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Investigation of the influence of visual attention span and a range of literacy-related variables on writing (spelling) to dictation in Mandarin-speaking children aged 10 to 12 years

Tianyi Wang [a,*,1], Liory Fern-Pollak [a], Jackie Masterson [a]

[a] Department of Psychology and Human Development, IOE, UCL's Faculty of Education and Society, London, UK

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ABSTRACT

This study explored the influence of a range of literacy-related variables on writing (spelling) to dictation in Mandarin-speaking children aged 10 to 12 years. The children were assessed with tasks of nonverbal ability, phonological awareness (PA), rapid automatised naming (RAN), visual attention span, character identification, morphological awareness (MA), vocabulary, and verbal short-term memory. Visual attention span (VAS) was assessed with a global report task using Chinese characters. Results of hierarchical regression analysis revealed that PA, RAN, MA and character identification significantly explained 54% of the variance in spelling accuracy. After controlling for these predictors, age and nonverbal ability, VAS scores predicted a further 6% of the variance. The path analysis suggested the mediating role of VAS between RAN and spelling accuracy. The results support the view that visual simultaneous processing plays an important role in spelling in Chinese due to the complex nature of the orthography.

1. Introduction

The cognitive and linguistic processes underlying spelling have been far less studied than those associated with reading. However, evidence to date indicates that phonological awareness and rapid automatised naming play important roles in spelling, at least in alphabetic writing systems (e.g., Portuguese; Botelho da Silva, 2020; English, French, German, Hungarian and Finnish; Moll et al., 2014; English; Niolaki et al., 2022; Dutch; Van Den Boer et al., 2015). Since the early 2000s, researchers have investigated alternative underlying processes, including visual perceptual and attentional processes. In particular, evidence has accumulated supporting a role of visual attention span in relation to the development of reading and spelling.

Visual attention span (VAS) refers to simultaneous visual processing of multi-element arrays (e.g., Bosse et al., 2007; Lobier et al., 2012). It has been commonly assessed in tasks where report of briefly presented arrays of, for example, letters or symbols, is required. Studies conducted with children and adults with and without reading difficulty have indicated that VAS is a predictor of reading performance independent of phonological skills (e.g., Ans et al., 1998; Awadh et al., 2022; Chen et al., 2019; Valdois et al., 2003; Valdois et al., 2004). The current study explored the role of VAS in addition to other child-related variables that have been associated with spelling in Mandarin-speaking children.

In the research into processes underlying reading and spelling with alphabetic writing systems, it has been common to employ dual route theories. In relation to spelling, the proposal is that phonological (phoneme-to-grapheme) processes are used to spell unfamiliar words and regularly spelled words effectively, while whole-word lexical processes are employed for irregularly and regularly spelled words (e.g., Barry, 1994; Hepner et al., 2017; Kreiner & Gough, 1990). Words processed lexically are stored in an orthographic lexicon and accessed directly from that lexicon following activation in the semantic system or the phonological input lexicon (Barry, 1994). Output is usually not influenced by word length (Valle-Arroyo, 1990), but length effects may influence the written production of words relying on sublexical processes. This is because parsing, conversion from phonemes to graphemes, and assembly in a short-term output buffer are all involved. Printed word frequency, on the other hand, is likely to be associated with lexical processing, since the strength of an entry in the orthographic lexicon is influenced by the number of times the child/adult has been exposed to the printed word and has had the opportunity to write it (Spencer, 2007).

* Corresponding author.
E-mail addresses: qtnvtw6@ucl.ac.uk (T. Wang), l.fern-pollak@ucl.ac.uk (L. Fern-Pollak), j.masterson@ucl.ac.uk (J. Masterson).
[1] 20 Bedford Way, London WC1H 0AL, Psychology and Human Development

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Unlike alphabetic writing systems, Chinese, as a logographic writing system, does not rely on correspondences between graphemes and phonemes to produce character pronunciations and spellings. 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. Usually, simplified characters have less visual complexity than traditional characters (e.g., simplified 礼 with 10 strokes vs. traditional 禮 with 18 strokes). In Mainland China, teaching is accompanied by the Pinyin alphabetic system to help children learn character pronunciation in the early grades of primary school. The use of Pinyin script in character teaching means that Mandarin speakers can map sounds to precise visual-orthographic forms with the aid of phonological processing, while instruction for Cantonese speaking children relies on rote visual memorisation of characters. The higher visual complexity of traditional characters may tax visual attention resources and increase cognitive demands for spelling.

In Chinese character writing, three aspects are involved: stroke order, radicals and configuration (Chung & Leung, 2008). 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 comprised of 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 a clue 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 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/). Moreover, Chinese possesses a great number of homophones and characters that are similar in shape. These factors all increase the difficulty associated with spelling in Chinese.

For children in Mainland China, where simplified characters are used, as noted earlier, the alphabetic and transparent Pinyin script is taught, and Pinyin transcription accompanies the introduction of characters (Wang et al., 2014) until Grade 2 (when children are approximately 8 years old). Character copying is introduced after Grade 1. There are usually two stages of copying practice. In the first stage, teachers teach children the stroke order of characters on the blackboard in class. Children learn to trace strokes of Chinese characters following the teachers' instructions through a copybook, which can help learners become aware of stroke order. In the second stage, children try to reproduce the written characters including all strokes and radicals on paper without the copybook (e.g., Wang et al., 2014).

Having provided information regarding the linguistic background of the participants in the current study, we now turn to the theoretical lens through which the findings can be interpreted. We note that Ye and McBride (2022) outlined a dynamic interactive model of spelling development, which posits that Chinese children use multiple skills - phonological and visual-motor, as well as visual-orthographic and semantic, which are in use at different stages. In the current study, we employed the static adapted dual route model proposed by Mo (2023) that outlines the component processes involved in skilled spelling, as in the dual route theory of spelling outlined above, that was originally proposed for English. We employed the static model since our study did not address the development of spelling processes (the participants were all in a single grade at school), and in addition, the participants were aged 10 to 12 and thus were likely to be approaching adult-like levels of spelling performance. Thus, a model of skilled spelling performance was considered appropriate to interpret our results.

According to Mo (2023), the adapted theory of spelling processes accounts for the unique logographic and morphosyllabic nature of Chinese. The lexical processing route is comparable to the one in the original dual route models of spelling, involving access to stored whole-word representations in the orthographic lexicon. The sublexical processing route of the original model, based on grapheme-phoneme correspondence knowledge, is not appropriate for spelling in Chinese, and is instead posited to involve radical activation, and character formation based on radical combinations. In the sublexical processing route, targeted characters are processed at the radical level. Phonetic radicals provide the minimal sound-bearing units for character formation, with semantic radicals offering the meaning. Phonetic and semantic radicals are the foundation of the sublexical route in this model. Their statistical sound-mapping properties and visual-spatial demands redefine sublexical spelling as a radical-centric (not phoneme-centric) process. The information generated by either the lexical or sublexical processing routes is held temporarily in orthographic working memory (OWM) while motor plans for character formation are generated. The execution of these plans is then followed by the production of the written form.

The description of OWM as a temporary store for retaining the position and identity of written word components prior to the final stages of spelling production was originally motivated by studies of adult aphasic patients with acquired spelling disorder (e.g., Caramazza et al., 1987; Schiller et al., 2001), and more recently on the basis of studies using the delayed copying task with typically developing children (e.g., Chung et al., 2011; Wang et al., 2014; Yeung et al., 2016). Mo et al. (2018) reflected that since both visual-orthographic skills and memory capacity are encompassed in OWM, then due to the complex orthographic structure of Chinese written forms, OWM may be particularly important for spelling Chinese words. We return to the theoretical models in the Discussion. In the following sections we review research conducted over the last twenty or so years that has examined the processes children use in spelling alphabetic words and in writing Chinese characters.

1.1. Linguistic skills associated with spelling development: Alphabetic words vs. Chinese characters

Relationships between spelling performance and the child-based variables phonological awareness (PA) and rapid automatised naming (RAN) have been explored in many studies of alphabetic writing systems. For example, in a study of Dutch speaking children, Van Den Boer et al. (2015) reported that PA and RAN significantly predicted spelling accuracy in children in Grade 2, 4 and 5 after nonverbal ability and verbal short-term memory were controlled. In an investigation of English spelling with children aged 7 to 10 years, Niolaki et al. (2020) reported that PA and RAN measures predicted spelling at age 7 but not in the older children.

An association between morphological awareness (MA) and spelling in alphabetic writing systems has also been found. MA refers to the ability to recognise and manipulate the smallest units of meaning in the language (Carlisle, 1995). It has been argued that MA facilitates the binding of print, sound and meaning of words (e.g., Kirby & Bowers, 2017). It has been measured in a variety of tasks, such as asking the testee to complete a sentence involving transformation of a word (e.g., ‘today Dan is cooking lunch for his family, yesterday he ……. lunch for his friends.’). Casalis et al. (2011) assessed spelling in 8- and 9-year-old French-speaking children and reported a significant association between MA and spelling accuracy after partialling out PA. Görgen et al. (2021) carried out a study with German children aged 9 to 10 years, and reported that MA was better than PA at predicting spelling and reading accuracy after controlling for nonverbal ability and chronological age.

PA, RAN and MA have also been found to be significantly associated with the spelling of traditional and simplified Chinese characters. While PA and RAN have been assessed with tasks equivalent in nature to those used in studies involving alphabetic writing systems, assessments of MA in alphabetic languages and Chinese are different, since inflectional and derivational suffixes that are used for MA tasks in alphabetic languages do not apply in Chinese. A compounding task has been commonly used to assess MA in Chinese, since complex concepts can be expressed by combining simpler, or previously learned morphemes. For example, Li et al. (2020) employed a compounding task where children were asked to produce a novel word using familiar morphemes that were included in a question, according to the presented scenario (for example, 'If we see the sun rising in the morning we call that a sunrise. What would we call it if we saw the moon rising?" Answer: "moonrise"). Li et al. also employed a homophone awareness task where children were asked to produce words with different meanings but the same pronunciation as a target morpheme (for example, for the target morpheme 书 (book)/shu1/ in 书籍 (book)/shu1ji2/ a word with the same sound but a different meaning would be 输赢 (win or lose)/shu1ying2/). This task targets children's ability to distinguish homophonic characters—argued by many to be an important skill for Chinese literacy development due to the high level of homophone density (e.g., /shi4/ - 是 (yes), 事 (thing), 市 (city) and 室 (room) etc.).

Yeung et al. (2011) examined the spelling of traditional characters by 6-year-old children in Hong Kong and reported that RAN and MA were significant predictors of spelling accuracy after controlling for age, nonverbal ability, and vocabulary knowledge. Similar results were found in a longitudinal study of Cantonese-speaking children from Grades 1 to 4 by Yeung et al. (2013). The researchers found that RAN was the only significant longitudinal predictor of spelling accuracy, although PA significantly predicted spelling of the second and fourth graders, and MA was a significant predictor for Grade 1 children.

Ye et al. (2022) conducted a study of spelling in Cantonese speaking kindergarten children in Hong Kong. The children were assessed in measures of vocabulary, PA, RAN, MA, motor coordination and copying. An additional measure of orthographic awareness was taken, and this involved presenting real characters, pseudo characters, noncharacters and visual symbols. The task was adopted from the study of Tong et al. (2009) and the children were asked to decide whether each target was a real Chinese character or not. Results revealed that PA, RAN, MA and orthographic awareness, motor coordination and delayed copying were significant unique predictors of spelling accuracy.

Exploring simplified Chinese character spelling, Li et al. (2020) conducted a three-year longitudinal study tracking Mandarin-speaking children from Grade 1 to 3 (approximately aged 6 to 10 years). The authors assessed PA and MA and reported a significant association between PA and spelling accuracy for the first- and third-grade children, and a unidirectional association between MA and spelling from Grade 2 to 3.

In summary, PA, RAN, and MA have all been reported to be significantly associated with the spelling of both traditional and simplified Chinese characters The same association was previously reported in studies on spelling in alphabetic writing systems.

1.2. Visual attention span and spelling development: Alphabetic words vs. Chinese characters

As noted earlier, many studies have pointed to the contribution of visual attention span (VAS) in the development of orthographic representations (Bosse et al., 2013). Bosse (2015) suggested that effective literacy acquisition is largely dependent on the ability to distribute visual attention over whole words, beyond the contribution of decoding skills. The argument was that if relatively large letter sequences can be processed in one glance, representations can be effectively established in the orthographic lexicon. This was supported, for example, by a case study reported by Valdois et al. (2003) of a French-speaking dyslexic and dysgraphic teenager, Nicolas, who was found to have excellent phonological skills but extremely poor performance in VAS letter report tasks. VAS may be critical especially for efficient spelling, which requires the use of well-established and detailed orthographic entries (Van Den Boer et al., 2015).

There have been three recent regression-based studies that report a significant influence of VAS in spelling in typically developing children in alphabetic orthographies. Niolaki et al. (2020), in the previously mentioned study with English-speaking children aged 7 to 10 years, examined the influence of VAS using a global letter report task, previously used by Bosse et al. (2007), and involving report of briefly presented arrays of consonant letters. The authors found that VAS scores predicted single word spelling for both the younger and older children in the study, but more strongly in the older children. Similar findings were reported by Van Den Boer et al. (2015) in a study with Dutch-speaking fourth grade children with a mean age of 9;11. The authors found that, along with RAN and PA, global letter report performance was a significant predictor of single word spelling and also of scores in an orthographic knowledge task where children were asked to select the correct spelling from pseudohomophone-target word pairs. Niolaki et al. (2024) carried out a spelling to dictation task with Greek-speaking children in grades 1 to 7 and reported that VAS global report scores significantly predicted spelling accuracy for the older children, with mean age 10;5 years.

The Chinese writing system has been considered to have the highest degree of visual complexity of all writing systems (e.g., Chang et al., 2017). There are only five basic strokes (i.e., 一, 丨, 丿, 丶, and 乙); however, as noted in the earlier section, nearly all characters are composed of multiple stroke patterns in a square configuration (Liu et al., 2016), and many Chinese characters differ by just one or two strokes, such as 末/mo4/(final/end) and 未/wei4/(not). 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). This has been supported by findings indicating that VAS is a unique predictor of children's character and sentence reading. These studies have employed diverse measures of VAS, including global and partial report using characters (Chen et al., 2019) and a visual 1-back task with digits and colours (Cheng et al., 2021) or symbols (Huang et al., 2019; Zhao et al., 2018).

1.3. The current study

Spelling in Chinese is considered to be a cognitively demanding task because processing the exact spatial positioning of strokes in complex configurations is required (Liu et al., 2016). It has been argued that the ability to simultaneously process multi-element arrays is critical for effective Chinese literacy acquisition (Chen et al., 2019). As discussed above, so far three regression-based studies have explored the relation between VAS and spelling in typically developing children (Niolaki et al., 2020; Niolaki et al., 2024; Van Den Boer et al., 2015). The findings revealed that VAS scores in the global letter report task significantly predicted spelling accuracy across shallow and opaque alphabetic writing systems, and especially in children in the older elementary school grades. In the present study, we aimed to examine whether a similar association of VAS and spelling accuracy could be observed in Mandarin-speaking children, using a global report task with simplified Chinese characters.

Following early studies on VAS in alphabetic writing systems, some authors suggested that the global letter report task may not be a pure measure of visual attention span since it involves verbal report of letters and thus entails visual-verbal mapping, and the VAS deficit may follow from a deficit in visual to phonological code mapping rather than a visual processing deficit (e.g., Ziegler et al., 2010). In the current study, we incorporated a measure of single character identification, with the intention that this would be controlled in the analysis of the prediction of VAS to spelling accuracy scores. This way, the remaining variance could be attributed to participants' ability to simultaneously process the multi-element array.

We also included assessment of RAN as a predictor in the analyses, since this is thought to reflect phonological-lexical retrieval processes that are important for establishing lexical representations (e.g., Moll et al., 2014). We predicted that VAS and RAN would be significantly associated with spelling accuracy in the Mandarin-speaking 10- to 12-year-old children in the current study. We also expected to find significant associations between spelling and PA and MA, on the basis of previous research on spelling in Chinese. Finally, we included assessment of verbal short-term memory, since this has been found to be associated with spelling ability in previous research (e.g., Deacon et al., 2009; Niolaki et al., 2020; Tong et al., 2009; Van Den Boer et al., 2015; Yeung et al., 2011).

The age range of the children in the present study was from 10 to 12 years. This corresponds with the age of children in the regression-based studies examining the relationship of VAS and spelling ability in alphabetic writing systems (Niolaki et al., 2020; Niolaki et al., 2024; Van Den Boer et al., 2015), and we were aiming to see whether the results would be comparable across languages. In these previous studies, a reliable prediction of VAS to spelling accuracy was found for older elementary school children (aged 9 and upwards). Results of the study by Zhao et al. (2018) looking at the influence of VAS on reading in Chinese speaking children indicated that VAS might be more critical for literacy in Chinese students in higher school grades (Grade 5 and 6) 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. Thus, we targeted children in Grade 5.

In summary, the contribution of VAS to Chinese reading seems to be supported by findings from several studies. While studies carried out with alphabetic writing systems have extended the association of VAS to spelling, this has not yet occurred for Chinese spelling. We used correlation analyses to first examine interrelationships among the variables, and then hierarchical regression analysis to determine the significant predictors of spelling accuracy. Finally, two structural equation models were constructed. We predicted that, given the previous findings with alphabetic orthographies of a significant unique prediction of VAS after controlling for a range of other literacy related processes, then, due to the greater demands on visual orthographic processing posed by written Chinese, we would find that VAS would be a significant predictor of spelling accuracy in Grade 5 Mandarin-speaking children after controlling for the effect of character recognition ability, and the literacy related abilities PA, RAN, MA and verbal short-term memory.

2. Method

2.1. Participants

Fifty-six children aged 10 to 12 years ($M = 10.65$, $SD = 0.63$, 26 girls) were participants in the present study. The children attended Grade 5 of a primary school in northeastern mainland China with a mixed middle to low SES background (on the basis of school district). None of the children had any learning difficulties 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 32 children, so the sample size of 56 children was sufficient for this study.

Given evidence of gender differences in cognitive development and linguistic processing (e.g., Adams & Simmons, 2019; Ardila et al., 2011), we conducted independent *t*-tests to assess potential gender-based variation in demographic and cognitive and linguistic measures. We did this to ensure that any observed effects in the main analyses were not due to confounding effects of gender. The results for the boys and girls separately are summarised in Table 1 (details of the assessments are given in the *Materials* section). Results of the t-tests indicated that there were no significant gender differences, except for the variable of chronological age - girls: Mage = 10.45, boys: Mage = 10.82, $t(53) = 2.08$, $p = .04$.

All the children had Mandarin as their first and main language, and they used simplified Chinese characters. According to the curriculum of the Ministry of Education in mainland China, primary schools teach children in the first grade the Pinyin system within 42 to 46 sessions (with duration usually 40–45 min per session). In addition, across all grades children are taught to copy characters in notebooks, and teachers are required to assess character learning through administration of writing (spelling)-to-dictation tasks. The recruited children followed this national curriculum for pinyin and character copying instruction.

Table 1
Mean Chronological Age and Assessment Scores for the Boys and Girls, Together with Results of Independent t-tests.

	Boys ($n = 30$)	Girls ($n = 26$)	t	p
Variables	Mean (SD)	Mean (SD)		
Age	10.82 (0.62)	10.45 (0.60)	2.08	0.04
Spelling accuracy (/60)	43.75 (7.66)	45.81 (6.60)	−1.05	0.30
Nonverbal ability (/60)	30.11 (4.49)	30.85 (3.52)	−0.67	0.51
Vocabulary (/120)	98.10 (7.92)	98.77 (7.19)	−0.33	0.74
Visual Attention Span (/120)	66.48 (12.48)	65.84 (13.10)	0.18	0.85
Character identification (/150)	108.77 (12.16)	108.46 (18.68)	0.07	0.94
Phonological awareness (/26)	18.82 (4.02)	20.21 (4.47)	−1.18	0.24
Morphological awareness (/124)	89.73 (14.59)	91.52 (8.55)	−0.56	0.58
RAN (seconds)	37.60 (8.26)	35.61 (7.47)	0.92	0.36
Verbal short-term memory (/13)	8.21 (1.20)	8.44 (1.71)	−0.50	0.62

In the classroom children are instructed that if they come across a character with unknown pronunciation, they should search for it in their dictionary (every child has a Chinese dictionary with pinyin transcription for each Chinese character). English language instruction is provided from Grade 3 to 6 and involves first learning how to sound out and write letters of the Latin alphabet, then word reading and writing, grammar and text reading, and finally composition writing.

Ethical approval for the study was obtained from the authors' university ethical review board. Written informed consent to participate in the research was obtained from the children, the children's parents/guardians, and the teachers before testing began.

2.2. Materials

2.2.1. Writing (Spelling) to dictation task

Spelling was assessed using the 60-item list from Masterson et al. (2008) and translated into Mandarin by Wong (2017). Wong referred to the Zhonghua Dictionary (Luk & Au Yeung, 1978) to ensure target items were selected with the most similar meaning to the original English target words. The words were originally chosen on the basis that they were 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 writing (spelling) to dictation task. The translated list of items comprises 41 single character words, 18 two-character words and one three-character word.

Printed frequency values for the 60 words were obtained from the database of words in children's books compiled by Li et al. (2023, Chinese Children's Lexicon of Written Words, CCLOWW database). Zipf frequency values were extracted. Zipf frequency is a standardised frequency measure that was introduced by van Heuven et al. (2014). It is calculated as log10 (frequency per million words) + 3 and has the advantage over raw frequency values that its interpretation does not depend on the size of an individual corpus. The Zipf scale is a logarithmic scale and ranges from 1 to 7 (with 7 being highest frequency). For the words in the 60-item list in the present study the mean was 4.42 ($SD = 0.90$). The word list and Zipf frequency values can be found at Appendix A.

We asked five Chinese teachers, one teaching Grade 4, two Grade 5, and two Grade 6, to rate how familiar they thought the words were to children aged 10 to 12 years. To obtain the ratings we used a five-point Likert scale (with 1 representing 'highly unfamiliar' and 5 representing 'highly familiar'). The mean familiarity rating for the words was 4.76 ($SD = 0.5$). We investigated the association of the teachers' familiarity ratings and the Zipf frequency values from Li et al. (2023), as well as the association of these two variables with Zipf frequencies for the English translations of the 60 words (the English frequency values were obtained from the Children and Young People's Books-Lexicon, CYP-LEX, Korochkina et al., 2024). Pearson's correlations revealed a significant association between the Chinese frequency values and the teacher ratings, $r = 0.60$, $p < .001$, as well as between the teacher ratings and the English frequency values, $r = 0.52$, $p < .001$, and the Chinese and English frequency values, $r = 0.58$, $p < .001$. The frequency values and the teacher familiarity ratings can be found in Appendix A.

In administering the writing (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. Scoring involved awarding one point for each correctly spelled word. If one character in a multi-character word was misspelt, the child received no score for that target. This meant that for multi-character words, children would not earn any points, even if they correctly spelt the other characters but made a mistake with just one. The maximum correct score was 60. Cronbach's alpha was calculated as 0.88, based on the scores from the current study.

2.3. *Cognitive and linguistic measures*

Verbal short-term memory, PA, RAN, VAS, character identification, morphological awareness (MA) and vocabulary were evaluated. Nonverbal ability was controlled for in the analyses, as this has also been found to be associated with spelling skill (e.g., Lim et al., 2014). Raven's Standard Progressive Matrices was employed as the assessment of nonverbal ability (Raven et al., 1996).

2.3.1. *Visual attention span (VAS)*

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 (the reliability was reported in that study to be 0.83 for adults). For the present study, the characters from Chan and Yeung's study were employed but in simplified form because the participants were Mandarin speakers. The simplified characters were tested in a pilot study with five 10- to 12-year-old children who were randomly selected at the participants' school (these children did not take part in the main study). The characters were common ones, usually learned by children in Grade 1, and they were all found to be familiar to the children in the pilot 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 with two practice trials. Characters in each array were randomly arranged, and none of the arrays contained or constituted semantically meaningful sequences. The task was programmed in PsychoPy. 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 asked 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 was 120, and Cronbach's alpha was 0.92 based on the scores in the present study.

2.3.2. *Single-character identification*

A character identification task was employed. The stimuli were the 10 Chinese characters used in the VAS task. 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) and each character appeared once at each presentation duration (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) and Awadh et al. (2016), that is, accuracy at 33 ms $\times$ 5 + accuracy at 50 ms $\times$ 4 + accuracy at 67 ms $\times$ 3 + accuracy at 84 ms $\times$ 2 + accuracy at 101 ms. Cronbach's alpha was 0.74 based on the scores of the participants in the present study.

2.3.3. *Verbal short-term memory*

Verbal short-term memory was assessed using the Digit Span Forward subtest of the Chinese Wechsler Intelligence Scale for Children (C-WISC for Urban cases; Gong & Cai, 1993, with test-retest reliability reported to be 0.76). Cronbach's alpha was 0.75 based on the scores of the participants in the present study. Materials were randomly ordered digits 1 to 9, and no digits were repeated in individual arrays. 26 arrays in total were presented, with an increasing number of digits (two arrays for each number of digits, the number of digits ranging from 1 to 13). The researcher read out the digit sequence and the child was asked to repeat the digits in the correct order. If the child made a mistake, the alternative sequence with the same number of digits was read out by the researcher. If participants still made a mistake, the task would be stopped and their score for the task was n-1. Otherwise, the task would continue until participants made a mistake in both arrays with the same number of digits. The children's score was determined by the highest number of digits they were able to repeat correctly.

2.3.4. *Phonological awareness (PA)*

The phoneme deletion task from Song et al. (2020) was adopted to assess phonological awareness. Children were presented with monosyllabic words with one, two, or three phonemes spoken (in Chinese) by the tester, and were asked to repeat the item 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/‘). The task comprised 26 items for the main task and eight practice items. Correct responses were given one point. Cronbach's alpha was 0.80 on the basis of participants' scores in the present study.

2.3.5. *Rapid automatised naming (RAN)*

The RAN task was from the Phonological Assessment Battery (Frederickson et al., 1997) and involved Arabic numerals 1 to 9. There was a practice trial with eight digits. For the main testing, the children were shown a grid of 100 digits randomly ordered, in two rows consisting of 10 five-digit arrays. The children were asked to name the digits in sequence as quickly and accurately as they could. The time to complete naming the digits was recorded in seconds. Test-retest reliability was 0.88 on the basis of participants' scores in the present study.

2.3.6. *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 was 124 (four points × 31 items). Cronbach's alpha was 0.75 based on the scores in the present study.

2.3.7. Vocabulary

Based on the Peabody Picture Vocabulary Test developed by Dunn and Dunn (1997), the Peabody Picture Vocabulary Test – Chinese edition (PPVT-C, Gong & Guo, 1984), was used to assess receptive vocabulary. The test-retest reliability and split-half reliability are reported to be 0.95. Trials were conducted using PowerPoint presentation, with the researcher sharing the computer screen to display the materials. For each trial, a spoken word was provided via recorded audio, and the child was asked to point to the number corresponding to the correct picture out of four choices. The task ended when children made more than five errors on a set of eight trials. Performance was measured in terms of raw scores (i.e., ceiling item – total errors). The maximum score was 120. Cronbach's alpha was 0.82 based on scores in the present study.

2.4. Procedure

The data were collected over the autumn school term in 2021. Two trained class teachers helped to collect the nonverbal ability and spelling data. Group testing for nonverbal ability (lasting c. 30 mins) and writing (spelling)-to-dictation (lasting c. 15 min) was first carried out in the classroom, with a 15-min break after the children finished the nonverbal ability test.

One week later, the assessments of VAS, RAN, PA, MA, vocabulary and verbal short-term memory, were completed in one session (lasting c. 70 min including rest breaks) and conducted individually online by the first author due to COVID-19 restrictions. The assessments were carried out in the school IT room, and Lenovo computers with 21.5-in. screens and a display resolution of 1920 × 1080 were used. Before the assessments began, children were seated by their class teacher at a distance approximately 50 cm from the computer screen. The computer microphone was checked, and the shared screen was used (by the first author) to introduce the tasks.

For the tasks that required children to respond to stimuli presented on the computer screen (vocabulary, VAS 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, PA and MA), the shared screen was turned off after the introduction of the trials. Rest breaks were given between the tasks. Three months later the character identification task (lasting c. 6 min) was administered by the first author, again online, and under the same conditions as for the other tasks that involved presentation of stimuli on the computer screen.

2.5. Data analysis

Pearson's correlation and partial correlation analyses were employed to explore the relationship between cognitive and linguistic skills and spelling performance. Subsequently, hierarchical regression analysis was conducted to examine which measures were significant predictors of spelling accuracy. Path analysis was also conducted.

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 short-term memory, vocabulary and VAS with the children's spelling accuracy are presented. Table 2 provides a summary of the children's scores in all the assessments.

We examined the data for outlier scores and excluded those that were more than three standard deviations above or below the group mean on the different assessments. This resulted in between one and two scores for 13 of the 56 children being excluded. In terms of the distribution of excluded datapoints within the individual assessments - two were for nonverbal ability, RAN and VAS, three for MA and verbal short-term memory, and four for PA. Following the exclusion of these datapoints, exploratory data analysis was conducted. Results of Shapiro-Wilk test revealed that scores for verbal short-term memory alone were not normally distributed. The scores for this variable were subjected to inverse-normal transformation (Templeton, 2011). *Re*-testing revealed that the assumption of normality was not violated and the transformed scores for verbal short-term memory were used in the analyses.

3.1. Correlations among the measures

There were no significant gender differences in any of the variables except for chronological age. When gender was treated as a binary variable in the correlation analyses there were no significant simple or partial (controlling for age and nonverbal ability) correlations of gender with the other variables.

The results for simple correlation and partial correlation analysis, controlling for age and nonverbal ability, are reported in Table 3.

Spelling accuracy scores were significantly associated with those for VAS, single character identification, PA, and RAN in the partial correlation analysis. These variables, together with MA and nonverbal ability, were included as predictors in the regression analyses.

3.2. Regression analyses

Hierarchical regression analyses were conducted with spelling accuracy as the dependent variable. In Step 1, age and nonverbal ability was entered. In Step 2, PA, RAN, MA and character identification were entered, and then VAS was entered in Step 3. The results of the analysis are presented in Table 4.

At Step 2, PA, RAN, MA and character identification were all significant predictors and together explained 54% of the variance in spelling scores. At Step 3, VAS was a unique predictor and explained 6% of the variance ($p < .05$).

3.3. Path analysis

Finally, two path analysis models were conducted using the *Lavaan* package in R. Model A in Appendix C was constructed on the basis that all independent variables were postulated to predict spelling accuracy, based on the background literature covered in the Introduction. Model B in Appendix D was based on the hierarchical regression results. The overall fit of Model B was not significantly different from that of the first model, $\Delta\chi^2(12, N = 56) = 7.43$, $p = .83$, but Model B fit the data better and was more focused and clearer than the first model. So, the second model was the preferred model for conceptualising the interrelations among the variables in the study. A significant mediating role for VAS, between RAN and spelling accuracy, was found in this model.

Table 2
Descriptive Statistics for Spelling Accuracy, Nonverbal Ability, Vocabulary, VAS, Character Identification, Phonological Awareness, Morphological Awareness, RAN, and Verbal Short-Term Memory.

Variables	*Mean* (*SD*)	Range
Spelling accuracy (/60)	44.74 (7.18)	30–60
Nonverbal ability (/60)	30.46 (4.03)	21–41
Vocabulary (/120)	98.41 (7.53)	86–114
VAS (/120)	66.19 (12.65)	37–91
Character identification (/150)	108.63 (15.38)	39–132
Phonological awareness (/26)	19.46 (4.25)	10–26
Morphological awareness (/124)	90.51 (12.27)	55–115
RAN (seconds)	36.68 (7.89)	21.41–57.3
Verbal short-term memory (/13)	8.32 (1.45)	5–12

Table 3
Pearson's Correlation Above the Diagonal and Partial Correlation Controlling for Age and Nonverbal Ability Below the Diagonal.

		2	3	4	5	6	7	8	9	10
1	Age	−0.21	0.05	−0.09	0.06	−0.08	−0.03	−0.05	−0.18	0.06
2	Nonverbal Abil.	–	0.31*	0.02	−0.12	0.11	0.25	0.11	0.40**	0.24
3	Vocabulary	–	–	0.10	0.17	−0.05	0.09	0.01	0.22	0.19
4	Spelling	–	0.19	–	0.41**	0.19	0.52***	−0.37**	0.36**	0.11
5	VAS	–	0.24	0.42**	–	−0.14	0.07	−0.45**	0.14	0.04
6	Char. Ident.	–	0.06	0.44**	−0.03	–	0.23	−0.12	0.16	0.09
7	PA	–	−0.02	0.52**	0.01	0.24	–	−0.09	0.31*	0.10
8	RAN	–	0.02	−0.41**	−0.39*	−0.20	−0.13	–	−0.07	−0.05
9	MA	–	0.29	0.25	0.02	−0.01	0.12	0.04	–	0.10
10	Verbal STM	–	−0.07	0.24	0.17	0.13	0.06	−0.06	−0.03	–

Note. Nonverbal Abil.: Nonverbal Ability, Char. Ident.: character identification, PA: phonological awareness, RAN: rapid automatised naming, MA: morphological awareness, Verbal STM: verbal short-term memory.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

Table 4
Hierarchical Regression Analyses with Spelling Accuracy as the Dependent Variable.

Spelling accuracy							
Step		ΔR^2	ΔF	β	*t*	Tol	VIF
1		0.01	0.16				
	Age			−0.08	−0.52	0.93	1.07
	Nonverbal Abil.			0.02	0.11	0.93	1.07
2		0.54***	11.33				
	PA			0.39**	3.36	0.88	1.14
	RAN			−0.27*	−2.40	0.95	1.05
	MA			0.29*	2.38	0.82	1.22
	Char. Ident.			0.31*	2.66	0.86	1.17
3	VAS	0.06*	6.06	0.29*	2.46	0.76	1.32

Note. Nonverbal Abil.: Nonverbal Ability, PA: phonological awareness, RAN: rapid automatized naming, MA: morphological awareness, Char. Ident.: character identification.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

4. Discussion

To the authors' knowledge, this was the first study to explore the impact of visual attention span (VAS) on the writing (spelling)-to-dictation performance of Mandarin-speaking children. Covid-19 restrictions in place at the time that the study was carried out meant that testing was largely conducted remotely. However, the internal consistency scores for the different assessments were high, and we obtained results in keeping with those from previous relevant studies (e.g., Chan & Yeung, 2020; Liu & McBride-Chang, 2010; Song et al., 2020), indicating that the assessments were reliable. The scores in the VAS assessment were a main focus of interest in the current study. We calculated the results for accuracy in the task according to array position as reported in Bosse et al. (2007), in order to be able to examine the reliability of our VAS results (presented in Fig. 1 in the Appendix B). The results are comparable with those obtained in previous studies examining the association of VAS and children's spelling to dictation (Niolaki & Masterson, 2013; Valdois et al., 2003; Van Den Boer et al., 2015), again suggesting that the testing procedures were robust.

We observed significant correlations of PA, RAN, and MA with spelling accuracy, 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 54% 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 enabling the deconstruction of complex Chinese words such as compound words, through distinguishing and organising the morphemes, which may be helpful for spelling production (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 English instruction from the third grade. 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.

We found that individual character identification skill predicted spelling accuracy, highlighting the importance of recognition of single characters for effective Chinese spelling, which is in line with studies in alphabetic writing systems that have shown a high degree of association of word reading and word spelling ability (e.g., Graham & Hebert, 2011). This character identification task may engage visual processing in global configuration of 10 target characters and position coding of radical combinations, which may relate to Chinese character processing.

We found that VAS and PA were not significantly associated, which supports the independence of VAS and phonological skills, as previously argued by, for example, Valdois et al. (2003) and Bosse et al. (2007). A significant association between VAS and RAN was found, which may suggest 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 (Stainthorp et al., 2010). Considering potential non-overlapping aspects of the VAS and RAN measures, the additional feature required in the task used to assess VAS is the requirement to rapidly process the stimuli in parallel. Previous studies with Chinese-speaking adults found that the number of character strokes, as a measure of visual complexity, was associated with processing speed in recognizing characters (e.g., Peng & Wang, 1997; Zhang & Feng, 1992). It seems logical then that the ability to carry out efficient parallel visual processing, as measured by the VAS global report task, will be particularly important for developing detailed representations of complex Chinese orthographic forms that can be drawn on for spelling.

Supporting this view, we found in the regression analysis that VAS remained a significant predictor of spelling accuracy when entered after scores for PA, RAN, and character identification were entered. Van Den Boer et al. (2015), Niolaki et al. (2020) and Niolaki et al. (2024) also reported that VAS (assessed with a letter 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.

In terms of the theoretical model presented in the Introduction, VAS capacity has been associated with lexical reading and spelling processes more than sublexical processes (e.g., Bosse, 2015; Bosse et al., 2007). The observation of more reliable prediction of VAS to spelling in older than younger English-speaking children in Niolaki et al. (2020) was interpreted in terms of the predominant reliance on sublexical processing in younger children and a switch to lexically-related processes in older children. The fact that a relationship of spelling with VAS was not found in the Greek-speaking younger children but in the older children in Niolaki et al. (2024) was interpreted as being due to the transparent nature of written Greek, which would encourage great reliance on sublexical processes at least in the early stages. By extension, the finding in the present study of an association of VAS and spelling accuracy would indicate that these children (who were aged 10 to 12 and therefore equivalent to the older groups in the previous regression-based studies) were employing lexically-based processes for spelling. On the basis of the findings for opaque English versus transparent Greek, we could then predict that we would find the association of VAS and spelling accuracy in younger Mandarin-speaking children. This prediction remains to be tested.

Previous studies already supported an influential role of VAS in Chinese reading development (e.g., Huang et al., 2019). It has been suggested that this is due to a significant role for VAS in orthographic knowledge acquisition (e.g., Bosse & Valdois, 2009; Bosse, 2015; Zhao et al., 2018). Van den Boer et al. (2015) suggest that an alternative interpretation of the role of VAS may relate to the quality of orthography-phonology connections and the ability to activate phonological representations in parallel upon encountering orthographic input, and vice versa, highlighting the bidirectional and dynamic nature of orthography-phonology connections in skilled reading and spelling. This interpretation seems to resonate with aspects of the orthographic working memory component of current models of spelling (e.g., McCloskey & Rapp, 2017; Mo, 2023), since the strength of activation of orthographic units by phonological units will be a limiting factor for output processes. It may be informative in future studies to examine performance in tasks that have been used to examine orthographic working memory, such as delayed copying, in conjunction with VAS tasks.

The finding from Model B, whereby VAS mediated the relationship between RAN and spelling, can be interpreted in terms of views of the role of VAS and of RAN in literacy acquisition. Research indicates that RAN reflects the efficiency of serial processing and the retrieval of phonological codes (de Jong & van den Boer, 2021). Thus, children with good rapid naming ability will be able to build orthographic entries due to the effective association of phonological codes and orthographic forms in reading and during instruction. However, accurate spelling, especially in a character-based system like Chinese, will be further facilitated by the precise retention of elements of orthographic forms, and this is where VAS may play a mediating role. A wider VAS is thought to facilitate the parallel processing of the multiple, complex strokes and radicals that constitute a Chinese character, creating a robust orthographic template (Chan et al., 2020). Therefore, even if a child has good RAN ability, they may only achieve fully effective spelling if they also possess sufficiently developed VAS ability to encode and recall the detailed visual-orthographic structure of characters.

While we acknowledge that the mediation effect observed should be interpreted with caution due to the sample size, it offers a potentially valuable theoretical insight: it suggests that beyond phonological retrieval, the ability to efficiently process visual-orthographic information in parallel is a key mechanism that contributes to spelling mastery in Chinese.

In terms of implications for instruction of the findings, one reason for poor spelling among Chinese children may be a weakness of VAS. If a VAS deficit is detected in poor spellers, educators may consider VAS-targeted interventions. Prior training studies focusing on a VAS deficit have proved to be effective in improving reading skill in children with reading difficulties (Niolaki et al., 2020; Niolaki & Masterson, 2013; Valdois et al., 2014; Zhao et al., 2019). Valdois et al. (2024) recently reported spelling (and reading) improvement following a training programme that involved rapid detection of alphanumeric strings in grade 1 typically developing French speaking children. The findings from the current study indicate that VAS-focused training may also be effective for a spelling weakness due to a VAS deficit in Mandarin speaking children.

4.1. Limitations and future directions

Limitations of this study include the fact that the findings may have limited generalizability since the children 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 generalizable 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.

A second potential limitation arises from the fact that we used only a single measure for the variables MA, RAN, VAS, PA, character identification and verbal STM. Although this was necessitated by considerations of testing time for the children, we need to acknowledge that different results may be observed if alternative measures are employed. A future study could also 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. Finally, it will be informative for exploring the causality of relationships in future research through longitudinal and intervention studies. Despite the limitations of the current study, the findings indicate that VAS, PA, RAN, and character identification are influential processes in the spelling of Mandarin-speaking children.

5. Conclusion

In conclusion, PA, RAN, MA and character identification significantly explained 54% of the variance in spelling accuracy of Mandarin speaking 10- to 12-year-old children after controlling for age and nonverbal ability. When VAS was entered in a final step in the hierarchical regression analysis it was found to be a unique predictor of spelling accuracy. The findings suggest an important role for simultaneous multi-element processing in spelling in Chinese.

CRediT authorship contribution statement

Tianyi Wang: Writing – original draft, Software, Methodology, Investigation, Data curation. **Liory Fern-Pollak:** Writing – review & editing, Software. **Jackie Masterson:** Writing – review & editing, Validation, Supervision, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

The author(s) did not use any AI tools during the writing process.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Items in the Writing (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 B

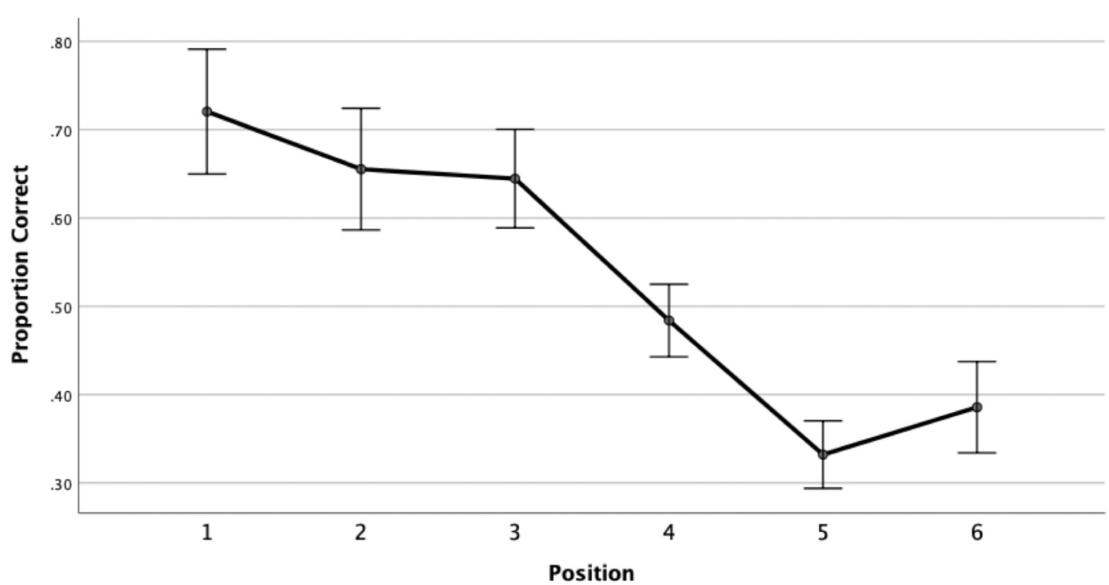
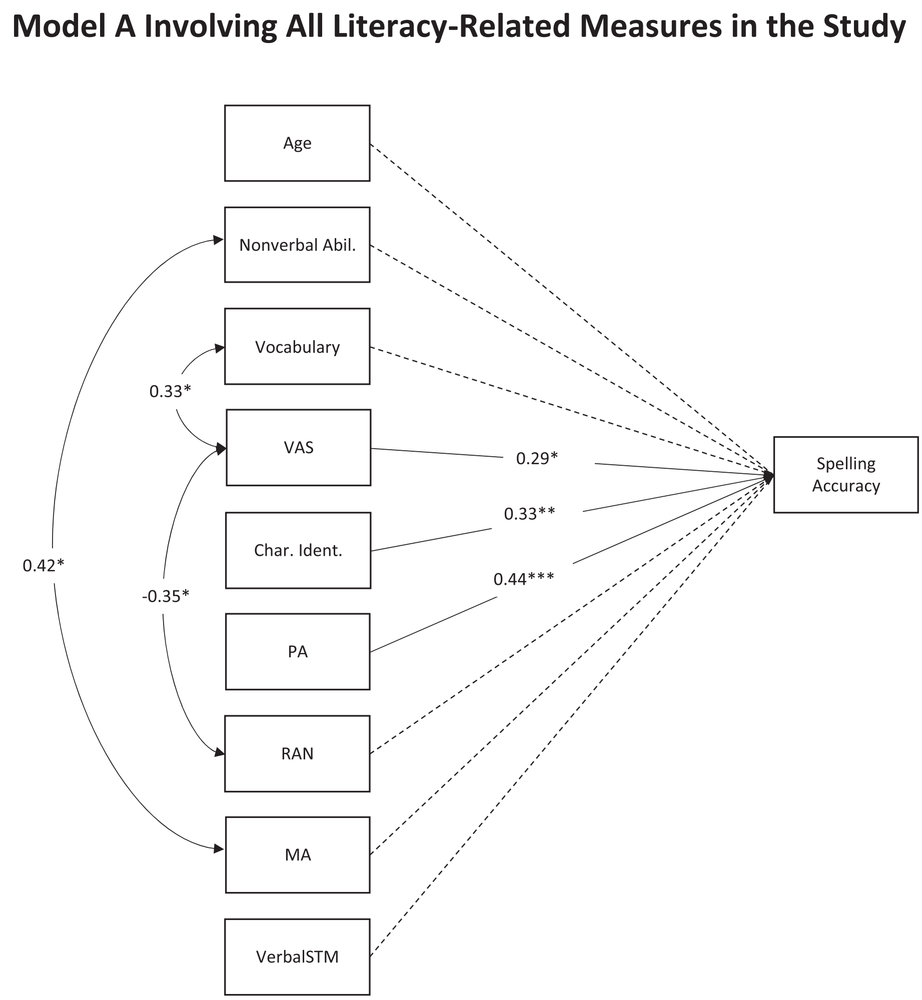


Fig. 1. Proportion of Correctly Identified Items Calculated Across Participants at Each Array Position in the VAS Task

Appendix C



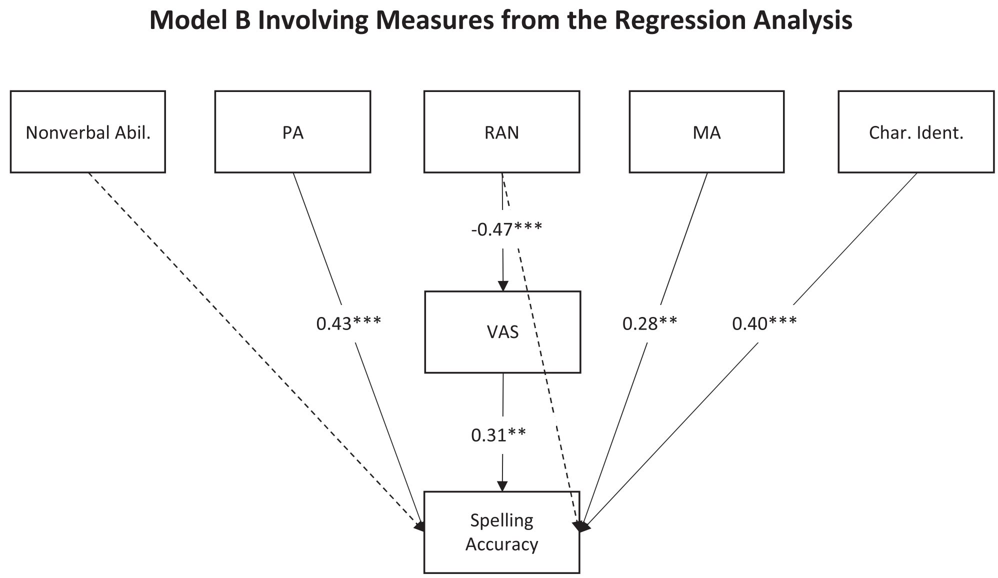
Model A Involving All Literacy-Related Measures in the Study

Note. Dashed lines indicate non-significant path loadings. The curve lines with two arrows indicate significant covariances.

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

$\chi 2$ (22) = 22.56, p = .43, GFI = 0.91, CFI = 0.99, RMR = 6.96, SRMR = 0.12, RMSEA = 0.03, AIC = 2451.840.

Appendix D



Model B Involving Measures from the Regression Analysis
Note. Dashed lines indicate non-significant path loadings.
$^*p < .05$. $^{**}p < .01$. $^{***}p < .001$.
$\chi 2$ (10) = 15.13, p = .13, GFI = 0.91, CFI = 0.90, RMR = 7.12, SRMR = 0.13, RMSEA = 0.11, AIC = 2157.29.

Data availability

The data are available on request from the corresponding author.

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