China's language input system in the digital age affects children's reading development

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Written Chinese as a logographic system was developed over 3,000 y ago. Historically, Chinese children have learned to read by learning to associate the visuo-graphic properties of Chinese characters with lexical meaning, typically through handwriting. In recent years, however, many Chinese children have learned to use electronic communication devices based on the pinyin input method, which associates phonemes and English letters with characters. When children use *pinyin* to key in letters, their spelling no longer depends on reproducing the visuo-graphic properties of characters that are indispensable to Chinese reading, and, thus, typing in pinyin may conflict with the traditional learning processes for written Chinese. We therefore tested character reading ability and pinyin use by primary school children in three Chinese cites: Beijing (n = 466), Guangzhou (n = 477), and Jining (n = 4,908). Children with severe reading difficulty are defined as those who were normal in nonverbal IQ but two grades (i.e., 2 y) behind in character-reading achievement. We found that the overall incidence rate of severe reading difficulty appears to be much higher than ever reported on Chinese reading. Crucially, we found that children's reading scores were significantly negatively correlated with their use of the pinyin input method, suggesting that pinyin typing on e-devices hinders Chinese reading development. The Chinese language has survived the technological challenges of the digital era, but the benefits of communicating digitally may come with a cost in proficient learning of written Chinese.

child development | developmental dyslexia | language learning

Reading is a crucial skill for children to master. It is not only necessary for success in school, but also important for maintaining a decent quality of life in our increasingly literate society. Cognitive scientists and psycholinguists have maintained that learning to read requires skills in orthographic (i.e., the appearance of a word), phonological, and semantic facets of printed words (1). This basic, lexical-level knowledge highly correlates with text comprehension and thus constitutes a major behavioral marker of reading ability (1).

Although formation of a coherent and integrated reading circuit is universally critical for successful reading development (2), strategies toward helping children develop and retain such a reading network vary with the nature of writing systems. For example, children's awareness of the phonological structure of speech sounds and their knowledge of letter–sound correspondences play a pivotal role in reading development in English and other alphabetic languages, and reading instruction and remediation programs have therefore centered on phonological training (1–16). For Chinese readers, children's reading acquisition begins with a demanding visuospatial analysis of characters' graphic forms composed of strokes and subcharacter components that are packed into a square (2, 17, 18), followed by rote memory of arduous lexical mappings of orthography to phonology, orthography to meaning, and phonology to meaning (19, 20). A prevalent strategy in facilitating the development of these mappings is handwriting, which requires children to repeatedly copy single characters to help them to elaborate the visuo-orthographic analysis of characters and to establish their representation in long-term memory (21–25).

Severe reading difficulty arises when children fail to establish a cohesive reading circuit that links orthography, phonology, and meaning. Reading difficulty is defined as an unexpectedly low reading ability in people who have adequate nonverbal intelligence, have acquired typical schooling, and have experienced sufficient sociocultural opportunities (1–12). Estimates of prevalence of severe reading difficulty in English range from 5% to 17% (3, 8, 11, 13). Severe reading difficulty has also been found in Chinese speakers, with incidence rates ranging from 1.92% to 7.96% in mainland China (26, 27) and 7.9% in Taiwan (28), as reported in studies conducted before the mid-1990s.

Learning to read in the information age is even more challenging. Electronic forms of communication via computers, cell phones, and other devices make digitized books accessible to everyone with Internet access, thus opening up the availability of education beyond pencil and paper to digital media. On the other hand, increasing reliance on electronic modes over handwriting for communications may impact children's reading skill acquisition. The input method for English words is straightforward: pronouncing words silently and mapping sounds onto letters, keying in letters on the keyboard, and viewing them on the monitor almost simultaneously. This method connects phonological and visuographic properties of words and may enhance knowledge of letter–sound correspondences. Written Chinese presents a different case. Its logographic nature makes it difficult to adopt an input method that relies on its orthographic structure (29). One solution is to create an input method that is based on the pronunciation of whole characters—the *pinyin* method. This method, most popularly used in mainland China, allows users to input a character (e.g., 梨, pronounced /li/, meaning "pear") by typing its pinyin (li) and then select the appropriate character from a list of characters sharing the same pinyin (e.g., 里利力利梨立例丽荔理离礼). With this input technique, users type alphabetic letters instead of characters' components (strokes, components, or radicals), and thus visuospatial properties of characters indispensable to Chinese reading are never involved during the typing process. As a result, typing in pinyin may conflict with the typical reading development processes that start with visual-graphic analysis of written characters and that are enhanced by handwriting. If children use the pinyin input method early and frequently, particularly before reading skills have been acquired, their reading development could be slowed. Consequently, the prevalence rate

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of severe character-reading difficulty in China may increase in the information age.

Results

We conducted two experiments with a large sample of primary school children from three cities in China to test this hypothesis (Table 1). In experiment 1, fourth and fifth graders from one primary school in Beijing (n = 466) and one primary school in Guangzhou (n = 477) were administered individually a reading test. The test was composed of 300 Chinese characters, among which 250 were selected from their textbooks (the children in these two cities used identical Chinese language textbooks) and the other 50 low-frequency items were from a language corpus. The numbers of characters from first to sixth grade textbooks were 20, 30, 40, 50, 60, and 50, respectively. Characters were arranged in a list from easy to difficult based on grade level and visual complexity or stroke number. Children were asked to read the characters aloud as quickly and accurately as possible. They were also tested on nonverbal intelligence (IQ) by the Raven's Progressive Matrices test. Children were excluded from the sample if their IQ scores were lower than the 25th percentile. There were 419 children in the final sample in Beijing (241 fourth graders, mean age: 9 y, 7 mo; 178 fifth graders, mean age: 10 y, 7 mo) and 401 in Guangzhou (208 fourth graders, mean age: 10 y, 2 mo; 193 fifth graders, mean age: 11 y, 2 mo).

We report children's reading skills in terms of "grade-level equivalents" (or "expected reading level") in a similar way to Zhang et al. (27) and Stevenson et al. (28), the two most cited studies of the prevalence of Chinese reading problems. Children of severe reading difficulty were defined as those who had a reading performance two grades behind the expected reading level. Specifically, the expected reading level was measured with two methods. Method 1 followed the character/word reading test in Stevenson et al. (28) and Zhang (27), and each grade level was calculated by adding together the number of items for the preceding grades and 75% of the items for the actual grade (hereafter "the Stevenson criterion"). For example, to meet the criteria for the third-grade level, children would need to respond correctly on 80 items (20 for grade 1, 30 for grade 2, and 75% of the 40 items for grade 3). Method 2 followed China's standard grading principle, and each grade level was calculated by adding together the number of items for the preceding grades and 60% of the items for the actual grade (60% means a "pass" in China's scoring system) (hereafter "the China scoring criterion").

The reading score distribution, which is trimodal, is shown in Fig. 1. The first peak represents the scores of children who performed at the second-grade level; the second and third peak corresponds to the characters acquired at the beginning of grade 3 and grade 4, respectively, implying that representation quality might be higher for characters learned early in a new grade. Fig. 1 indicates that a large portion of children in both Beijing and Guangzhou obtained very low scores. The percentages of children who were two grades below the expected reading level are surprisingly high, as illustrated in Fig. 2. For fourth graders, the percentages of children who had severe reading difficulty were 31.12% in Beijing and 30.29% in Guangzhou, according to the Stevenson criterion, or 20.75% in Beijing and 25% in Guangzhou in terms of the China scoring criterion. For fifth graders, the percentages increased to 35.39% and 57.51%, respectively, according to the Stevenson criterion, or 29.78% and 51.81% according to the China scoring criterion. The difference between the two cities, especially for fifth graders, may be related to the socioeconomic status of our subjects.

To investigate whether these high-incidence rates of severe reading difficulty are generalizable to nonmajor cities in China, we conducted experiment 2 with another large group of children in Jining, a subordinate city 30 miles away from Confucius' hometown in Shandong Province and more representative of China. Reading skills of third to fifth graders from five primary schools and fifth graders from a sixth primary school were tested individually (n = 4,908). All these schools were in the center of the city and used Putonghua, the official language of mainland China, as the medium of instruction. A different reading test was constructed because Jining primary schools used different Chinese language textbooks from those in Beijing and Guangzhou and because Jining has adopted a 5-y basic education system whereas Beijing and Guangzhou use a 6-y system. The reading test contained 250 Chinese characters, of which 200 were from the textbooks for first to fifth graders (40 characters for each grade), and the other 50 low-frequency items were not covered in the textbooks but from a Chinese language corpus. Again, characters were arranged in increasing difficulty based on grade level and visual complexity or stroke number. Children were excluded from the

Table 1. Demographic characteristics and descriptive statistics for all children in Beijing, Guangzhou, and Jining

	Beijing		Guangzhou		Jining		
	Grade 4	Grade 5	Grade 4	Grade 5	Grade 3	Grade 4	Grade 5
No. of children	263	203	250	227	1,262	1,322	2,324
No. of boys	146	109	145	114	669	714	1,288
No. of girls	117	94	105	113	593	608	1,036
Mean age in months (SD)	114.55 (4.58)	126.90 (5.50)	121.71 (4.22)	134.21 (4.72)	110.18 (5.38)	121.80 (6.14)	133.83 (5.08)
No. of children administered the nonverbal IQ test	262	203	248	226	1,222	1,247	1,209*
Mean nonverbal IQ in percentile (SD)	75.02 (21.16)	73.08 (23.52)	67.94 (25.15)	70.71 (24.66)	72.31 (24.51)	68.64 (23.78)	70.45 (24.40)
No. of missing data (date of birth, reading score)	—	—	2	1	21	44	4
No. of children with nonverbal IQ below 25th percentile	21	25	38	32	152	154	165
No. of children in the final sample	241	178	208	193	1,049	1,049	1,040
Mean character-reading score (maximum = 300 for Beijing and Guangzhou and 250 for Jining) (SD)	63.31 (30.62)	100.92 (45.44)	64.87 (33.75)	89.88 (48.46)	71.56 (24.43)	79.84 (30.93)	102.79 (38.92)

SDs are shown in parentheses.

*One primary school in Jining was cooperative in giving us time to administer the reading test to its 1,115 children in grade 5 but had difficulty giving us time for the nonverbal IQ test. So, in the final sample, the children's data from that school were not included. However, we performed an independent analysis of the incidence rate of reading difficulty in that school and found that 55.61% of children had reading scores that were two grades behind the expected reading level. This percentage is quite similar to what we have obtained from another five schools.

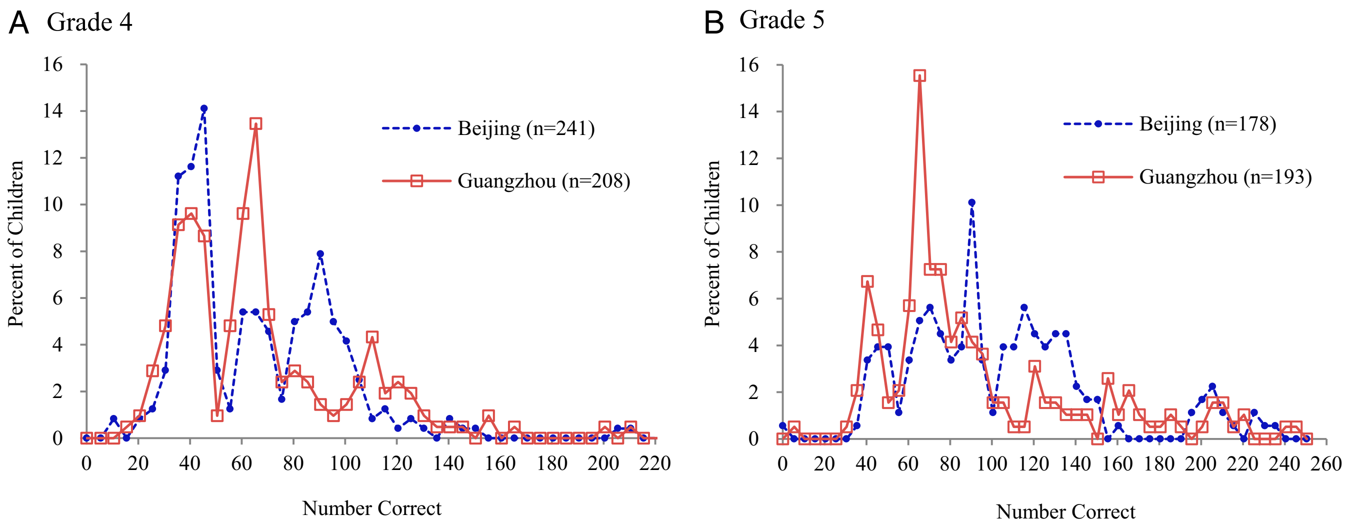

Fig. 1. Percentage of children reading characters correctly at (*A*) grade 4 and (*B*) grade 5 in Beijing and Guangzhou.

sample if their nonverbal IQ scores were below the 25th percentile. (The sixth primary school did not give us time to test children's nonverbal IQ; therefore, their reading performance data were not included in our final data analysis.) The numbers of children in the final sample in grades 3–5 were 1,049 (mean age: 9 y, 2 mo), 1,049 (mean age: 10 y, 1 mo) and 1,040 (mean age: 11 y, 2 mo), respectively.

The reading scores of children are shown in Fig. 2 (reading level) and Fig. 3 (distribution). The number of children who failed to meet the expected grade level was even higher for fourth and fifth graders than that in experiment 1. The percentages of readers with severe difficulty were 66.73% for fourth graders and 61.06% for fifth graders, according to the Stevenson criterion, or 24.50% for fourth graders and 57.50% for fifth graders using the China scoring criterion. However, the performance of children in grade 3 was much better, with only 1.62% (the Stevenson criterion) or 0.38% (the China scoring criterion) being readers with severe difficulty.

To obtain an overall picture of reading difficulty in China's primary schools, we collapsed data from the fourth and fifth graders in Beijing and Guangzhou as well as from the third to fifth graders in Jining to compute the percentage of children with normal IQ who were two grades behind the expected reading level. The overall incidence was 42.04% in terms of the Stevenson criterion or 28.15% according to the China scoring criterion.

Next, we sought to elucidate whether the use of e-communication tools (e.g., computers and mobile phones) affects Chinese reading development. Children in Jining had been learning to use computers in classrooms since grade 3 for an average of 40 min/wk. They started to learn to type Chinese characters from the second semester of grade 3 by using an intelligent pinyin input system. In grade 4, they commenced to use Microsoft word and e-mails. Thus, children in grade 4 or above were more frequent users of computers. Along with using computers to type Chinese characters via pinyin, many children also started to use mobile phones to send text messages. To determine whether children's reading performance is negatively associated with their utilization of these electronic communication tools, particularly the pinyin input method, we asked a subgroup of the Jining sample to participate in a survey study. Children with reading performance in the top 15% or bottom 15% in grades 3–5 were invited to answer several questions with the help of their parents. These questions evaluated (*i*) if children had computers at home; (*ii*) the average time they spent each day using computers; (*iii*) the average time that they spent

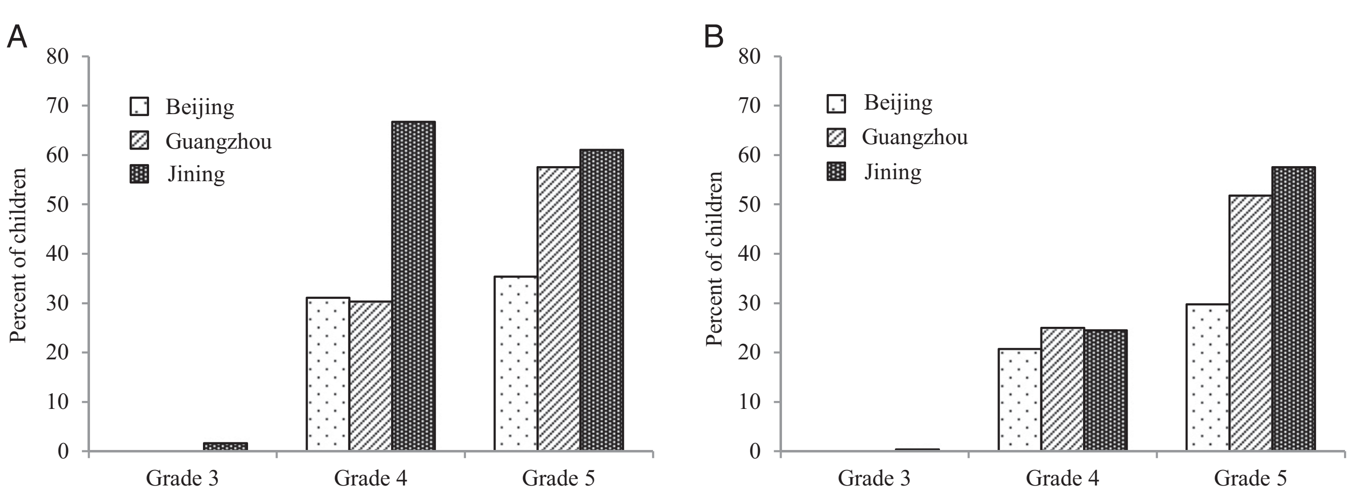

Fig. 2. Percentage of children who were two grades (i.e., 2 y) behind in reading achievement in Beijing, Guangzhou, and Jining. The incidence rates of severe reading difficulty are higher according to the Stevenson criterion (*A*) than the incidence rates in terms of the China scoring criterion (*B*).

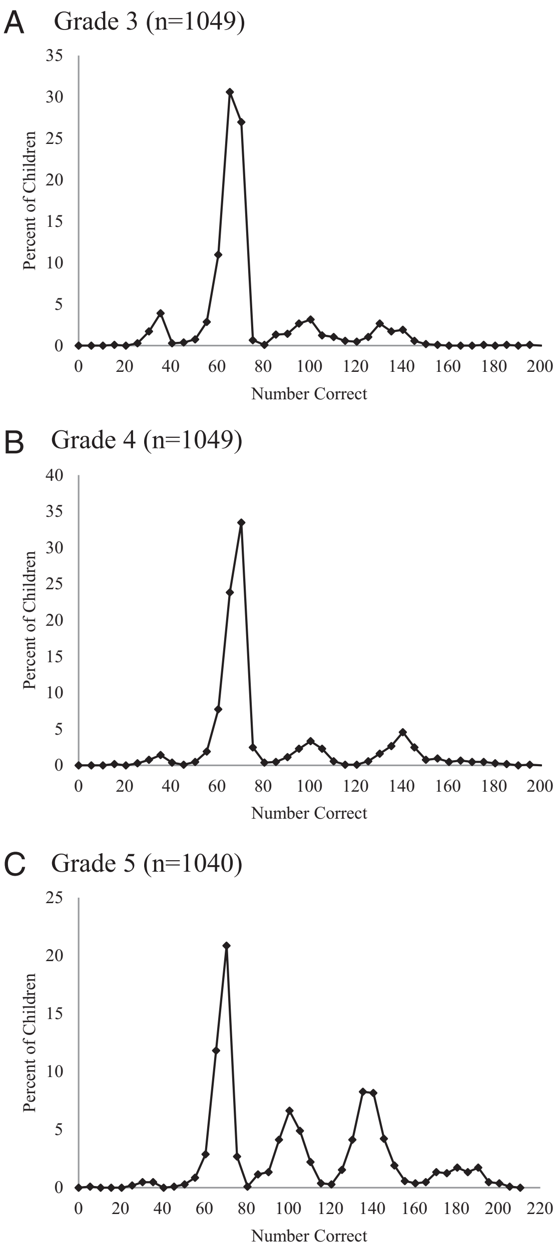

Fig. 3. Percentage of children reading characters correctly at (*A*) grade 3, (*B*) grade 4, and (*C*) grade 5 in Jining.

each day typing pinyin using computers; and (*iv*) the average time that they spent each day typing pinyin using cell phones. In addition, children's time spent handwriting and reading at home was also covered. Children without a computer at home, as well as those who had not completed the questionnaire, were excluded from further analysis. The numbers of children remaining in the sample were 203, 224, and 226 for grades 3, 4, and 5, respectively. We coded the time data according to the five optional answers in the questionnaire: Children who spent less than half an hour (about 15 min) were given a score of 1; half an hour, a score of 2; about 1 h, a score of 3; more than 1 h (about 90 min), a score of 4; and more than 2 h (about 150 min), a score of 5.

We first calculated the total time that children spent on handwriting and on e-communication tools each day (Table 2). For all three grades, good readers spent about 1.5 h on handwriting and poor readers spent about 1 h; the difference is significant: t's > 2.32, p's < 0.02. Considering e-device use, for third graders, both good and poor readers spent 2 h each day. For fourth and fifth graders, good readers spent 2 h whereas poor readers spent 3 h, and the 1-h difference is highly significant: $t = 4.82$ and $P < 10^{-5}$ for fourth graders, and $t = 5.21$ and $P < 10^{-6}$ for fifth graders.

To determine whether typing pinyin affects reading development, we computed the total time that children spent on pinyin use each day (Table 2). For third graders, both good and poor readers spent 1 h each day. For both fourth and fifth graders, good readers spent 0.5 h whereas poor readers spent 1 h, and the difference is highly significant: $t = 3.16$ and $P < 0.01$ for fourth graders, and $t = 3.77$ and $P < 0.001$ for fifth graders.

To better understand the relationship between individual variability in handwriting and pinyin typing and reading performance, we conducted a multiple regression/correlation analysis by using optimal scaling (30, 31), i.e., categorical regression termed CATREG in SPSS 20.0. The optimal scaling in CATREG transforms the original ordinal integer scales in the independent variables (i.e., time in our experiment) to continuous numerical values through a one-to-one mapping that preserves the order in the original scales so that the multiple correlation coefficient after variable transformation is better characterized. We found significant and positive correlations between reading performance and handwriting: $r = 0.29$ and $P < 10^{-4}$ for third graders, $r = 0.34$ and $P < 10^{-6}$ for fourth graders, and $r = 0.45$ and $P < 10^{-11}$ for fifth graders. The data confirmed the previous finding that learning to read Chinese is associated with handwriting (21).

Importantly, we found that children's reading scores were negatively correlated with the use of the pinyin input method, with a stronger correlation found at the higher grade: $r = -0.347$ and $P < 10^{-7}$ for fourth graders, and $r = -0.405$ and $P < 10^{-9}$ for fifth graders. Partial correlation analysis after nonverbal IQ was controlled also revealed significant correlations: $r = -0.332$ and $P < 10^{-6}$ for fourth graders, and $r = -0.404$ and $P < 10^{-9}$ for fifth graders. To rule out the possibility that the effect of the pinyin input method arises from the general use of computers instead of the pinyin typing per se, a partial correlation analysis was performed after the time on computer use was partialled out. Again, significant correlations were obtained: $r = -0.34$ and $P < 10^{-6}$ for fourth graders, and $r = -0.40$ and $P < 10^{-9}$ for fifth graders.

We did not find a significant correlation between pinyin typing time and handwriting time ($r = -0.015$ and $P = 0.805$ for grade 4, and $r = -0.13$ and $P = 0.054$ for grade 5). Thus, the negative association between pinyin use and reading performance does not appear to be mediated by time spent handwriting. Pinyin use seems to have its own negative impact on reading, presumably because it interferes with the learning of the visuospatial properties of characters.

Discussion

This pattern of findings indicates that children's Chinese character-reading performance significantly decreases with the utilization of the pinyin input method and e-tools in general. Pinyin typing appears to be harmful in itself; it interferes with Chinese reading acquisition, which is characterized by fine-grained analysis of visuographic properties of characters. Handwriting, however, enhances children's reading ability.

At present other factors associated with the high percentages of poor readers in China are unknown. Chinese language textbooks may be difficult for primary school children. Reduction of handwriting time in primary schools might be another possible contributor. Primary school teachers encourage students to guess the meaning of characters rather than decoding characters as a fine-grained unit, which is inconsistent with contemporary psycholinguistic theories of reading acquisition (1). In addition, our reading tests might be difficult, although characters used in the major sections of the tests were from the textbooks. It is also difficult to formally equate the criteria for poor reading across time because there is no standardized reading test in China. Future research

Table 2. Average time (h) children spent on handwriting and e-communication tools each day

Group	Grade 3	Grade 4	Grade 5
Total time (h) children spent on handwriting			
Good readers	1.5	1.5	1.5
Poor readers	1	1	1
Difference	0.5*	0.5*	0.5****
Total time (h) children used e-devices in general			
Good readers	2	2	2
Poor readers	2	3	3
Difference	0	1****	1****
Average time (h) children used pinyin typing each day			
Good readers	1	0.5	0.5
Poor readers	1	1	1
Difference	0	0.5**	0.5***

*$P < 0.02$; **$P < 0.002$; ***$P = 0.0002$; ****$P < 0.0001$.

may address these questions by including more factors related to reading skill development.

The Chinese language has survived the technological challenges of modernization in the digital age (29), but the use of its most popular input method, pinyin, unfortunately hinders children's reading acquisition. This method seems to interfere with the learning of the graphical representation of Chinese characters. Conversely, handwriting seems to facilitate this learning. The rapid advancement of technology has considerably improved people's lives worldwide. The present results suggest that more research is needed on the impact of these new technologies on child development (32).

Materials and Methods

The materials consisted of measures of nonverbal IQ and reading achievement, as described in *Results*. The standardized Chinese version of Raven's Standard Progressive Matrices was used as an index of nonverbal intelligence. The intelligence test was administered on a group basis. The reading test was administered individually.

All children were native speakers of Putonghua, the official dialect of mainland China and the language of instruction in school. The subjects' demographic characteristics are shown in Table 1.

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