent reading fluency for children groups, while the NVT may be only beneficial for oral reading rather than for silent reading.

VAS

Similarly, one child, Child 5 SHANXT, had not attended two post-test assessments of all computer tasks (including v1b tasks) after her second intervention (NVT) and the second wash-out period, so the results in her v1b accuracy and correct RTs were left blank. Results of the case series analyses for VAS are presented in Table 32.

Table 32

Weighted Statistics for VAS Measures of Children

		Children						**Number showing improvement**
		VO			**VPD**			
WWT		Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	
Global	t	0.13	5.35**	2.74*	-1.83	2.48*	1.3	3
Partial	t	-0.21	1.26	3.14*	-0.21	4.39**	-2.30	2
V1b accu	t	0.68	-0.95	-2.11	2.65*	N/A	3.06*	2
V1b RTs	t	-1.15	-0.43	1.16	-4.43**	N/A	-3.28*	2
		VO			**VPD**			
V1BT		Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	
Global	t	-1.17	-0.70	4.43**	-0.23	0.47	2.10*	2
Partial	t	0.42	3.34*	5.01**	-1.25	4.18**	0.84	3
V1b accu	t	0.29	3.91**	0.10	3.72**	2.77*	6.59**	4
V1b RTs	t	-0.44	-1.25	-1.71	-5.87**	-4.99**	-5.65**	3
		VO			**VPD**			
NVT		Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	
Global	t	-2.32	-1.05	-4.43	1.27	1.69	1.27	0
Partial	t	1.17	-0.50	3.68**	2.17*	0.33	-3.18	2
V1b accu	t	-0.55	-1.66	-0.74	3.87**	N/A	1.66	1
V1b RTs	t	0.59	0.37	0.69	2.66	N/A	5.64	0

Note:. Global: global report; Partial: partial report; V1b accu: visual 1-back accuracy; V1b RTs: visual 1-back correct reaction times; VO: participants who only suffer from VAS deficits; VPD: participants who suffer from both PA and VAS deficits.
$*p<.05$; $**p<.01$; $***p<.001$

Results revealed that, after WWT, there was significant improvement in all VAS variables, including in global report (Child 2, Child 3 and Child 5), in partial report (Child 3 and Child 5), and in v1b accuracy and correct RTs (Child 4 and Child 6). After V1BT, there was also significant improvement in all VAS variables, including in global report (Child 3 and Child 6), in partial report (Child 2, Child 3 and Child 5), and in v1b accuracy (Child 2, Child 4, Child 5 and Child 6) and correct RTs (Child 4, Child 5 and Child 6). After NVT, there was only significant improvement in partial report (Child 3 and Child 4) and v1b accuracy (Child 4). It should be noted that only after the NVT, there was no significant improvement in global report and v1b correct RTs.

In summary, each case had significant improvement in at least one VAS measure during at least one training, except for Child 1. WWT and V1BT, especially V1BT, showed better improvement in VAS than NVT.

Adults

WEST-ROC was also used to test whether there was significantly greater improvement of these poor adult readers' reading performance and VAS during the treated phase (WWT, V1BT and NVT) than the untreated phase (baselines and washout periods). Three participants were classified into two groups (Adult 1 only with VAS deficits-VO group, and Adult 2 and Adult 3 with both VAS and phonological deficits-VPD group) by the deficits they had.

Reading

Results of the case series analyses for adults' reading fluency are presented in Table 33.

Table 33

Weighted Statistics for Oral and Silent Reading Fluency Measures of Adults

		Adults			Number showing improvement
		VO	**VPD**		
WWT		Adult 1	Adult 2	Adult 3	
		HL	LM	ZJF	
Of	t	-0.07	0	2.97*	1
Sf	t	0.02	3.46*	1.38	1
		VO	**VPD**		
V1BT		Adult 1	Adult 2	Adult 3	
Of	t	-0.67	-3.67	-0.67	0
Sf	t	1.11	-1.82	1.24	0
		VO	**VPD**		
NVT		Adult 1	Adult 2	Adult 3	
Of	t	3.83*	4.07*	6.94*	3
Sf	t	-3.00	-2.06	0.36	0

Note:. Of: oral word reading fluency; Sf: silent sentence reading fluency; VO: participants who only suffer from VAS deficits; VPD: participants who suffer from both PA and VAS deficits.
**p*<.05; ***p*<.01; ****p*<.001

Results revealed that after WWT, oral word reading fluency (Adult 3) and silent sentence reading fluency (Adult 2) revealed significant improvement. After V1BT, no reading fluency was improved. After NVT, all adults showed an increase in oral word reading fluency.

In summary, each case had significant improvement in at least one reading fluency measure during at least one training. The WWT than V1BT resulted in more improvement in oral and silent reading fluency for adults, and the NVT may be only beneficial for oral reading rather than for silent reading.

VAS

Results of the case series analyses for VAS are presented in Table 34.

Table 34

Weighted Statistics for VAS Measures of Adults

		Adults			Number showing improvement
		VO	**VPD**		
WWT		Adult 1 HL	Adult 2 ZJF	Adult 3 LM	
Global	t	0.55	4*	2	1
Partial	t	2.08	5.42*	2.92*	2
V1b accu	t	-0.80	1.50	-1.90	0
V1b RTs	t	0.47	1.26	-2.06	0
		VO	**VPD**		
V1BT		Adult 1	Adult 2	Adult 3	
Global	t	2.84	-0.22	-0.09	0
Partial	t	0	-2.38	-3.37	0
V1b accu	t	0.54	0	-2.69	0
V1b RTs	t	0.27	-0.36	-2.99*	1
		VO	**VPD**		
NVT		Adult 1	Adult 2	Adult 3	
Global	t	-0.13	3.32*	1.86	1
Partial	t	0.72	2.51	1.97	0
V1b accu	t	-1.98	1.48	-0.12	0
V1b RTs	t	0.29	2.91	-0.36	0

Note:. Global: global report; Partial: partial report; V1b accu: visual 1-back accuracy; V1b RTs: visual 1-back correct reaction times. VO: participants who only suffer from VAS deficits; VPD: participants who suffer from both PA and VAS deficits.
**p*<.05; ***p*<.01; ****p*<.001

Results revealed that, after WWT, only global and partial report showed significant improvement (Adult 2 and Adult 3). After V1BT, only v1b correct RTs showed significant improvement (Adult 3). After NVT, Adult 2’ s global report showed a significant increase. After V1BT, partial report of Adult 3 was found to show a significant decrease.

In summary, the WWT showed adults’ better improvement in VAS than V1BT and NVT, in terms of report tasks.

4.5.2 Group analyses

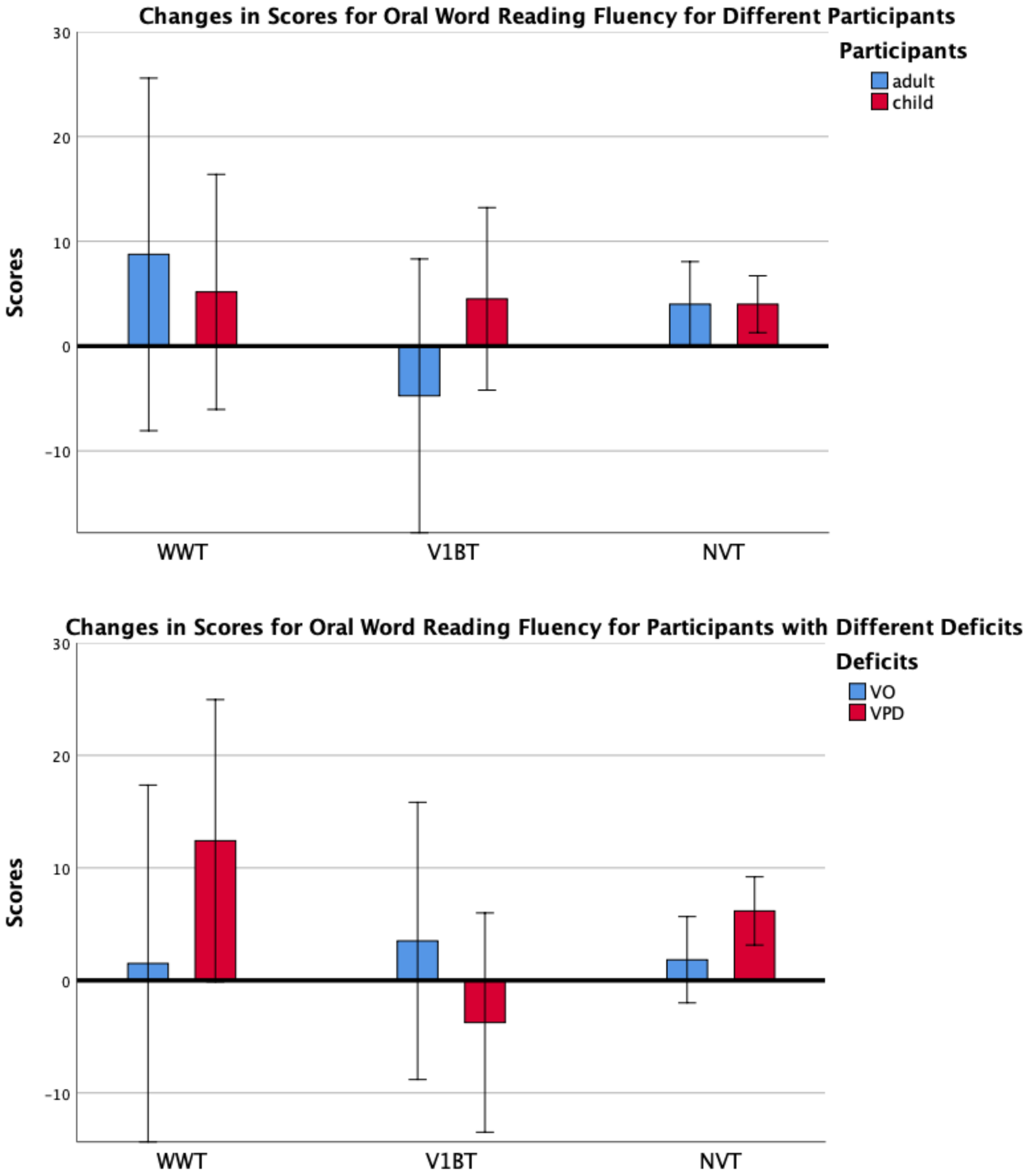
Reading

Oral word reading fluency

A comparison of intervention changes in oral word reading fluency after three types of intervention across different groups was revealed in Figure 12.

Figure 12

Intervention Changes in Oral Word Reading Fluency after Different Interventions across Different Groups (Participant Groups – Top, Deficit Groups - Bottom)



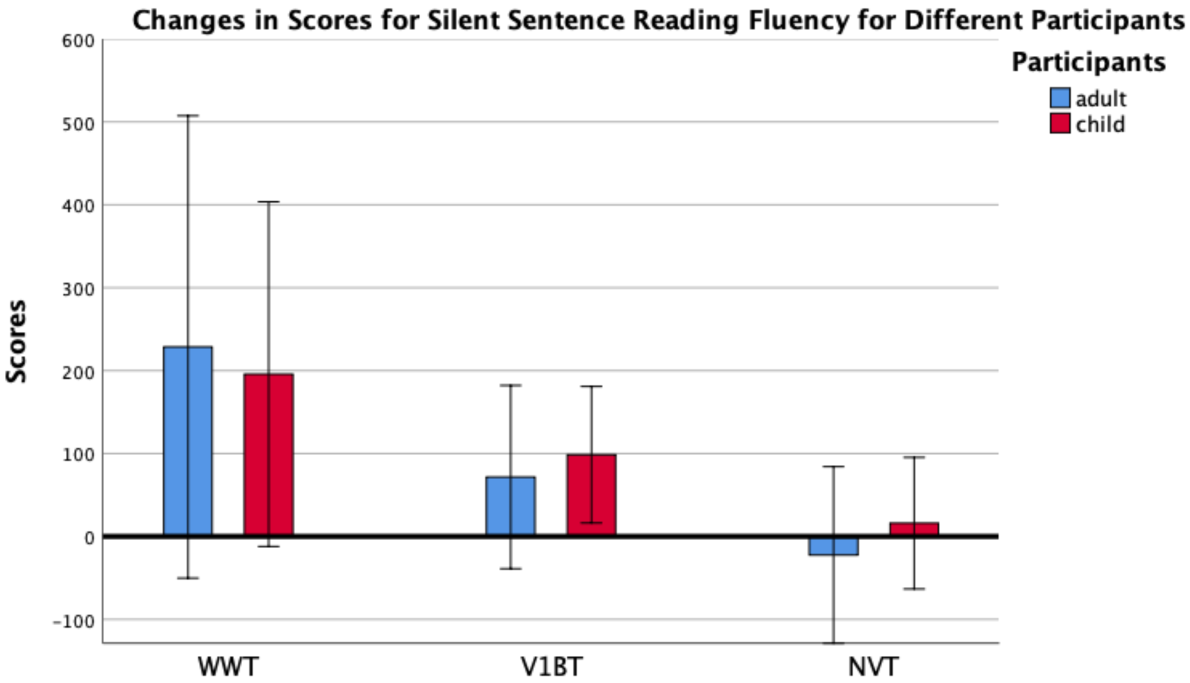
The main effects of Types, Participant groups and Deficit groups in oral word reading fluency were not significant (Types: F (2, 10) = 1.31, p=.31; Participants: F (1, 5) = 0.42, p=.55; Deficits: F (1, 5) = 0.84, p=.40). Also, all interaction effects were not significant, Type x Participant, F (2, 10) = 1.13, p =.36; Type x Deficits, F (2, 10) = 2.19, p =.16; Type x Participant x Deficits, F (2, 10) = 1.07, p =.38.

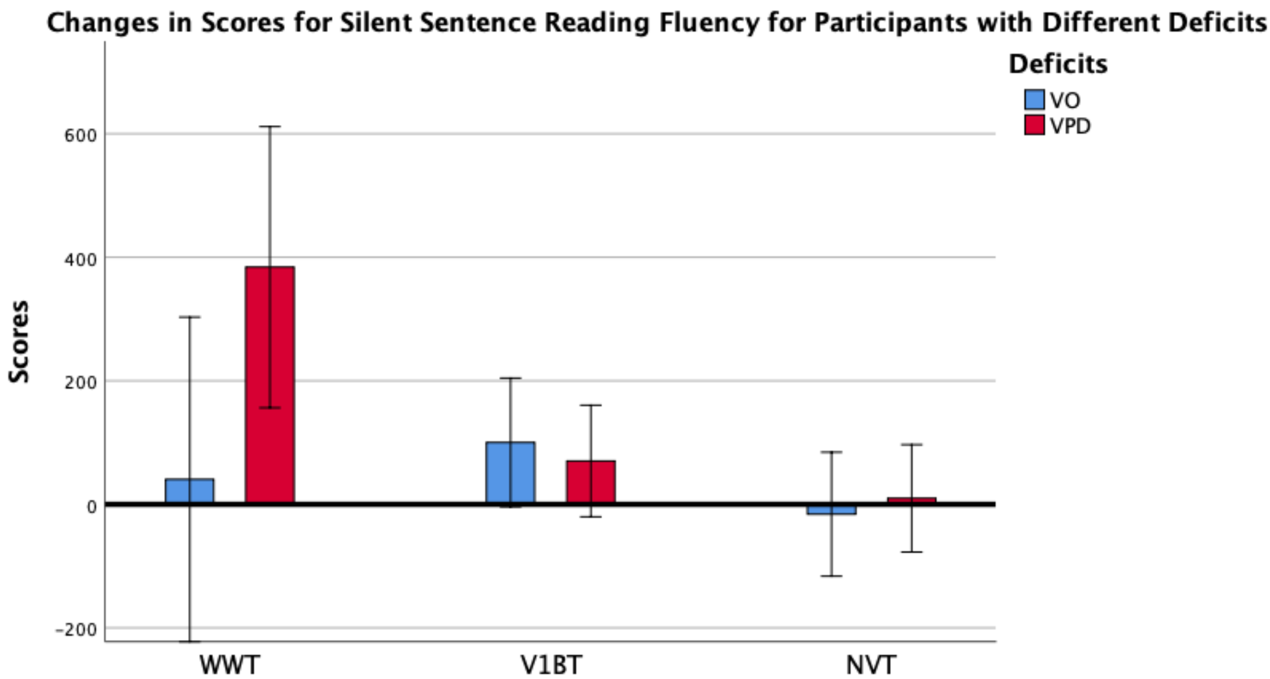
Silent sentence reading fluency

Data of post wash-out 2 and post intervention 3 of Child 2 (SHANXT) was missing because of her absence. Comparison of intervention changes in silent sentence reading fluency after three types of intervention across different groups is revealed in Figure 13.

Figure 13

Intervention Changes in Silent Sentence Reading Fluency after Different Interventions across Different Groups (Participant Groups – Top, Deficit Groups – Bottom)





The main effects of Types and Deficits in silent sentence reading fluency were significant (Types: *F* (2, 8) = 5.20, *p*=.04; Deficits: *F* (1,4) = 13.11, *p*=.02), but the main effects of Participant groups were not significant, *F* (1, 4) = 0.17, *p*=.71). Also, the interaction effects were not significant, Type x Participant, *F* (2, 8) = 0.17, *p* =.85, and Type x Participant x Deficits, *F* (2, 8) = 0.04, *p* =.97, but the interaction effect between Type and Deficits was significant, *F* (2, 8) = 4.60, *p* =.05.

The further simple effect of Types of interventions showed that only for WWT, the VPD group and VO group showed significantly different effectiveness in silent sentence reading fluency (WWT, *p*=.000, V1BT, *p*=.38, NVT, *p*=.85). The further simple effect of Deficits showed that the intervention effects of the VO group after three interventions did not show any significant differences, but the ones of the VPD group did. As for the VPD group, there were only significant differences in silent sentence reading fluency between WWT and V1BT (*p*=.000), as well as WWT and NVT (*p*=.000). There were no significant differences between V1BT and NVT (*p*=.41) for the VPD group.

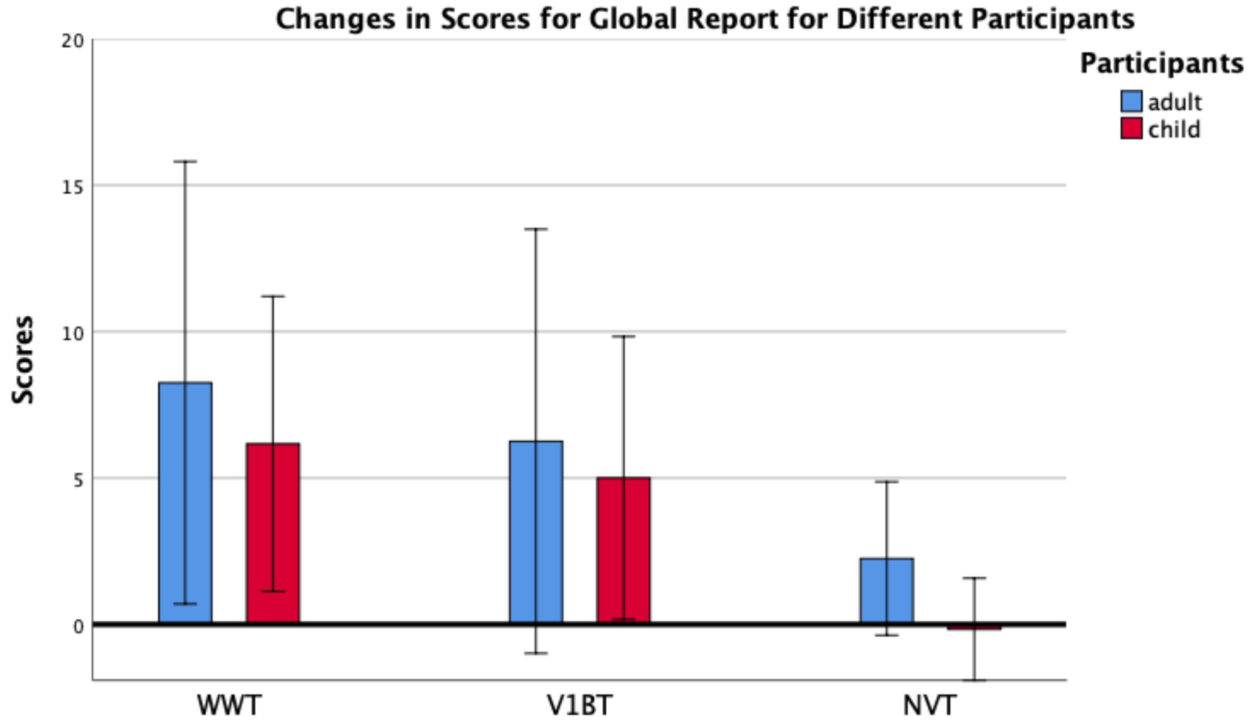
VAS

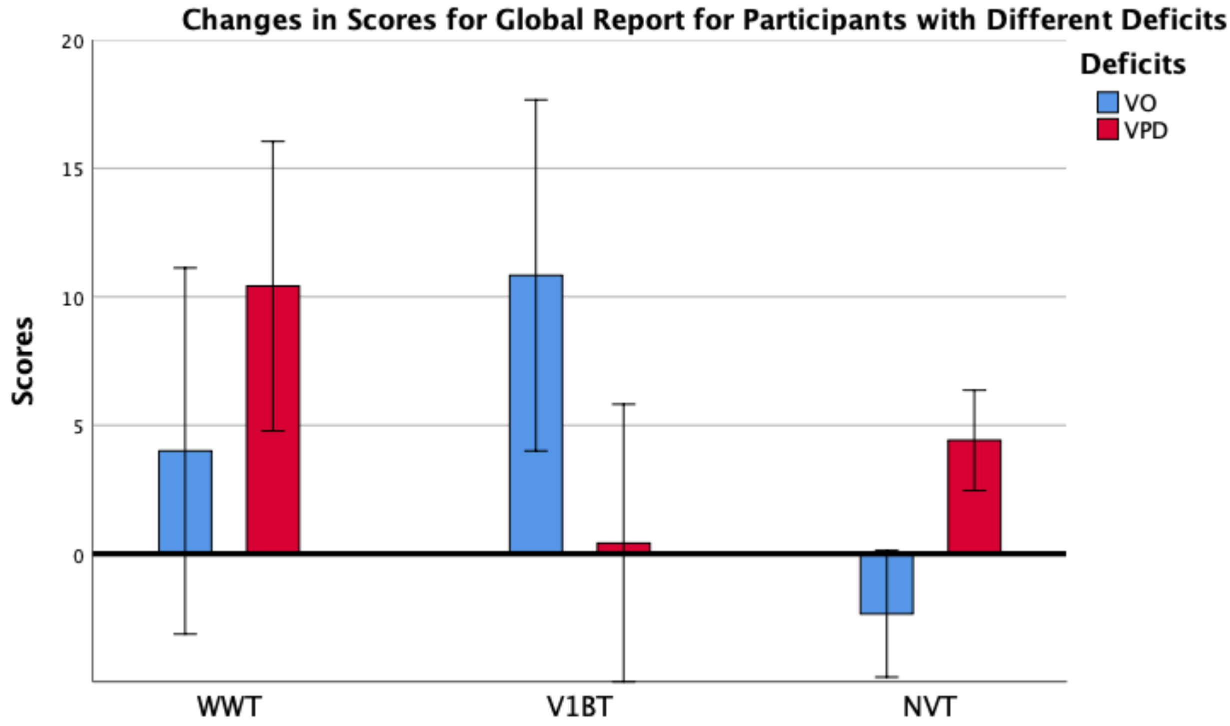
Global report

A comparison of intervention changes in scores in global report after three types of intervention across different groups was revealed in Figure 14.

Figure 14

Intervention Changes in VAS Global Report after Different Interventions across Different Groups (Participant Groups - Top, Deficit Groups - Bottom)





The main effects of Types in VAS global report were significant (*F* (2, 10) = 4.79, *p*=.04), but the main effects of Participant groups and Deficit groups were not significant, Participants: *F* (1, 5) = 1.32, *p*=.30; Deficits: *F* (1, 5) = 0.30, *p*=.61. Also, the interaction effects were significant, Type x Deficits (*F* (2, 10) = 11.26, *p* =.003), and Type x Participant x Deficits (*F* (2, 10) = 6.78, *p* =.01), but the interaction effects between Type and Participants were not significant, *F* (2, 10) = 0.04, *p* = 0.96. This may mean that the intervention influence on VAS global report from intervention types and participants with different deficits may interact.

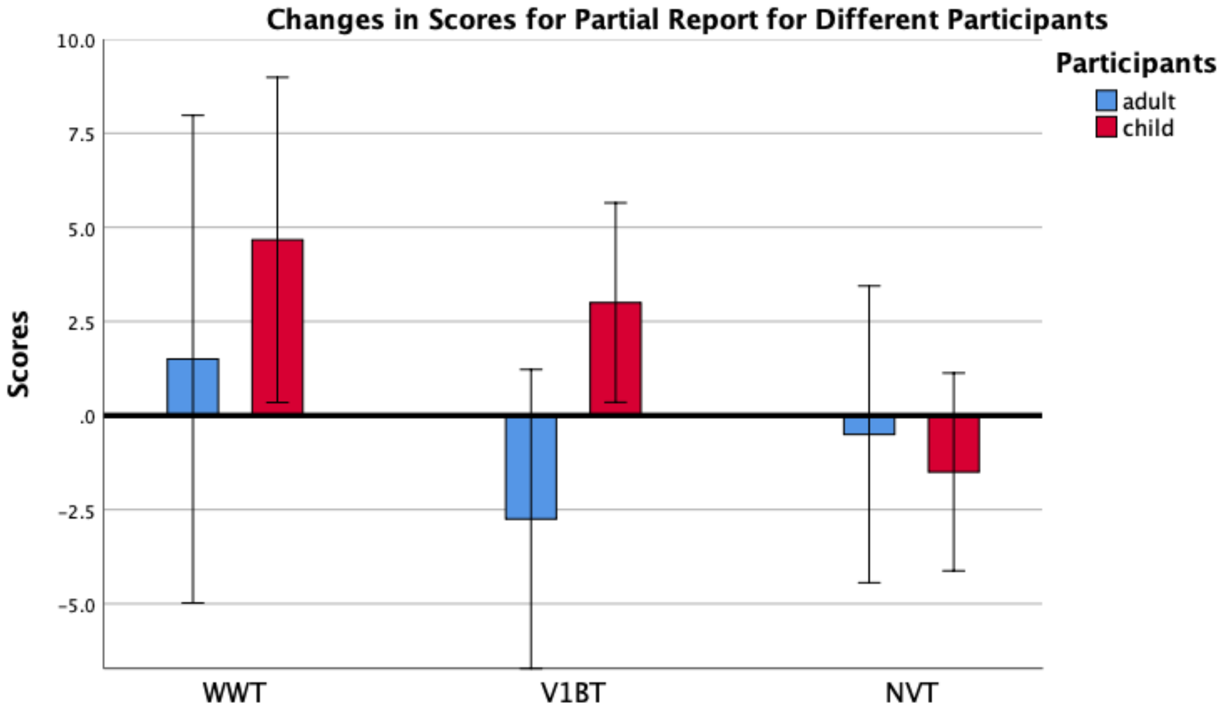
The further simple effect of Types of interventions showed that only for V1BT, the VPD group and VO group showed significantly different effectiveness in global report (WWT, *p*=.25, V1BT, *p*=.03, NVT, *p*=.06). The further simple effect of Deficits showed that, as for the VO group, the intervention effects of the NVT revealed significant differences from those of the other two VAS-based interventions. There were no significant differences between WWT and V1BT. As for the VPD group, there were only significant differences in global report between WWT and V1BT (*p*=.01), but there were no significant differences between V1BT and NVT (*p*=.34) and between WWT and NVT (*p*=.10) for the VPD group.

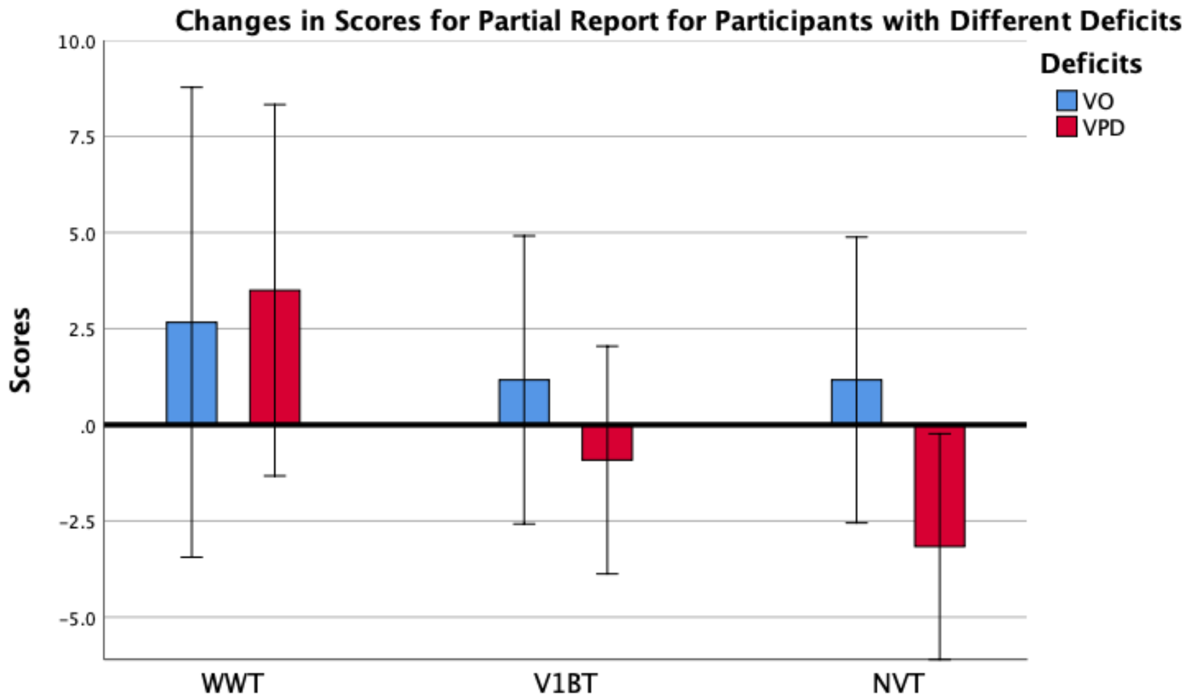
Partial report

Intervention changes in scores in partial report after three types of intervention across different groups are shown in Figure 15.

Figure 15

Intervention Changes in VAS Partial Report after Different Interventions across Different Groups (Participant Groups - Top, Deficit Groups - Bottom)





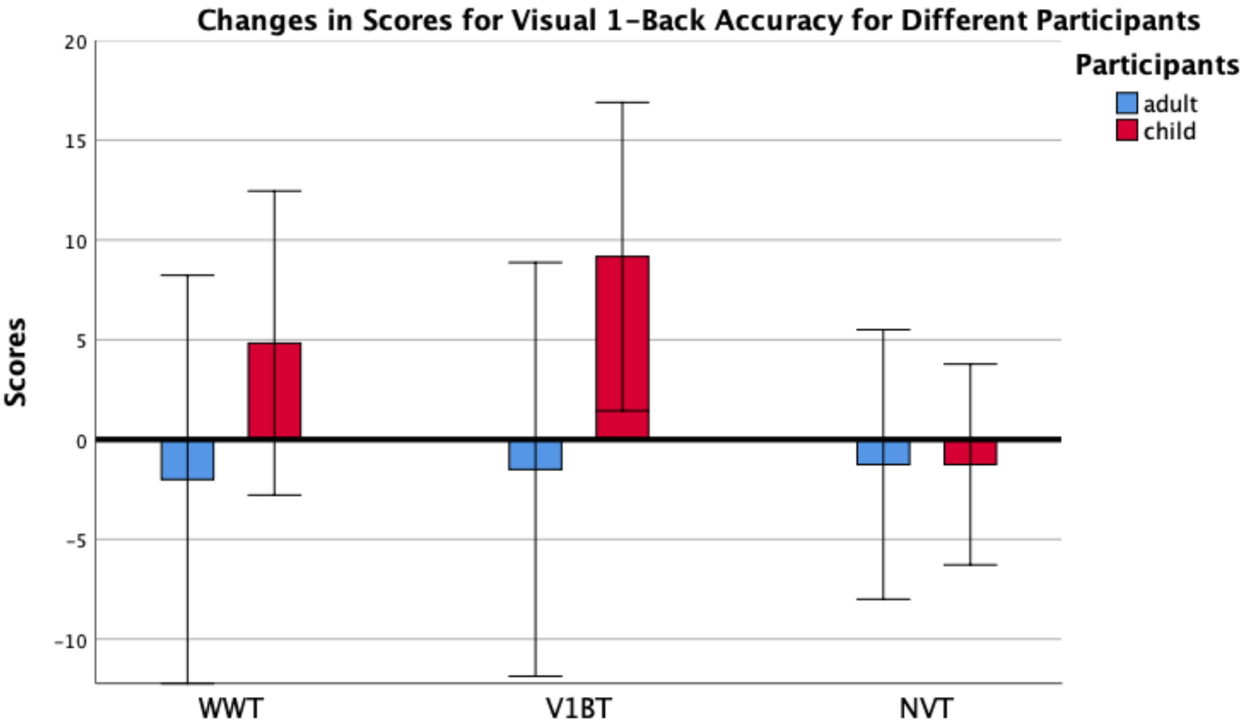
The main effects of Types and Participants in VAS partial report were not significant (Type: $F(2, 10) = 3.12$, $p=.09$; Participants: $F(1, 5) = 4.55$, $p=.09$), and the main effects of Deficit groups were still not significant, $F(1, 5) = 2.26$, $p=.19$. Also, all the interaction effects were not significant, Type x Participants were not significant, ($F(2, 10) = 2.03$, $p=.18$), Type x Deficits ($F(2, 10) = 1.18$, $p=.35$), and Type x Participant x Deficits ($F(2, 10) = 0.62$, $p=.56$).

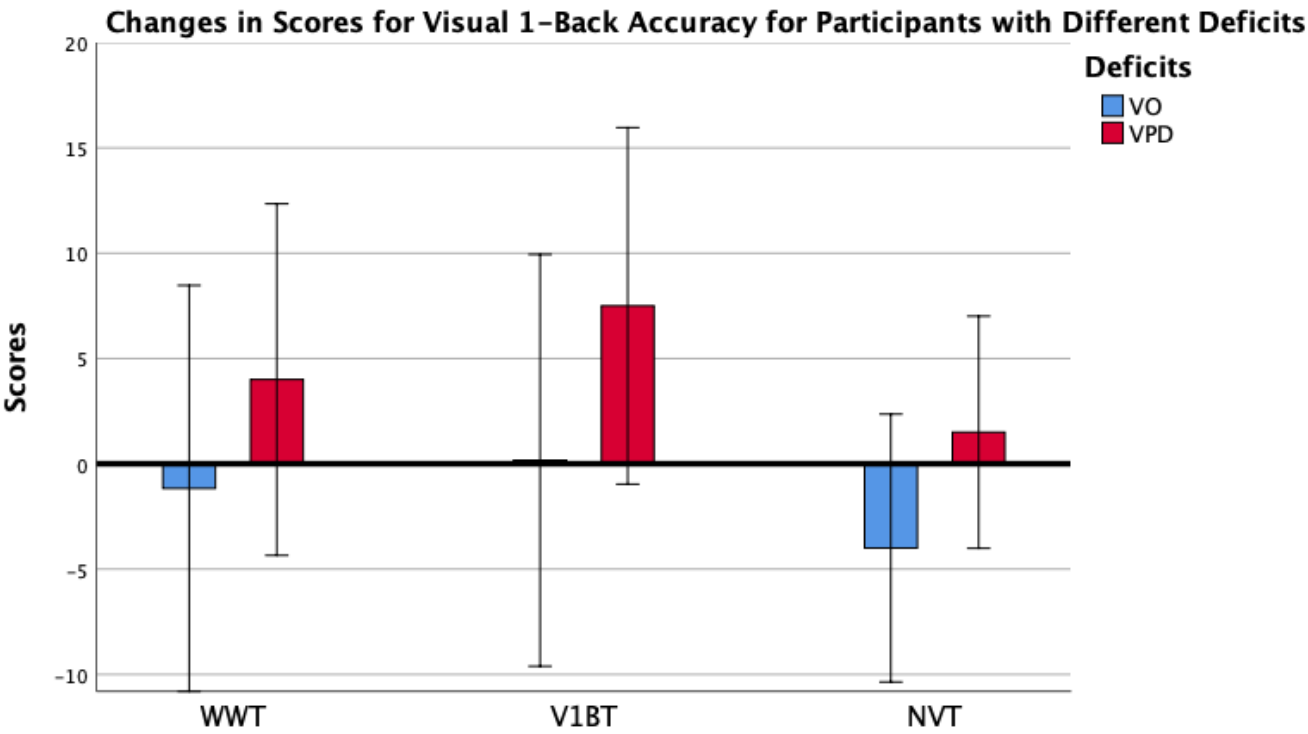
V1b accuracy

Data of post wash-out 2 and post intervention 3 of Child 5 SHANXT was missing because of absence. Except for this child, intervention changes in v1b accuracy after three types of intervention across different groups were shown in Figure 16.

Figure 16

Intervention Changes in VAS Visual 1-Back Accuracy after Different Interventions across Different Groups (Participant Groups - Left, Deficit Groups - Right)





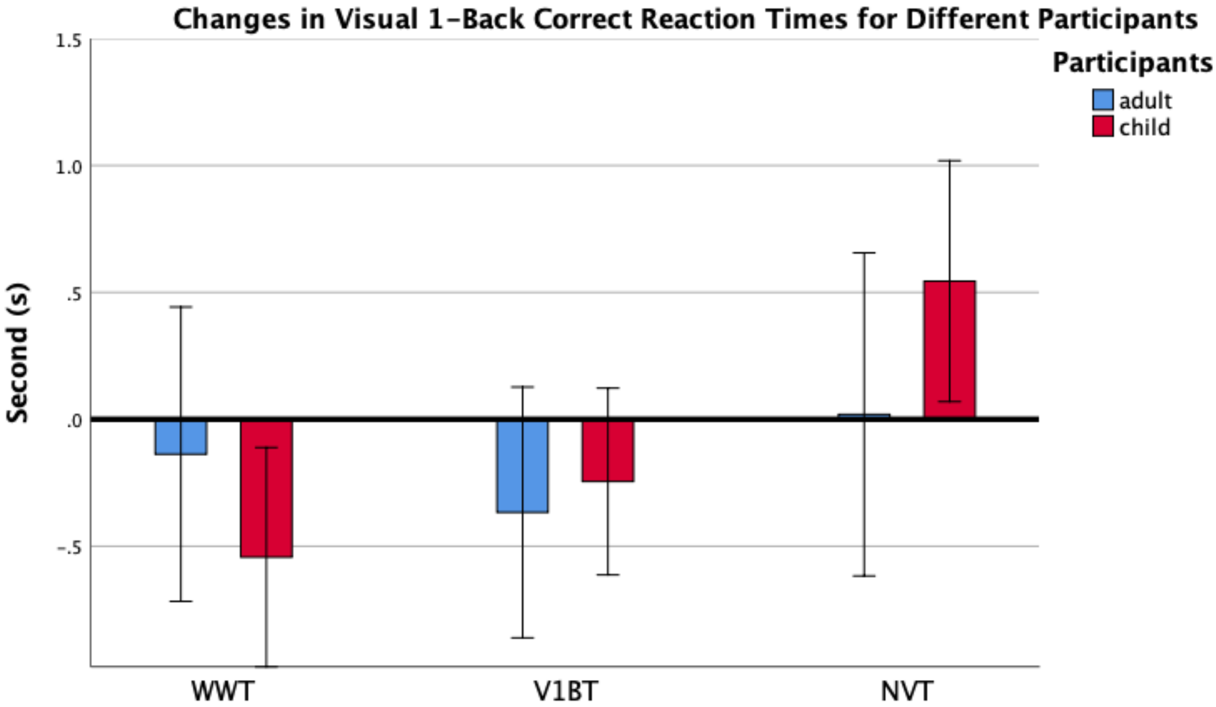
The main effects of Types, Participant groups and Deficit groups in VAS v1b accuracy were not significant (Types: F (2, 8) = 1.87, p=.22; Participants: F (1, 4) = 4.21, p=.11; Deficits: F (1, 4) = 4.45, p=.10). Also, all interaction effects were not significant, Type x Participant, F (2, 8) = 2.11, p =.18; Type x Deficits, F (2, 8) = 0.10, p = .91; Type x Participant x Deficits, F (2, 8) = 2.31, p =.16.

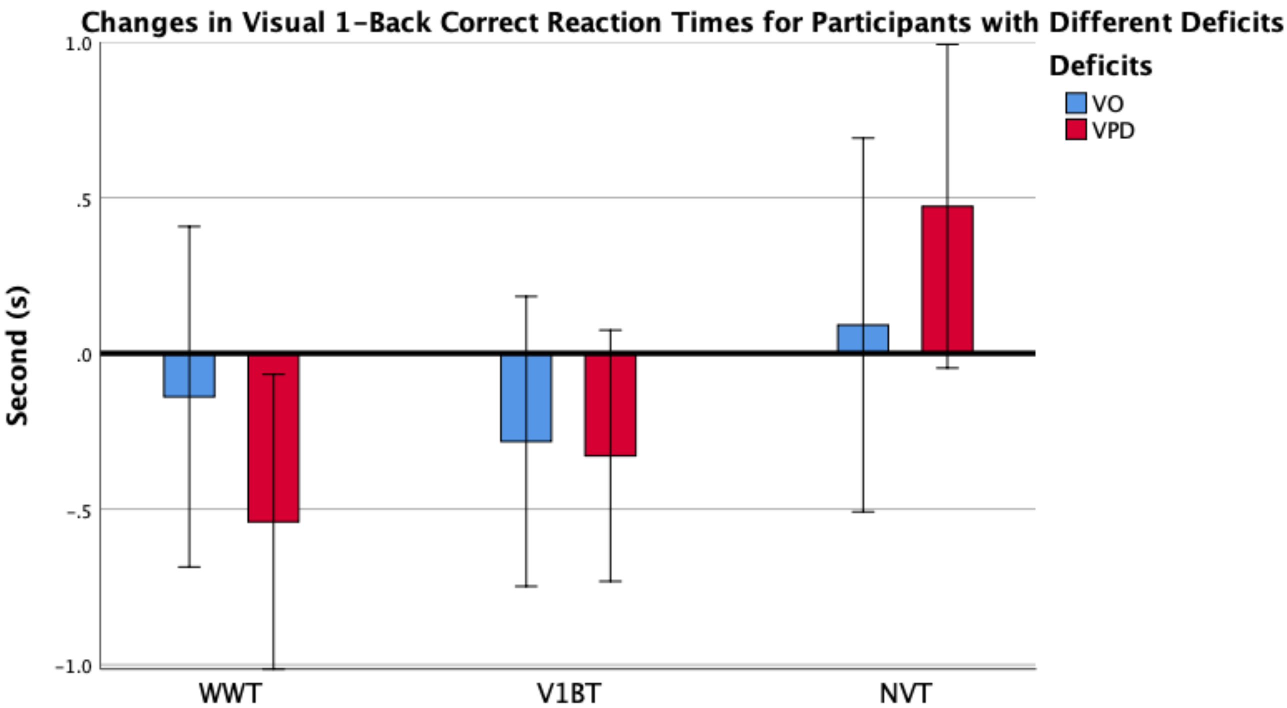
V1b correct RTs

Except for the Child 5 SHANXT, intervention changes in v1b correct RTs after three types of intervention across different groups are shown in Figure 17.

Figure 17

Intervention Changes in VAS Visual 1-Back Correct Reaction Times after Different Interventions across Different Groups (Participant Groups - Top, Deficit Groups - Bottom)





The main effect of Type for V1b correct RTs was significant, *F* (2, 8) = 6.62, *p*=.02), but the main effects of Participant group and Deficit group were not significant (Participants: *F* (1, 4) = 0.38, *p*=.57; Deficits: *F* (1, 4) = 0.03, *p*=.87). The interaction effects were not significant, Type x Participant, *F* (2, 8) = 2.95, *p* =.11; Type x Deficits, *F* (2, 8) = 2.08, *p* =.19; Type x Participant x Deficits, *F* (2, 8) = 1.44, *p* =.29. The results showed that the three interventions led to significantly different effects for V1B correct RTs. The simple effect analysis showed that there were no significant differences in v1b correct RTs of children and adults after WWT and V1BT. Children in the VPD group showed the worst performance in v1b correct RTs after the NVT than after WWT and V1BT.

4.5.3 Intervention effects analyses based on participants with different deficits

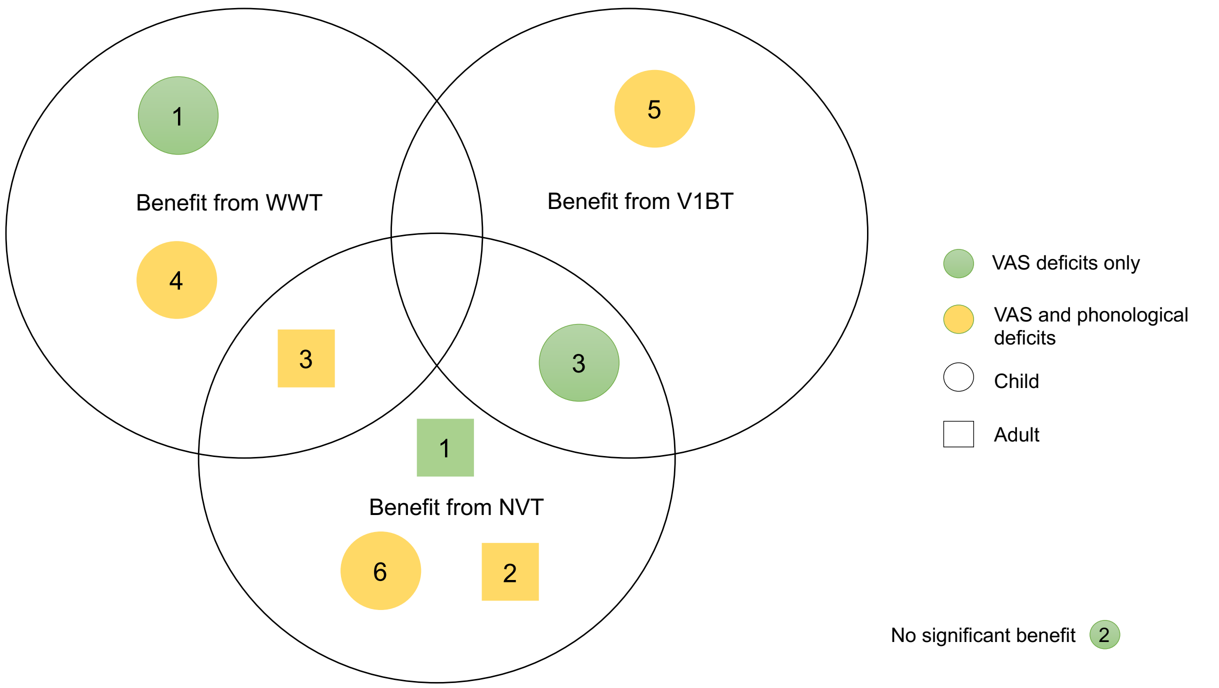
The following figures more clearly illustrate the significant progress in reading fluency and VAS of intervention per participant with different sub-type deficits (VO group-only VAS deficit group; VPD group-VAS and Phonological deficit group) with Venn diagrams.

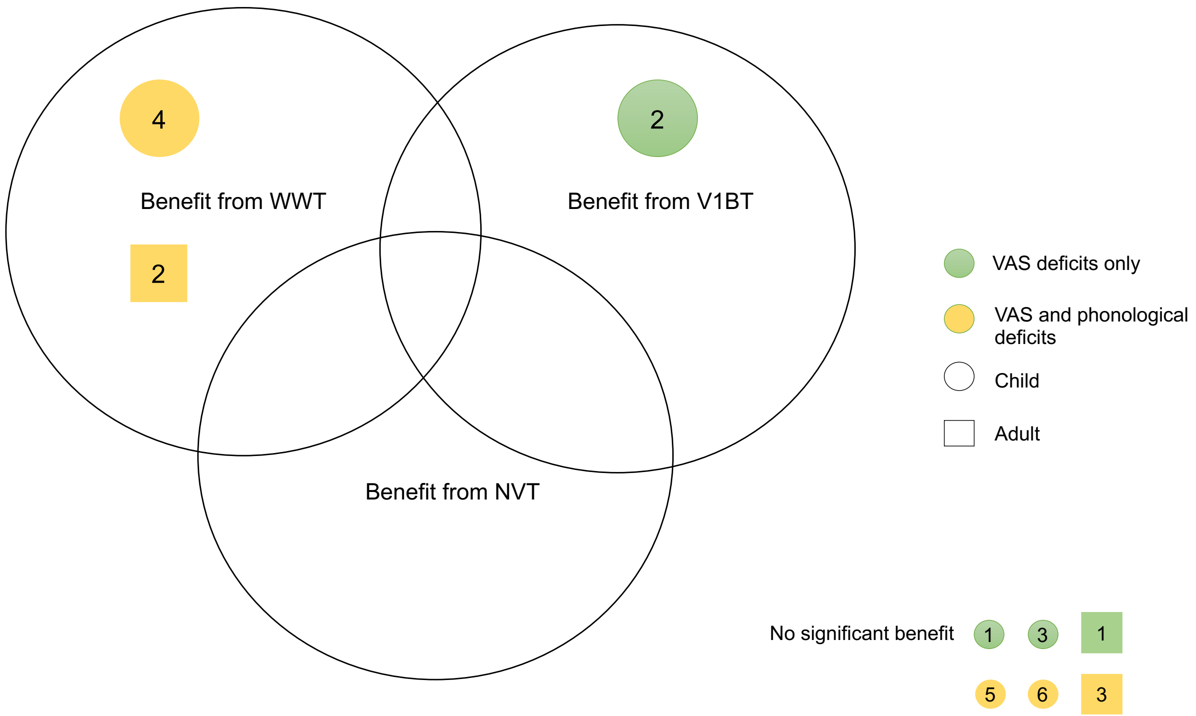
Reading

Venn diagrams showing results for oral word reading fluency and silent sentence reading fluency are presented in Figure 18.

Figure 18

Venn Diagram Illustrating Significant Improvement of Oral Word Reading Fluency (Top) and Silent Sentence Reading Fluency (Bottom) as Assessed by Significant Change with Intervention in Relation to Sub-Group





VO group (only VAS deficit group: Child 1, 2 and 3; Adult 1)

In terms of oral word reading fluency, Child 1 showed significant benefits only from the WWT, Child 3 from both V1BT and NVT, Adult 1 only from the NVT, and Child 2 from nothing. By contrast, only Child 2 showed significant benefits in silent sentence reading fluency, and only from the V1BT, not from the NVT.

VPD group (VAS and phonological deficit group: Child 4, 5 and 6; Adult 2 and 3)

In terms of oral word reading fluency, Child 4 showed significant improvement only from the WWT, Child 5 only from the V1BT, Child 6 and Adult 2 only from the WWT, and Adult 3 from both WWT and NVT. In contrast, only Child 4 and Adult 2 presented significant improvement in silent sentence reading fluency, and only from WWT, not from the NVT.

VAS

The Venn diagrams of global report and partial report are presented in Figure 19.

Figure 19

Venn Diagram Illustrating Significant Improvement of Global Report (Top) and Partial Report (Bottom) of Intervention per Participant as Assessed by Significant Change with Intervention in Relation to Sub-Group

VO group (only VAS deficit group: Child 1, 2 and 3; Adult 1)

Only Child 2 and Child 3 showed significant benefits in global report from the WWT or V1BT, not from the NVT. Child 3 showed improvement from both WWT and V1BT. Child 2 showed significant benefits in partial report from the V1BT but Child 3 showed significant benefits in partial report from all interventions. By contrast, Adult 1 did not show any improvement in partial report from any intervention.

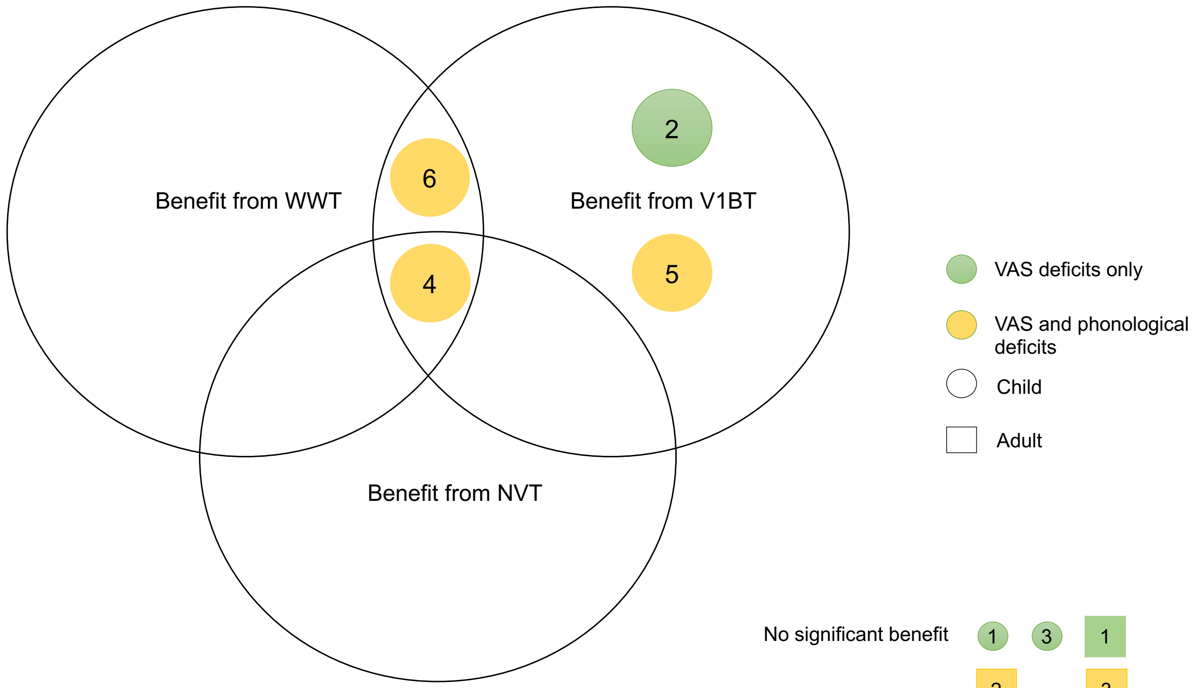
VPD group (VAS and phonological deficit group: Child 4, 5 and 6; Adult 2 and 3)

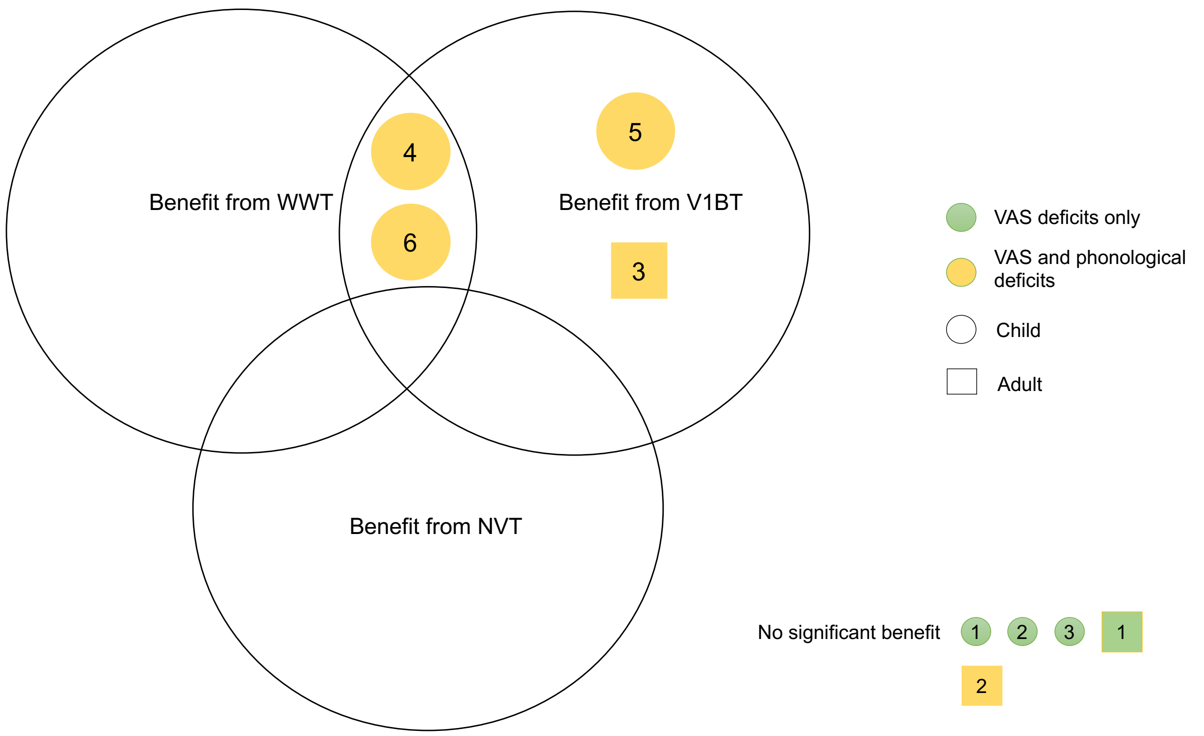
Child 5 and Child 6 showed significant improvement in global report from WWT or V1BT. Adult 2 also showed improvement from the WWT and NVT. Child 4 revealed improvement from the NVT, and Adults 2 and 3 showed improvement from the WWT. Child 5 showed improvement in partial report from both WWT and V1BT.

The Venn diagrams of v1b accuracy and v1b correct RTs are presented in Figure 20.

Figure 20

Venn Diagram Illustrating Significant Improvement of Visual 1-Back Accuracy (Top) and Correct Reaction Times (Bottom) of Intervention as Assessed by Significant Change with Intervention in Relation to Sub-Group





VO group (only VAS deficit group: Child 1, 2 and 3; Adult 1)

Only Child 2 showed significant benefits in v1b accuracy from the V1BT. No VO adults benefited from any interventions in terms of v1b accuracy. No VO children and adults showed significant improvement in v1b correct RTs after any intervention.

VPD group (VAS and phonological deficit group: Child 4, 5 and 6; Adult 2 and 3)

All VPD children revealed significant improvement in v1b accuracy or correct RTs from all three interventions, except for Adult 2. Among these, Child 6 showed improvement from the WWT and V1BT, and Child 4 from all interventions. By contrast, no VPD adults benefited from any interventions in terms of v1b accuracy.

In summary, regarding reading fluency, except for Child 2, the other participants obtained benefits in oral word reading fluency with both VAS-based and non-VAS-based interventions, whichever subtype of deficits they had. This meant that some participants without phonological deficits also showed significant improvement during the non-VAS-based intervention (phonological training). By contrast, not many participants' silent sentence reading fluency showed improvement, but where this occurred it was only in association with the VAS-based interventions. Among these, the VO group seemed to benefit only from the nonverbal VAS intervention, while the VPD group seemed to benefit only from the verbal VAS intervention.

Regarding VAS, most participants who showed improvement in VAS showed improvement in association with the VAS-based interventions. Most participants showed significant improvement in global and partial report, rather than v1b accuracy and correct RTs. Only VPD, not VO participants, showed benefits in VAS from the NVT (global report of Adult 2, partial report and v1b accuracy of Child 4), except for partial report of Child 3.

4.5.4 Spelling with WWT

There were differences in the number of misspelt characters across participants, so, each participant was trained with a different number of characters according to individual baseline spelling performance. When the WWT was complete, all previously misspelt characters, including the untrained characters were re-tested.

WWT was the first training for Child 1, Child 4, Adult 2, so their spelling scores were tested at A2 (after six weeks). WWT was the second training for Child 3, Child 6 and Adult 3, so their spelling was tested at A4 (after 15 weeks). WWT was the third training for Child 2, Child 5 and Adult 1 at A6 (after 24 weeks).

Accuracy scores and the number of errors for trained and untrained characters before and after WWT are given in Table 35.

Table 35

Children's Spelling Performance of Trained and Untrained Characters after WWT

		Accuracy before WWT	Error before WWT	Accuracy after WWT	Error after WWT	Percentage of accuracy (increase)	Chi-square	*p*
Child 1 XMH	Trained	0	101	89	12	88.12%	87.01	.000
	Untrained	0	101	78	23	77.23%	76.01	.000
Child 2 SONGXT	Trained	0	110	89	21	80.91%	87.01	.000
	Untrained	0	109	78	31	71.56%	76.02	.000
Child 3 GHW	Trained	0	121	107	14	88.43%	104.01	.000
	Untrained	0	121	102	19	84.30%	102.01	.000
Adult 1 HL	Trained	0	105	83	22	79.05%	81.01	.000
	Untrained	0	105	82	23	78.10%	80.01	.000
With spelling difficulty								
Child 4 QJW	Trained	0	144	88	56	61.11%	36.03	.000
	Untrained	0	143	96	47	67.13%	55.02	.000
Child 5 SHANXT	Trained	0	144	124	20	86.11%	122.01	.000
	Untrained	0	143	109	34	76.22%	107.01	.000
Child 6 ZN	Trained	0	140	91	49	65%	89.01	.000
	Untrained	0	140	102	38	72.86%	100.01	.000
Adult 2 LM	Trained	0	166	37	129	22.29%	35.03	.000
	Untrained	0	166	49	117	29.52%	42.02	.000
Adult 3 ZJF	Trained	0	153	113	40	73.86%	111.01	.000
	Untrained	0	153	109	44	71.24%	107.01	.000

Note: Trained: trained characters; Untrained: untrained characters

Inspection of Table 35 reveals that all participants showed significant improvements in trained characters and untrained characters, regardless of their intervention order of WWT.

To be comparable with results from Study 2b, qualitative analyses of changes in spelling errors in the 60-word spelling-to-dictation task were conducted. Results are presented in Table 36.

Table 36

Comparison of Percentage (and Number) of Spelling Errors in the 60-Word List in Each Error Category of Children and Adults Before and After WWT

Error category	Before WWT	After WWT
Phonologically based errors	**24.49 (36)**	**21.05 (4)**
Pinyin substitution	2.05 (3)	0 (0)
Homophone and Semi-homophone substitution	22.45 (33)	21.05 (4)
Orthographic errors	**44.90 (66)**	**52.63 (10)**
Partial character	3.40 (5)	0 (0)
Invention of an unconventional character	0.68 (1)	0 (0)
Transposition	2.04 (3)	0 (0)
Deletion	21.77 (32)	15.79 (3)
Addition	9.52 (14)	26.32 (5)
Substitution (real words)	4.08 (6)	5.26 (1)
Substitution (nonword)	3.40 (5)	5.26 (1)
Meaning-related errors	**0 (0)**	**0 (0)**
Synonym substitution	0 (0)	0 (0)
Substitution of meaning-similar character	0 (0)	0 (0)
No responses	**30.61 (45)**	**26.32 (5)**

Table 36 shows the differences in spelling errors in the 60-word list before and after WWT. Before WWT, all participants made more orthographic errors and no responses. Among the orthographic errors, participants made the most orthographic errors in *deletion*.

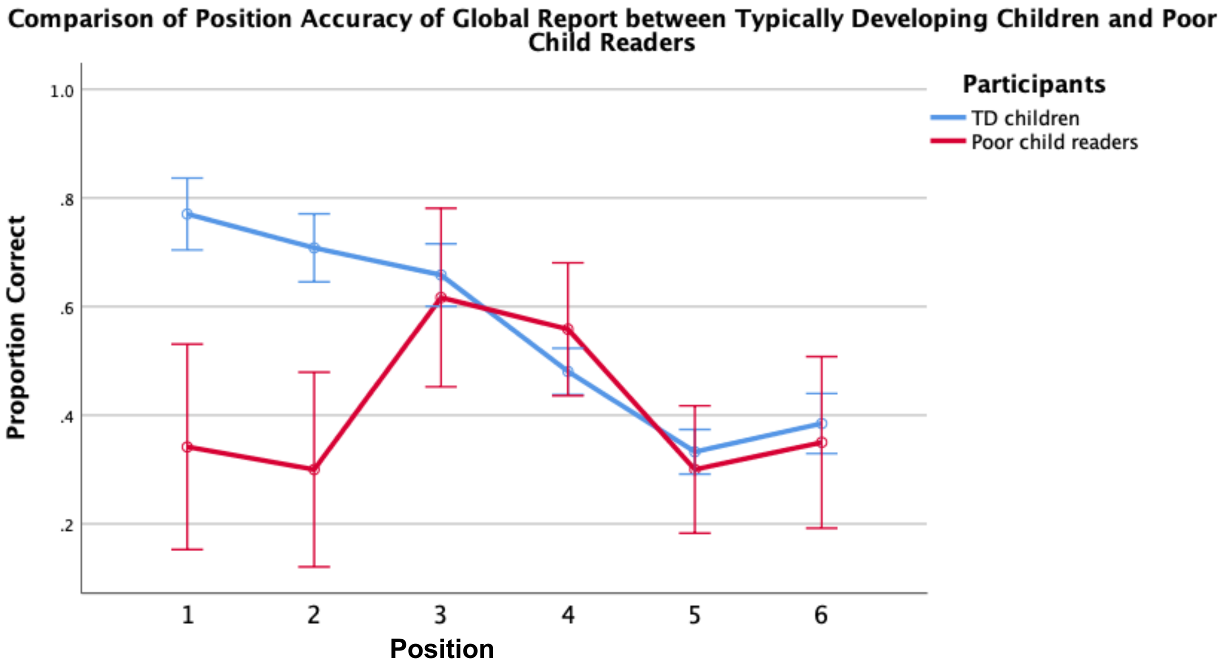
By contrast, after WWT, participants still made the greatest number of orthographic errors, where errors in *addition* not *deletion* accounted for the largest proportion. This change is highlighted in red.

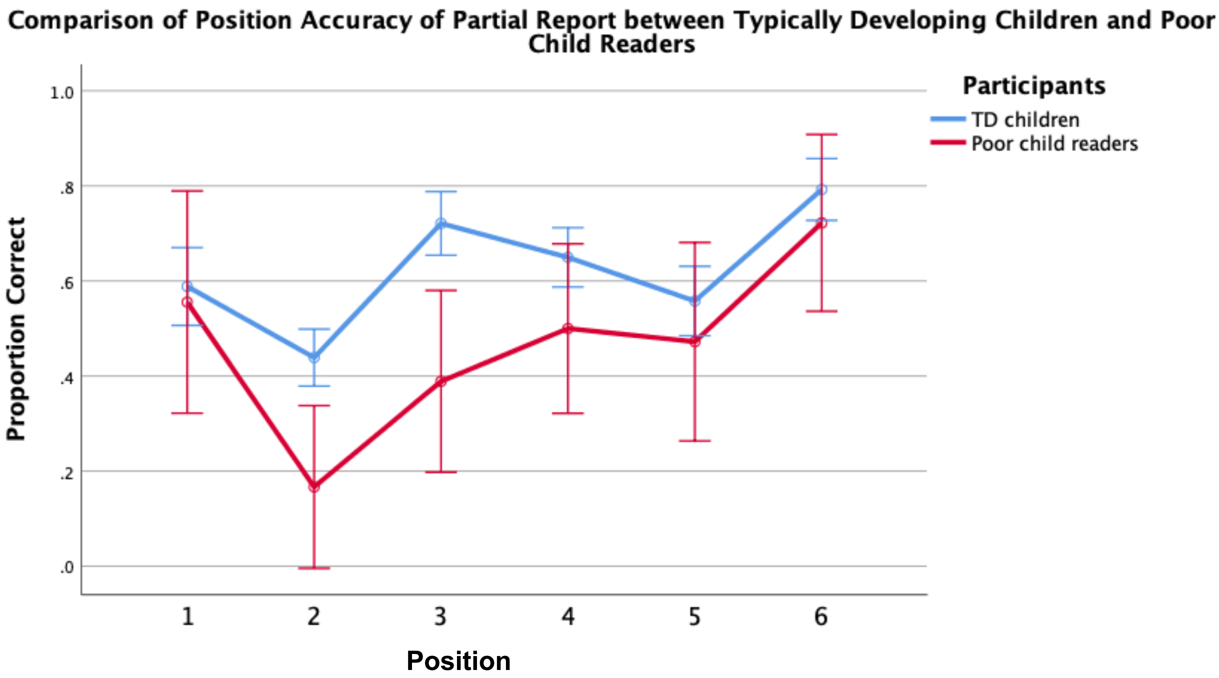
4.5.5 Comparison in pattern of VAS tasks between poor child readers and TD readers

Plots of accuracy according to array position in the global and partial report tasks are shown in Figure 21.

Figure 21

Responses across Array Positions in the Global Report (Top) and Partial Report (Bottom) of Children





The results of the mixed ANOVA showed that for global report, the main effects of Position and Participant were significant (Position: F (2.52, 133.78) = 11.62, p=.00; Participants: F (1, 53) = 7.56, p=.01). The interaction effect was significant, Position x Participant, F (2.52, 133.78) = 9.46, p =.00).

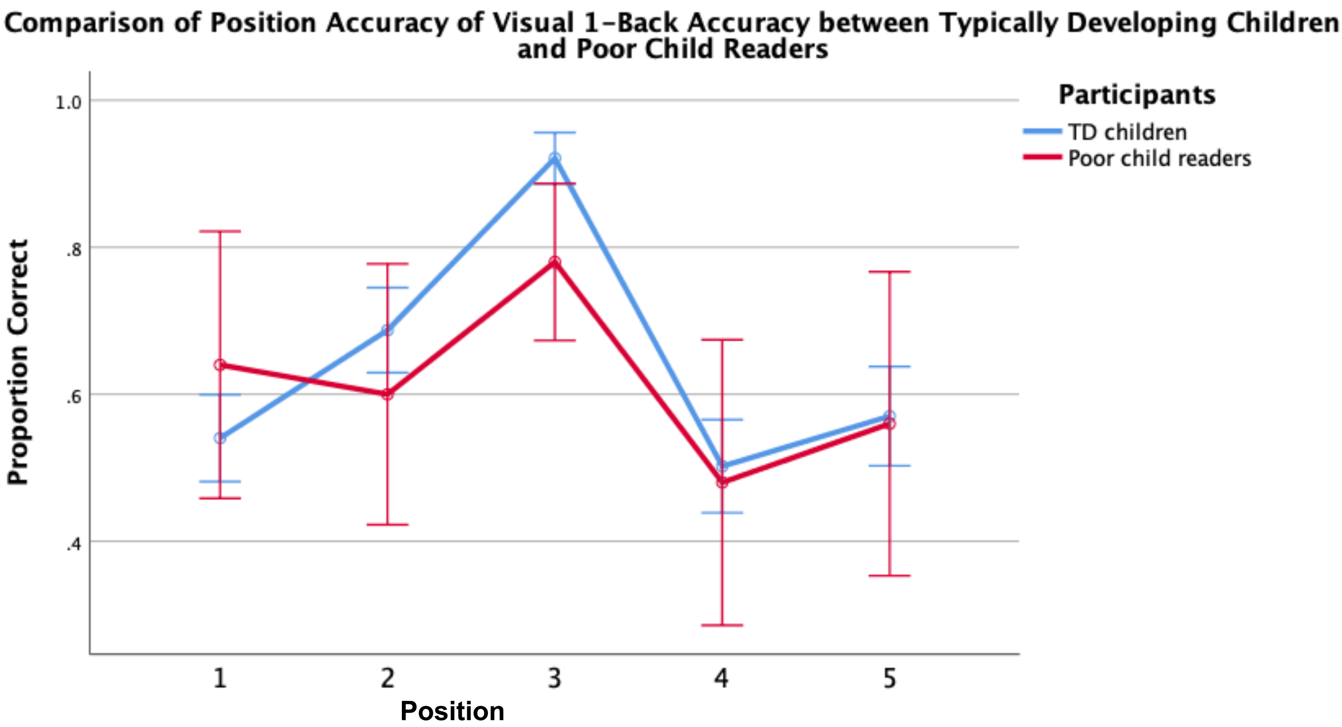
The further simple main effects in global report showed that poor child readers with VAS deficits had significantly poor accuracy only in Position 1 and Position 2 than the corresponding TD age groups (P1: p=.00; P2: p=.00).

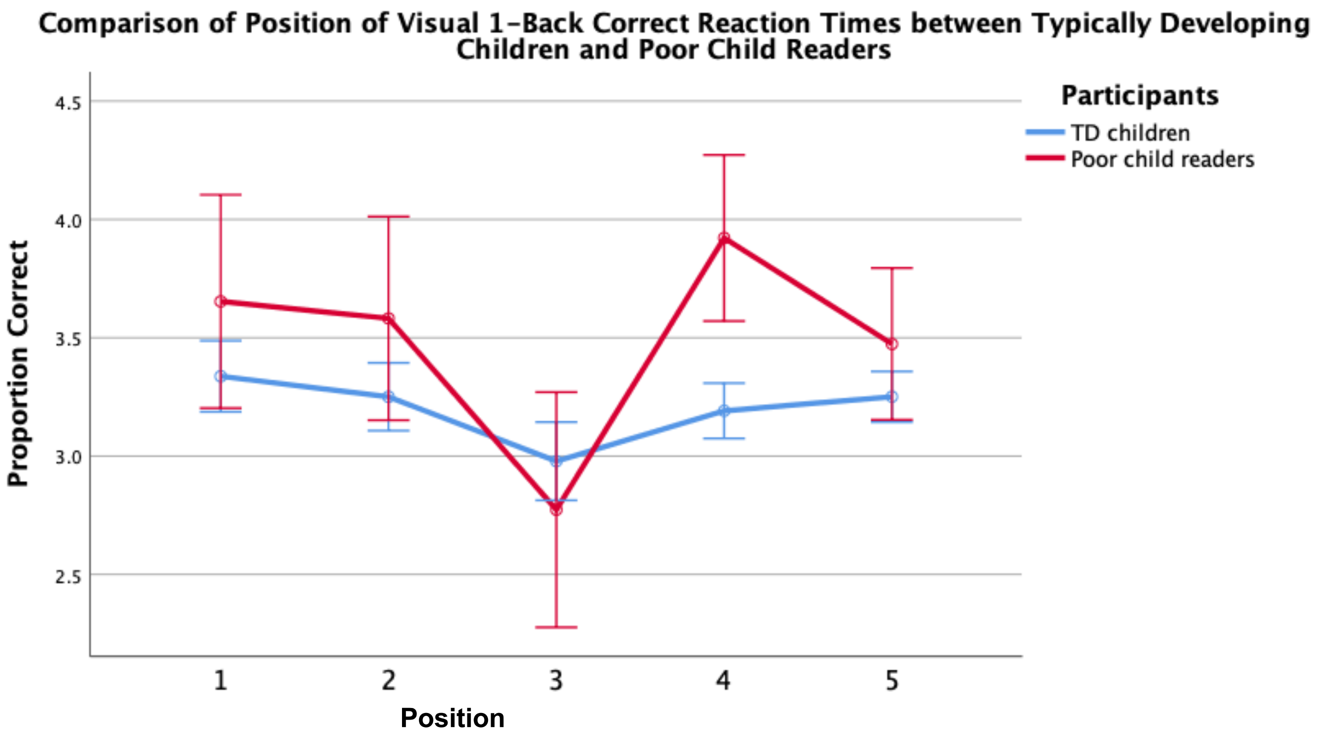
For partial report, the main effects of Position and Participant were significant (Position: F (5, 265) = 13.44, p=.00; Participants: F (1, 53) = 4.54, p=.04). The interaction effect was significant, Position x Participant, F (5, 265) = 2.27, p =.048). The further simple main effects in partial report showed that poor child readers with VAS deficits had significantly poor accuracy only in Position 2 and Position 3 than the corresponding TD age groups (P2: p=.01; P3: p=.00).

Plots of accuracy according to array position in the v1b accuracy and correct RTs are shown in Figure 22.

Figure 22

Responses across Array Positions in the Visual 1-Back Accuracy (Top) and Visual 1-Back Correct Reaction Times (Bottom) of Children





The results of the mixed ANOVA analyses showed that for v1b accuracy, the main effect of Position was significant, *F* (3.73, 186.3) = 8.58, *p*=.00, but the main effect of Participants was not significant, *F* (1, 50) = 0.62, *p*=.44. The interaction effect was not significant, Position x Participant, *F* (3.73, 186.3) = 0.95, *p* =.43.

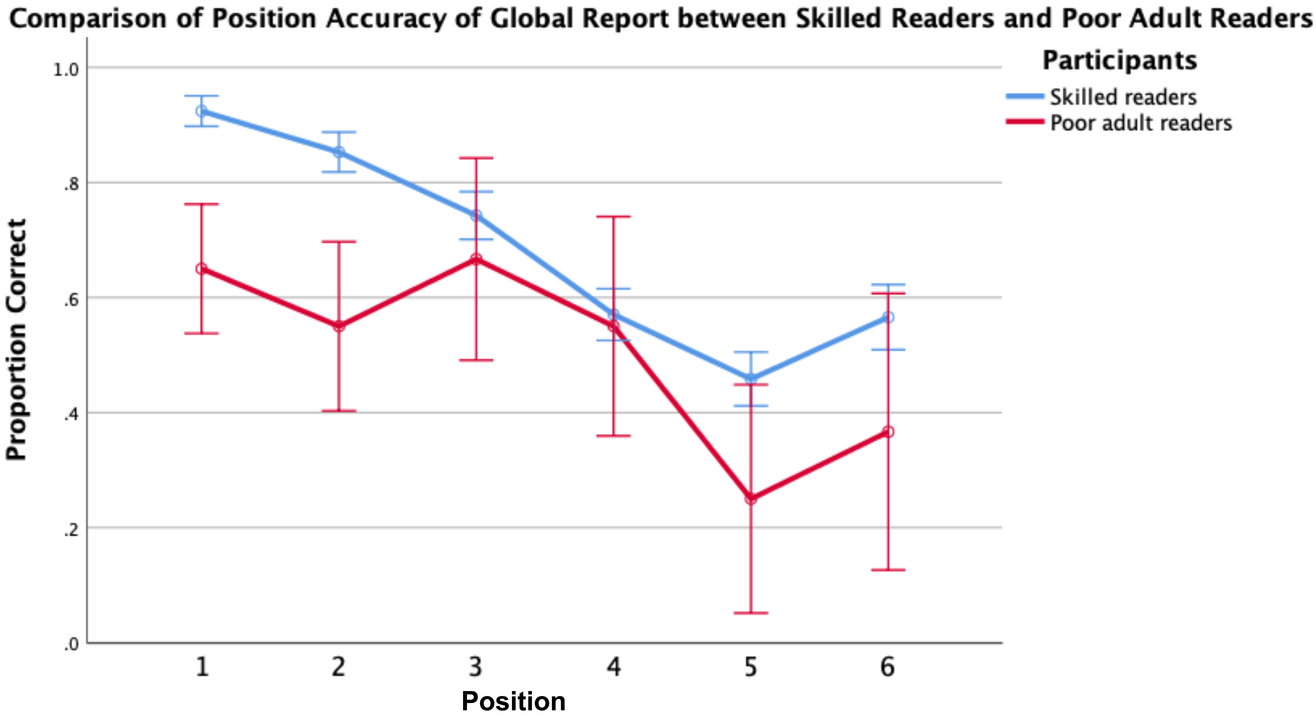
For v1b correct RTs, the main effects of Position were significant (Position: *F* (2.83, 136.04) = 8.43, *p*=.00), but the main effect of Participants was not significant, Participants: *F* (1, 48) = 3.99, *p*=.052). The interaction effects were significant, Position x Participant, *F* (2.83, 136.04) = 3.20, *p* =.03). The further simple main effects showed that poor child readers had significantly slower v1b correct RTs only in Positions 3 and 4 than the corresponding TD age groups (P3, *p*=.04; P4, *p*=.00).

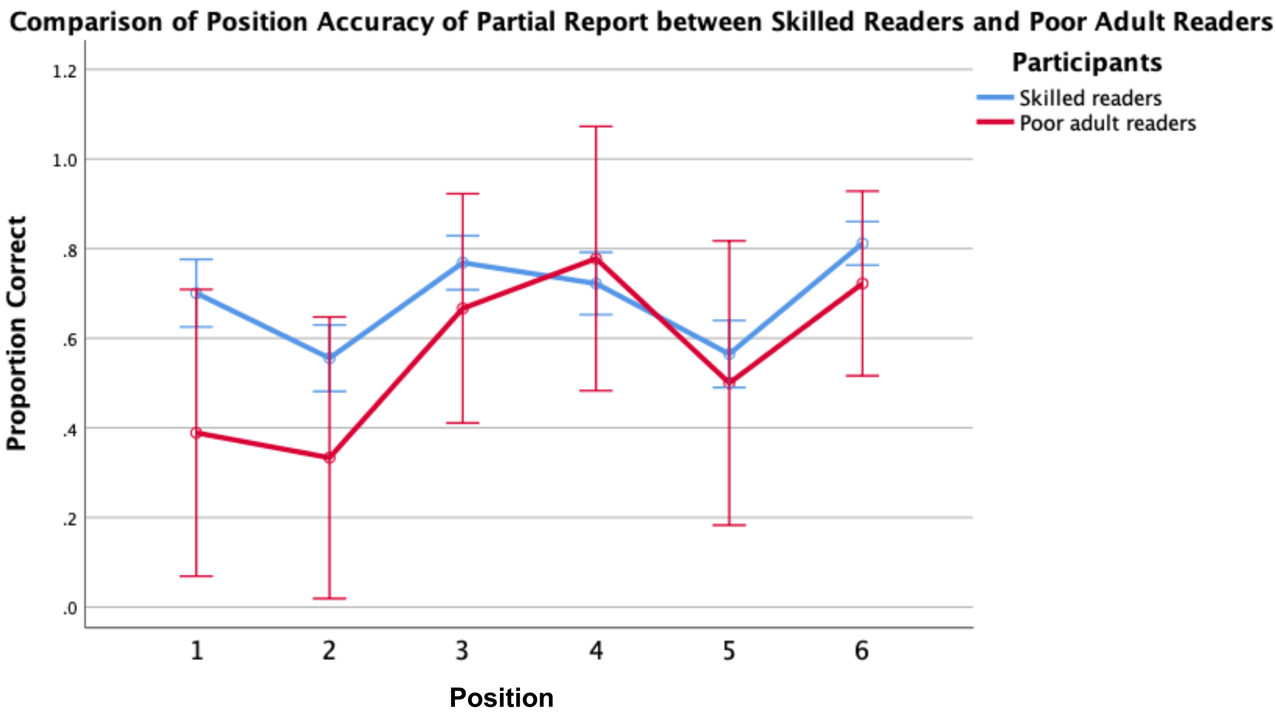
4.5.6 Comparison in patterns of VAS tasks between poor adult readers and skilled readers

Plots of accuracy according to array position in the global and partial report tasks are shown in Figure 23.

Figure 23

Responses across Array Positions in the Global Report (Top) and Partial Report (Bottomt) of Adults





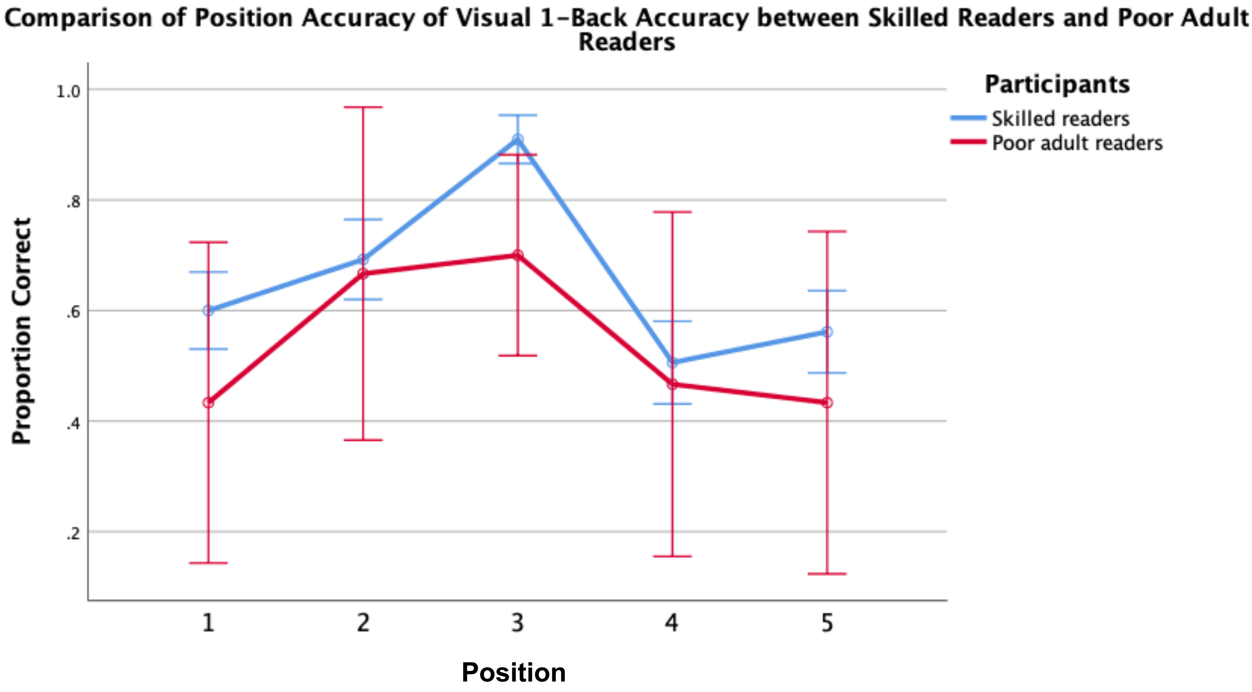
The results of the mixed ANOVA showed that for global report, the main effects of Position and Participant were significant (Position: F (3.46, 190.53) = 18.95, p=.00; Participants: F (1, 55) = 8.28, p=.01). The interaction effect was not significant, Position x Participant, F (3.46, 190.53) = 2.14, p =.09).

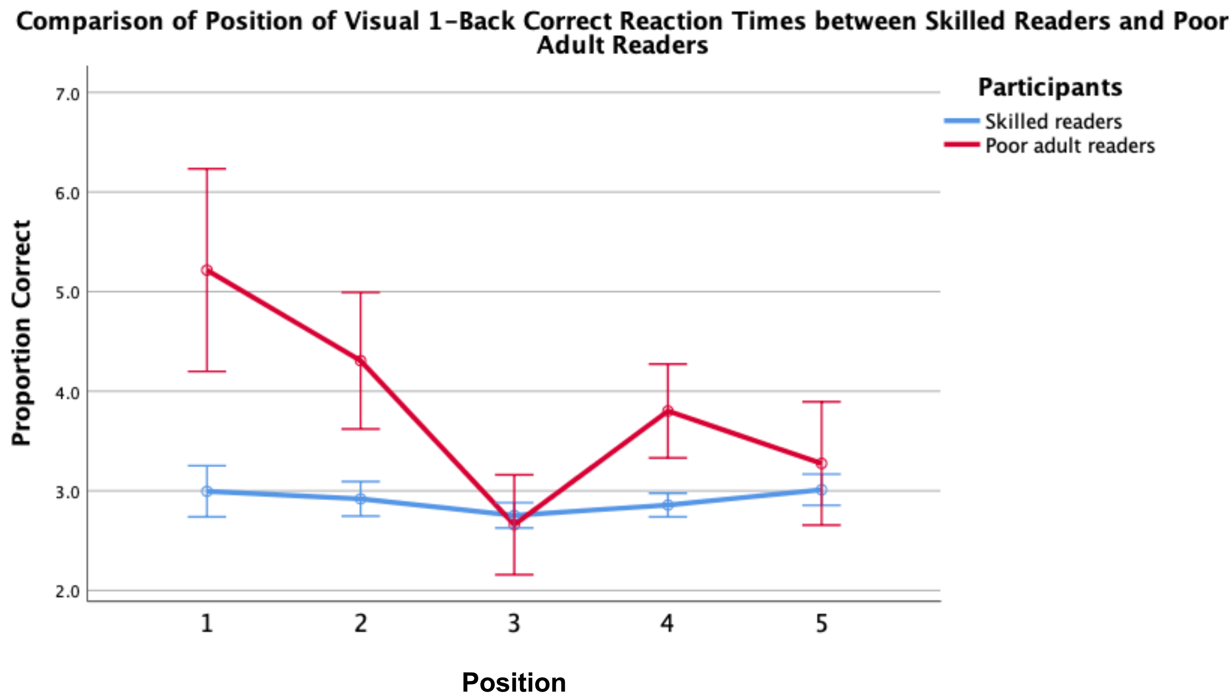
For partial report, the main effects of Position were significant (Position: F (5, 275) = 4.49, p=.00), but the main effects of Participants were not significant (Participants: F (1, 55) = 1.85, p=.18). The interaction effect was also not significant, Position x Participant, F (5, 275) = 1.01, p =.42).

Plots of accuracy according to array position in the v1b accuracy and correct RTs are shown in Figure 24.

Figure 24

Responses across Array Positions in the Visual 1-Back Accuracy (Top) and Visual 1-Back Correct Reaction Times (Bottom) of Adults





The results of the mixed ANOVA analyses showed that for v1b accuracy, the main effect of Position was significant, *F* (4, 212) = 4.43, *p*=.00, but the main effect of Participants was not significant, *F* (1, 53) = 1.88, *p*=.0.18. The interaction effect was not significant, Position x Participant, *F* (4, 212) = 0.36, *p* =.84.

For v1b correct RTs, the main effects of Position and Participant were significant (Position: *F* (2.23, 106.92) = 17.54, *p*=.00; Participants: *F* (1, 48) = 11.98, *p*=.00). The interaction effects were significant, Position x Participant, *F* (2.23, 106.92) = 13.51, *p* =.00). The further simple main effects showed that poor adult readers had significantly slower v1b correct RTs in Positions 1, 2 and 4 than the corresponding TD age groups (P1, *p*=.00; P2, *p*=.00; P4, *p*=.01).

Testing for specificity of the intervention

There was no significant difference in arithmetic scores of the participants before and after the interventions in Table 37. Also, the intervention order did not significantly affect the training effects (please see Appendix H for more details)

Table 37

Scores in Arithmetic Scores for Each Screened Participant and the Comparison Groups (n=7 for each group, standard deviations are in parentheses)

Children	Child 1 XMH	Child 2 SONGXT	Child 3 GHW	Child 4 QJW	Child 5 SHANXT	Child 6 ZN	Comparison group
Arithmetic (/29)	19	16	14	19	12	14	17.43 (5.71)
Arithmetic (after all ints.)	22	19	17	22	17	17	21.71 (3.20)

Adults	Adult 1 HL	Comparison group	Adult 2 LM	Comparison group	Adult 3 ZJF	Comparison group
Arithmetic (/29)	16	12.43 (3.74)	15	12.86 (2.79)	10	14.42 (3.91)
Arithmetic (after all ints.)	19	15.86 (2.79)	15	15.71 (3.45)	13	15 (3.11)

Note:. Arithmetic (after all ints.): arithmetic scores after all interventions

4.6 Discussion

The aim of Study 3 was to investigate the effectiveness of different types of intervention on literacy and VAS of Mandarin-speaking children and adults to address the issue raised in Chapter 1 (Section 1.4) about whether VAS training generalises across languages. Three types of training were employed, two were deficit-focused (WWT and V1BT) and one was a non-VAS training (NVT). The case series analyses (Section 4.5.1) extend Valdois et al.'s (2014) French case study (Section 1.4) by demonstrating VAS improvement in Mandarin-speaking poor readers, supporting the universality of attentional deficits in dyslexia.

The first research question was "Would the three interventions be effective in bringing about improvement in reading fluency in Mandarin-speaking children and adults with difficulties in VAS, and reading or spelling?". The prediction was that the three interventions would be associated with significant improvement in reading fluency.

The findings were in line with the prediction. The case series analyses showed that all three interventions resulted in significant improvement in reading fluency of children and adults. However, following NVT improvement was only shown in oral word reading fluency, not silent sentence reading fluency. This finding was consistent with that of Zoubrinetzky et al. (2019) who reported significant improvement in oral word reading fluency of French-speaking dyslexic children aged 10 years after both phonological and VAS training. The group analyses confirmed the findings from the case series analyses - WWT and V1BT resulted in greater improvement in silent sentence reading fluency than NVT.

Most participants showed significant improvement in oral word reading fluency with all three interventions. Two participants (Child 3 and Adult 1) without phonological deficits also benefited from the NVT. This could be due to their poor verbal processing (poor RAN for Child 3, poor RAN and verbal short-term memory for Adult 1). So, although they did not present with pronounced phonological difficulties in PA tasks, their phonological processing ability was still relatively weak. During the NVT, verbal retrieval speed and verbal working memory were presumably trained, so this may have resulted in an improvement in oral reading fluency with NVT.

VAS-based interventions could improve oral reading fluency by increasing the width of the visual attentional window, as suggested by Huang et al. (2019). As noted in the literature review, an alternative perspective was provided by the results of the intervention studies carried out by Sage and Ellis (2006) and Kohnen et al (2008). They interpreted their findings to indicate that WWT leads to increased top-down activation from the orthographic lexicon to support processing in orthographic working memory. The nonverbal VAS intervention (V1BT) could improve oral reading by extending the visual attentional window, as Valdois et al. (2014) found, so more characters are simultaneously processed during oral reading. A potential reason for the improvement in oral reading after NVT was that Cheng et al. (2021) and Huang et al. (2021) claimed that practice in phonological skills might boost the retrieval speed of pronunciations of characters, thus increasing oral reading fluency (as found with Mandarin-speaking children aged 8 to 9 in the study of Cheng et al., 2021, and with Mandarin-speaking children aged 6 to 7 years in the study of Huang et al. (2021).

In line with the findings of the case series analyses, results of the group analyses showed that only WWT and V1BT were associated with significant improvement in silent sentence reading fluency. This is in accord with the findings of Zhao et al.

(2019) who reported improvement in silent sentence reading in Chinese dyslexic children with VAS disorders. Significant improvement in silent reading fluency with VAS-based interventions might be ascribed to a larger visual attention window, as noted in the explanation for improvement in oral reading above. Ren et al. argued that the top-down processing involved in WWT could result in improvement in allocating attentional resources to the global orthographic processing of characters. Ren also suggested that, based on the theory of visual attention of Bundesen (1990, 1998) that V1BT could result in improved reading because the bottom-up processing involved in V1BT is necessary in automatic cognitive processing, and this is the basis of the silent sentence reading task, where readers should process several characters in parallel and rapidly ascertain the mapping between orthography and semantics (Ekstrand et al., 2019). The reason why NVT was not found to be associated with improvement in silent reading, then would be because this training does not involve skills required in silent reading such as visual simultaneous processing and rapid decision making.

Although the group analyses revealed that improvement in reading fluency following intervention did not differ according to participants' age, the findings of the case series analyses revealed that oral reading fluency in the adult participants improved following NVT. According to the background assessment results, all three adults had poor RAN scores prior to the intervention, suggesting relatively weak phonological processing. As discussed above, since NVT involved training in several aspects of phonological processing, oral reading fluency would be likely to improve. This is in line with the results in Study 1b where it was reported that RAN was a significant predictor of participants' oral word reading fluency.

Regarding RQ2 “Would the two VAS-based interventions be effective in bringing about improvement in VAS in the Mandarin-speaking children and adults with difficulties in VAS, and reading or spelling?”, the prediction was that the two VAS-based interventions would be associated with significant improvement of VAS but the non-VAS-based intervention would not.

The findings were partially in line with the prediction. VAS was found to improve following the two VAS-based interventions, however, the NVT was also associated with improvement in VAS, although not for as many participants. These results are in accord with those of Valdois et al. (2025) and Zoubrinetzky et al. (2019) who reported more improvement in VAS with a VAS-focused than non-VAS focused training. By contrast, NVT was associated with improvement in VAS for Child 3, Child 4 and Adult 2. A potential reason may be that the three participants all had poor RAN suffered from RAN skills in picture. RAN involved the oral retrieval of pronunciation of items and may also share cognitive processes with VAS, as mentioned above.

The group analyses revealed that improvement in global report and v1b correct RTs was significantly greater following WWT and V1BT than following NVT, but there were no differences in v1b correct RTs for the two VAS-based interventions. These findings are in accord with those of Zoubrinetzky et al. (2019) indicating a larger increase in VAS after VAS training and a much smaller increase in VAS after phonological training. Zoubrinetzky et al. suggested that VAS-related interventions improve VAS more than non-VAS-related interventions because VAS-related interventions require rapid multi-element processing in conditions of presentation time that favour parallel processing.

The group analyses also revealed that different deficit groups differed in patterns of improvement across intervention types for global report and v1b correct RTs. The improvement in global report following NVT for the VO group (but not for the VPD group) was significantly lower than following the two VAS-based interventions. These results may be due to no influence of PA deficits, so for VO participants without PA deficits, the NVT showed least training effects on VAS.

More importantly, V1BT was significantly better than WWT in the increase of global report for VO group than the VPD group. That may be because the VO participants did not have problem in PA disorder, so the pure visual training targeting multiple item processing could directly benefit their VAS. It showed the great effectiveness of pure visual training based in VAS to participants only with VAS deficits. The result also suggested that poor readers only with VAS deficits may be due to restricted visual attentional window, according to the Multitrace model framework, as mentioned in the Section 4.2. By contrast, the VPD showed more improvement in global report after WWT than V1BT but there were no significant differences in global report between the two interventions for the VO group. This may suggest double PA and VAS deficit of these participants may be due to weak top-down support from the orthographic lexicon, as mentioned in the Section 4.2.

Consistently, the analyses showed that more VPD participants revealed improvement in VAS tasks than VO participants, which was because VPD participants had poorer performance in VAS than VO groups before intervention (see the Tables for case profiles). The lower the baseline of VAS the VPD participants have, the greater improvement could possibly be obtained. To check this assumption, correlational analyses were conducted with pre-test z scores and the improvement scores (the final post-test score minus the pre-test score) for VAS (global report, partial report, v1b accuracy and v1b correct RTs). Results showed that there was a significant correlation between pre-test scores and the improved scores in terms of global report (r=.70*). It suggested that the difficulty level in global report before training may associate with its improvement after training.

Moreover, the Venn diagrams showed that relatively more participants showed improvement in global and partial report after WWT than V1BT, while relatively more participants showed improvement in v1b accuracy and correct RTs after V1BT than WWT. Kohnen et al. (2008) and others have suggested that WWT enhances orthographic representations and correspondingly, top-down feedback allows for improved function of orthographic working memory. Perfetti and Hart (2008) argued that a higher lexical quality would benefit word retrieval. Thus, compared with V1BT, WWT showed better effects in global and partial report. By contrast, V1BT improved performance in the v1b task, due to improved bottom-up processing (Zhao et al., 2019).

Regarding RQ3 "If the whole-word training is accompanied by improvement in reading and spelling, do the effects generalise to untrained words?", the prediction was that generalisation of improvement to untrained words could also be found in spelling in Chinese after the WWT.

The results were in line with the prediction. The findings in the current study showed significant spelling improvement of trained characters (between 22% and 88% increase in accuracy across participants). The results are in line with Kohnen et al. (2008) who reported a high percentage improvement of trained words (60% to 90%, see Table 38) in English.

Table 38

Intervention Studies Involving Generalisation Effects of Untrained Words in Spelling

Studies	Methods	Misspelt words	Duration	Findings
Brunsdon et al. (2005)	Whole-word training (spelling and reading)	222 irregular words 48 homophones	Four weeks	Generalisation effects Accuracy in trained words: 14.86% to 67.12% Accuracy in untrained words: 21.1% to 27.6%
Roncoli & Masterson (2016)	Whole-word training (spelling: flashcard + mnemonic strategy)	34 for trained words 34 for untrained words (regular + irregular, from 174 words in total)	Four weeks, one hour each week	Generalisation effects Accuracy in trained words: 79%, 76%, 82%, 71% (Post-test 1, 2, 3, 4) Accuracy in untrained words: 35%, 41%, 50%, 50% (Post-test 1, 2, 3, 4)
Kohnen et al. (2008)	Whole-word training (spelling)	Trained words: 42 words Untrained items: 176 words	22 weeks	Generalisation effects Accuracy in trained words: 60% to 90% (from 19% to 20% at baseline) Accuracy in untrained words: 37%-38% (from 16% to 18% at baseline)
Sage & Ellis (2006)	Whole-word training (spelling)	Trained words: 15 words Untrained words: 15 words Partially trained words: 15 words (not trained, but one neighbour of its was trained)	Two weeks, one hour per week	Generalisation effects Accuracy in trained words: 60% to 66.7% Accuracy in untrained words: 6.7% to 20% Accuracy in partially trained words: 40% to 66.7%
My study (Study 3)	Whole-word training (spelling)	Trained words Untrained words (the number of words depending on individuals)	Six weeks, 1.5 hours each week	Generalisation effects Accuracy in trained words: 22.29% to 88.43% Accuracy in untrained words: 29.52% to 84.30%

It should be noted that half of the participants in Study 3 had poor spelling as well as poor reading (Child 4, Child 5, Child 6, Adult 2 and Adult 3), but significant improvement was still found in all participants, not only for participants with spelling difficulty but also for participants without spelling difficulty. This highlights the effectiveness of WWT. Nearly all previous studies with WWT reported amelioration effects. For example, Rowse and Wilshire (2007) compared the effects of phonological intervention and WWT in the reading of dyslexic children. Roncoli and Masterson (2016) explored the effectiveness of WWT in improving the spelling of a boy with spelling difficulty. To my knowledge, this is the first study to examine the influence of WWT on the spelling of participants with reading difficulties.

Generalisation of the improvement in spelling accuracy to untrained words (30% to 84%) was observed in all participants in Study 3, which is in line with the findings of Sage and Ellis (2006), Kohnen et al. (2008) as well as Roncoli and Masterson (2016) (please see Table 38). As mentioned in this chapter, Sage and Ellis (2006) suggested that an increase in activation in a target's neighbour in the lexicon due to the intervention allowed the target to receive support within the OWM due to cascading activation. So, the untreated words that were orthographic neighbours of the treated words improved as a result of WWT. Chinese characters are composed of radical combinations. Different organisation of these radical combinations produces different characters. The generalisation effects in untrained characters in Chinese could be ascribed to the activation of similar radical combinations of the trained characters in the OWM (39 trained-49 unrtained-79.59%).

Compared with the generalisation effects of untrained words in English reported by Roncoli and Masterson (2016, from 35% to 50%), and Sage and Ellis (2006, from 6.7% to 20%), relatively higher accuracy of untrained words after WWT were found in nearly every participant (at least above 67.13%), except for Adult 2. Such higher accuracy of untrained characters after WWT may be due to differences between alphabetic languages and Chinese language, basic spelling skills of participants, and training hours. First of all, there is the grapheme-phoneme correspondence rule in alphabetic languages, but not in Chinese. Untrained words included in Roncoli and Masterson (2016) and Sage and Ellis (2006) include some regular words that are mainly produced through the grapheme-phoneme correspondence rule, but untrained words in Chinese do not include such words due to the Chinese writing system, so all of the untrained words in Chinese can be produced only by visual processing.

So relatively, more untrained words with the orthographic neighbours in Chinese than alphabetic languages could be activated in lexical orthographic representations (from Mo, 2023, see Figure 8). Also, several trained words could activate many untrained words, because there are only five basic strokes in Chinese (i.e., 一, 丨, 丿, 丶, and 乙) (Liu et al., 2016), so although different radical combinations are based on the five strokes, the number of radical combinations is still much more limited than the number of 26-letter combinations. Correspondingly, there are more similarities between trained and untrained words in Chinese than alphabetic languages, thus higher accuracy percentage being obtained. For example, ‘愁’ as a trained character may activate the writing of the following untrained characters ’忽，葱，忠，惠’, due to the similar ‘心’ as the same radical at the bottom position of these characters.

Secondly, not all participants in Study 3 have spelling difficulties, so this could mean that participants without spelling difficulties have relatively good spelling, which may mean that it is easier to activate more untrained words due to their better storage in the orthographic lexicon than for participants with spelling difficulty. Thirdly, the training duration of WWT in this study (nine hours) is longer than four hours of Roncoli and Masterson (2016) and two hours of Sage and Ellis (2006) so this may have led to greater generalisation effects. Thus, these differences from previous studies may have led to the greater generalisation levels observed.

The qualitative spelling error analyses revealed that different types of spelling errors were made before and after WWT. Before WWT, more orthographic errors (especially involving *deletion*) and 'no responses' were made, while after WWT, participants still made the greatest number of orthographic errors, with *addition* errors accounting for the largest proportion of the orthographic errors and a reduction in the number of 'no responses'. The results are in line with those from Study 2.1b, where it was observed that poorer adult spellers made larger percentages of *deletion* orthographic errors, while better spellers made a larger percentage of *addition* orthographic errors. This change could be due to improved VAS function following WWT, so that more detailed orthographic representations could be formed, or else retention of the written form for output was improved.

Regarding RQ4 "What is the poor readers' pattern of responses across array positions in the global report task, the partial report task, v1b accuracy and v1b correct RTs?", the prediction was that compared with participants without reading difficulty, poor readers with poor VAS may show lower performance across positions in nearly all VAS tasks. Also, patterns of responses of poor readers in VAS should be different from the ones of readers without reading difficulties.

Results were in line with the prediction. Comparisons of position accuracy between participants without reading difficulty and the poor readers/spellers with poor VAS revealed that the participants with poor reading and VAS had lower position accuracy across nearly all positions in all VAS measures than participants without reading difficulties. There were also different patterns in VAS tasks for the participants with deficits in reading and VAS.

For children, patterns in global report, partial report, v1b correct RTs were significantly different from those of the TD children. Unlike the TD children (discussed in Study 1c, Chapter 2), poor child readers did not show a left-right asymmetry and a leftward letter advantage in global report, but showed a symmetrical trend with the highest accuracy in the centre position. At the same time, poor child readers' pattern in partial report did not show a 'w-shape' as reported in Study 1c. Poor child readers' accuracy in Positions 2 and 3 were significantly lower than those of the TD children. They appeared to process the centre array items well in partial report, which may be due to less influence of visual crowding from neighbouring array items (as discussed in Study 1c). V1b correct RTs at Positions 3 and 4 were also significantly different from the pattern for the TD children. Their V1b correct RTs at Position 3 were signficantly shorter than those of the TD children, but their V1b correct RTs at Position 4 were significantly slower than those of the TD children.

For adults, the pattern of v1b correct RTs of the poor readers with VAS deficits was significantly different from that of the skilled readers, especially in Positions 1, 2 and 4. The pattern of v1b correct RTs did not show a 'v' shape, as found in Study 1c, because the shortest RTs were at the centre and final positions. Similarly, in the v1b task, the pattern of the poor adult readers was different from that of the skilled readers. These findings for the children and adults are in line with those of existing studies mentioned in Chapter 1 of Prado et al. (2007), Valdois et al. (2003), Valdois et al. (2011), Zhao et al. (2018b) and indicate atypical attention allocation.

4.7 Conclusion

This study involved examining the effectiveness of three types of intervention in relation to improvement in reading fluency and VAS in Mandarin-speaking children and adults with difficulties in VAS and reading/spelling.

The case series analyses showed the improvement of reading fluency and VAS in individual cases. In the case series analyses, not every intervention was observed to be effective for every participant, but every participant benefited from at least one intervention in terms of reading fluency. Discrepant results in reading and VAS of several cases could be due to poor RAN skills. All participants had difficulties in at least one of the VAS measures. Half of them had poor RAN skills (poor RAN: Child 3, Child 4, Adult 1, Adult 2 and Adult 3), which may suggest shared underlying processes between RAN and VAS, as discussed in Study 1 and previous studies (Chen et al., 2019; Moll et al., 2009; Nielsen & Juul, 2016; Stainthorp et al., 2010; Van Den Boer et al., 2014; Ziegler et al., 2010).

The group analyses revealed greater improvement for the VAS-based interventions, in relation to silent reading fluency, global report and v1b correct RTs, than the non-VAS-based intervention. The types of interventions showed different effectiveness for groups with different deficits in the improvement of reading fluency and VAS. For example, WWT showed better effects in silent sentence reading fluency for the VPD group than the VO group. V1BT showed better effects in global report for the VO group than the VPD group.

The analyses revealed improvement following training in reading fluency of every case, irrespective of participants' age and deficit group. Relatively, more participants showed improvement in global and partial report following WWT than after V1BT, while relatively more participants showed improvement in v1b accuracy and correct RTs following V1BT than WWT.

Results for spelling at post-test with WWT showed generalisation to untrained items in all the participants in Study 3. Qualitative analysis of the spelling errors showed a change in the types of errors made (less *deletion* errors and more *addition* errors) which may indicate a change in the visual attentional window after WWT.

In summary, the VAS-based interventions were associated with significant improvement in reading fluency and VAS, and the improvement was significantly better than that observed with the non-VAS-based intervention. After WWT generalisation effects to untrained characters occurred. Poor readers with VAS deficits showed different patterns in the VAS tasks from the participants without reading difficulties, suggesting atypical attention allocation.

Limitations

There are some limitations of Study 3 that need to be considered. The study involved comparing the effectiveness of three intervention types. Although it was important to include the three the total duration of the study was long (eight months, including wash-out and retesting periods). Some children reported fatigue during the interventions, especially the third one. The training time for the adults was variable, due to their different work schedules. Thus the effectiveness of intervention may have been detrimentally affected due to lack of time spent on training, but it is not possible to ascertain this.

Secondly, there are no established phonological training programmes available for speakers of Chinese, unlike English such as Hatcher's *Sound Linkage* programme that is only available in English. The phonological training employed was from a Master's dissertation study conducted in China, so the comparison of intervention types could be better if more standardised phonological training were used. Thirdly, the reading tasks employed in Study 3 were oral word reading and silent sentence reading, without the oral sentence and silent word tasks, because no poor readers with difficulties in oral sentence or silent word performance were found, except Child 2 who had low scores in oral sentence reading fluency. Thus, although the effectiveness of VAS-based interventions in silent reading was significant, it is not possible to know whether it was because the VAS-based interventions benefited sentence-level reading, or benefited silent mode reading rather than oral reading. It will therefore be informative to explore this issue in future studies. Finally, unlike WWT, that involved interactive communication with the experimenter, V1BT was conducted via computer, tablets, or phones by participants in a self-paced way. Such differences may have affected engagement/effectiveness in V1BT.

For future research, it will be important to record the amount of time spent engaged in the tasks. It will also be informative to conduct a replication with larger samples of participants and with training that involves different types of attention processing to contrast results.

Chapter 5: General discussion and implications

So far, much research is over-reliant on English, together with a handful of Western European languages, to study reading development. An appreciation of the specifics of the particular language (or languages) and orthography (or orthographies) a child is learning to read within the broader context of global linguistic, orthographic, and cultural diversity is crucial not only for a deeper understanding of learning to read a specific language but for a truly global non-ethnocentric science of reading (e.g., Share, 2025). Share (2025) emphasises the importance of the end-goal of reading fluency. He claims a universal 3-stage progression from pre-readers to skilled readers from analytic-type reading in novices to the build-up of morphemic then whole-word reading, which must become very efficient in order to read fluently and be able to understand text. According to this, unlike alphabetic languages, Chinese, as a logographic language with characteristics of the highest level of visual complexity and no grapheme-phoneme correspondence, was investigated in this research. As mentioned in Chapter 3, Su and Samuels (2010) indicated the developmental trend of processing Chinese characters from an analytical to a global mode. The findings of my research support the theory put forward by Share (2025) and Su and Samuels (2010) for this developmental progression in reading and also in spelling.

The literature review in Chapter 1 revealed the importance of VAS in literacy across languages regardless of the VAS paradigms used, in particular for Chinese due to its higher visual complexity through cross-sectional and intervention studies. However, the existing cross-sectional studies investigating the relationship between Chinese and VAS did not provide a comprehensive picture due to various reasons, including participant samples from only a single age group, use of one type of VAS paradigm, and/or one type of reading task. The existing intervention studies in VAS with Chinese participants with reading difficulties were also subject to limitations, such as the employment of a range of types of VAS-focused exercises, which meant that it was not possible to ascertain which type of training was effective. In addition the intervention studies did not utilise control training programmes, the training has been conducted with children only, or detailed background testing of participants was not carried out. This thesis sought to address these issues and to increase our understanding of the role of VAS in Chinese reading and spelling.

5.1 Implications for theory

Study 1 exploring the unique prediction of VAS to reading fluency of children and adults, revealing the importance of orthographic processing in Chinese literacy. The development trend of VAS with age growth suggests the increasing significance of global not the analytical processing in literacy acquisition.

Study 2 as the spelling research found the poor adult spellers accompanying with poor VAS, suggesting the overlapped of VAS based on the Multitrace Memory Model and orthographic working memory based on the Dual-Route Model.

VAS-based interventions showed significant improvements in reading and VAS of participants with poor literacy skills and VAS, which supports the causal relation between VAS and reading fluency. Some participants with VAS deficits but intact PA were found, which suggested the independence between VAS and PA according to the Dual-Route Model.

These findings can help better understand multielement parallel processing in Chinese literacy in terms of position pattern of attention allocation, predictive roles, developmental trend and its influence on literacy and VAS. At the same time, the results of this research are in line with prior research in Chinese (Huang et al., 2019;

Ren et al., 2023; Zhao et al., 2018a, 2018b; Zhao et al., 2019) and alphabetic languages across transparencies (Arabic: Awadh et al., 2022; English: Roncoli & Masterson, 2016; Dutch: Van Den Boer et al., 2015; French: Awadh et al., 2016; Bosse et al., 2007; Bosse & Valdois, 2009; Lallier et al., 2014; Lobier et al., 2013; Zoubrinetzky et al., 2019; Greek: Niolaki & Masterson, 2013; Niolaki et al., 2020). It means the findings in the current research provides the theoretical evidence of VAS in the Multitrace Memory Model and supports the common role of VAS across languages, which thus would build a solid theoretical foundation to conduct interventions according to language processing models to dyslexics and dysgraphics.

5.2 Clinical and Educational Implications

As noted at the beginning of the chapter, the field of reading research has been largely dominated by studies with alphabetic writing systems from a handful of western European languages (e.g., Coltheart, 1981; Démonet et al., 2004; Nicolson et al., 2011; Shaywitz, 1998). The research has involved, in addition to the study of literacy acquisition, the identification of reading and spelling difficulties and intervention programmes to ameliorate the difficulties. For example, many UK schools have implemented early interventions to provide reading support for children whose reading is behind expected levels. Due to the recognition of phonological deficits, many specialised books with systematic phonological awareness activities, such as a series of P.A.T books by Jo Wilson and flashcards, have been published and widely used for behavioural interventions. However, due to the late start of research on reading in China, little relevant research has been conducted. So far, several researchers in Hong Kong have started to focus on exploring literacy processes and reasons for literacy difficulties in Chinese children (mainly in

Cantonese and traditional Chinese scripts) (e.g., Chung & Ho, 2010; Law et al., 2005; Law & Leung, 2000; McBride et al., 2018). Accordingly, there are some specialised institutions, such as the *Dyslexia Association of Hong Kong*, that provide diagnoses and interventions in Hong Kong. At the same time, literacy assessments developed by Ho et al. (2007) are specialised for Hong Kong children, namely *The Hong Kong test of specific learning difficulties in reading and writing for primary school students-[HKT-P (II)].*

However, none of these facilities exist in Mainland China. In Mainland China, Mandarin and simplified Chinese characters are used, which are largely different from Cantonese and traditional Chinese scripts used in Hong Kong in terms of complexity and pronunciation. As mentioned in Chapter 1, simplified Chinese characters are supported with the pinyin system in early instruction, but traditional Chinese characters are memorised through rote repetition. There are more strokes and radicals of traditional Chinese characters than simplified ones. Thus, the above professional assessments and interventions from Hong Kong focusing on Cantonese and traditional Chinese cannot be used in Mainland China. Rose (2006, 2009) noted that early literacy intervention could improve the prospect of improvement for children with reading difficulty.

In light of the importance of VAS in Chinese literacy of Mandarin-speaking children found in my research, VAS-based training projects thus could be considered in clinical interventions. Activities targeting multiple simultaneous processing could be used in primary schools to improve early literacy, such as in the format of games used by Valdois et al. (2025). The results of intervention studies in Study 3 indicated the better effects of VAS-based interventions than the phonological intervention in VAS and silent reading fluency. More importantly, every participant in Study 3 showed improvement in reading at least after one VAS-based intervention. At the same time, this action could ameliorate the disorder in VAS and literacy of children. Unlike phonological training requiring interactive responses between the experimenter and participants, VAS-based training, especially as V1BT (10-20 mins), could be conducted by participants in the software at their own pace, which increases the possibility of conducting this intervention in children's study life at school or home. VAS-based interventions could be used in children's daily practice at a young age without any cost, which would be beneficial to their future reading.

On the other hand, nearly all interventions have been aimed at children regardless of language (Jones, 2013; Niolaki & Masterson, 2013; Niolaki et al., 2020; Roncoli & Masterson, 2016; Ren et al., 2023; Valdois et al., 2014; Valdois et al., 2024; Zhao et al., 2019; Zoubrinetzky et al., 2019). Adults with reading difficulties are usually less focused. Compared with Mandarin-speaking children, VAS plays a more critical role in the literacy of Mandarin-speaking adults based on results in Study 1b and Study 2b. This shows the expectation to effectiveness of VAS interventions to Mandarin-speaking adults. Correspondingly, one of the most important findings in this research was to show no significant differences in improvement in reading fluency and VAS between children and adults. Thus, VAS-based interventions could also be implemented in adults with reading difficulties and achieve the improvements. Adults could even be trained by themselves according to their available time. At the same time, the long-term effects of reading fluency and VAS were maintained after interventions, suggesting a good sustainability of VAS training in clinical applications.

Finally, compared with phonological training (the non-VAS training used in Chapter 4), VAS training showed the effects on participants' reading not only with VAS deficits but also with phonological deficit.

5.3 Benefits, Limitations and Possibility for Future Research

The studies in this thesis included cross-sectional studies on the reading and spelling of 56 children and 58 adults using Mandarin and simplified Chinese and an intervention study to investigate the effectiveness of VAS-based and non-VAS-based training in children and adults with VAS deficits and reading or spelling difficulties. The benefits and limitations of the research are discussed next.

In terms of benefits, compared with previous research, the cross-sectional studies include more literacy-related variables, including not only age, nonverbal ability, PA, and RAN but also vocabulary, verbal short-term memory, visual short-term memory and single character identification. In this case, the influence of VAS could be rigorously examined after partialling out the effect of variables for children and adults. Secondly, various tasks for reading and VAS were used. As discussed in Chapter 2, there have been no studies that included various VAS measures in one study, except for Chan and Yeung (2020). Different VAS paradigms were used and all VAS variables including reaction times were included. At the same time, compared with nearly all prior studies that only focused on one type of reading (except for Huang et al., 2019), multiple types of reading fluency in this research were used, such as word and sentence reading in oral and silent modes.

Thirdly, various participants speaking Chinese were recruited. Chinese, has an opaque writing system, with very high visual complexity. Researchers have argued that VAS is expected to play a more primary role in this language. Different from most existing VAS studies that only involved children, adults were also investigated. As for the intervention study, the participants not only had VAS deficits but also PA deficits. The comparison group for each adult in Study 3 was different according to their age group. More conditions were considered than all existing VAS intervention studies.

Fourthly, most data were collected online due to the influence of COVID-19, which was different from the traditional way of collecting data face-to-face. However, the results of visual attention patterns of different VAS variables were found to be reliable and similar to those in prior studies (e.g., for global and partial report: Awadh et al. 2016; for v1b correct RTs and d prime: Huang et al., 2019), suggesting the effectiveness and potentiality of online data collection as a new trend.

Finally, multiple and comprehensive research methods were used to make sure the convincing of findings. In the analyses of reading, composite scores were considered, which may provide greater statistical power, as reported by Serlin and Mailloux (1999). The analyses covered both quantitative and qualitative analyses. Spelling studies involved participant-based analyses, item-based analyses and qualitative spelling error analyses. The intervention study included case series analyses with weighted statistics), group analyses and qualitative spelling error analyses.

In terms of the limitations of this research, the sample size of all studies could be increased. The sample size for the intervention study was not enough to conduct post-hoc tests under the mixed ANOVA analysis. Moreover, there are no professional institutions and assessments specialised for literacy difficulty in simplified Chinese. If these become available it will be important to include them in future studies so that samples of participants can be compared across studies in a precise way. Furthermore, although the adults were from different places and had varied socioeconomic status, education levels and ages, child participants were from a single school grade from one location. However, the use of a national curriculum and consistent literacy teaching materials across a number of provinces (including the one from which the study participants were drawn) mean that the results are likely generalisable to a wider population of Mandarin-speaking children in the targeted age range. In a future study, data for older (and younger) children and adults should be collected to examine potential developmental trends.

The association between VAS and RAN was found in correlation analyses in Study 1 and in Study 3 in the case profiles before intervention. Some researchers have also noted the association (e.g., Antzaka et al., 2018; Chan et al., 2020; Stainthorp et al., 2010). It will be informative to conduct a study to further explore the relationship between RAN and VAS. The research could also address the issue of potential overlap between orthographic working memory and VAS, since, as noted at several points in the thesis the two theoretical constructs seem to overlap in function a great deal.

A future study for spelling could include additional constructs, such as a measure of orthographic knowledge since this variable has also been associated with spelling in Mandarin-speaking children (e.g., Liu & Liu, 2020). Different types of characters, such as homophones and homographs, can also be employed.

For interventions, neuroimaging techniques such as fMRI, fNIRS and EEG could be considered to detect potential neuroanatomical change with interventions. Furthermore, there was no control group for the intervention study, so a waiting list control group (participants with literacy difficulty) could be added in future.

In closing I return to the discussion at the start of this chapter, where I noted that much of the research on reading has been over-reliant on English and a handful of other alphabetic languages. As Share (2004, 2025) points out, this is a strange state of affairs, in light of the fact that most children around the world learn to read in nonalphabetic writing systems (such as abjads for Arabic, syllabic systems for Japanese Kana). Also, among the languages that use the Roman alphabet, English is the most opaque (Seymour et al., 2003), and therefore is an outlier. Many authors have argued that data from different writing systems is needed in order to make theories of reading applicable to more than a narrow range of alphabetic languages including English. Although the situation has begun to change, for example with special issues of journals such as *Reading Research Quarterly*, there is still a great need for cross-language investigation of components of reading and spelling. The current studies aimed to contribute to this endeavour. Research such as this is important, not only for theory development, but also for understanding underlying reasons for reading and spelling difficulties, and for effective literacy instruction.

References

Adams, M. J. (1990). *Beginning to read: Thinking and learning about print.* Cambridge, MA: MIT Press.

Aliminosa, D., McCloskey, M., Goodman-Schulman, R., & Sokol, S. M. (1993). Remediation of acquired dysgraphia as a technique for testing interpretations of deficits. *Aphasiology*, *7*(1), 55-69. https://doi.org/10.1080/02687039308249499

Ans, B., Carbonnel, S., & Valdois, S. (1998). A connectionist multiple-trace memory model for polysyllabic word reading. *Psychological Review, 105*(4), 678-723. https://doi.org/10.1037/0033-295X.105.4.678-723

Anthony, J. L., & Francis, D. J. (2005). Development of phonological awareness. *Current directions in psychological Science*, *14*(5), 255-259. https://doi.org/10.1111/j.0963-7214.2005.00376.x

Antzaka, A., Martin, C., Caffarra, S., Schlöffel, S., Carreiras, M., & Lallier, M. (2018). The effect of orthographic depth on letter string processing: the case of visual attention span and rapid automatized naming. *Reading and Writing*, *31*(3), 583-605. https://doi.org/10.1007/s11145-017-9799-0

Averbach, E., & Coriell, A. S. (1961). Short-term memory in vision. *The Bell System Technical Journal, 40*(1), 309-328. Doi: 10.1002/j.1538-7305.1961.tb03987.x

Awadh, F. H., Phénix, T., Antzaka, A., Lallier, M., Carreiras, M., & Valdois, S. (2016). Cross-language modulation of visual attention span: an Arabic-French-Spanish comparison in skilled adult readers. *Frontiers in psychology, 7*, 307. https://doi.org/10.3389/fpsyg.2016.00307

Awadh, F. H., Zoubrinetzky, R., Zaher, A., & Valdois, S. (2022). Visual attention span as a predictor of reading fluency and reading comprehension in Arabic. *Frontiers in Psychology, 13*. https://doi.org/10.3389/fpsyg.2022.868530

Bahr, R. H., Silliman, E. R., Berninger, V. W., & Dow, M. (2012). Linguistic pattern analysis of misspellings of typically developing writers in grades 1–9. https://doi.org/10.1044/1092-4388(2012/10-0335)

Banfi, C., Kemény, F., Gangl, M., Schulte-Körne, G., Moll, K., & Landerl, K. (2018). Visual attention span performance in German-speaking children with differential reading and spelling profiles: No evidence of group differences. *PLoS One, 13*(6). https://doi.org/10.1371/journal.pone.0198903

Barisic, K., Kohnen, S., & Nickels, L. (2017). Developmental graphemic buffer dysgraphia in English: A single case study. In *Developmental Dysgraphia* (pp. 30-54). Routledge. DOI: 10.1080/02643294.2017.1359154

Baron, J., Treiman, R., Wilf, J. F., & Kellman, P. (1980). Spelling and reading by rules. *Cognitive processes in spelling*, 159-194. London: Academic Press

Barry, C. (1994). Spelling routes (or roots or rutes). In G.D.A. Brown & N.C. Elis (eds.) *Handbook of spelling: Theon, process and intervention* (pp. 27-49). Chichester, UK: John Wiley.

Bastug, M. (2014). The structural relationship of reading attitude, reading comprehension and academic achievement. *International Journal of Social Sciences and Education*, *4*(4), 931-946. DOI: 10.33394/jollt.v9i4.4008

Behrmann, M. (1987). The rites of righting writing: Homophone remediation in acquired dysgraphia. *Cognitive Neuropsychology*, *4*(3), 365–384. https://doi.org/10.1080/02643298708252044

Bi, Y., Han, Z., & Zhang, Y. (2009). Reading does not depend on writing, even in Chinese. *Neuropsychologia*, *47*(4), 1193-1199. https://doi.org/10.1016/j.neuropsychologia.2008.11.006

Blau, V., Reithler, J., van Atteveldt, N., Seitz, J., Gerretsen, P., Goebel, R., & Blomert, L. (2010). Deviant processing of letters and speech sounds as proximate cause of reading failure: a functional magnetic resonance imaging study of dyslexic children. *Brain, 133*(3), 868-879. https://doi.org/10.1093/brain/awp308

Blau, V., van Atteveldt, N., Ekkebus, M., Goebel, R., & Blomert, L. (2009). Reduced neural integration of letters and speech sounds links phonological and reading deficits in adult dyslexia. *Current Biology, 19*(6), 503-508. https://doi.org/10.1016/j.cub.2009.06.008

Bosse, M. L. (2015). Learning to read and spell: How children acquire word orthographic knowledge. *Child Development Perspectives, 9*(4), 222-226. https://doi.org/10.1111/cdep.12133

Bosse, M.L., Chaves, N., Largy, P., & Valdois, S. (2013). Orthographic learning during reading: The role of whole-word visual processing. *Journal of Research in Reading*. http://dx.doi.org/10.1111/j.1467-9817.2012.01551.x.

Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition, 104*(2), 198-230. https://doi.org/10.1016/j.cognition.2006.05.009

Bosse, M. L., & Valdois, S. (2009). Influence of the visual attention span on child reading performance: a cross-sectional study. *Journal of research in reading, 32*(2), 230-253. https://doi.org/10.1111/j.1467-9817.2008.01387.x

Boudelaa, S. (2014). Is the Arabic mental lexicon morpheme-based or stem-based? Implications for spoken and written word recognition. In *Handbook of Arabic literacy: Insights and perspectives* (pp. 31-54). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-8545-7_2

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read—a causal connection. *Nature*, *301*(5899), 419-421. https://doi.org/10.1038/301419a0

Broom, Y. M., & Doctor, E. A. (1995). Developmental surface dyslexia: A case study of the efficacy of a remediation programme. *Cognitive neuropsychology*, *12*(1), 69-110. https://doi.org/10.1080/02643299508251992

Browne Rego, L. L., & Bryant, P. E. (1993). The connection between phonological, syntactic and semantic skills and children’s reading and spelling. *European Journal of Psychology of Education*, *8*, 235-246. https://doi.org/10.1007/BF03174079

Bruck, M., & Waters, G. (1988). An analysis of the spelling errors of children who differ in their reading and spelling skills. *Applied psycholinguistics*, *9*(1), 77-92. doi:10.1017/S0142716400000461

Brunsdon, R., Coltheart, M., & Nickels, L. (2005). Treatment of irregular word spelling in developmental surface dysgraphia. *Cognitive Neuropsychology*, *22*(2), 213-251. https://doi.org/10.1080/02643290442000077

Bryant, P., & Bradley, L. (1985). *Children's reading problems: Psychology and education*. Blackwell.

Bundesen, C. (1990). A theory of visual attention. *Psychological review, 97*(4), 523. DOI: 10.1037/0033-295X.97.4.523

Bundesen, C. (1998). Visual selective attention: Outlines of a choice model, a race model and a computational theory. *Visual Cognition, 5*(1-2), 287-309. https://doi.org/10.1080/713756774

Bundesen, C., Habekost, T., & Kyllingsbæk, S. (2005). A neural theory of visual attention: bridging cognition and neurophysiology. *Psychological review, 112*(2), 291. DOI: 10.1037/0033-295X.112.2.291

Burden, V. (1992). *Why are some "normal" readers such poor spellers?* In C. M. Sterling & C. Robson(Eds.), Psychology, spelling and education (pp. 200–214). Clevedon, UK: Multilingual Matters.

Burt, J. S., & Shrubsole, C. S. (2000). Processing of phonological representations and adult spelling proficiency. *Australian Journal of Psychology*, *52*(2), 100-109. https://doi.org/10.1080/00049530008255375

Cai, Q., & Brysbaert, M. (2010). SUBTLEX-CH: Chinese word and character frequencies based on film subtitles. *PloS one*, *5*(6), e10729. https://doi.org/10.1371/journal.pone.0010729

Campbell, R., & Butterworth, B. (1985). Phonological dyslexia and dysgraphia in a highly literate subject: A developmental case with associated deficits of phonemic processing and awareness. *The Quarterly Journal of Experimental Psychology*, *37*(3), 435-475. https://doi.org/10.1080/14640748508400944

Caramazza, A., & Miceli, G. (1990). The structure of graphemic representations. *Cognition, 37*(3), 243-297. https://doi.org/10.1016/0010-0277(90)90047-N

Caramazza, A., Miceli, G., & Villa, G. (1986). The role of the (output) phonological buffer in reading, writing, and repetition. *Cognitive Neuropsychology*, *3*(1), 37-76. https://doi.org/10.1080/02643298608252669

Caramazza, A., Miceli, G., Villa, G., & Romani, C. (1987). The role of the graphemic buffer in spelling: Evidence from a case of acquired dysgraphia. *Cognition*, *26*(1), 59-85. https://doi.org/10.1016/0010-0277(87)90014-X

Casalis, S., Deacon, S. H., & Pacton, S. (2011). How specific is the connection between morphological awareness and spelling? A study of French children. *Applied Psycholinguistics, 32*(3), 499-511. DOI:10.1017/S014271641100018X

Casco, C., Tressoldi, P. E., & Dellantonio, A. (1998). Visual selective attention and reading efficiency are related in children. *Cortex, 34*, 531–546. https://doi.org/10.1016/S0010-9452(08)70512-4

Castles, A. (2006). The dual route model and the developmental dyslexias. *London Review of Education, 4*(1), 49-61. London Review of Education.

Chan, K. S. C., Georgiou, G. K., & Yeung, P. S. (2020). The contribution of visual attention span and rapid automatized naming to reading fluency in Chinese. In *Fourth Annual Conference of the Association for Reading and Writing in Asia (ARWA)*.

Chan, K. S. C., & Yeung, P. S. (2020). Prediction of Chinese reading fluency by verbal and non-verbal visual attention span measures. *Frontiers in psychology, 10*, 3049. https://doi.org/10.3389/fpsyg.2019.03049

Chen, C., Schneps, M. H., Masyn, K. E., & Thomson, J. M. (2016). The effects of visual attention span and phonological decoding in reading comprehension in dyslexia: A path analysis. *Dyslexia, 22*(4), 322-344. https://doi.org/10.1002/dys.1543

Chen, N. T., Zheng, M., & Ho, C. S. H. (2019). Examining the visual attention span deficit hypothesis in Chinese developmental dyslexia. *Reading and Writing, 32*, 639-662. https://doi.org/10.1007/s11145-018-9882-1

Cheng, C., Yao, Y., Wang, Z., & Zhao, J. (2021). Visual attention span and phonological skills in Chinese developmental dyslexia. *Research in Developmental Disabilities*, 116. https://doi.org/10.1016/j.ridd.2021.104015

Chica, A. B., Paz-Alonso, P. M., Valero-Cabre, A., & Bartolomeo, P. (2013). Neural bases of the interactions between spatial attention and conscious perception. *Cerebral Cortex, 23*(6), 1269-1279. https://doi.org/10.1093/cercor/bhs087

Chung, K. K., & Ho, C. S. H. (2010). Dyslexia in Chinese language: An overview of research and practice. *Australian Journal of Learning Difficulties*, *15*(2), 213-224. https://doi.org/10.1080/19404158.2010.495830

Chung, F. H. K., & Leung, M. T. (2008). Data analysis of Chinese characters in primary school corpora of Hong Kong and mainland China: Preliminary theoretical interpretations. *Clinical Linguistics & Phonetics, 22*(4-5), 379-389. https://doi.org/10.1080/02699200701776757

Collis, N. L., Kohnen, S., & Kinoshita, S. (2013). The role of visual spatial attention in adult developmental dyslexia. *Quarterly Journal of Experimental Psychology, 66*(2), 245-260. https://doi.org/10.1080/17470218.2012.705305

Coltheart, M. (1981). Disorders of reading and their implications for models of normal reading. *Visible language*, *15*(3), 245. Retrieved from https://www.proquest.com/scholarly-journals/disorders-reading-their-implications-models/docview/1297974274/se-2

Coltheart, M., Curtis, B., Atkins, P., & Hailer, M. (1993). Models of reading aloud: Dual-route and parallel-processing-distributed approaches. *Psychological Review, 100*, 589-608. DOI: 10.1037/0033-295X.100.4.589

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: a dual route cascaded model of visual word recognition and reading aloud. *Psychological review, 108*(1), 204. DOI: 10.1037/0033-295X.108.1.204

Compton, D. L., DeFries, J. C., & Olson, R. K. (2001). Are RAN-and phonological awareness-deficits additive in children with reading disabilities? *Dyslexia, 7*(3), 125–149. https://doi.org/10.1002/dys.198

Cooke, A. (1997). Learning to spell difficult words: why look, cover, write and check is not enough. *Dyslexia*, *3*(4), 240-243. https://doi.org/10.1002/(SICI)1099-0909(199712)3:4<240::AID-DYS90>3.0.CO;2-J

Costa, V., Fischer-Baum, S., Capasso, R., Miceli, G., & Rapp, B. (2011). Temporal stability and representational distinctiveness: Key functions of orthographic working memory. *Cognitive neuropsychology*, *28*(5), 338-362. https://doi.org/10.1080/02643294.2011.648921

Dall, J. O., Wang, Y. M., Cai, X. L., Chan, R. C., & Sørensen, T. A. (2021). Visual short-term memory and attention: An investigation of familiarity and stroke count in Chinese characters. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *47*(2), 282. https://doi.org/10.1037/xlm0000950

Démonet, J. F., Thierry, G., & Cardebat, D. (2005). Renewal of the neurophysiology of language: functional neuroimaging. *Physiological reviews*, *85*(1), 49-95. https://doi.org/10.1152/physrev.00049.2003

Dixon, P., & Shedden, J. M. (1993). On the nature of the span of apprehension. *Psychological Research, 55*, 29-39. https://doi.org/10.1007/BF00419891

Dunn, L., & Dunn, L. (1997). *Peabody Picture Vocabulary Test* (3rd ed.). Circle Pines, MN: American Guidance Service.

Eenshuistra, R. M., Weidema, M. A., & Hommel, B. (2004). Development of the acquisition and control of action–effect associations. *Acta Psychologica*, *115*(2-3), 185-209. https://doi.org/10.1016/j.actpsy.2003.12.006

Ekstrand, C. (2019). *Functional and structural neural contributions to skilled word reading* (Doctoral dissertation, University of Saskatchewan).

Eviatar, Z., & Ibrahim, R. (2014). Why is it hard to read Arabic?. In *Handbook of Arabic literacy: Insights and perspectives* (pp. 77-96). Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-017-8545-7_4

Fischer, F. W., Shankweiler, D., & Liberman, I. Y. (1985). Spelling proficiency and sensitivity to word structure. *Journal of memory and language, 24*(4), 423-441. https://doi.org/10.1016/0749-596X(85)90038-5

Franklin, S., Buerk, F., & Howard, D. (2002). Generalised improvement in speech production for a subject with reproduction conduction aphasia. *Aphasiology*, *16*(10-11), 1087-1114. https://doi.org/10.1080/02687030244000491

Frederickson, N., Frith, U., & Reason, R. (1997). *Phonological assessment battery*. London: GL Assessment.

Frith U. (1980). Unexpected spelling problems. Frith U. *Cognitive processes in spelling.* London: Academic Press 495–516.

Frith U. (1985) `Developmental dyslexia' in K E Patterson et al(editors): *Surface Dyslexia*, Hove: Lawrence Erlbaum Associates

Giazitzidou, S., Mouzaki, A., & Padeliadu, S. (2024). Pathways from morphological awareness to reading fluency: the mediating role of phonological awareness and vocabulary. *Reading and Writing*, *37*(5), 1109-1131. https://doi.org/10.1007/s11145-023-10426-2

Giazitzidou, S., & Padeliadu, S. (2022). Contribution of morphological awareness to reading fluency of children with and without dyslexia: evidence from a transparent orthography. *Annals of Dyslexia*, *72*(3), 509-531. https://doi.org/10.1007/s11881-022-00267-z

Gill, C. E. (1980). *An analysis of spelling errors in French*. University of Virginia. Retrieved from https://www.proquest.com/dissertations-theses/analysis-spelling-errors-french/docview/303087259/se-2

Ginestet, E., Phénix, T., Diard, J., & Valdois, S. (2019). Modeling the length effect for words in lexical decision: The role of visual attention. *Vision research, 159,* 10-20. https://doi.org/10.1016/j.visres.2019.03.003

Ginestet, E., Valdois, S., Diard, J., & Bosse, M. L. (2020). Orthographic learning of novel words in adults: Effects of exposure and visual attention on eye movements. *Journal of Cognitive Psychology, 32*(8), 785-804. https://doi.org/10.1080/20445911.2020.1823987

Gong, Y. X. (1983). Revision of Wechsler's Adult Intelligence Scale in China. *Acta psychologica sinica*. Retrieved from https://psycnet.apa.org/record/1984-22187-001

Gong, Y. X., & Cai, T. S., (1993). *Chinese Wechsler Intelligence Scale for Children (C-WISC).* Hunan Map Publishing House.

Gong, Z., & Guo, D. (1984). *Peabody picture vocabulary test – Chinese edition.* Xinhua Hospital affiliated to Shanghai econd Medical University.

Görgen, R., De Simone, E., Schulte-Körne, G., & Moll, K. (2021). Predictors of reading and spelling skills in German: The role of morphological awareness. *Journal of Research in Reading*, *44*(1), 210-227. https://doi.org/10.1111/1467-9817.12343

Goswami, U., & Bryant, P. E. (1990). *Phonological skills and learning to read*. Hillsdale, NJ:

Grainger, J., Tydgat, I., & Isselé, J. (2010). Crowding affects letters and symbols differently. *Journal of Experimental Psychology: Human Perception and Performance, 36*(3), 673. https://doi.org/10.1037/a0016888

Greenacre, M., Groenen, P.J.F., & Hastie, T. et al. (2022) Principal component analysis. *Nat Rev Methods Primers 2*, 100. https://doi.org/10.1038/s43586-022-00184-w

Greenberg, D., Ehri, L. C., & Perin, D. (2002). Do adult literacy students make the same word-reading and spelling errors as children matched for word-reading age?. *Scientific studies of reading*, *6*(3), 221-243. https://doi.org/10.1207/S1532799XSSR0603_2

Guan, C. Q., Liu, Y., Chan, D. H. L., Ye, F., & Perfetti, C. A. (2011). Writing strengthens orthography and alphabetic-coding strengthens phonology in learning to read Chinese. *Journal of Educational Psychology*, *103*(3), 509. DOI: 10.1037/a0023730

Gustafson, S., Ferreira, J., & Rönnberg, J. (2007). Phonological or orthographic training for children with phonological or orthographic decoding deficits. *Dyslexia*, *13*(3), 211-229. https://doi.org/10.1002/dys.339

Habekost, T. (2015). Clinical TVA-based studies: a general review. *Frontiers in Psychology*, *6*, 290. https://doi.org/10.3389/fpsyg.2015.00290

Hair, J.F., Black, W.C., Babin, B.J. and Anderson, R.E. (2014). *Multivariate Data Analysis*. 7th Edition, Pearson Education, Upper Saddle River.

Hamilton, E. E. (2007). *The Importance of Phonological Processing in English-and Mandarin-speaking Emergent and Fluent Readers* (Doctoral dissertation). Retrieved from https://hdl.handle.net/2027.42/57695

Han, Z., Zhang, Y., Shu, H., & Bi, Y. (2007). The orthographic buffer in writing Chinese characters: Evidence from a dysgraphic patient. *Cognitive neuropsychology, 24*(4), 431-450. https://doi.org/10.1080/02643290701381853

Hanley, J. R., Hastie, K., & Kay, J. (1992). Developmental surface dyslexia and dysgraphia: An orthographic processing impairment. *The Quarterly Journal of Experimental Psychology*, *44*(2), 285-319. https://doi.org/10.1080/02724989243000046

Hawelka, S., & Wimmer, H. (2005). Impaired visual processing of multi-element arrays is associated with increased number of eye movements in dyslexic reading. *Vision research, 45*(7), 855-863. https://doi.org/10.1016/j.visres.2004.10.007

Hepner, C., McCloskey, M., & Rapp, B. (2017). Do reading and spelling share orthographic representations? Evidence from developmental dysgraphia. In *Developmental Dysgraphia* (pp. 55-79). Routledge. DOI: 10.1080/02643294.2017.1375904

Herbers, J. E., Cutuli, J. J., Supkoff, L. M., Heistad, D., Chan, C. K., Hinz, E., & Masten, A. S. (2012). Early reading skills and academic achievement trajectories of students facing poverty, homelessness, and high residential mobility. *Educational Researcher*, *41*(9), 366-374. https://doi.org/10.3102/0013189X12445320

Hermens, F., & Ernst, U. (2008). Visual backward masking: Modeling spatial and temporal aspects. *Advances in cognitive psychology*, *3*(1-2), 93. DOI: 10.2478/v10053-008-0017-0

Ho, C.S.H., Chan, D., Chung, K.K.H., Tsang, S.M., Lee, S.H., & Cheng, R.W.Y. (2007). *The Hong Kong Test of Specific Learning Difficulties in Reading and Writing for Primary*

Ho, C. S.-H., Chan, D. W.-O., Tsang, S.-M., & Lee, S.-H. (2002). The cognitive profile and multiple-deficit hypothesis in Chinese developmental dyslexia. *Developmental Psychology, 38*(4), 543– 553. https://doi.org/10.1037/0012-1649.38.4.543.

Holmes, V. M., & Castles, A. E. (2001). Unexpectedly poor spelling in university students. *Scientific Studies of Reading*, *5*(4), 319-350. https://doi.org/10.1207/S1532799XSSR0504_02

Holmes, V. M., & Dawson, G. (2014). Visual-attentional span and lexical decision in skilled adult readers. *Journal of Research in Reading, 37*(4), 331-355. https://doi.org/10.1111/j.1467-9817.2012.01543.x

Holmes, V. M., Malone, A. M., & Redenbach, H. (2008). Orthographic processing and visual sequential memory in unexpectedly poor spellers. *Journal of Research in Reading*, *31*(1), 136-156. https://doi.org/10.1111/j.1467-9817.2007.00364.x

Holmes, V. M., & Ng, E. (1993). Word-specific knowledge, word-recognition strategies, and spelling ability. *Journal of Memory and Language, 32*(2), 230-257. https://doi.org/10.1006/jmla.1993.1013

Holmes, V. M., & Quinn, L. (2009). Unexpectedly poor spelling and phonological-processing skill. *Scientific Studies of Reading, 13*(4), 295-317. https://doi.org/10.1080/10888430903001225

Howard, D. (1986). Beyond randomised controlled trials: the case for effective case studies of the effects of treatment in aphasia. *International journal of language &*

communication disorders, *21*(1), 89-102. https://doi.org/10.3109/13682828609018546

Howard, D., Best, W., & Nickels, L. (2015). Optimising the design of intervention studies: Critiques and ways forward. *Aphasiology*, *29*(5), 526-562. https://doi.org/10.1080/02687038.2014.985884

Huang, H. S., & Hanley, J. R. (1995). Phonological awareness and visual skills in learning to read Chinese and English. *Cognition*, *54*(1), 73-98. https://doi.org/10.1016/0010-0277(94)00641-W

Huang, C., Liu, N., & Zhao, J. (2021). Different predictive roles of phonological awareness and visual attention span for early character reading fluency in Chinese. *The Journal of general psychology, 148*(1), 45-66. https://doi.org/10.1080/00221309.2019.1711356

Huang, C., Lorusso, M. L., Luo, Z., & Zhao, J. (2019). Developmental differences in the relationship between visual attention span and Chinese reading fluency. *Frontiers in psychology, 10*, 2450. https://doi.org/10.3389/fpsyg.2019.02450

Huang, L., & Pashler, H. (2005). Attention capacity and task difficulty in visual search. *Cognition*, *94*(3), B101-B111. https://doi.org/10.1016/j.cognition.2004.06.006

Hulme, C. (1981). *Reading retardation and multi-sensory teaching*. London: Routledge.

Institute of Language Teaching and Research (ILTR). (1986). *Frequency Dictionary of Modern Chinese (Xiandai Hanyu Pinlv Cidian)*. Beijing, China: Beijing Language Institute Press.

Jasińska, K. K., & Petitto, L. A. (2014). Development of neural systems for reading in the monolingual and bilingual brain: new insights from functional near infrared spectroscopy neuroimaging. *Dev. Neuropsychol. 39*, 421–439. DOI: 10.1080/87565641.2014.939180

Jones, B. (2013). *Treatment of Developmental Reading Disorders: A Visual Attention Span Deficit Approach* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington).

Joye, N., Broc, L., Marshall, C. R., & Dockrell, J. E. (2022). Spelling errors in French elementary school students: A linguistic analysis. *Journal of Speech, Language, and Hearing Research*, *65*(9), 3456-3470. https://doi.org/10.1044/2022_JSLHR-21-00507

Kim, Y. S. G., Harris, K. R., Goldstone, R., Camping, A., & Graham, S. (2025). The science of teaching reading is incomplete without the science of writing: A randomized control trial of integrated teaching of reading and writing. *Scientific Studies of Reading*, *29*(1), 32-54. https://doi.org/10.1080/10888438.2024.2380272

Kim, Y. S. G., & Petscher, Y. (2023). Do Spelling and Vocabulary Improve Classification Accuracy of Children's Reading Difficulties Over and Above Word Reading?. *Reading Research Quarterly*, *58*(2), 240-253. https://doi.org/10.1002/rrq.496

Kohnen, S., Nickels, L., Brunsdon, R., & Coltheart, M. (2008). Patterns of generalisation after treating sub-lexical spelling deficits in a child with mixed dysgraphia. *Journal of Research in Reading*, *31*(1), 157-177. https://doi.org/10.1111/j.1467-9817.2007.00366.x

Kohnen, S., Nickels, L., & Coltheart, M. (2010). Skill generalisation in teaching spelling to children with learning difficulties. *Australian Journal of Learning Difficulties*, *15*(2), 115-129. https://doi.org/10.1080/19404158.2010.502588

Korochkina, M., Marelli, M., Brysbaert, M., & Rastle, K. (2024). The Children and Young People's Books Lexicon (CYP-LEX): A large-scale lexical database of books read by children and young people in the United Kingdom. *Quarterly Journal of Experimental Psychology*, *77*(12), 2418-2438. https://doi.org/10.1177/17470218241229694

Krajenbrink, T., Nickels, L., & Kohnen, S. (2021). Serial position effects in graphemic buffer impairment: An insight into components of orthographic working memory. *Cognitive Neuropsychology*, *38*(2), 153-177. https://doi.org/10.1080/02643294.2021.1914015

Kreiner, D. S., & Gough, P. B. (1990). Two ideas about spelling: Rules and word-specific memory. *Journal of memory and language*, *29*(1), 103-118. https://doi.org/10.1016/0749-596X(90)90012-O

Lallier, M., Acha, J., & Carreiras, M. (2016). Cross-linguistic interactions influence reading development in bilinguals: a comparison between early balanced French-Basque and Spanish-Basque bilingual children. *Developmental science, 19*(1), 76-89. https://doi.org/10.1111/desc.12290

Lallier, M., Donnadieu, S., & Valdois, S. (2013). Investigating the role of visual and auditory search in reading and developmental dyslexia. *Frontiers in human neuroscience*, *7*, 597. https://doi.org/10.3389/fnhum.2013.00597

Lallier, M., Mallouh, R. A., Mohammed, A. M., Khalifa, B., Perea, M., and Carreiras, M. (2018). Does visual attention span play a role in reading in Arabic? *Sci. Stud. Read.* *22*, 181–190. DOI: 10.1080/10888438.2017.1421958

Lallier, M., Valdois, S., Lassus-Sangosse, D., Prado, C., & Kandel, S. (2014). Impact of orthographic transparency on typical and atypical reading development: Evidence in French-Spanish bilingual children. *Research in developmental disabilities, 35*(5), 1177-1190. https://doi.org/10.1016/j.ridd.2014.01.021

Language Teaching and Research Institute of Beijing Language Institute. (1986). *Dictionary of Modern Chinese Frequency (in Chinese).*

Law, S. P., & Leung, M. T. (2000). Structural representations of characters in Chinese writing: Evidence from a case of acquired dysgraphia. *Psychologia*. http://hdl.handle.net/10722/82491

Law, S. P., Wong, W., & Chiu, K. M. (2005). Whole-Word Phonological Representations of Disyllabic Words in the Chinese Lexicon: Data From Acquired Dyslexia. *Behavioural Neurology*, *16*(2-3), 169-177. DOI: 10.1155/2005/597581.

Li L., Li R., & Wu X. (2020) The reciprocal relation between morphological awareness and spelling in Chinese: A longitudinal study of primary school students. *PLoS ONE 15*(12). https://doi.org/10.1371/journal.pone.0243050 e0243050.

Li, L., Yang, Y., Song, M., Fang, S., Zhang, M., Chen, Q., & Cai, Q. (2023). CCLOWW: A grade-level Chinese children's lexicon of written words. *Behavior Research Methods*, *55*(4), 1874-1889. https://doi.org/10.3758/s13428-022-01890-9

Liesefeld, H. R., & Müller, H. J. (2020). A theoretical attempt to revive the serial/parallel-search dichotomy. *Attention, Perception, & Psychophysics*, *82*, 228-245. https://doi.org/10.3758/s13414-019-01819-z

Liu, D., Chen, X., & Chung, K. K. (2015). Performance in a visual search task uniquely predicts reading abilities in third-grade Hong Kong Chinese children. *Scientific Studies of Reading*, *19*(4), 307-324. https://doi.org/10.1080/10888438.2015.1030749

Liu, D., Chen, X., & Wang, Y. (2016). The impact of visual-spatial attention on reading and spelling in Chinese children. *Reading and Writing, 29,* 1435-1447. https://doi.org/10.1007/s11145-016-9644-x

Liu, M. (2023). An overview on the impact of the exam-oriented education in China. In SHS Web of Conferences (Vol. 180, p. 02036). *EDP Sciences.* https://doi.org/10.1051/shsconf/202318002036

Liu, Y., & Liu, D. (2020). Morphological awareness and orthographic awareness link Chinese writing to reading comprehension. *Reading and Writing*, *33*(7), 1701-1720. https://doi.org/10.1007/s11145-019-10009-0

Liu, P. D., & McBride-Chang, C. (2010). What is morphological awareness? Tapping lexical compounding awareness in Chinese third graders. *Journal of Educational Psychology, 102*, 62– 73. https://doi.org/10.1037/a0016933

Liu, J., Ren, X., Wang, Y., & Zhao, J. (2023). Visual attention span capacity in developmental dyslexia: A meta-analysis. *Research in Developmental Disabilities*, 135. https://doi.org/10.1016/j.ridd.2023.104465

Liu, T., Thiebaut de Schotten, M., Altarelli, I., Ramus, F., & Zhao, J. (2022). Neural dissociation of visual attention span and phonological deficits in developmental dyslexia: A hub-based white matter network analysis. *Human Brain Mapping, 43*(17), 5210-5219. https://doi.org/10.1002/hbm.25997

Llaurado, A., & Tolchinsky, L. (2016). The developmental pattern of spelling in Catalan from first to fifth school grade. *Writing Systems Research*, *8*(1), 64-83. https://doi.org/10.1080/17586801.2014.1000812

Lobier, M., Dubois, M., & Valdois, S. (2013). The role of visual processing speed in reading speed development. *PloS one, 8*(4). https://doi.org/10.1371/journal.pone.0058097

Lobier, M., Peyrin, C., Le Bas, J. F., & Valdois, S. (2012). Pre-orthographic character string processing and parietal cortex: A role for visual attention in reading? *Neuropsychologia, 50,* 195–204. https://doi.org/10.1016/j.neuropsychologia.2012.05.023

Lobier, M. A., Peyrin, C., Pichat, C., Le Bas, J. F., & Valdois, S. (2014). Visual processing of multiple elements in the dyslexic brain: evidence for a superior parietal dysfunction. *Frontiers in human neuroscience, 8,* 479. https://doi.org/10.3389/fnhum.2014.00479

Lobier, M., Zoubrinetzky, R., & Valdois, S. (2012). The visual attention span deficit in dyslexia is visual and not verbal. *cortex, 48*(6), 768-773. https://doi.org/10.1016/j.cortex.2011.09.003

Luo, Y. C., Chen, X., Deacon, S. H., Zhang, J., & Yin, L. (2013). The role of visual processing in learning to read Chinese characters. *Scientific Studies of Reading*, *17*(1), 22-40. https://doi.org/10.1080/10888438.2012.689790

Marschark, M., Rhoten, C., & Fabich, M. (2007). Effects of cochlear implants on children's reading and academic achievement. *Journal of deaf studies and deaf education*, *12*(3), 269-282. https://doi.org/10.1093/deafed/enm013

Masterson, J., Colombo, L., Spencer, K., Ftika, K., & Syntili, A. (2008). *Factors affecting spelling of English- and Greek-speaking Grade 1 and 2 children*. Presented at the 1st Writing Systems Conference, Institute of Education London.

Masterson, J., Laxon, V., Lovejoy, S., & Morris, V. (2007). Phonological skill, lexical decision and letter report performance in good and poor adult spellers. *Journal of*

Research in Reading, 30(4), 429-442. https://doi.org/10.1111/j.1467-9817.2007.00347.x

McBride-Chang, C., Chung, K. K., & Tong, X. (2011). Copying skills in relation to word reading and writing in Chinese children with and without dyslexia. *Journal of experimental child psychology*, *110*(3), 422-433. https://doi.org/10.1016/j.jecp.2011.04.014

McBride, C., Wang, Y., & Cheang, L. M. L. (2018). Dyslexia in Chinese. *Current Developmental Disorders Reports*, *5*, 217-225. https://doi.org/10.1007/s40474-018-0149-y

McCloskey, M., & Rapp, B. (2017). Developmental dysgraphia: An overview and framework for research. *Developmental Dysgraphia*, 1-18. Retrieved from https://www.taylorfrancis.com/chapters/edit/10.4324/9781351020107-1/developmental-dysgraphia-overview-framework-research-michael-mccloskey-brenda-rapp

Meade, G. (2020). The role of phonology during visual word learning in adults: An integrative review. *Psychonomic Bulletin & Review*, *27*(1), 15-23. https://doi.org/10.3758/s13423-019-01647-0

Mo, J. (2023). Does Orthographic Working Memory Matter in Chinese Spelling?. *Routledge International Handbook of Visual-motor skills, Handwriting, and Spelling*, 123-135. https://doi-org.libproxy.ucl.ac.uk/10.4324/9781003284048

Moll, K., Fussenegger, B., Willburger, E., & Landerl, K. (2009). RAN is not a measure of orthographic processing. Evidence from the asymmetric German orthography. *Scientific Studies of Reading*, *13*(1), 1-25. https://doi.org/10.1080/10888430802631684

Montgomery, D. (2012). The contribution of handwriting and spelling remediation to overcoming dyslexia. *Dyslexia: A comprehensive and international approach,* 109-186. Retrieved from https://books.google.co.uk/books?id=mTCRDwAAQBAJ&lpg=PA109&ots=8XbcV568P1&dq=Look-cover-write-check%E2%80%99%20spelling%20UK&lr&hl=zh-CN&pg=PR7#v=onepage&q&f=false

Nickels, L., Kohnen, S., & Biedermann, B. (2010). An untapped resource: Treatment as a tool for revealing the nature of cognitive processes. *Cognitive Neuropsychology*, *27*(7), 539-562. https://doi.org/10.1080/02643294.2011.609811

Nickels, L., Rapp, B., & Kohnen, S. (2015). Challenges in the use of treatment to investigate cognition. *Cognitive neuropsychology*, *32*(3-4), 91–103. https://doi.org/10.1080/02643294.2015.1056652

Nicolson, R. I., & Fawcett, A. J. (2011). Dyslexia, dysgraphia, procedural learning and the cerebellum. *Cortex*, *47*(1), 117-127. https://doi.org/10.1016/j.cortex.2009.08.016

Nielsen, A. M. V., & Juul, H. (2016). Predictors of early versus later spelling development in Danish. *Reading and Writing*, *29*, 245-266. https://doi.org/10.1007/s11145-015-9591-y

Niolaki, G. Z., & Masterson, J. (2012). Transfer effects in spelling from transparent Greek to opaque English in seven-to-ten-year-old children. *Bilingualism: Language and Cognition*, *15*(4), 757-770. DOI:10.1017/S1366728911000721

Niolaki, G. Z., & Masterson, J. (2013). Intervention for a multi-character processing deficit in a Greek-speaking child with surface dyslexia. *Cognitive*

Neuropsychology, *30*(4), 208-232. https://doi.org/10.1080/02643294.2013.842892

Niolaki, G. Z., Negoita, A., Vousden, J. I., Terzopoulos, A. R., Taylor, L., & Masterson, J. (2023). What spelling errors can tell us about the development of processes involved in children's spelling. *Frontiers in Psychology*, *14*, 1178427. https://doi.org/10.3389/fpsyg.2023.1178427

Niolaki, G. Z., Papadimitriou, V., Terzopoulos, A. R., & Masterson, J. (2024). Greek-spelling predictors; an investigation of literacy-and cognitive-related factors. *Journal of Cognitive Psychology, 36*(3), 378-393. https://doi.org/10.1080/20445911.2024.2322766

Niolaki, G. Z., Terzolpoulos, A. R., & Masterson, J. (2020). Intervention for a visual attention span processing deficit in a Greek-speaking child with slow reading speed. *Preschool and Primary Education*, *7*(3). http://dx.doi.org/10.12681/ppej.21181

Niolaki, G. Z., Vousden, J., Terzopoulos, A. R., Taylor, L. M., Sephton, S., & Masterson, J. (2020). Predictors of single word spelling in English speaking children: a cross sectional study. *Journal of Research in Reading, 43*(4), 577-596. https://doi.org/10.1111/1467-9817.12330

Pan, J., Song, S., Su, M., McBride, C., Liu, H., Zhang, Y., ... & Shu, H. (2016). On the relationship between phonological awareness, morphological awareness and Chinese literacy skills: Evidence from an 8-year longitudinal study. *Developmental Science*, *19*(6), 982-991. https://doi.org/10.1111/desc.12356

Paterson, K. B., McGowan, V. A., Warrington, K. L., Li, L., Li, S., Xie, F., ... & Wang, J. (2020). Effects of normative aging on eye movements during reading. *Vision*, *4*(1), 7. https://doi.org/10.3390/vision4010007

Pelli, D. G., Burns, C. W., Farell, B., & Moore-Page, D. C. (2006). Feature detection and letter identification. *Vision research, 46*(28), 4646-4674. https://doi.org/10.1016/j.visres.2006.04.023

Perea, M., Mallouh, R. A., & Carreiras, M. (2010). The search for an input-coding scheme: transposed-letter priming in Arabic. *Psychon. Bull. Rev. 17*, 375–380. DOI: 10.3758/PBR.17.3.375

Perfetti, C. A., & Hart, L. (2008). The lexical quality hypothesis. In *Precursors of functional literacy* (pp. 189-213). John Benjamins Publishing Company. https://doi.org/10.1075/swll.11.14per

Perry, C., Ziegler, J. C., & Zorzi, M. (2010). Beyond single syllables: Large-scale modeling of reading aloud with the Connectionist Dual Process (CDP++) model. *Cognitive psychology, 61*(2), 106-151. https://doi.org/10.1016/j.cogpsych.2010.04.001

Peyrin, C., Démonet, J. F., N'Guyen-Morel, M. A., Le Bas, J. F., & Valdois, S. (2011). Superior parietal lobule dysfunction in a homogeneous group of dyslexic children with a visual attention span disorder. *Brain and language, 118*(3), 128-138. https://doi.org/10.1016/j.bandl.2010.06.005

Peyrin, C., Lallier, M., Demonet, J. F., Pernet, C., Baciu, M., Le Bas, J. F., & Valdois, S. (2012). Neural dissociation of phonological and visual attention span disorders in developmental dyslexia: FMRI evidence from two case reports. *Brain and language, 120*(3), 381-394. https://doi.org/10.1016/j.bandl.2011.12.015

Peyrin, C., Lallier, M., & Valdois, S. (2008). Visual attention span brain mechanisms in normal and dyslexic readers. *Neuropsychology and cognition of language: Behavioural, neuropsychological and neuroimaging studies of oral and written language*, 22-40. Kerala (India): Research Signpost publisher.

Phénix, T., Ginestet, É., Valdois, S., & Diard, J. (2025). Visual attention matters during word recognition: A Bayesian modeling approach. *Psychonomic Bulletin & Review*, 1-39. https://doi.org/10.3758/s13423-024-02591-4

Pinheiro, Â. M. V. (1995). Reading and spelling development in Brazilian Portuguese. *Reading and Writing*, *7*, 111-138. https://doi.org/10.1007/BF01026950

Prado, C., Dubois, M., & Valdois, S. (2007). The eye movements of dyslexic children during reading and visual search: impact of the visual attention span. *Vision research, 47*(19), 2521-2530. https://doi.org/10.1016/j.visres.2007.06.001

Rapp, B., & Kane, A. (2002). Remediation of deficits affecting different components of the spelling process. *Aphasiology*, *16*(4-6), 439-454. https://doi.org/10.1080/02687030244000301

Raven, J. (1989). The Raven progressive matrices: A review of national norming studies and ethnic and socioeconomic variation within the United States. *Journal of Educational Measurement, 26*(1), 1–16. https://doi.org/10.1111/j.1745-3984.1989.tb00314.x

Raven, J. C., Court, J. H., & Raven, J. (1996). *Standard progressive matrices.* Oxford, England: Oxford Psychologists Press.

Reason, R., & Boote, R. (2013). Spelling. In *Addressing Difficulties in Literacy Development* (pp. 354-380). Routledge.

Reilhac, C., Peyrin, C., Démonet, J. F., & Valdois, S. (2013). Role of the superior parietal lobules in letter-identity processing within strings: FMRI evidence from skilled and dyslexicreaders. *Neuropsychologia, 51*(4), 601-612. https://doi.org/10.1016/j.neuropsychologia.2012.12.010

Ren, X., Li, J., Liu, J., Liu, D., & Zhao, J. (2023). Intervention targeting different visual attention span components in Chinese children with developmental dyslexia: a study based on Bundesen's theory of visual attention. *Annals of Dyslexia*, *73*(3), 487-509. https://doi.org/10.1007/s11881-023-00288-2

Roman, A. A., Kirby, J. R., Parrila, R. K., Wade-Woolley, L., & Deacon, S. H. (2009). Toward a comprehensive view of the skills involved in word reading in Grades 4, 6, and 8. *Journal of experimental child psychology, 102*(1), 96-113. https://doi.org/10.1016/j.jecp.2008.01.004

Roncoli, S., & Masterson, J. (2016). 'Unexpected'spelling difficulty in a 10-year-old child with good reading skills: An intervention case study. *Writing Systems Research*, *8*(2), 143-166. https://doi.org/10.1080/17586801.2016.1159539

Rose, D. (2006). Reading genre: A new wave of analysis. *Linguistics and the human sciences*, *2*(2), 185. DOI: 10.1558/lhs.v2i2.185

Rose, S. J. (2009). *Identifying and teaching children and young people with dyslexia and literacy difficulties: An independent report from Sir Jim Rose to the Secretary of State for Children, Schools and Families*. Department for Children, Schools and Families.

Rowse, H. J., & Wilshire, C. E. (2007). Comparison of phonological and whole-word treatments for two contrasting cases of developmental dyslexia. *Cognitive Neuropsychology*, *24*(8), 817-842. https://doi.org/10.1080/02643290701764207

Ruan, Y., Ye, Y., Lui, K. F. H., McBride, C., & Ho, C. S. H. (2023). How do word reading and word spelling develop over time? A three-year longitudinal study of Hong Kong Chinese–English bilingual children. *Reading Research Quarterly*, *58*(1), 78-102. https://doi.org/10.1002/rrq.478

Sage, K., & Ellis, A. W. (2004). Lexical influences in graphemic buffer disorder. *Cognitive Neuropsychology, 21*(2-4), 381-400. https://doi.org/10.1080/02643290342000438

Sage, K., & Ellis, A. (2006). Using orthographic neighbours to treat a case of graphemic buffer disorder. *Aphasiology*, *20*(9), 851-870. https://doi.org/10.1080/02687030600738945

Scarborough, D. L. (1972). Memory for brief visual displays of symbols. *Cognitive psychology, 3*, 408-429. https://doi.org/10.1016/0010-0285(72)90015-1

Schiller, N. O., Greenhall, J. A., Shelton, J. R., & Caramazza, A. (2001). Serial order effects in spelling errors: Evidence from two dysgraphic patients. *Neurocase*, *7*(1), 1-14. https://doi.org/10.1093/neucas/7.1.1

School Students-[HKT-P(II)]. Hong Kong: Hong Kong Specific Learning Difficulties

Seidenberg, M. S., & McClelland, J. L. (1989). A distributed, developmental model of word recognition and naming. *Psychological review, 96*(4), 523-568. https://doi.org/10.1037/0033-295X.96.4.523

Serlin, R. C., & Mailloux, M. (1999). An empirical comparison of three methods for performing univariate analyses with multivariate data. In *annual meeting of the American Educational Research Association, Montreal, Québec*.

Seymour, P. H., Aro, M., Erskine, J. M., & Collaboration with COST Action A8 Network. (2003). Foundation literacy acquisition in European orthographies.

British Journal of psychology, 94(2), 143-174. https://doi.org/10.1348/000712603321661859

Shallice, T. (1979). Case study approach in neuropsychological research. *Journal of clinical and experimental neuropsychology*, *1*(3), 183-211. https://doi.org/10.1080/01688637908414450

Share, D. L. (2004). Orthographic learning at a glance: On the time course and developmental onset of self-teaching. *Journal of experimental child psychology, 87*(4), 267-298. https://doi.org/10.1016/j.jecp.2004.01.001

Share, D. L. (2025). Blueprint for a universal theory of learning to read: The Combinatorial Model. *Reading Research Quarterly*, *60*(2), e603. https://doi.org/10.1002/rrq.603

Shaywitz, S. E. (1998). Dyslexia. *New England Journal of Medicine*, *338*(5), 307-312. doi: 10.1056/NEJM199801293380507

Shen, H. H., & Bear, D. R. (2000). Development of orthographic skills in Chinese children. *Reading and Writing*, *13*, 197-236. https://doi.org/10.1023/A:1026484207650

Shih, S. I., & Sperling, G. (2002). Measuring and modeling the trajectory of visual spatial attention. *Psychological review, 109*(2), 260. DOI: 10.1037//0033-295X.109.2.260

Shu, H., Peng, H., & McBride-Chang, C. (2008). Phonological awareness in young Chinese children. *Developmental science*, *11*(1), 171-181. https://doi.org/10.1111/j.1467-7687.2007.00654.x

Siok, W. T., & Fletcher, P. (2001). The role of phonological awareness and visual-orthographic skills in Chinese reading acquisition. *Developmental psychology*, *37*(6), 886. https://doi.org/10.1037/0012-1649.37.6.886

Song, M. K., Lin, F. C., Ward, S. E., & Fine, J. P. (2013). Composite variables: when and how. *Nursing research*, *62*(1), 45-49. DOI: 10.1097/NNR.0b013e3182741948

Song, S., Zhang, Y., Shu, H., Su, M., & McBride, C. (2020). Universal and specific predictors of Chinese children with dyslexia–Exploring the cognitive deficits and subtypes. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02904 2904

Spencer, K. (2007). Predicting children's word-spelling difficulty for common English words from measures of orthographic transparency, phonemic and graphemic length and word frequency. *British Journal of Psychology*, *98*(2), 305-338. https://doi.org/10.1348/000712606X123002

Stainthorp, R., Stuart, M., Powell, D., Quinlan, P., & Garwood, H. (2010). Visual processing deficits in children with slow RAN performance. *Scientific Studies of Reading*, *14*(3), 266-292. https://doi.org/10.1080/10888431003724070

State Language Commission. (1998). The Chinese character component standard of GB13000. 1 character set for information processing. *Language & Culture Press*.

Steinhilber, A., Diard, J., Ginestet, E., & Valdois, S. (2023). Visual attention modulates the transition from fine-grained, serial processing to coarser-grained, more parallel processing in reading: A computational modeling study. *Vision Research, 207*, 108211. https://doi.org/ 10.1016/j.visres.2023.108211

Su, M., Peyre, H., Song, S., McBride, C., Tardif, T., Li, H., ... & Shu, H. (2017). The influence of early linguistic skills and family factors on literacy acquisition in Chinese children: Follow-up from age 3 to age 11. *Learning and Instruction, 49,* 54-63. https://doi.org/10.1016/j.learninstruc.2016.12.003

Su, Y. F., & Samuels, S. J. (2010). Developmental changes in character-complexity and word-length effects when reading Chinese script. *Reading and Writing*, *23*, 1085-1108. https://doi.org/10.1007/s11145-009-9197-3

Tainturier, M. J., & Caramazza, A. (1996). The status of double letters in graphemic representations. *Journal of Memory and Language*, *35*(1), 53-73. https://doi.org/10.1006/jmla.1996.0003

Tan, L. H., Laird, A. R., Li, K., & Fox, P. T. (2005). Neuroanatomical correlates of phonological processing of Chinese characters and alphabetic words: A meta-analysis. *Human brain mapping*, *25*(1), 83-91. https://doi.org/10.1002/hbm.20134

Tang, J., Peng, P., Cha, K., & Zhao, J. (2023). Visual attention span deficit in developmental dyslexia: A meta-analysis. *Research in Developmental Disabilities*, 141. https://doi.org/10.1016/j.ridd.2023.104590

Templeton, G. F. (2011). A two-step approach for transforming continuous variables to normal: implications and recommendations for IS research. *Communications of the association for information systems*, *28*(1), 4. https://doi.org/10.17705/1CAIS.02804

Tong, X., McBride-Chang, C., Shu, H., & Wong, A. M. (2009). Morphological awareness, orthographic knowledge, and spelling errors: Keys to understanding early Chinese literacy acquisition. *Scientific Studies of Reading, 13*(5), 426-452. https://doi.org/10.1080/10888430903162910

Tunmer, W.E. & Chapman, J.W. (1998). Language prediction skill, phonological recoding ability, and beginning reading. In: C. Hulme & R.M. Joshi (eds.), *Reading and spelling: Development and disorders* (pp. 33-67). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Valdois, S. (2022). The visual-attention span deficit in developmental dyslexia: Review of evidence for a visual-attention-based deficit. *Dyslexia, 28*(4), 397-415. https://doi.org/10.1002/dys.1724

Valdois, S., Bidet-Ildei, C., Lassus-Sangosse, D., Reilhac, C., N'guyen-Morel, M. A., Guinet, E., & Orliaguet, J. P. (2011). A visual processing but no phonological disorder in a child with mixed dyslexia. *Cortex, 47*(10), 1197-1218. https://doi.org/10.1016/j.cortex.2011.05.011

Valdois, S., Bosse, M. L., Ans, B., Carbonnel, S., Zorman, M., David, D., & Pellat, J. (2003). Phonological and visual processing deficits can dissociate in developmental dyslexia: Evidence from two case studies. *Reading and Writing, 16,* 541-572. https://doi.org/10.1023/A:1025501406971

Valdois, S., Lassus-Sangosse, D., Lallier, M., Moreaud, O., & Pisella, L. (2019). What bilateral damage of the superior parietal lobes tells us about visual attention disorders in developmental dyslexia. *Neuropsychologia, 130*, 78-91. https://doi.org/10.1016/j.neuropsychologia.2018.08.001

Valdois, S., Lassus-Sangosse, D., & Lobier, M. (2012). The visual nature of the visual attention span disorder in developmental dyslexia. *Visual aspects of dyslexia*, 111-122. DOI: 10.1093/acprof:oso/9780199589814.003.0007

Valdois, S., Peyrin, C., Lassus-Sangosse, D., Lallier, M., Démonet, J. F., & Kandel, S. (2014). Dyslexia in a French–Spanish bilingual girl: behavioural and neural modulations following a visual attention span intervention. Cortex, 53, 120-145. https://doi.org/10.1016/j.cortex.2013.11.006

Valdois, S., Phénix, T., Fort, M., & Diard, J. (2021). Atypical viewing position effect in developmental dyslexia: A behavioural and modelling investigation. *Cognitive*

Neuropsychology, 38(5), 319-335. https://doi.org/10.1080/02643294.2021.2004107

Valdois, S., Zaher, A., Meyer, S., Diard, J., Mandin, S., & Bosse, M. L. (2025). Effectiveness of Visual Attention Span Training on Learning to Read and Spell: A Digital-game-based Intervention in Classrooms. *Reading Research Quarterly*, *60*(1). https://doi.org/10.1002/rrq.576

Valle-Arroyo, F. (1990). Spelling errors in Spanish. *Reading and Writing*, *2*, 83-98. https://doi.org/10.1007/BF00383375

Van Den Boer, M., Van Bergen, E., & de Jong, P. F. (2014). Underlying skills of oral and silent reading. *Journal of experimental child psychology*, *128*, 138-151. https://doi.org/10.1016/j.jecp.2014.07.008

Van Den Boer, M., Van Bergen, E., & de Jong, P. F. (2015). The specific relation of visual attention span with reading and spelling in Dutch. *Learning and individual differences, 39*, 141-149. https://doi.org/10.1016/j.lindif.2015.03.017

Van Heuven, W. J., Mandera, P., Keuleers, E., & Brysbaert, M. (2014). SUBTLEX-UK: A new and improved word frequency database for British English. *Quarterly journal of experimental psychology*, *67*(6), 1176-1190. https://doi.org/10.1080/17470218.2013.850521

Verhoeven, L., & Perfetti, C. (2022). Universals in learning to read across languages and writing systems. *Scientific Studies of Reading, 26*(2), 150-164. https://doi.org/10.1080/10888438.2021.1938575

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., Hecht, S. A., Barker, T. A., Burgess, S. R., ... & Garon, T. (1997). Changing relations between phonological processing abilities and word-level reading as children develop from beginning to skilled readers: a 5-year longitudinal study. *Developmental psychology, 33*(3), 468. Retrieved from https://psycnet.apa.org/buy/1997-06205-008

Wang, Y., McBride-Chang, C., & Chan, S. F. (2014). Correlates of Chinese kindergarteners' word reading and writing: The unique role of copying skills?. *Reading and Writing, 27*(7), 1281-1302. https://doi.org/10.1007/s11145-013-9486-8

Wang, X. L., & Tao, B. P. (1996). *The scale and assessment of vocabulary for primary school (in Chinese)*. Shanghai: Shanghai Educational.

Wang, X., Yang, J., Yang, J., Mencl, W. E., Shu, H., & Zevin, J. D. (2015). Language differences in the brain network for reading in naturalistic story reading and lexical decision. *PLoS ONE 10*:e0124388. DOI: 10.1371/journal.pone.0124388

Wang, Y., Yin, L., & McBride, C. (2015). Unique predictors of early reading and writing: A one-year longitudinal study of Chinese kindergarteners. *Early Childhood Research Quarterly*, *32*, 51-59. https://doi.org/10.1016/j.ecresq.2015.02.004

Wang, X. W., Zhu, Y. J., & Zhang, Y. C. (2022). An empirical study of college students' reading engagement on academic achievement. *Frontiers in Psychology*, *13*, https://doi.org/10.3389/fpsyg.2022.1025754

Weekes , B & Coltheart , M . (1996) . Surface dyslexia and surface dysgraphia: Treatment studies and their theoretical implications . *Cognitive Neuropsychology* , 13 : 277 – 315 .

Wolford, G. (1975). Perturbation model for letter identification. Psychological review, 82, 184-199. https://doi.org/10.1037/0033-295X.82.3.184

Wong, H. L. S., (2017). *An investigation into processes involved in spelling in Mandarin speaking children aged 7-9* (Unpublished master's thesis, IOE University College London)

Yachini, M., & Friedmann, N. (2010). Developmental graphemic buffer dysgraphia. *Procedia-Social and Behavioral Sciences*, *6*, 148-149. doi:10.1016/j.sbspro.2010.08.073

Yang, L. Y., Guo, J. P., Richman, L. C., Schmidt, F. L., Gerken, K. C., & Ding, Y. (2013). Visual skills and Chinese reading acquisition: A meta-analysis of correlation evidence. *Educational Psychology Review*, *25*, 115-143. https://doi.org/10.1007/s10648-013-9217-3

Ye, Y., & McBride, C. (2022). A dynamic interactive model of Chinese spelling development. *Educational Psychology Review*, *34*(4), 2897-2917. https://doi.org/10.1007/s10648-022-09684-3

Ye, Y., Tong, C. K. Y., McBride, C., Yin, L., & Tse, C. Y. (2021). Concurrent and longitudinal predictors of beginning writing in Chinese: the unique role of copying skills. *Reading and Writing*, 1-21. https://doi.org/10.1007/s11145-021-10149-2

Yeari, M., Isser, M., & Schiff, R. (2017). Do dyslexic individuals present a reduced visual attention span? Evidence from visual recognition tasks of non-verbal multi-character arrays. *Annals of Dyslexia, 67*, 128-146. https://doi.org/10.1007/s11881-016-0132-4

Yeung, P. S., Ho, C. S. H., Chik, P. P. M., Lo, L. Y., Luan, H., Chan, D. W. O., & Chung, K. K. H. (2011). Reading and spelling Chinese among beginning readers: What skills make a difference?. *Scientific studies of reading*, *15*(4), 285-313. https://doi.org/10.1080/10888438.2010.482149

Yeung, P. S., Ho, C. S. H., Wong, Y. K., Chan, D. W. O., Chung, K. K. H., & Lo, L. Y. (2013). Longitudinal predictors of Chinese word reading and spelling among elementary grade students. *Applied Psycholinguistics*, *34*(6), 1245-1277. https://doi.org/10.1017/S0142716412000239

Zhang, H. C., & Wang, X. P. (1989). Standardization research on Raven's Standard Progressive Matrices in China. *Acta Psychologica Sinica*. Retrieved from https://psycnet.apa.org/record/1991-72444-001

Zhao, J., Kwok, R. K., Liu, M., Liu, H., & Huang, C. (2017). Underlying skills of oral and silent reading fluency in Chinese: Perspective of visual rapid processing. *Frontiers in Psychology, 7*, 2082. https://doi.org/10.3389/fpsyg.2016.02082

Zhao, J., Liu, H., Li, J., Sun, H., Liu, Z., Gao, J., ... & Huang, C. (2019). Improving sentence reading performance in Chinese children with developmental dyslexia by training based on visual attention span. *Scientific reports*, *9*(1), 18964. https://doi.org/10.1038/s41598-019-55624-7

Zhao, J., Liu, M., Liu, H., & Huang, C. (2018a). Increased deficit of visual attention span with development in Chinese children with developmental dyslexia. *Scientific reports, 8*(1), 3153. https://doi.org/10.1038/s41598-018-21578-5

Zhao, J., Liu, M., Liu, H., & Huang, C. (2018b). The visual attention span deficit in Chinese children with reading fluency difficulty. *Research in developmental disabilities, 73*, 76-86. https://doi.org/10.1016/j.ridd.2017.12.017

Zhao, J., Wang, J., Huang, C., & Liang, P. (2022). Involvement of the dorsal and ventral attention networks in visual attention span. *Human brain mapping, 43*(6), 1941-1954. https://doi.org/10.1002/hbm.25765

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory. *Psychological bulletin, 131*(1), 3. DOI: 10.1037/0033-2909.131.1.3

Ziegler, J. C., Pech-Georgel, C., Dufau, S., & Grainger, J. (2010). Rapid processing of letters, digits and symbols: what purely visual-attentional deficit in developmental dyslexia?. *Developmental science, 13*(4), F8-F14. https://doi.org/10.1111/j.1467-7687.2010.00983.x

Zoubrinetzky, R., Bielle, F., & Valdois, S. (2014). New insights on developmental dyslexia subtypes: Heterogeneity of mixed reading profiles. *PloS one*, *9*(6), e99337. https://doi.org/10.1371/journal.pone.0099337

Zoubrinetzky, R., Collet, G., Nguyen-Morel, M. A., Valdois, S., & Serniclaes, W. (2019). Remediation of allophonic perception and visual attention span in developmental dyslexia: A joint assay. *Frontiers in Psychology*, *10*, 1502. https://doi.org/10.3389/fpsyg.2019.01502

Appendix A

Post Hoc Test of D Prime of Children and Adults

	Children		*p*	Adult		*p*
Section	1	2	.53	1	2	.26
		3	.99		3	.65
		4	.99		4	.23
	2	3	.37	2	3	.91
		4	.37		4	1.00
	3	4	1.00	3	4	.87

Appendix B

Hierarchical Regression Analyses with Oral Reading Fluency as the Dependent Variables in Study 1a

		Oral word reading fluency						Oral sentence reading fluency					
Step		ΔR^2	ΔF	β	t	Tol	VIF	ΔR^2	ΔF	β	t	Tol	VIF
1	Nonverbal Abil.	0.00	0.05	-0.03	-0.21	1.00	1.00	0.02	0.71	0.13	0.84	1.00	1.00
2		0.59***	10.04					0.59***	10.63				
	Vocabulary			0.04	0.30	0.88	1.14			0.12	1.08	0.88	1.14
	PA			0.05	0.44	0.90	1.11			-0.04	-0.31	0.90	1.11
	RAN comp			-0.72***	-6.26	0.88	1.14			-0.71***	-6.33	0.88	1.14
	MA			-0.01	-0.08	0.86	1.16			0.24*	2.13	0.86	1.16
	Char. Ident			0.14	1.25	0.95	1.06			0.05	0.49	0.95	1.06
3	VAS report comp	0.02	2.08	0.17	1.44	0.80	1.27	0.07**	7.85	0.31**	2.80	0.79	1.27

		Silent word reading fluency						Silent sentence reading fluency					
Step		ΔR^2	ΔF	β	t	Tol	VIF	ΔR^2	ΔF	β	t	Tol	VIF
1	Nonverbal Abil.	0.07+	2.84	0.26+	1.69	1.00	1.00	0.03	1.13	0.16	1.06	1.00	1.00
2		0.16	1.45					0.21+	2.13				
	Vocabulary			-0.05	-0.30	0.89	1.12			0.04	0.28	0.88	1.14
	PA			-0.05	-0.33	0.88	1.14			-0.18	-1.21	0.89	1.12
	RAN comp			-0.06	-0.36	0.87	1.15			-0.35*	-2.33	0.90	1.12
	MA			-0.07	-0.41	0.79	1.26			0.34*	2.20	0.84	1.20
	Char. Ident			0.38*	2.53	0.96	1.05			-0.06	-0.42	0.94	1.06
3	V1b comp	0.00	0.00	-0.01	-0.03	0.91	1.11	0.11*	6.49	-0.36*	-2.55	0.88	1.14

Note:. Nonverbal Abil.: nonverbal ability, PA: phonological awareness, RAN comp: RAN composite z scores, MA: morphological awareness, Char. Ident.: character identification, VAS report comp: composite scores in the global and partial report tasks, V1b comp: visual 1-back composite z scores of errors and correct reaction times.
$^+$ *p*<.1, **p*<.05; ***p*<.01; ****p*<.001

Appendix C

Items in the Spelling to Dictation Task with Printed Word Frequencies and Teachers' Familiarity Ratings

Items	Frequency English	Frequency Chinese	Familiarity ratings	Items	Frequency English	Frequency Chinese	Familiarity ratings
兽 (beast)	4.63	4.2	4.8	静 (silence)	5.26	4.07	4.8
骂 (blame)	3.22	3.26	4.8	银 (silver)	5.22	4.21	4.8
色 (colour)	4.88	4.5	5	天 (sky)	5.34	5.43	5
日 (day)	5.95	4.73	5	皂 (soap)	4.18	1.95	4.2
鹿 (deer)	4.32	4.82	4.8	夏 (summer)	5.00	4.25	4.8
狗 (dog)	5.27	5.48	5	寺 (temple)	4.32	3.84	4.4
排 (drain)	3.94	4.71	5	信 (trust)	4.95	4.76	5
象 (elephant)	4.19	4.79	5	龟 (turtle)	3.87	4.07	4.8
家 (family)	5.51	5.21	5	妻 (wife)	4.96	4.22	4.4
爸 (father)	5.81	4.85	5	字 (word)	5.41	5.54	5
粉 (flour)	4.14	4.06	5	虫 (worm)	4.17	4.83	5
鬼 (ghost)	4.89	4.57	4.8	议会 (council)	4.45	4.13	4.2
手 (hand)	5.97	6	5	板球 (cricket)	3.81	2.49	3.8
光 (light)	5.66	5.19	5	脚印 (footprint)	3.38	4.55	4.8
瓜 (melon)	3.30	4.13	5	朋友 (friend)	5.42	5.65	5
钱 (money)	5.38	5.58	5	花园 (garden)	5.18	4.95	5
猴 (monkey)	4.34	5.06	4.8	天才 (genius)	4.29	4.37	5
谜 (mystery)	4.64	4.54	4.8	医院 (hospital)	4.86	4.92	5
鼻 (nose)	5.27	4.26	4.4	飓风 (hurricane)	3.95	3.85	3.8
管 (pipe)	4.58	5	4.6	磁铁 (magnet)	3.89	4.11	4.2
地 (place)	5.77	5.48	5	噪音 (noise)	5.18	3.94	4.6
池 (pool)	4.70	4.01	5	麻烦 (nuisance)	3.73	3.45	4.8
雨 (rain)	5.05	5.03	5	和平 (peace)	4.66	3.23	5
路 (road)	5.36	5.52	5	自豪 (pride)	4.52	2.13	4.8
房 (room)	5.93	4.45	5	问题 (question)	5.17	5.72	5
赛 (race)	4.71	3.76	4.6	海绵 (sponge)	4.01	3.94	4.6
河 (river)	5.24	5.28	5	故事 (story)	5.39	5.64	5
航 (sail)	4.48	2.9	4.6	蒸气 (vapor)	3.57	3.41	4.2
海 (sea)	5.49	5.1	5	嘉年华(carnival)	3.73	2.35	4.2
印 (seal)	4.10	4.24	4.6	彗星 (comet)	3.25	4.49	4

Appendix D

Hierarchical Regression Analyses with Spelling Accuracy as the Dependent Variable in Study 2a

		Spelling accuracy					
Step		ΔR^2	ΔF	β	t	Tol	VIF
1	Nonverbal Abil.	0.01	0.30	0.08	0.55	1.00	1.00
2		0.55***	7.79				
	VerbalBack STM			0.14	1.05	0.69	1.45
	VisualSeq STM			-0.05	-0.32	0.60	1.68
	PA			0.33*	2.46	0.66	1.53
	RAN picture			-0.28*	-2.43	0.87	1.15
	MA			0.29*	2.33	0.77	1.30
	Char. Ident.			0.34**	3.00	0.93	1.07
3	Global	0.05*	5.10	0.27*	2.26	0.75	1.33

Note:. Nonverbal Abil.: nonverbal ability, VerbalBack STM: verbal digit backward short-term memory, VisualSeq STM: visual sequential short-term memory,PA: phonological awareness, RAN picture: RAN picture task, MA: morphological awareness, Char. Ident.: character identification, Global: global report

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

Appendix E

Actual Spelling Errors of the Children

		1md	2cmh	3mcc	4nhd	5yyh	6lzm	7zyf	8lbw	9wjs	10tc	11yhx	12lyc	13yyz	14shr
1	兽 (beast)	[illegible]				[illegible]							shò	blank	[illegible]
2	骂 (blame)	mù						mù	mà				mà	mà	
3	色 (color)														
4	日 (day)														
5	鹿 (deer)												[illegible]	[illegible]	[illegible]
6	狗 (dog)														
7	排 (drain)	blank					[illegible]								
8	象 (elephant)														
9	家 (family)														
10	爸 (father)														
11	粉 (flour)														
12	鬼 (ghost)												guǐ	gué	
13	手 (hand)														
14	光 (light)														
15	瓜 (melon)														
16	钱 (money)	[illegible]	前				前	前	前				piǎn		前
17	猴 (monkey)		[illegible]		[illegible]							侯		[illegible]	
18	谜 (mystery)	迷	[illegible]	迷			迷	迷	迷	[illegible]	迷	迷	mǐ	mí	迷
19	鼻 (nose)	[illegible]	[illegible]	[illegible]	[illegible]		bí	bíe	[illegible]		bǐ	bí	bǐ	bǐ	[illegible] bí
20	管 (pipe)							[illegible]	[illegible]				guǎn		[illegible]
21	地 (place)														
22	池 (pool)		食												
23	雨 (rain)														
24	路 (road)		陆												
25	房 (room)														[illegible]
26	赛 (race)			[illegible]										[illegible]	[illegible]
27	河 (river)														
28	航 (sail)	[illegible]						[illegible]			行		hǎng	háng	行
29	海 (sea)							blank							
30	印 (seal)							blank					yìn	yìn	[illegible]
31	静 (silence)													[illegible]	
32	银 (silver)				yín	yín					吟				yín
33	天 (sky)														
34	皂 (soap)	zào		zào	blank	zào		[illegible]	[illegible]			zào	zhào	zào	[illegible]
35	夏 (summer)					下		[illegible]					blank		[illegible]
36	寺 (temple)	cì				sì				侍	blank		shì	sì	sì
37	信 (trust)														
38	龟 (turtle)														
39	妻 (wife)			[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	qī			pī	qī	qī
40	字 (word)														
41	虫 (worm)														
42	议会 (council)						Yì huì			[illegible]		yìhuì	yì h	yì	
43	板球 (cricket)			bǎn [illegible]	bǎn	bǎn		柏				bǎn		bǎn	[illegible]
44	脚印 (footprint)							[illegible]					yìn	yìn	[illegible] yìn
45	朋友 (friend)														
46	花园 (garden)													[illegible]	[illegible]
47	天才 (genius)														
48	医院 (hospital)					Yuàn		[illegible]					Yuàn	yī yuàn	
49	飓风 (hurricane)	[illegible]	巨	巨	巨	巨	巨	巨	jùi	巨	blank	巨	巨	巨	巨
50	磁铁 (magnet)	cí		cí	cí	cí	qí	zí	chí	cí	cí tiě	[illegible]	chǐ	cí	cí
51	噪音 (noise)	zào	[illegible]		[illegible]	zào	造 blank	[illegible]	[illegible]	Zào	造	blank	zhào	zào	[illegible]
52	麻烦 (nuisance)			[illegible]									mǎ fàn	má	
53	和平 (peace)										合				
54	自豪 (pride)							háo		[illegible]			hǎng	hǎo	[illegible]
55	问题 (question)					提							[illegible]	[illegible]	
56	海绵 (sponge)			[illegible]				miǎn	棉		棉		miǎn	mián	mián
57	故事 (story)	[illegible]			[illegible]		[illegible]								
58	蒸气 (vapor)	[illegible]		zhēng	[illegible]	zhēng	争	[illegible] blank	[illegible]	zhēng	争	[illegible]	zhāng	zhen	[illegible]
59	嘉年华 (carnival)	jiā		加	jiā	jiā	jiā	加	jiā	[illegible]	加	[illegible]	加年huá	加年huá	吉
60	彗星 (comet)	bùi	慧	huì	慧	huì xīng	[illegible]	heì	hùi	huì	huì xīng	慧	blank	hùe	huì

		15ljx	16wyh	17wq	18lql	19sjq	20znx	21syb	22wzh	23ljl	24yzy	25wzy	26lml	27cxy	28wcb
1	兽 (beast)	曾	blank					blank		blank					[illegible]
2	骂 (blame)	骂	骂							mà				mà	
3	色 (colour)														
4	日 (day)														
5	鹿 (deer)		[illegible]							lù					
6	狗 (dog)	狗													
7	排 (drain)									pái					
8	象 (elephant)														
9	家 (family)														
10	爸 (father)														
11	粉 (flour)														
12	鬼 (ghost)								鬼	兜					
13	手 (hand)														
14	光 (light)														
15	瓜 (melon)														
16	钱 (money)	前					前		前		前				前
17	猴 (monkey)		猴		猴		猴	猴			猴				
18	谜 (mystery)	迷	迷	迷	迷	米迷	迷	迷	迷	mí	迷		迷	迷	迷
19	鼻 (nose)		鼻	鼻	[illegible]	鼻		鼻	鼻	鼻	bí				
20	管 (pipe)	guǎn	guǎn [illegible]							guǎn	guǎn				
21	地 (place)														
22	池 (pool)								食			chí			
23	雨 (rain)														
24	路 (road)				陆										
25	房 (room)														
26	赛 (race)									shài					
27	河 (river)														
28	航 (sail)		[illegible]	杭			行	páng	háng	háng	blank				páng
29	海 (sea)														tǎi
30	印 (seal)		blank							yìn	印				
31	静 (silence)	blank	blank												
32	银 (silver)		blank												
33	天 (sky)														
34	皂 (soap)				zào	zào	zào		臭	[illegible]	[illegible]				
35	夏 (summer)		复					夏			xià				
36	寺 (temple)	blank	blank				sì		sìx	sì	sì		sì		
37	信 (trust)														
38	龟 (turtle)	blank	鱼							guǐ		guī			
39	妻 (wife)		[illegible]	妻	[illegible]		qī	pī		qī	qī			[illegible]	
40	字 (word)														
41	虫 (worm)							书							
42	议会 (council)		yì		yì huì	yì			yì绘	义		yì huì			yì huì
43	板球 (cricket)							bǎn		bǎn					
44	脚印 (footprint)		yìn							yìn	印				
45	朋友 (friend)														
46	花园 (garden)										园				
47	天才 (genius)														
48	医院 (hospital)		[illegible]					院		衣yào					
49	飓风 (hurricane)	巨	巨	巨	jù	jù	巨	巨	巨	巨	jù		巨	巨	巨
50	磁铁 (magnet)	cí	cí	cí	cí	cí	cí	cí铁	cí	chí	cí teǐ	cí	cí	cí	cī
51	噪音 (noise)		zào	[illegible]			zào	zhào	燥	zhāo	槽	zào		造	燥
52	麻烦 (nuisance)		[illegible]					má		má fán	má fán		烦		
53	和平 (peace)														
54	自豪 (pride)		豪	豪				háo		háo	豪				
55	问题 (question)										问				
56	海绵 (sponge)	眠	眠			mián		mián		mián		绵	棉		
57	故事 (story)		胡					胡							
58	蒸气 (vapor)	蒸 blank	zhēn	zhēng	蒸 blank	zhēng	zhēng气	zhēng	zhēng	blank	zhēng		zhēng	蒸	zhēng
59	嘉年华(carnival)	jiā	加		佳	jiā	佳	加	加	家	qiā	jiā	加		jiā
60	彗星 (comet)	会	会	huì	huì	huì	huì	huì	彗	huì	huài	huì	慧	huì	huì

		29ljl	30zjx	31hzb	32qjw	33cwhy	34sch	35xmh	36zhz	37ln	38shxt	39lyx	40wsm	41lhy	42cyt
1	兽 (beast)				[illegible]		blank		[illegible]			blank		曾	
2	骂 (blame)				骂							blank		blank	
3	色 (colour)											[illegible]			
4	日 (day)				[illegible]										
5	鹿 (deer)	鹿		鹿	[illegible]		blank		[illegible]			blank	鹿	路	
6	狗 (dog)				狗										
7	排 (drain)											blank			
8	象 (elephant)											blank			
9	家 (family)				家										
10	爸 (father)														
11	粉 (flour)								纷			木分			
12	鬼 (ghost)				[illegible]		[illegible]					blank	[illegible]	鬼	
13	手 (hand)														
14	光 (light)											blank			
15	瓜 (melon)						blank								
16	钱 (money)			blank					钱			blank			
17	猴 (monkey)				[illegible]		猴		blank		[illegible]	blank	[illegible]	[illegible]	
18	谜 (mystery)	迷	迷	迷	[illegible]	迷			[illegible]	迷		blank	[illegible]	[illegible]	
19	鼻 (nose)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			[illegible]	blank	[illegible]	[illegible]	
20	管 (pipe)			[illegible]	管						blank	blank		blank	
21	地 (place)														
22	池 (pool)								blank		[illegible]	blank	食	blank	
23	雨 (rain)											blank			
24	路 (road)			灯	[illegible]							blank			
25	房 (room)				[illegible]		防					blank		blank	
26	赛 (race)			[illegible]			blank		[illegible]	[illegible]	[illegible]	blank		blank	
27	河 (river)											和			
28	航 (sail)			行	[illegible]		行		舟		行	blank		[illegible]	
29	海 (sea)											blank			
30	印 (seal)			抑			[illegible]		[illegible]			blank	印	blank	
31	静 (silence)		静		[illegible]							blank			
32	银 (silver)											blank		银	
33	天 (sky)											blank			
34	皂 (soap)			[illegible]	blank		[illegible]	皂	blank		blank	blank		blank	
35	夏 (summer)											blank		[illegible]	
36	寺 (temple)	si	si	木厶	[illegible]	[illegible]		si	祀		四	blank		blank	
37	信 (trust)											blank			
38	龟 (turtle)	[illegible]										blank			
39	妻 (wife)	妻	妻					blank			[illegible]	blank	妻	blank	
40	字 (word)						[illegible]					blank			
41	虫 (worm)											blank			
42	议会 (council)											blank		blank	
43	板球 (cricket)											blank			
44	脚印 (footprint)	印		blank	[illegible]		[illegible]		[illegible]		影	blank	印	[illegible]	
45	朋友 (friend)											blank			
46	花园 (garden)											blank			
47	天才 (genius)											blank			
48	医院 (hospital)											blank			
49	飓风 (hurricane)	巨	巨	blank	[illegible]		blank	巨	[illegible]	巨	[illegible]	blank	巨	风	
50	磁铁 (magnet)	cí	blank	[illegible]	blank		[illegible]			铣	chī	blank		铣	
51	噪音 (noise)	blank		[illegible] blank		blank	blank	blank	[illegible]	blank	[illegible]	blank	[illegible]	blank [illegible]	blank
52	麻烦 (nuisance)		烦	麻	[illegible]						blank	blank		blank	
53	和平 (peace)											[illegible]			
54	自豪 (pride)	豪			[illegible]		blank		blank			blank			
55	问题 (question)			题			[illegible]	是				blank			
56	海绵 (sponge)			棉	[illegible]	[illegible]	blank		[illegible]		锦	blank	棉		
57	故事 (story)										[illegible]	blank		blank	
58	蒸气 (vapor)	blank	zhēng	生	[illegible]		[illegible]	blank	[illegible]	蒸	[illegible]	blank	争	blank	
59	嘉年华(carnival)	家	家	家[illegible]华	家	加	家	加	[illegible]	佳	家年化	blank	佳	家	
60	彗星 (comet)	慧	慧	blank	会	慧			慧	慧	会	blank	慧	[illegible]	慧

		43cp	44dzz	45fyf	46songxt	47xzr	48ghw	49zn	50lxq	51zs	52gjy	53zsy	54wyb	55wmx	56sxy
1	兽 (beast)	blank	# NA							blank					
2	骂 (blame)														
3	色 (colour)														
4	日 (day)														
5	鹿 (deer)												blank		
6	狗 (dog)														
7	排 (drain)					blank									
8	象 (elephant)														
9	家 (family)		# NA												
10	爸 (father)														
11	粉 (flour)														
12	鬼 (ghost)							blank							
13	手 (hand)														
14	光 (light)														
15	瓜 (melon)														
16	钱 (money)														
17	猴 (monkey)														
18	谜 (mystery)														
19	鼻 (nose)		blank					blank					blank		blank
20	管 (pipe)							blank							
21	地 (place)														
22	池 (pool)														
23	雨 (rain)														
24	路 (road)														
25	房 (room)														
26	赛 (race)												Blank*		
27	河 (river)														
28	航 (sail)					blank									
29	海 (sea)														
30	印 (seal)														
31	静 (silence)														
32	银 (silver)														
33	天 (sky)														
34	皂 (soap)									blank					
35	夏 (summer)														
36	寺 (temple)	blank													
37	信 (trust)														
38	龟 (turtle)	blank													
39	妻 (wife)		blank										blank		
40	字 (word)														
41	虫 (worm)														
42	议会 (council)														
43	板球 (cricket)														
44	脚印 (footprint)	blank						blank							blank
45	朋友 (friend)														
46	花园 (garden)														
47	天才 (genius)														
48	医院 (hospital)														
49	飓风 (hurricane)	blank	blank							blank					
50	磁铁 (magnet)	blank				blank		blank		blank					blank
51	噪音 (noise)			blank	blank	blank	blank		blank	blank	blank	blank			blank
52	麻烦 (nuisance)	blank						blank				blank			blank
53	和平 (peace)							blank							
54	自豪 (pride)							blank							
55	问题 (question)														
56	海绵 (sponge)											blank			
57	故事 (story)														
58	蒸气 (vapor)	blank	blank						*						blank
59	嘉年华(carnival)	blank	blank												
60	彗星 (comet)		blank			blank							blank		

Appendix F

Actual Spelling Errors of the Adults

	Poor adults	1sgh	2ldg	3ml	4xc	5am	6dxs	7lyz	8hl	9lm	10pdx	11zjf	12xsy	13lmf	14cy
1	兽 (beast)														
2	骂 (blame)														
3	色 (colour)														
4	日 (day)														
5	鹿 (deer)														
6	狗 (dog)														
7	排 (drain)														
8	象 (elephant)														
9	家 (family)														
10	爸 (father)														
11	粉 (flour)														
12	鬼 (ghost)														
13	手 (hand)														
14	光 (light)														
15	瓜 (melon)														
16	钱 (money)														
17	猴 (monkey)														
18	谜 (mystery)														
19	鼻 (nose)														
20	管 (pipe)														
21	地 (place)														
22	池 (pool)														
23	雨 (rain)														
24	路 (road)														
25	房 (room)														
26	赛 (race)														
27	河 (river)														
28	航 (sail)														
29	海 (sea)														
30	印 (seal)														
31	静 (silence)														
32	银 (silver)														
33	天 (sky)														
34	皂 (soap)									blank					
35	夏 (summer)														
36	寺 (temple)														
37	信 (trust)														
38	龟 (turtle)									blank					
39	妻 (wife)														
40	字 (word)														
41	虫 (worm)														
42	议会 (council)	blank		blank					blank			blank	blank		blank
43	板球 (cricket)						Blank blank		blank			blank	blank	Blank blank	
44	脚印 (footprint)					blank									
45	朋友 (friend)												blank		
46	花园 (garden)														
47	天才 (genius)														
48	医院 (hospital)														
49	飓风 (hurricane)											blank			
50	磁铁 (magnet)	blank										blank			blank
51	噪音 (noise)		blank					blank				blank	blank	blank	
52	麻烦 (nuisance)									Blank blank					
53	和平 (peace)														
54	自豪 (pride)									blank					
55	问题 (question)														
56	海绵 (sponge)									blank					
57	故事 (story)														
58	蒸气 (vapor)	blank											blank		
59	嘉年华 (carnival)			Blank blank		Blank blank			blank blank						
60	彗星 (comet)	blank		blank	blank	blank			blank	blank		blank	blank		

		15ss	16lys	17yw	18jhy	19wy	20pdx	21hth	22ww	23bb	24zjy	25hy	26ttj	27wx
1	兽 (beast)													
2	骂 (blame)													
3	色 (colour)													
4	日 (day)													
5	鹿 (deer)													
6	狗 (dog)													
7	排 (drain)													
8	象 (elephant)													
9	家 (family)													
10	爸 (father)													
11	粉 (flour)													
12	鬼 (ghost)													
13	手 (hand)													
14	光 (light)													
15	瓜 (melon)													
16	钱 (money)													
17	猴 (monkey)													
18	谜 (mystery)													
19	鼻 (nose)													
20	管 (pipe)													
21	地 (place)													
22	池 (pool)													
23	雨 (rain)													
24	路 (road)													
25	房 (room)													
26	赛 (race)													
27	河 (river)													
28	航 (sail)													
29	海 (sea)													
30	印 (seal)													
31	静 (silence)													
32	银 (silver)													
33	天 (sky)													
34	皂 (soap)													
35	夏 (summer)						blank							
36	寺 (temple)													
37	信 (trust)													
38	龟 (turtle)													
39	妻 (wife)		blank											
40	字 (word)													
41	虫 (worm)													
42	议会 (council)				blank		blank			blank				
43	板球 (cricket)									blank				
44	脚印 (footprint)													
45	朋友 (friend)													
46	花园 (garden)													
47	天才 (genius)													
48	医院 (hospital)													
49	飓风 (hurricane)		blank								blank			
50	磁铁 (magnet)													
51	噪音 (noise)				blank				blank	blank				
52	麻烦 (nuisance)													
53	和平 (peace)													
54	自豪 (pride)													
55	问题 (question)													
56	海绵 (sponge)													
57	故事 (story)													
58	蒸气 (vapor)				blank				blank	blank	blank			
59	嘉年华(carnival)				blank blank				Blank blank	blank blank				
60	彗星 (comet)				blank		blank		blank	blank		blank		

	Better adults	1lfn	2tm	3kjc	4lyr	5shx	6zty	7wdw	8pp	9wwy	10grg	11lzc	12lmc	13zwb	14tjc
1	兽 (beast)														
2	骂 (blame)														
3	色 (colour)														
4	日 (day)														
5	鹿 (deer)														
6	狗 (dog)														
7	排 (drain)														
8	象 (elephant)														
9	家 (family)														
10	爸 (father)														
11	粉 (flour)														
12	鬼 (ghost)														
13	手 (hand)														
14	光 (light)														
15	瓜 (melon)														
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19	鼻 (nose)														
20	管 (pipe)														
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39	妻 (wife)														
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41	虫 (worm)														
42	议会 (council)														
43	板球 (cricket)														
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45	朋友 (friend)														
46	花园 (garden)														
47	天才 (genius)														
48	医院 (hospital)														
49	飓风 (hurricane)														
50	磁铁 (magnet)														
51	噪音 (noise)				blank										
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53	和平 (peace)														
54	自豪 (pride)														
55	问题 (question)														
56	海绵 (sponge)														
57	故事 (story)														
58	蒸气 (vapor)														
59	嘉年华(carnival)														
60	彗星 (comet)		blank												

		15zny	16my	17chl	18ann	19cuiy	20ckw	21zck	22lh	23zyn	24lht	25cdy	26hzh	27lyh	28jm
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6	狗 (dog)														
7	排 (drain)														
8	象 (elephant)														
9	家 (family)														
10	爸 (father)														
11	粉 (flour)														
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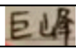
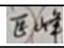
49	飓风 (hurricane)														
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52	麻烦 (nuisance)														
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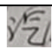
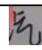
58	蒸气 (vapor)			 blank											
59	嘉年华(carnival)														
60	彗星 (comet)														

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2	骂 (blame)			
3	色 (colour)			
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7	排 (drain)			
8	象 (elephant)			
9	家 (family)			
10	爸 (father)			
11	粉 (flour)			
12	鬼 (ghost)			
13	手 (hand)			
14	光 (light)			
15	瓜 (melon)			
16	钱 (money)			
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18	谜 (mystery)			
19	鼻 (nose)			
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25	房 (room)			
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34	皂 (soap)			
35	夏 (summer)			
36	寺 (temple)			
37	信 (trust)			
38	龟 (turtle)			
39	妻 (wife)			
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43	板球 (cricket)			
44	脚印 (footprint)			
45	朋友 (friend)			
46	花园 (garden)			
47	天才 (genius)			
48	医院 (hospital)			
49	飓风 (hurricane)			
50	磁铁 (magnet)			
51	噪音 (noise)		blank	

52	麻烦 (nuisance)			
53	和平 (peace)			
54	自豪 (pride)			
55	问题 (question)			
56	海绵 (sponge)			
57	故事 (story)			
58	蒸气 (vapor)		blank	
59	嘉年华(carnival)			
60	彗星 (comet)			

52	麻烦 (nuisance)			
53	和平 (peace)			
54	自豪 (pride)			
55	问题 (question)			
56	海绵 (sponge)			
57	故事 (story)			
58	蒸气 (vapor)		blank	
59	嘉年华(carnival)			
60	彗星 (comet)			

Appendix G

Intervention Phases of All Participants

Children			
Intervention type	Intervention time	Frequency	Duration
WWT	45 mins per session	Twice a week	90 mins
V1BT	15-20 mins per session	Five times a week	75-100 mins
NVT	45 mins per session	Twice a week	90 mins
	Order of interventions		
Child 1 XMH	WWT+V1BT+NVT		
Child 2 SONGXT	V1BT+NVT+WWT		
Child 3 GHW	NVT+WWT+V1BT		
Child 4 QJW	WWT+V1BT+NVT		
Child 5 SHANXT	V1BT+NVT+WWT		
Child 6 ZN	NVT+WWT+V1BT		
Adults			
Intervention type	Intervention time	Frequency	Duration
WWT	90 mins per session	Once a week	90 mins
V1BT	15-20 mins per session	Five times a week	75-100 mins
NVT	90 mins per session	Once a week	90 mins
	Order of interventions		
Adult 1 HL	V1BT+NVT+WWT		
Adult 2 LM	WWT+V1BT+NVT		
Adult 3 ZJF	NVT+WWT+V1BT		

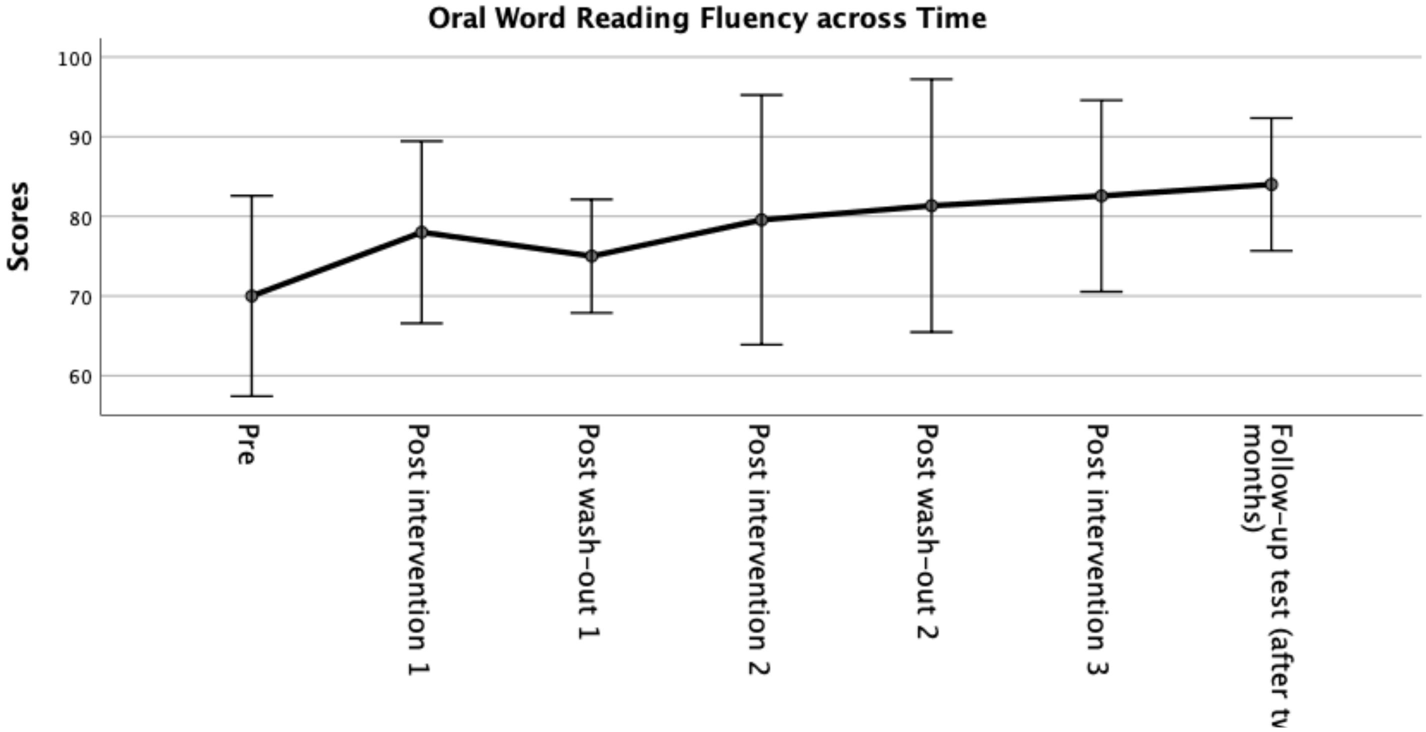
Appendix H

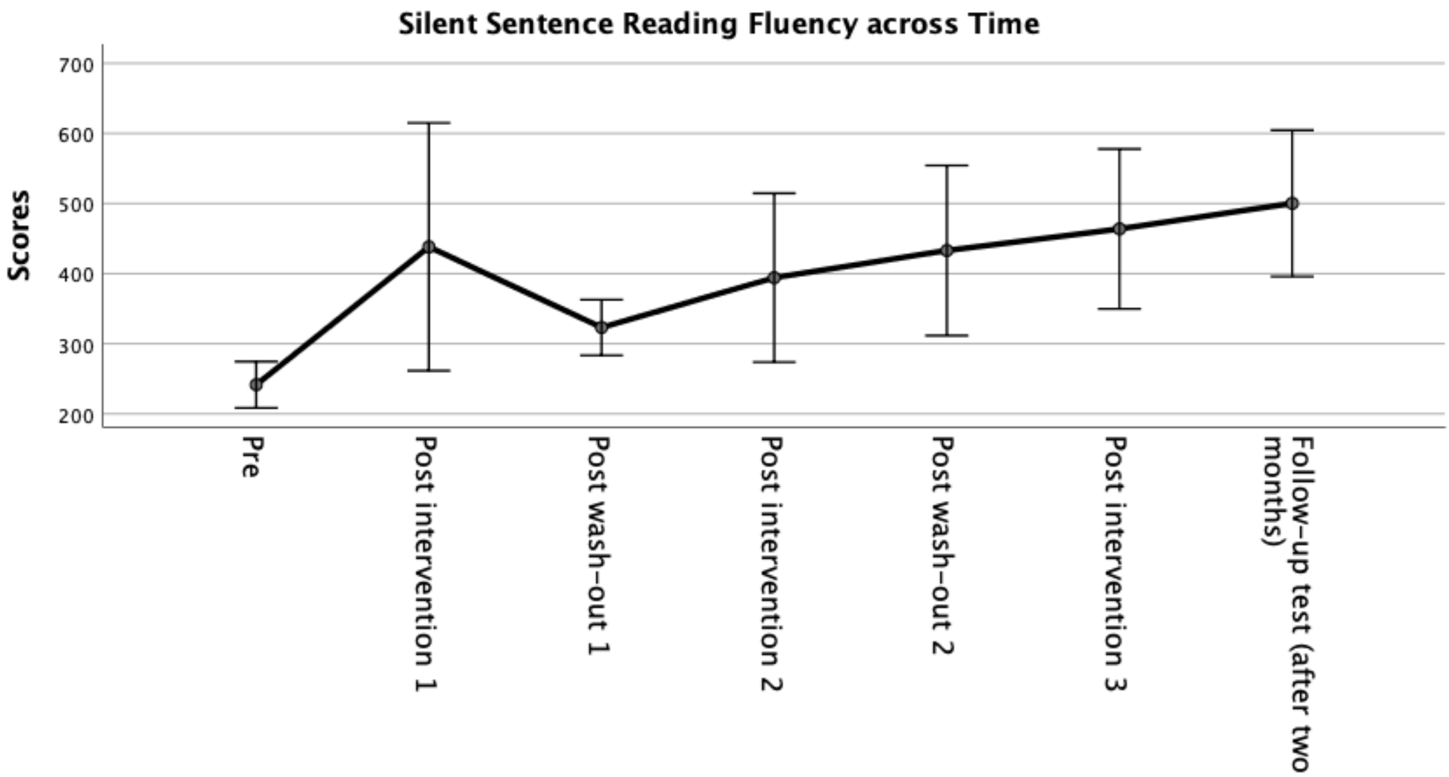
Influence of Order of Intervention and Time on Reading and VAS

Mixed ANOVA was used to test order of intervention and Time (pre, post intervention 1, post wash-out 1, post intervention 2, post wash-out 2, post intervention 3, the follow-up test) in terms of oral and silent reading fluency, as well as VAS. The results showed that for oral and silent reading fluency, the main effect of Order of Intervention was not significant (oral: F (2, 6) = 0.92, p=.45; silent: F (2, 5) = 1.97, p=.23), but the main effect of Time in silent reading fluency was significant, silent: F (6, 30) = 5.23, p=.00), but the main effect of Time in oral reading fluency was not significant, oral: F (2.36, 14.18) = 3.25, p=.06. The interaction effects were not significant, oral: F (4.73, 14.18) = 0.56, p=.72., silent: F (12, 30) = 1.04, p=.44. The changes in oral word reading fluency and silent sentence reading fluency are shown in Figure 25.

Figure 25

Changes in Oral Word Reading Fluency and Silent Sentence Reading Fluency over All Interventions



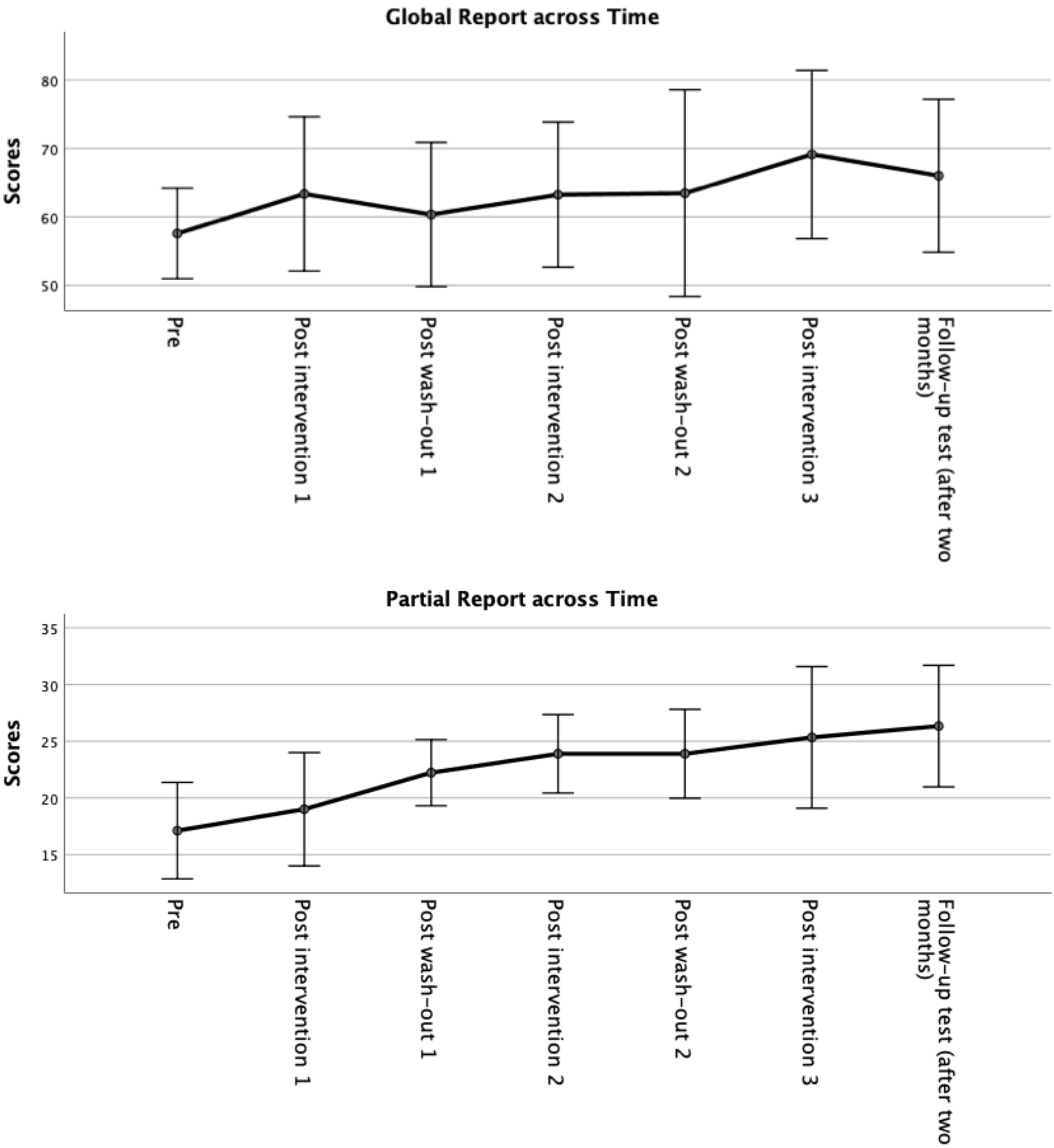


The ANOVA results showed that for the global report, the effect of order of intervention was not significant (F (2, 6) = 1.72, p=.26), but the main effect of Time was significant (F (6, 36) = 4.19, p=.00). The interaction was not significant, F (12, 36) = 0.91, p=.54. For partial report, the main effect of Order of Intervention was not significant, F (2, 6) = 2.39, p=.17), but the main effect of Time was significant, F (2.24, 13.42) = 8.42, p=.00). The interaction effects were not significant, F (4.47, 13.42) = 1.50, p=.26.

The changes in scores for global report and partial report during the whole project were separately shown in Figure 26.

Figure 26

Changes in Global Report and Partial Report over All Interventions

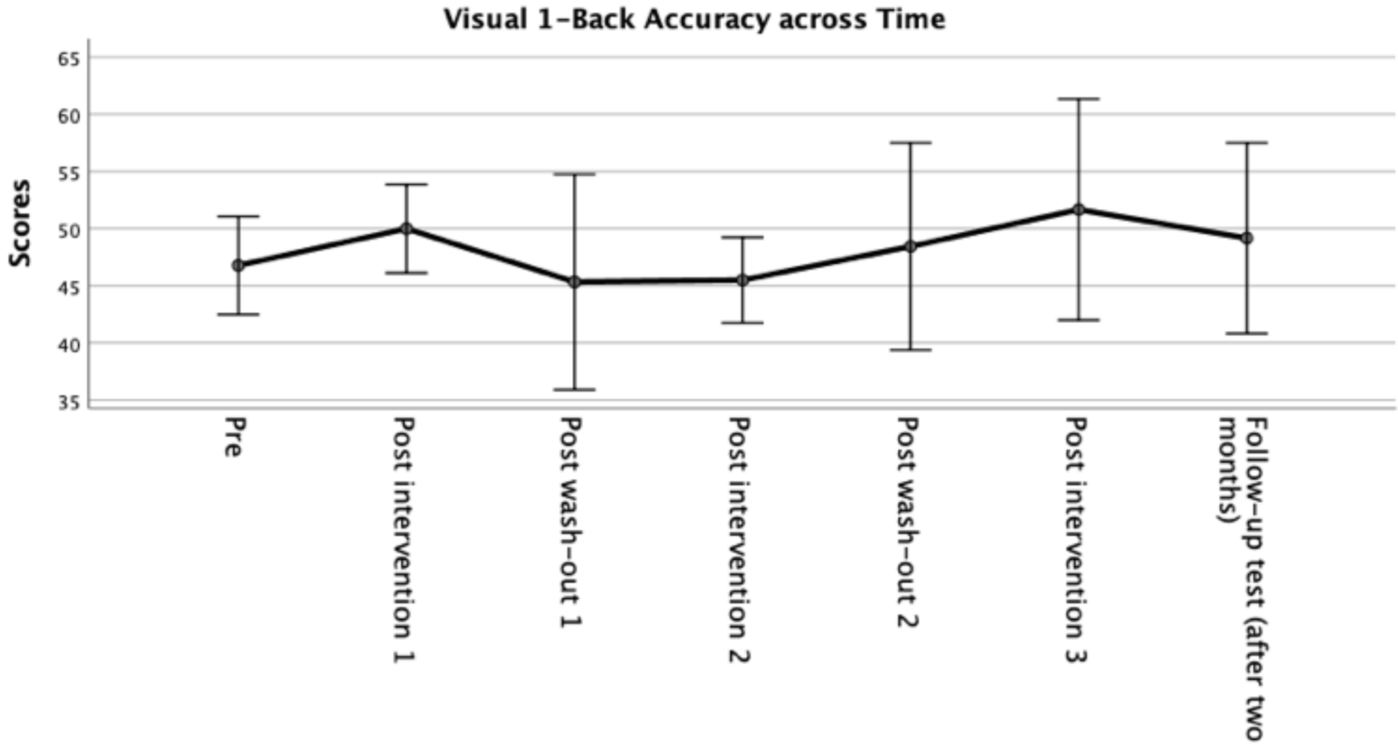


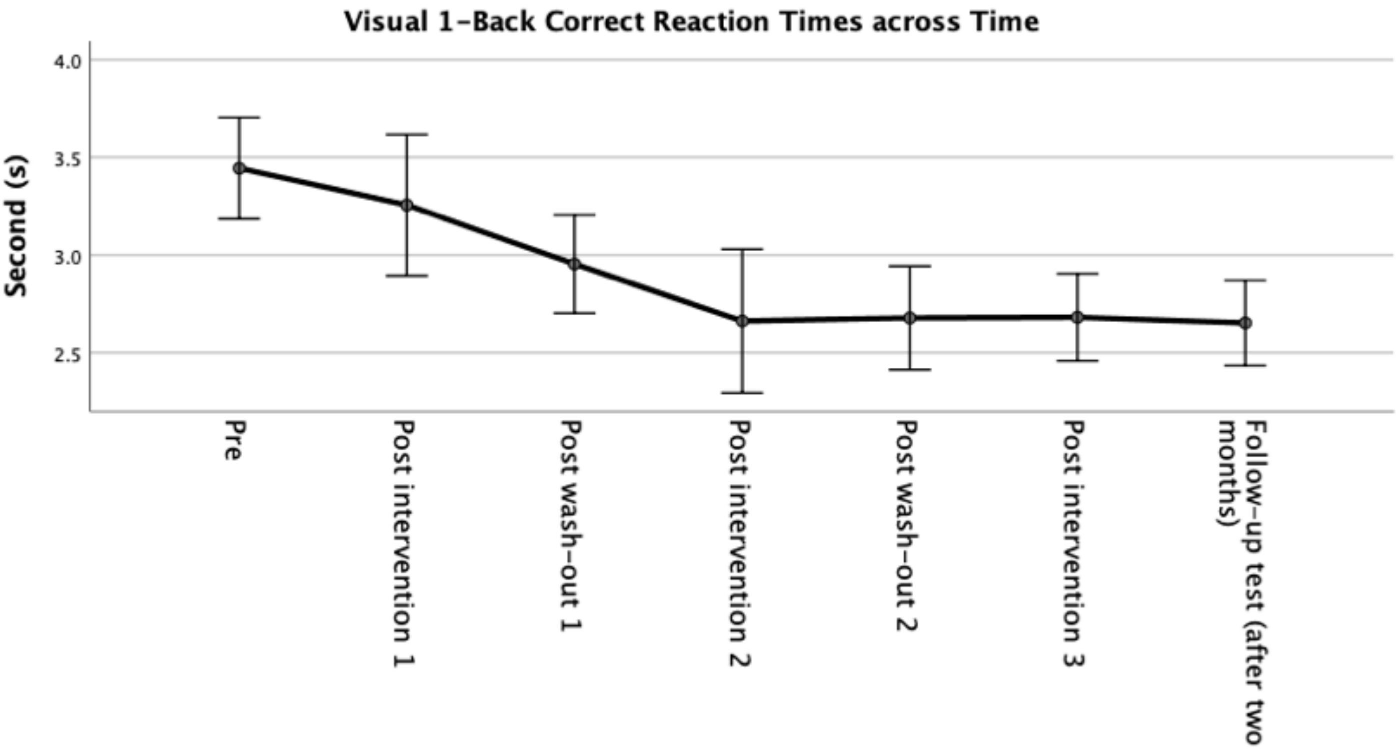
The results showed that for v1b accuracy, the effect of order of intervention was not significant, *F* (2,5) < 1, *p*=.99), and the effect of time was also not significant, *F* (6, 30) = 1.21, *p*=.33). The interaction was not significant, *F* (12, 30) = 0.50, *p*=.90. As for the v1b correct RTs, the main effect of order of intervention was not significant, *F* (2, 5) = 1.36, *p*=.34). The main effect of time was significant, *F* (1.84, 9.18) = 13.03, *p*=.00). The interaction effect was not significant, *F* (3.67, 9.18) = 2.90, *p*=.09.

The changes in v1b accuracy and v1b correct RTs are shown in Figure 27.

Figure 27

Changes in Visual 1-Back Accuracy and Correct Reaction Times over All Interventions





Overall, the order of intervention did not influence the intervention effectiveness but there was an effect of time, except for oral word reading fluency and v1b accuracy.

Appendix I

Consent Forms for Children's Guardians and Adults

a. children's guardians

CONSENT FORM FOR *CHILDREN'S PARENTS/GUARDIANS*
Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.

Title of Study: Two types of training for visual attention span in Chinese-speaking children with reading difficulties aged ten to twelve years

Department: Department of Psychology and Human Development

Name and Contact Details of the Researcher(s): Tianyi WANG

Name and Contact Details of the Principal Researcher: Jackie Masterson; Liory Fern-Pollak

This study has been approved by the UCL Research Ethics Committee: Project ID number: ______________

Thank you for considering taking part in this research. The person organising the research must explain the project to you before you agree to let your child take part. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes means that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that my child may be deemed ineligible for the study.

Item number	Potential consent item	Tick Box
1.	*I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information and what will be expected of my child whose guardian is me. I have also had the opportunity to ask questions which have been answered to my satisfaction and would like to let the child to take part in: (Please tick one or more of the following) -online assessments -online interventions	
2.	*I understand that I will be able to withdraw data of my child at any time.	
3.	*I consent let my child participate in the study although some his/her personal information might be explored (Please see the details in the *Consent for Child's Personal Information* section at the end of the document)	
4.	*I understand that all personal information will remain confidential and that all efforts will be made to ensure my child's information cannot be identified *(unless you state otherwise, because of the research design or except as required by law).* I understand that my child's data gathered in this study will be stored anonymously and securely. It will not be possible to identify my child in any publications.	
5.	*I understand that my child's information may be subject to review by responsible individuals from the University for monitoring and audit purposes.	
6.	*I understand that my child's participation is voluntary and that my child and I are free to withdraw at any time without giving a reason, without the care we receive or our legal rights being affected. I understand that if I decide to withdraw, any personal data my child and I have provided up to that point will be deleted unless we agree otherwise.	
7.	I understand the potential risks of my child's participation and the support that will be available to my child should I become distressed during the course of the research.	
8.	I understand the direct/indirect benefits of my child's participation.	
9.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.	
10.	I understand that my child and I will not benefit financially from this study or from any possible outcome it may result in in the future.	
11.	I understand that my child will not be compensated for the portion of time spent in the study (if applicable) or fully compensated if my child and I choose to withdraw.	
12.	I agree that my child's anonymised research data may be used by others for future research. [No one will be able to identify your child when this data is shared.]	
13.	I understand that the information my child and I have submitted will be published as a report and we wish to receive a copy of it. Yes/No	
14.	I consent to my child's and my sessions with the researcher being audio/video recorded and understand that the recordings will be stored anonymously, using password-protected software and will be used for training, quality control, audit and specific research purposes. To note: If you do not want your participation recorded you can still take part in the study.	
15.	I hereby confirm that my child and I understand the inclusion criteria as detailed in the Information Sheet and explained to us by the researcher.	
16.	I hereby confirm that: (a) My child and I understand the exclusion criteria as detailed in the Information Sheet and explained to us by the researcher; and (b) My child does not fall under the exclusion criteria.	
17.	I agree that my child's GP may be contacted if any unexpected results are found in relation to my child's health.	
18.	I have informed the researcher of any other research in which my child is currently involved or has been involved in during the past 12 months.	
19.	I am aware of who I should contact if I wish to lodge a complaint.	
20.	I agree to let my child voluntarily take part in this study.	
21.	I would be happy for the educational background and assessment results of my child and I provide to be archived at UCL, IOE. I understand that other authenticated researchers (Jackie Masterson and Liory Fern-Pollak) will have access to my child's anonymised data.	
22.	I understand, as child's parent/guardian, I can be present during the remote testing but will not provide any input during the administration of the assessments, which will be carried out by the researcher.	
23.	**Overseas Transfer of Data** I understand that my child's personal data will be transferred to UCL, IOE, and the necessary safeguards will be put in place IOE.	

Data Protection Privacy Notice

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information from research studies can be found in our 'general' privacy notice for participants in research studies here.

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices. The lawful basis that will be used to process any personal data is: 'Public task' for personal data and ' Research purposes' for special category data. We will be collecting your child's personal data such as: ***age, gender, educational background.***

Your child's personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your child's personal data is being processed, or if you would like to contact us about your child's rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

UCL Data Protection: ☐
Consent for Child's Personal Information

If you would like us to use your child's personal information for the research purposes, please tick the appropriate box below.

• Yes, I understand my child's following personal information will be used:

- name acronym ☐

- age ☐

- gender ☐

- educational history ☐

• No, I would not like my child's any personal information to be explored. ☐

If you would like your contact details to be retained so that you can be contacted in the future by UCL researchers who would like to invite your child and you to participate in follow up studies to this project, or in future studies of a similar nature, please tick the appropriate box below.

Yes, I would be happy to be contacted in this way ☐ No, I would not like to be contacted ☐

________________	________________	________________
Name of participant	Date	Signature
________________	________________	________________
Researcher	Date	Signature

b. adults

CONSENT FORM FOR ADULTS

Please complete this form after you have read the Information Sheet and/or listened to an explanation about the research.
Title of Study: Exploration of underlying linguistic and cognitive deficits (especially visual attention span deficit) in Chinese-speaking adults aged 18 to 45 years

Department: Department of Psychology and Human Development
Name and Contact Details of the Researcher(s): Tianyi WANG (tian.wang.20@ucl.ac.uk)
Name and Contact Details of the Principal Researcher: Prof. Jackie Masterson (j.masterson@ucl.ac.uk); Dr Liory Fern-Pollak (l.fern-pollak@ucl.ac.uk)
This study has been approved by the UCL Research Ethics Committee: Project ID number: ___________

Thank you for considering taking part in this research. The person organising the research must explain the project to you. If you have any questions arising from the Information Sheet or explanation already given to you, please ask the researcher before you decide whether to join in. You will be given a copy of this Consent Form to keep and refer to at any time.

I confirm that I understand that by ticking/initialling each box below I am consenting to this element of the study. I understand that it will be assumed that unticked/initialled boxes means that I DO NOT consent to that part of the study. I understand that by not giving consent for any one element that I may be deemed ineligible for the study.

Item number	Potential consent item	Tick Box
1.	*I confirm that I have read and understood the Information Sheet for the above study. I have had an opportunity to consider the information. I have also had the opportunity to ask questions which have been answered to my satisfaction and would like to take part in: (Please tick one or more of the following) -online assessments -online interventions	
2.	*I understand that I will be able to withdraw my data at any time.	
3.	*I consent to participate in the study although some of my personal information might be explored	
4.	*I understand that all personal information will remain confidential and that all efforts will be made to ensure my information cannot be identified *(unless you state otherwise, because of the research design or except as required by law).* I understand that my data gathered in this study will be stored anonymously and securely. It will not be possible to identify myself in any publications.	
5.	*I understand that my information may be subject to review by responsible individuals from the University for monitoring and audit purposes.	
6.	*I understand that my participation is voluntary and that I am free to withdraw at any time without giving a reason, without the care we receive or our legal rights being affected. I understand that if I decide to withdraw, any personal data I have provided up to that point will be deleted unless I agree otherwise.	
7.	I understand the potential risks of my participation and the support that will be available to me should I become distressed during the course of the research.	
8.	I understand the direct/indirect benefits of my participation.	
9.	I understand that the data will not be made available to any commercial organisations but is solely the responsibility of the researcher(s) undertaking this study.	
10.	I understand that I will not benefit financially from this study or from any possible outcome it may result in in the future.	
11.	I understand that I will not be compensated for the portion of time spent in the study (if applicable) or fully compensated if I choose to withdraw.	
12.	I agree that my anonymised research data may be used by others for future research. [No one will be able to identify me when this data is shared.]	
13.	I understand that the information I have submitted will be published as a report and I wish to receive a copy of it. Yes/No	
14.	I consent to my sessions with the researcher being audio/video recorded and understand that the recordings will be stored anonymously, using password-protected software and will be used for training, quality control, audit and specific research purposes. To note: If you do not want your participation recorded you can still take part in the study.	
15.	I hereby confirm that I understand the inclusion criteria as detailed in the Information Sheet and explained to me by the researcher.	
16.	I hereby confirm that: (c) I understand the exclusion criteria as detailed in the Information Sheet and explained to us by the researcher; and (d) I do not fall under the exclusion criteria.	
17.	I agree that my GP may be contacted if any unexpected results are found in relation to my health.	
18.	I have informed the researcher of any other research in which I am currently involved or has been involved in during the past 12 months.	
19.	I am aware of who I should contact if I wish to lodge a complaint.	
20.	I agree to voluntarily take part in this study.	
21.	I would be happy for the educational background and assessment results I provide to be archived at UCL, IOE. I understand that other authenticated researchers (Prof. Jackie Masterson, Dr Liory Fern-Pollak, and Tianyi WANG) will have access to my anonymised data.	
22.	**Overseas Transfer of Data** I understand that my personal data will be transferred to UCL, IOE, and the necessary safeguards will be put in place IOE.	

Data Protection Privacy Notice

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This ‘local’ privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information from research studies can be found in our ‘general’ privacy notice for participants in research studies here.

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the ‘local’ and ‘general’ privacy notices. The lawful basis that will be used to process any personal data is: ‘Public task’ for personal data and ’ Research purposes’ for special category data. We will be collecting your personal data such as: ***age, gender, educational background.***

Your personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

UCL Data Protection: ☐

Consent for Personal Information
If you would like us to use your personal information for the research purposes, please tick the appropriate box below.

- Yes, I understand my following personal information will be used:

- pseudonym ☐
-age ☐
-gender ☐
-educational history ☐

- No, I would not like any of my personal information to be explored. ☐

If you would like your contact details to be retained so that you can be contacted in the future by UCL researchers who would like to invite you to participate in follow up studies (e.g. interventions) to this project, or in future studies of a similar nature, please tick the appropriate box below.

Yes, I would be happy to be contacted if the interventions take place in the future ☐
No, I would not like to be contacted if the interventions take place in the future ☐
This study is to know the relationship between a visual skill and your Chinese reading skill. If you are selected as the further intervention participant and also happy to participate in the interventions, it is necessary for you to know the aim of interventions that is to compare the effects of two interventions. The Dyslexia Association of Hong Kong (https://www.dyslexiahk.com/) will provide related information and support to these studies.

Yes, I understand this. ☐

______________________	______________	________________
Name of participant	Date	Signature
______________________	______________	________________
Researcher	Date	Signature

Appendix J

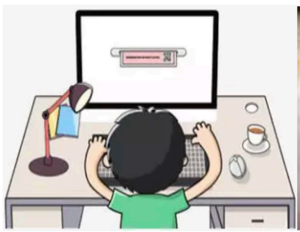
Information Sheets for Children, Children's Guardians and Adults

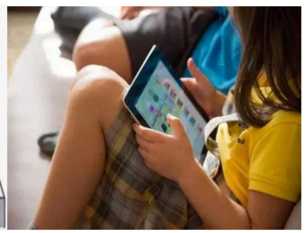
a. Children

INFORMATION SHRRT FOR CHILDREN

Hello! 😊😊 My name is Tianyi. I study at UCL Institute of Education which is a University in London. I want to learn more about children and their word knowledge. I am interested in how much Chinese character knowledge Chinese children aged 10 to 12 have.

I will give you an online test, and you need to open it via your computer or iPad at home. When you open it, you will hear a sound of a word and see 4 pictures at the same time. The only thing you need to do is to choose one picture that can show the same meaning as word you heard. Don't worry. You will have several practices.

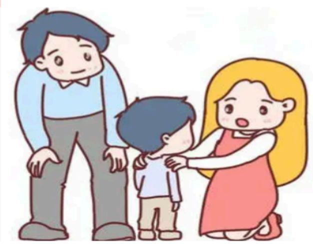




I hope you can give us your age, gender, and student ID. Whichever picture you choose will be kept safe. Nobody is going to know about your name or your school.

When you do not want to do the test, you can stop it at any time. You can also say 'No' if you no longer wish to take part in the project

Feel free to ask me any questions you have, and I will be happy to answer.



You may wish to talk with your parents about whether to take part in this study. If you decide not to take part, it is fine.

Please tick or color below:	YES	NO
Do you want to take part?	☐	☐
May I write about you?	☐	☐
May I record your student ID, age, and gender?	☐	☐

Thank You! 😊😊

For more information, please visit this website: https://www.ucl.ac.uk/legal-services/privacy/ucl-general-research-participant-privacy-notice

b. Children's guardians

Institute of Education

UCL

Two types of training for visual attention span in Chinese-speaking children aged ten to twelve years
August 2021-Feburary 2022

Information sheet for parents/guardians

My name is Tianyi WANG, a PhD student in Department of Psychology and Human Development, University College London (UCL), Institute of Education (IOE). My supervisors are Prof. Jackie Masterson and Dr. Liory Fern-Pollak in UCL IOE. We are inviting your child to take in part in my research project, 'Visual 1-back training and whole word training for a deficit of visual attention span in Chinese developmental dyslexics aged ten to twelve years'. Visual attention span (also VAS) refers to the number of visual elements that can be parallelly processed in a multi-element array. As a main researcher in this project, I am responsible for carrying out the assessments and intervention. The IOE as the educational school of UCL is ranked first in the world for education in the QS World University Rankings, and has been so every year since 2014.

I very much hope that your child would like to take part. This information sheet will try and answer any questions you might have about the project, but please do not hesitate to contact me if there is anything else you would like to know.

Please explain the research to your child and discuss whether or not they want to take part. I will also ask the children before the task and make it clear that they can drop out if they wish with no negative consequences.

Who is carrying out the research?

Main Researcher: Tianyi WANG

Principal Investigators: Prof. Jackie Masterson; Dr Liory Fern-Pollak

In the context of COVID-19, what kind of safety measure we will do?

Solutions for hazard 1: Infection transmission travelling to & from fieldwork
Members who are responsible for data collection will be asked to plan journeys ahead and use direct routes. They will be asked to travel at 'off peak' times. Before and after journey, hand sanitiser is encouraged to use. Face coverings are encouraged to be wore during the journey and data collection. When travelling, they need to try to maintain social distancing. The contactless payment is also encouraged.

Solutions for hazard 2: fieldwork sites and shared areas
Members of research team will be asked to face away from other people whilst passing them. The room for data collection will increase ventilation by opening windows. Researchers and participants will be asked to use appropriate PPE for the setting, including hand sanitisers and gloves (and possibly face coverings/masks) as indicated by government guidance. PPE must not be shared. Ideally, all research members and participants should wash their hands with soap and water for 20 seconds or more and more frequently than normal. Hand sanitiser will be used where hand washing is not convenient. Try to avoid the direct contact between people.

Solutions for hazard 3: heightened risk for vulnerable groups
All researchers have sensitive and comprehensive conversations with individuals who may be at heightened risk. They must listen carefully to concerns, provide support and consider adjustments. Adjustments may include undertaking lower-risk tasks, limiting exposure (for example through reducing working times) and working from home. All research participants, their parents and teachers will be told the hazards and risks arising from their participation that may be relevant in the context of the project.

Why are we doing this research?

About 30% Chinese children have reading difficulty from a visual perspective. Moreover, children speaking Chinese language than ones speaking western languages (such as English) are much easier to suffer from reading difficulty in terms of VAS deficit. So, it is necessary to ameliorate this problem.
Research questions in this study is to know whether children with reading difficulty in VAS will improve after interventions and even have a long-term improvement, and whether the whole-word training (WWT) and visual 1-back training (V1BT) will have different effects.

Why am I being invited to take part?

Assessment results of your child will contribute to this project, which will be collected to test the reliability of further official assessment at the same age group. Your child has been invited because he or she as a Chinese native speaker aged 10 to 12 have eading difficulty and at the same time, he or she has accepted primary education in China.

What will happen if I choose to take part?

If you agree to let your child take part in this study, your child will participate the following online assessments and then trainings.

Assessment

- Standard Raven progressive test (26-38 mins)

Children need to select the most matching picture according to the logical relationship of each question.

- Verbal short-term memory test (3-5 mins)

Children need to orally repeat numbers in sequence and in reverse order they heard from the experimenters.

- Arithmetic test (4-7 mins)

Children need to orally answer the experimenters' questions.

- Vocabulary test (about 21 mins)

Children need to see the pictures in the computer screen and select the most matching picture according to the audio.

- Phonological awareness (6-11 mins)

Children need to delete or combine some Pinyin syllables according to the question requirement.

- Rapid automising naming test (about 5 mins)

Children need to see the computer screen and orally report the name of picture at which the experimenter points as quickly as possible.

- Reading comprehension (10 mins)

Within 10 mins, children need to read two short passages and do the multiple-choice questions.

- 45s-character reading test (45s)

Children need to orally read every character from left to right and from top to down as quickly as possible.

- 45s- text reading test (45s)

Children need to orally read a whole passage from left to right and from top to down as quickly as possible.

- Single character reading (in the silent mode) (4-6 mins)

Children need to silently read single character from left to right and from top to down and at the same time circle the pseudo-characters.

- Sentence reading (in the silent mode) (9-10 mins)

Children need to judge whether the single sentence presented in the computer screen makes sense through press the computer keys.

- Pseudo-character reading (4-6 mins)

Children need to read aloud the pseudo-character according to the radicals of characters.

- Spelling dictation test (about 15-20 mins)

Children need to do the write down the characters they heard from the experimenters.

- Morphological awareness (4-8 mins)

According to question requirement, children need to combine several characters into one character and orally report them.

- Radical knowledge (about 10 mins)

Children need to select the most matching pictures according to the character radicals they saw.

- Visual simultaneous memory (about 7 mins)

Children need to simultaneously point out the Arabic characters in the correct order.

- Visual sequential memory (about 10 mins)

Arabic characters in different length are presented in the computer and then children need to select the Arabic characters in the correct order.

- Visual 1-back task (2-5 mins)

Children need to judge whether the one symbol or character that appear later presented in the symbol or character array that appeared before through pressing different computer keys.

- Global report task (about 6 mins)

Children need to orally report the characters they saw in the computer screen as many as possible.

- Partial report task (4-5 mins)

Children just need to orally report the characters with the underline.

Training

- Visual 1-back training (maybe 1 hour a week, lasting 4 weeks)

Same procedure as visual 1-back task, but the character length of a presented array that children will see varies, that is from two characters to seven characters.

- Whole-word training (WWT) (maybe 1 hour a week, lasting 4 weeks)

Children need to write down the Chinese character presented by the experimenter every time. If they make mistakes, they will be required to write it again until they have no mistakes.

- The phonological training (maybe 1 hour a week, lasting 4 weeks)

Children will have the oral Pinyin practice that will be conducted by the experimenter.

Will anyone know my child have been involved?

In addition to the main researcher and principal investigators, no one will know your child's involvement. No personal data will be collected, except for your child's age and gender. His or her real name will be replaced by the student ID or his/ her name acronym. All personal data will be held securely and strictly confidential to the researchers.
-Information that identifies your child will be kept separate from the anonymised data.
-All personal data in electronic form will be stored on a password-protected computer, and any hardcopies will be kept in locked storage.
-The third-party systems for processing your child's anonymous information, such as Excel, PsychoPy, Pavlovia and SPSS, will be used to transfer and analyse the data.

Could there be problems for my child if he or she takes part?

There are no potential problems. If your child and you feel uncomfortable during the assessments, you are entitled to stop at any point.

What will happen to the results of the research?

The collected data will be archived but no personal data will be shared with others for any purposes. Your child's name will be anonymous, replaced by his or her name/acronym or his/her student ID. All research data and records needed to validate the research findings will be stored for ten years after the end of active data collection based on the UCL IOE data management policy. Only the main researcher and principal investigators could access to your child's data. All individual information such as your child's gender, age and grade, in electronic form will be stored on a password-protected computer, and any hardcopies will be kept in locked storage.

Does my child have to take part?

It is entirely up to you whether or not you choose to let your child take part. We hope that if you do choose to be involved then you will find it a valuable experience.

***I reassure that if you choose not to let your child take part there will be no negative repercussions for them. For example, it would not influence his or her studying. Due to the context of COVID-19, all related people and stakeholders will strictly follow the risk control measure.**

Data Protection Privacy Notice

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

This 'local' privacy notice sets out the information that applies to this particular study. Further information on how UCL uses participant information from research studies can be found in our 'general' privacy notice for participants in research studies here.

The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices. The lawful basis that will be used to process any personal data is: 'Public task' for personal data and 'Research purposes' for special category data. We will be collecting your child's personal data such as: ***age, gender, educational background.***

Your child's personal data will be processed so long as it is required for the research project. If we are able to anonymise or pseudonymise the personal data you provide we will undertake this, and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your child's personal data is being processed, or if you would like to contact us about your child's rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Contact for further information

My name: Tianyi WANG

WeChat: TTaixizao

Tel: +86 15195890350
If you have any further questions before you decide whether to take part, you can reach me at tian.wang.20@ucl.ac.uk

If you would like to be involved, please complete the following consent form and return to my WeChat or my email address tian.wang.20@ucl.ac.uk by **[insert date].** This project has been reviewed and approved by the UCL IOE Research Ethics Committee.

Thank you very much for taking the time to read this information sheet.

c. Adults

Institute of Education

UCL

Exploration of underlying linguistic and cognitive deficits (especially visual attention span deficit) in Chinese-speaking adults aged 18 to 45 years

March 2022-March 2023

My name is Tianyi WANG, a PhD student in Department of Psychology and Human Development, University College London (UCL), Institute of Education (IOE). My supervisors are Prof. Jackie Masterson and Dr. Liory Fern-Pollak in UCL IOE. We are inviting you to take in part in my research project, 'Exploration of underlying linguistic and cognitive deficits (especially visual attention span deficit) in Chinese-speaking adults aged 18 to 45 years'. Visual attention span (also VAS) refers to the number of visual elements that can be parallelly processed in a multi-element array. As a main researcher in this project, I am responsible for administering and scoring the tasks. The IOE as the educational school of UCL is ranked first in the world for education in the QS World University Rankings, and has been so every year since 2014.

I very much hope that you would like to take part. This information sheet will try and answer any questions you might have about the project, but please do not hesitate to contact me if there is anything else you would like to know.

Who is carrying out the research?

Main Researcher: Tianyi WANG

Principal Investigators: Prof. Jackie Masterson; Dr Liory Fern-Pollak;

Why are we doing this research?

About 30% Chinese dyslexics have reading difficulty from a visual perspective. Moreover, readers speaking Chinese language compared to those western languages (such as English) are more likely to suffer from reading difficulty in terms of a VAS deficit. So, it is necessary to ameliorate this problem.
The research in this study aims to explore the relationship between VAS and Chinese reading of adults and whether adults with reading difficulty have a difficulty in VAS.

Why am I being invited to take part?

You have been invited because you are a Chinese speaking adult (native speaker) with and without reading difficulty.

What will happen if I choose to take part?

If you agree to take part in this study, you will participate in the following online assessments.

Assessment

- Standard Raven progressive test (26-38 mins)

Participants need to select the most matching picture according to the logical relationship of each question.

- Vocabulary test (about 21 mins)

Participants need to see the pictures in the computer screen and select the most matching picture according to the audio.

- Verbal short-term memory test (3-5 mins)

Participants need to orally repeat numbers in sequence and in reverse order they heard from the experimenters.

- Arithmetic test (4-7 mins)

Participants need to orally answer the experimenters' questions.

- Rapid automised naming test (about 5 mins)

Participants need to see the computer screen and orally report the name of picture at which the experimenter points as quickly as possible.

- Oral character reading (about 3-5 mins)

Participants need to read single words/characters.

- Silent sentence reading (about 5 mins)

Participants need to judge whether the sentences presented on computer screen make sense or not.

- Homophone reading (about 5-10 mins)

Participants need to identify words with the same pronunciation as other words.

- Spelling dictation test (about 15-20 mins)

Participants need to do the write down the characters they heard from the experimenters.

- Phonological awareness (6-11 mins)

Participants need to delete some phoneme/Pinyin syllables according to the question requirement.

- Visual simultaneous memory (about 7 mins)

Participants need to simultaneously point out the Arabic characters in the correct order.

- Visual sequential memory (about 10 mins)

Arabic characters in different length are presented in the computer and then participants need to select the Arabic characters in the correct order.

- Global report task (about 6 mins)

Participants need to orally report the characters they see on the computer screen.

- Partial report task (4-5 mins)

Participants just need to orally report one of the characters, indicated with the underline.

- Visual 1-back task (letters) (2-5 mins)

Participants need to judge whether a letter presented on the screen appeared in the letter array that was presented before through pressing one of two computer keys.

- Visual 1-back task (symbols) (2-5 mins)

Participants need to judge whether an unfamiliar presented on the screen appeared in the symbol array that was presented before through pressing one of two computer keys.

Training for potential dyslexics

- Visual 1-back training (approx. 10-20 minutes every day, lasting 8 weeks)

Same procedure as visual 1-back task, but the character length of a presented array that children will see varies, that is from two characters to seven characters.

- Whole-word training (WWT) (approx. 1 hour a week, lasting 8 weeks)

Participants need to write down the Chinese character presented by the experimenter every time. If they make mistakes, they will be required to write it again until they have no mistakes.

Will anyone know I have been involved?

In addition to the main researcher and principal investigators, no one will know of your involvement. No personal data will be collected, except for your age,

educational background and gender. Your real name will be replaced by an anonymised identifier (code name). All personal data will be held securely and strictly confidential to the researchers.
-Information that identifies you will be kept separate from the anonymised data.
-All personal data in electronic form will be stored on a password-protected computer, and any hardcopies will be kept in locked storage.
-The third-party systems for processing your anonymous information, such as Excel, PsychoPy, Pavlovia and SPSS, will be used to transfer and analyse the data.

Could there be problems for me if I take part?

There are no potential problems. If you feel uncomfortable during the assessments, you are entitled to stop at any point.

What will happen to the results of the research?

The collected data will be archived but no personal data will be shared with others for any purposes. Your name will be anonymous, replaced by your name/acronym. All research data and records needed to validate the research findings will be stored for 10 years after the end of active data collection based on the UCL IOE data management policy. Only the main researcher and principal investigators could access to your data. All individual information such as your gender and age, in electronic form will be stored on a password-protected computer, and any hardcopies will be kept in locked storage.

Do I have to take part?

It is entirely up to you whether or not you choose to take part. We hope that if you do choose to be involved then you will find it a valuable experience.

Data Protection Privacy Notice

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

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The information that is required to be provided to participants under data protection legislation (GDPR and DPA 2018) is provided across both the 'local' and 'general' privacy notices. The lawful basis that will be used to process any personal data is: 'Public task' for personal data and 'Research purposes' for special category data. We will be collecting your personal data for ***age, gender, educational background.***

Your personal data will be processed so long as it is required for the research project. We will pseudonymise the personal data you provide, and will endeavour to minimise the processing of personal data wherever possible.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Contact for further information

My name: Tianyi WANG

WeChat: TTaixizao

Tel: +86 15195890350/ 4407765989231
If you have any further questions before you decide whether to take part, you can reach me at tian.wang.20@ucl.ac.uk

If you would like to be involved, please complete the following consent form and return to my WeChat or my email address tian.wang.20@ucl.ac.uk by **[insert date].** This project has been reviewed and approved by the UCL IOE Research Ethics Committee.

Thank you very much for taking the time to read this information sheet.

Institute of Education

Comparison of the effectiveness of two VAS-based training programs for Chinese adult dyslexics

July 2022-July 2023

My name is Tianyi WANG, a PhD student in Department of Psychology and Human Development, University College London (UCL), IOE, UCL's Faculty of Education and Society. My supervisors are Prof. Jackie Masterson and Dr. Liory Fern-Pollak in UCL IOE. We are inviting you to take in part in my research project. Our work focuses on Visual Attention Span (or VAS). VAS refers to the number of items we can see at one glance. As a main researcher in this project, I am responsible for administering and scoring the tasks. The IOE as the educational school of UCL is ranked first in the world for education in the QS World University Rankings, and has been so every year since 2014.

I very much hope that you would like to take part. This information sheet will try and answer any questions you might have about the project, but please do not hesitate to contact me if there is anything else you would like to know.

Who is carrying out the research?

Main Researcher: Tianyi WANG

Principal Investigators: Prof. Jackie Masterson; Dr Liory Fern-Pollak;

Why are we doing this research?

About 30% Chinese dyslexics have reading difficulty from a visual perspective. Moreover, readers speaking Chinese language compared to those western languages (such as English) are more likely to suffer from reading difficulty in terms of a VAS deficit. So, it is necessary to ameliorate this problem.

The research in this study aims to explore the relationship between VAS and Chinese reading of adults and whether adults with reading difficulty have a difficulty in VAS.

Why am I being invited to take part?

You have been invited because you are a Chinese speaking adult (native speaker) with reading or spelling difficulty.

What will happen if I choose to take part?

If you agree to take part in this study, you will participate in the following online tasks over three sessions of approximately 35 minutes each: nonverbal reasoning ability, vocabulary, verbal memory, arithmetic, rapid naming, reading (oral character and silent sentence), phoneme deletion, visual sequential memory, symbol report from arrays, judgement of whether symbol appeared in array.

After that, you will be trained one non-VAS training (a phonological training, approx.. 1.5 hour a week, six weeks) and two following VAS training. After completing one training, you will be tested immediately and also have 3-week rest without training any interventions. Once you finish all training, you will also be tested after two months.

- **Visual 1-back training (approx. 10-20 minutes x five days a week, six weeks)**

Same procedure as visual 1-back task, but the character length of a presented array that children will see varies, that is from two characters to seven characters.

- **Whole-word training (WWT) (approx. 1.5 hour a week, six weeks)**

Participants need to write down the Chinese character presented by the experimenter every time. If they make mistakes, they will be required to write it again until they have no mistakes.

- **The phonological training (approx. 1.5 hour a week, six weeks)**

Participants need to have oral Pinyin practice that will be conducted by the experimenters.

Will anyone know I have been involved?

Apart from the main researcher and principal investigators, no one will know of your involvement. No personal data will be collected, except for your age, educational background and gender. Your real name will be replaced by an anonymised identifier (code name). All personal data will be held securely and strictly confidential to the researchers. At the end of the project your anonymised data may be archived and shared with other authenticated researchers.

-All personal data in electronic form will be stored on a password-protected computer and UCL software such as the RDSS, and any hardcopies will be kept in locked storage.

-The third-party systems for processing your anonymous information, such as Excel, PsychoPy, Pavlovia and SPSS, will be used to transfer and analyse the data.

Could there be problems for me if I take part?

There are unlikely to be problems if you take part. If you feel uncomfortable during the assessments, you are entitled to stop at any point. If you find the tasks really difficult I can provide you with contact details of organisations that can support you. You can withdraw from the study at any time and without needing to give a reason. If you have any questions, you can email or have an online meeting with researchers.

This research will not involve any sensitive issues, but you are free to leave out any task item or task that you do not wish to complete, also you are free to withdraw from taking part in the study at any time and without giving reason.

If taking part makes you feel anxious or distressed you should contact the researcher or professional dyslexic institution for direction to relevant professionals (such as The Dyslexia Association of Hong Kong (https://www.dyslexiahk.com/).

What will happen to the results of the research?

The collected data will be archived but no personal data will be shared with others for any purposes. All anonymised research data and records needed to validate the research findings will be stored for 10 years after the end of active data collection, based on the UCL IOE data management policy. Only the main researcher and principal investigators will have access to your data. All individual information such as your gender and age, in electronic form will be stored on a password-protected computer and UCL software such as the RDSS, and any hardcopies will be kept in locked storage.

Do I have to take part?

It is entirely up to you whether or not you choose to take part. We hope that if you do choose to be involved then you will find it a valuable experience.

Data Protection Privacy Notice

The controller for this project will be University College London (UCL). The UCL Data Protection Officer provides oversight of UCL activities involving the processing of personal data, and can be contacted at data-protection@ucl.ac.uk

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Your personal data will be processed so long as it is required for the research project. We will pseudonymise the personal data you provide, and will endeavour to minimise the processing of personal data wherever possible. The main researcher and principal investigators will process and share your data and the data may also be shared with others for legitimate research purposes. The results will be published.

If you are concerned about how your personal data is being processed, or if you would like to contact us about your rights, please contact UCL in the first instance at data-protection@ucl.ac.uk.

Contact for further information

My name: Tianyi WANG

WeChat: Ttaixizao

Tel: +86 15195890350/ 4407765989231

If you have any further questions before you decide whether to take part, you can reach me at tian.wang.20@ucl.ac.uk

If you would like to be involved, please complete the following consent form and return to my WeChat or my email address tian.wang.20@ucl.ac.uk by **[insert date].** This project has been reviewed and approved via the Department of Psychology and Human Development at UCL IOE.

Thank you very much for taking the time to read this information sheet.