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A longitudinal study on sensitivity to symmetry in writing and associations with early literacy abilities

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Introduction: Young children reportedly find symmetrical prints, such as H, easier to copy and produce from memory than asymmetrical ones. Little is known about how sensitivity to symmetry in print relates to early word reading and writing development. We examined this in Chinese, a visually complex writing system featuring symmetrical patterns, such as 釜 or 类.

Methods: Sixty preschoolers in Beijing completed a character decision task (Experiment 1, M_{age}=62.16months) and a character learning task (Experiment 2, M_{age}=63.96months), using stimuli matched on visual complexity and frequency but differing in symmetry, and were assessed on Chinese word reading and word writing abilities twice with a 2-year interval.

Results: Children were significantly more likely to endorse symmetrical complex stimuli as possible Chinese than asymmetrical complex ones, and they learned to read symmetrical characters significantly better than asymmetrical ones, reflecting their sensitivity to symmetry in Chinese characters. However, with age and nonverbal IQ statistically controlled, sensitivity to symmetry was not uniquely associated with Chinese word reading or word writing abilities at any time; rather, asymmetrical character learning, which necessitates reduced sensitivity to symmetry, was uniquely associated with Chinese word writing concurrently and longitudinally.

Discussion: Findings highlight the close relationship between analytic perception of written words and early writing ability.

KEYWORDS
symmetry, writing, perception, early literacy, Chinese

Introduction

Symmetry in writing refers to that if a word or character were folded along an axis, the geometrical patterns of the two sides would largely overlap. Symmetrical patterns in writing can be around a vertical axis (such as M in English or 非 in Chinese), a horizontal axis (such as B or 臣), or both (such as H or 申). There are increasing observations showing the relative facility of symmetrical shape perception and production. For example, 4-month-old infants processed vertical symmetrical patterns more efficiently than asymmetrical or horizontally symmetrical ones (Bornstein et al., 1981). Young learners of the Latin alphabet found symmetrical letters easier to copy and write from memory than asymmetrical letters (Treiman and Kessler, 2011). Chinese preschoolers wrote their names better with symmetrical characters than with asymmetrical ones (Yin and Treiman, 2013). French 5 to 6-year-olds wrote symmetrical digits 0 and 8 with a higher percentage of correctness than the eight other asymmetrical digits (Fischer, 2018).

How is sensitivity to symmetry in writing associated with early word reading and writing abilities? For learning to read and write, unlearning symmetrization or mirror invariance is needed because children evolutionarily tend to treat symmetrical patterns as mirror images of one another and consequently take them as the same thing (Dehaene et al., 2010). For example, to correctly identify a word, children need to develop print-specific understanding that symmetrical images of *d* and *b* are two different letters. Sensitivity to spatial orientation has been found to significantly relate to reading skills in English-reading first graders (Fernandes et al., 2016) and Chinese-reading 6-year-olds (Zhang et al., 2021). Compared with early word reading, there is less report on the association between sensitivity to symmetry in print and early word writing. Writing a word requires a more detailed and accurate representation of the graphic unit in words than reading, thus writing may reveal more individual differences in the analytic perception of sub-word units than reading. This study examined young children's sensitivity to symmetry in Chinese and its associations with early writing as well as reading abilities.

Symmetry effect in reading and writing Chinese

Chinese writing features abundance of symmetrical patterns. According to the study by Xu (2012), among the 3,500 characters in the List of Common Characters in Modern Chinese (China National Working Committee on Languages and Characters, 1988), 414 characters are visually symmetrical. Of these, the majority (93.48%, 378 in total) are vertically symmetrical, which include 188 perfectly-symmetrical characters (45.41%), showing an absolute overlap of the two sides when folded along the vertical axis (such as 凹 or 草), and 199 relatively-symmetrical characters (48.07%) (such as 容 or 再). There are 3 characters that are only horizontally symmetrical (巨, 旧, and 臣) and 24 characters that are both vertically and horizontally symmetrical (such as 王 or 中). It should be noted that these symmetrical whole characters can also appear as sub-character components in a large number of compound characters in Chinese (such as 榕, 溶, 忠, 钟, 枉, 忹), as detailed below.

Chinese character is visually complex. The majority of the 2,570 characters in school Chinese in mainland China have 7 to 12 strokes; some have more than 20 strokes (Shu et al., 2003). Over 80% of Chinese characters are compound characters consisting of a semantic radical that gives a clue to the character's meaning and a phonetic radical that gives a clue to the character's pronunciation. Expert readers can identify the radical or reoccurring stroke pattern in a character, such as"艹" in characters "花" and "草," whereas novice readers may process the character as a whole rather than by sub-character components (Hsiao and Cottrell, 2009).

A symmetry effect in Chinese character recognition was reported in adults (Yu and Cao, 1992; Chen and Huang, 1999; Huang et al., 2002). Yu and Cao (1992) found that expert readers processed balanced characters, where strokes are distributed equally across the two halves of the character, faster than unbalanced ones. This effect was found in low-frequency characters but not in high-frequency ones. According to the researchers, symmetrical patterns enhance perceptual wholeness. In expert character recognition, whole character processing and component processing compete for attentional resources. For low-frequency characters, whole-character processing has a cognitive advantage over component processing in symmetrical characters due to enhanced perceptual wholeness, whereas for high-frequency (i.e., familiar) characters, whole-character processing has a cognitive advantage over component processing for both symmetrical and asymmetrical characters and thus no symmetry effect was found. According to Chen and Huang (1999), information redundancy also accounts for the symmetry effect in Chinese. In their study of adult readers, symmetrical characters were processed faster than asymmetrical ones in high-complexity characters but not in low-complexity ones. The researchers interpreted that in symmetrical complex characters, recognizing half of the character leads to recognition of the other, while in asymmetrical complex characters, two or more parts need to be recognized. This effect was not found in low-complexity characters because the processing time is short for both symmetrical and asymmetrical characters.

Few studies explicitly reported symmetry effect in Chinese acquisition in young children. Li (1964) examined Chinese preschoolers' perceptual sensitivity to graphemes in characters. Ten 6-year-olds were asked to look at a character and then write it. The researcher recorded the stroke order and stroke pause children made. It was found that children perceived similar and roughly symmetrical strokes as one group, such that in writing the character, they would first write these parts out and then filled in the remaining parts, showing a tendency to perceive similar or roughly symmetrical parts as one grapheme. For example, in writing the character "弼," children first wrote the two "弓" parts on the two sides and then filled in the middle part "百." However, the sample size of this study was small and the relation between sensitivity to perceptual symmetry in characters and children's reading or writing abilities was not examined.

Visual-perceptual sensitivity and early literacy development

Children begin to learn about the visual form of writing as early as 2 and 3 years old before they learn about how the visual form represents language (Zhang et al., 2017). By age 5, children have developed quite a bit of knowledge about the visual form of writing they are exposed to and such knowledge is significantly related to concurrent and subsequent reading and writing abilities (Kessler et al., 2013; Yin and McBride, 2015; Treiman, 2017). For example, in the study of Yin and McBride (2015), Chinese 5-year-olds demonstrated sensitivity to the positional regularity of radicals in Chinese and such sensitivity explained unique variance in their word reading and writing abilities 1 year later. To date, most studies investigated differentiation between writing and drawing (e.g., Levin and Bus, 2003), discrimination of native writing symbols from foreign symbols (e.g., Lavine, 1977; Zhang et al., 2017), and detection of graphotactic patterns in written words (e.g., Pollo et al., 2009). Less research has examined sensitivity to symmetry in writing, a visual feature that transcends orthographic units in a word and carries no phonological or semantic information, and its association with literacy abilities.

Learning to read or write involves more than visual perception of the written word. A meta-analysis of 34 studies on the relationship between visual skills and Chinese reading acquisition (Yang et al., 2013) showed that various visual skills (including visual perception, speed of processing visual information, and pure visual memory) had low-to-moderate correlations with Chinese reading for children in the lower grades (preschool to second grade), but not in higher graders (second through sixth grades). Contrastingly, visual-verbal association skill accounted for 34% and 41% of the variance in Chinese reading acquisition for children in both lower and higher grades, respectively. Learning to read asymmetrical characters may reveal more visual-verbal association skill than learning to read symmetrical characters and thus might be more closely associated with word reading or writing abilities because it involves more analytic perception of sub-components in a character. We tested this idea in this study.

The present study

The present study examined Chinese preschoolers' sensitivity to symmetry in characters and its concurrent and longitudinal associations with Chinese word reading and word writing abilities. We used a character decision task to tap pure perceptual sensitivity to symmetry in characters and a character learning task to tap analytic perception of sub-character components as well as sensitivity to symmetry across sub-character components. We assessed children's Chinese word reading and word writing abilities twice, with a 2-year interval.

In the character decision task, children were asked to decide whether a rare character was a possible Chinese. There were 25 symmetrical characters and 25 asymmetrical characters matched on frequency and visual complexity. If children were sensitive to symmetry in Chinese, they would more likely endorse symmetrical stimuli as possible Chinese than asymmetrical ones.

In the character learning task, children were taught to pronounce two sets of five rare characters matched on frequency and visual complexity but differing in symmetry. Given that learning to read involves mapping a visual form onto a spoken form, if children found symmetrical patterns easier to perceive than asymmetrical ones, they would learn to pair symmetrical characters with a pronunciation better than asymmetrical ones.

In view of the critical role of orthographic skills in early Chinese literacy development (Wang et al., 2015; Yin and McBride, 2015) and the limited role of pure visual perceptual skills compared with visual-verbal association skill in Chinese reading acquisition (Yang et al., 2013), we hypothesized that analytic perception of sub-character components, rather than pure perceptual sensitivity to symmetry in characters, may uniquely predict Chinese literacy abilities longitudinally.

Method

Participants

Sixty preschoolers from a public preschool in a middle-class neighborhood in Beijing participated in the study. Thirty children participated in Experiment 1 (M_{age} = 62.16 months, 10 girls,) and thirty children participated in Experiment 2 (M_{age} = 63.96 months, 12 girls). At Time 1, the majority (78.3%) of children were in their last (third) year of kindergarten and 21.7% were in their second year of kindergarten (7 and 6 children in Experiment 1 and 2, respectively). Written consent was obtained from the guardians of all children.

Procedure and tasks

At Time 1, we administered a character decision task in Experiment 1, and a character learning task in Experiment 2, and assessed Chinese word reading, Chinese word writing, and non-verbal IQ for all children. At Time 2, 2 years later, when the majority of children became second graders and 21.7% became first graders in the primary school, we assessed Chinese word reading and Chinese word writing for all children again.

Character decision

Children were asked to decide whether a stimulus was a possible Chinese character. The stimuli included 50 rare characters selected based on symmetry and visual complexity. Asymmetrical and symmetrical characters were matched on frequency (time of occurrence per million) and visual complexity (number of strokes) (frequency: *Mean* (SD) = 47 (93) and 56 (260) for asymmetrical and symmetrical characters, respectively, $p = 0.361$; visual complexity: *Mean* (SD) = 8.36 (1.89) and 8.24 (2.19) for asymmetrical and symmetrical characters, respectively, $p = 0.704$). High- and low-complexity characters were matched on the frequency and differed in complexity (frequency: *Mean* (SD) = 43 (92) and 60 (264) for high-complexity and low-complexity characters, respectively, $p = 0.07$; visual complexity: *Mean* (SD) = 9.96 (1.16) and 6.56 (1.12) for high-complexity and low-complexity characters, respectively, $p < 0.001$). Table 1 shows the sample stimuli. The Cronbach's α for this task was 0.95.

Character learning

This task was modeled on the word-learning paradigm used with young children in previous studies (McBride-Chang and Treiman, 2003). Children were taught to pronounce two sets of five rare characters differing in symmetry but matched on frequency (time of occurrence per million) and visual complexity (number of strokes) (frequency: *Mean* (SD) = 3 (6) and 72 (145) in Set A and 0 (0) and 1 (0) in Set B for asymmetrical characters and symmetrical characters, respectively, $ps > 0.278$; visual complexity: *Mean* (SD) = 9 (3.53) and 9 (3.46) in Set A and 9 (2.00) and 9.8 (2.59) in Set B for asymmetrical characters and symmetrical characters, respectively, $ps = 0.767$). Table 1 shows the sample stimuli. The task contained a demonstration phase and up to 8 learning trials. The experimenters began by saying that they would play a learning game with the child, that the characters to be learned were unfamiliar, and that the child should try his or her best. In the demonstration phase, the experimenter showed the child a card and pronounced the character, running her fingers under the character. The experimenter then asked the child to follow by saying "This character is read ______." We used a pseudo pronunciation, which was not the correct pronunciation for either the symmetrical or asymmetrical character. The procedure was repeated for all five stimuli in each set and the order of demonstration was randomized for each child. Once all five stimuli had been introduced in the first learning trial, the experimenter showed the child one of the cards and asked the child to give the pronunciation of the character to which it corresponded. The experimenter praised the child if s/he pronounced the character correctly and provided the correct answer if s/he pronounced it incorrectly. Learning trials continued until the child achieved the

TABLE 1 Sample stimuli in character decision in Experiment 1 (upper panel) and character learning in Experiment 2 (lower panel).

Condition	Sample stimulus in character decision	Complexity	Number of strokes
Symmetrical	卋	Low-complexity	6
	啚	High-complexity	11
Asymmetrical	舛	Low-complexity	6
	觖	High-complexity	11

Condition	Sample stimulus in character learning	Pseudo pronunciation used	Number of strokes
Symmetrical	芾	/bù/	7
Asymmetrical	甙		8
Symmetrical	幽	/fāng/	9
Asymmetrical	茛		9
Symmetrical	亜	/gǔ/	7
Asymmetrical	阽		7

criterion of responding correctly to all five items on two consecutive trials (McBride-Chang and Treiman, 2003). The Cronbach's α for this task was 0.97.

Chinese word reading

Children read aloud 50 Chinese single-character words presented in order of increasing difficulty (Wang et al., 2015). The Cronbach's α was 0.97 and 0.96 in Experiment 1 and 2, respectively at Time 1, and was 0.94 and 0.92 for Experiment 1 and 2, respectively, at Time 2.

Chinese word writing

Children were asked to write 10 orally-familiar words including 3 single-character words and 7 two-character words, totaling 17 characters (Wang et al., 2015). Each word was orally presented twice in a meaningful sentence to ensure the child understood the intended word. The Cronbach's α was 0.83 and 0.85 in Experiment 1 and Experiment 2, respectively, at Time 1, and was 0.89 and 0.87 for Experiment 1 and Experiment 2, respectively, at Time 2.

Non-verbal IQ

Sets A and B of Raven's Standard Progressive Matrices (Raven et al., 1996) were administered to measure children's nonverbal IQ at Time 1. The Cronbach's α was 0.85.

Results

Experiment 1

We analyzed the data in this study using IBM SPSS Version 27. Table 2 shows the descriptive statistics and correlation matrix in Experiment 1. We first analyzed the data of character decision using generalized linear mixed modeling (GLMM). As an extension of generalized linear modeling, GLMM allows for the linear predictors containing random effects as well as fixed effects and the response variables from different distributions, such as binary responses. In the model we built, the dependent variable was whether the rare character was endorsed as a possible Chinese or not (coded as 1 and 0, respectively), the random effects were child and item, and the fixed effects were symmetry (symmetrical vs. asymmetrical), visual complexity (high vs. low), and their interaction. We selected binary logistic regression for target distribution and logit link transformation. The final model that offered the best fit to the observed performance of children had an overall correct-classification rate of 73.7%, $F(3, 1{,}496) = 12.08$, $p < 0.001$. As shown in Figure 1, there was a main effect of visual complexity, $F(1, 1{,}496) = 23.31$, $p < 0.001$, such that children were more likely to endorse high-complexity stimuli as possible Chinese than low-complexity ones ($ß = 1.01$, SE = 0.20, 95% CI [0.62, 1.41], $p < 0.001$). There was also a significant interaction between symmetry and visual complexity, $F(1, 1{,}496) = 5.87$, $p = 0.016$. Children were more likely to endorse symmetrical high-complexity stimuli as possible Chinese than asymmetrical high-complexity ones ($ß = 0.68$, $SE = 0.28$, 95% CI [0.13, 1.22], $p = 0.016$). No such difference was found for low-complexity stimuli. The random effect of child was significant (EST = 3.58, SEE = 1.12, 95% CI [1.94, 6.61], $p = 0.001$). The random effect of item was not significant, $p = 0.502$. These results indicate that Chinese children averaging 5 years of age are sensitive to symmetry in visually-complex Chinese characters.

Before running association tests to examine the concurrent and longitudinal associations between sensitivity to symmetry tapped in the character decision task and children's literacy abilities, we examined the normality of the distribution of the data. Shapiro–Wilk tests showed that data of character decision in all conditions and literacy abilities at both time points were not normally distributed (except for symmetrical high-complexity character decision, $p = 0.074$), $ps < 0.05$. Considering that parametric analysis of transformed data is a potentially better strategy than non-parametric analysis as it appears to be more powerful than the latter (Rasmussen and Dunlap, 1991), we normalized the data using rank-case transformation, which was considered to work better for small sample size in association tests than logarithm and Box-Cox transformations (Goh and Yap, 2009) and used normal scores obtained using Blom's formula in subsequent analyses.

TABLE 2 Descriptive statistics and correlation matrix of variables in Experiment 1 (upper panel) and Experiment 2 (lower panel).

		Mean (SD)	1	2	3	4	5	6	7	8	9	10
1	Age (month)	62.16 (9.72)										
2	Non-verbal IQ (max: 24)	13.73 (4.73)	0.67**									
3	Symmetrical, low-complexity CD	0.52 (0.32)	−0.15	−0.21								
4	Symmetrical, high-complexity CD	0.69 (0.25)	0.17	0.14	0.72**							
5	Asymmetrical, low-complexity CD	0.54 (0.30)	−0.03	−0.14	0.82**	0.77**						
6	Asymmetrical, high-complexity CD	0.60 (0.33)	0.10	0.08	0.71**	0.85**	0.76**					
7	Time 1 Chinese word reading (max:50)	13.57 (14.30)	0.48**	0.40*	−0.46*	−0.32	−0.34	−0.38*				
8	Time 1 Chinese word writing (max: 17)	2.80 (2.89)	0.67**	0.51**	−0.30	−0.11	−0.20	−0.21	0.74**			
9	Time 2 Chinese word reading (max: 50)	32.33 (11.55)	0.61**	0.72**	−0.44*	−0.13	−0.30	−0.21	0.81**	0.71**		
10	Time 2 Chinese word writing (max:17)	13.01 (5.59)	0.83**	0.77**	−0.16	0.22	−0.07	0.14	0.37*	0.58**	0.68**	

		Mean (SD)	1	2	3	4	5	6	7	8
1	Age (month)	63.96 (8.70)								
2	Non-verbal IQ (max: 24)	14.53 (4.84)	0.72**							
3	Symmetrical character learning	0.62 (0.28)	0.60**	0.51**						
4	Asymmetrical character learning	0.68 (0.27)	0.45*	0.37*	0.80**					
5	Time 1 Chinese word reading (max: 50)	13.93 (13.90)	0.56**	0.43*	0.50**	0.50**				
6	Time 1 Chinese word writing (max: 17)	3.10 (2.88)	0.64**	0.43*	0.61**	0.63**	0.79**			
7	Time 2 Chinese word reading (max: 50)	32.77 (12.80)	0.61**	0.65**	0.53**	0.54**	0.85**	0.73**		
8	Time 2 Chinese word writing (max: 17)	14.03 (5.09)	0.80**	0.71**	0.62**	0.60**	0.45*	0.52**	0.68**	

$N = 30$. CD = character decision, *$p < 0.05$, **$p < 0.01$.

We conducted hierarchical regression analyses only on Chinese word reading because, as shown in Table 2, Chinese word writing was not significantly correlated with character decision in any condition concurrently or longitudinally ($ps > 0.113$). For Time-1 word reading, age and IQ were entered in the first step and the significant correlates of Time-1 word reading were entered in the second step. For Time-2 word reading, age and IQ were entered in the first step, Time-1 word reading was entered in the second step to control the autoregressive effect, and the significant correlate of Time-2 word reading was entered in the third step. Results show that character decision was not significantly associated with Chinese word reading at any time ($ps > 0.293$), suggesting that pure perception of symmetrical patterns in characters is not uniquely related to early word reading or writing abilities in Chinese.

Experiment 2

Table 2 also shows the descriptive statistics and correlation matrix of Experiment 2. As in Experiment 1, we first conducted GLMM analysis on the character learning data. The dependent variable was character learning accuracy (correct vs. incorrect, coded as 1 and 0, respectively), the random effects were child, set, and item, and the fixed effects were symmetry (symmetrical vs. asymmetrical), trial (1 to 8), and their interaction. The final best-fitting model had an overall correct-classification rate of 79.7%, $F(15, 2{,}384) = 18.59$, $p < 0.001$. As shown in Figure 1, there was a significant main effect of symmetry ($ß = 0.74$, SE = 0.36, 95% CI [0.04, 1.44], $p = 0.039$), such that children learned to read symmetrical characters significantly better than asymmetrical ones. There was a significant main effect of trial [$F(7, 2{,}384) = 38.23$, $p < 0.001$], children improved across trials in both conditions. There was no significant interaction between symmetry and trial ($p = 0.921$). For the random effects, child was significant (EST = 3.40, SEE = 0.97, 95% CI [1.94, 5.95], $p < 0.001$), set and item were not significant, $ps > 0.510$. These results indicate that Chinese young children are sensitive to symmetry in characters when learning to read them.

Normal scores obtained from rank case transformation with Blom's formula were used in association analyses ($ps < 0.05$ in Shapiro–Wilk tests for all variables). Hierarchical regression analyses were conducted for Chinese word reading and word writing at Time 1 and Time 2, respectively, since character learning was significantly correlated with them in both conditions at both time points. In all models, age and IQ were entered in the first step. For Time-1 word reading or writing, significant correlates were entered in the second step. For Time-2 word reading or writing, Time-1 reading or writing (depending on the analysis) was entered in the second step, and the corresponding significant correlates of Time 2 were entered in the third step. Table 3 presents the results of the final models. Results show that for Chinese word reading, neither symmetrical nor asymmetrical character learning was uniquely associated with it in both time points ($ps > 0.24$). For Chinese word writing, asymmetrical character learning was a significant unique predictor of Time-2 word writing, accounting for 9% additional variance after age, IQ, and Time-1 word writing were statistically

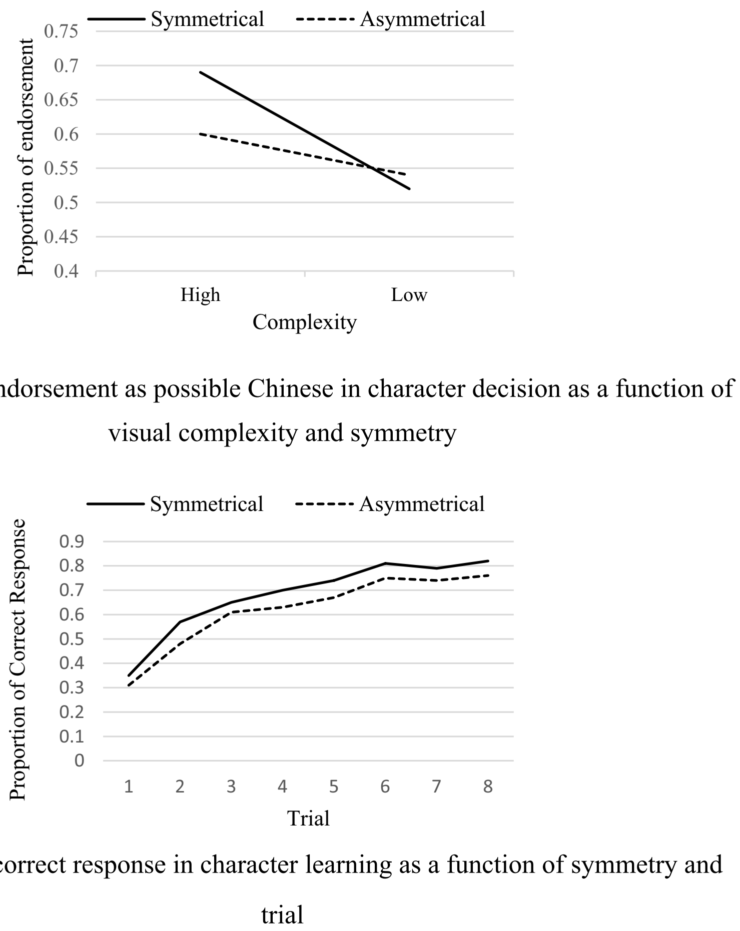

FIGURE 1
Illustration of symmetry effect in character decision in Experiment 1 (upper panel) and character learning in Experiment 2 (lower panel).

controlled ($\beta = 0.46$, SE = 0.15, $p = 0.017$). Asymmetrical character learning was also marginally significantly associated with Chinese word writing at Time 1 ($p = 0.052$). These results indicate that analytic perception of written characters, rather than pure sensitivity to symmetry in characters, is crucial for Chinese word writing ability, particularly longitudinally.

Discussion

This study examined Chinese preschoolers' sensitivity to symmetry in Chinese characters and its associations with Chinese word writing as well as word reading abilities. Corroborating the relative facility of symmetrical pattern recognition and production (Bornstein et al., 1981; Treiman and Kessler, 2011; Yin and Treiman, 2013; Fischer, 2018), we found that Chinese children averaging 5 years of age are sensitive to symmetry in characters: they endorsed symmetrical stimuli as possible Chinese more often than asymmetrical ones and they learned to read symmetrical characters better than asymmetrical ones. Extending existing literature, we found that pure sensitivity to symmetry in characters did not uniquely predict Chinese word reading or writing; rather, analytic perception of sub-character units, tapped in learning to read asymmetrical characters, uniquely predict Chinese word writing concurrently and longitudinally.

Perceptual wholeness and information redundancy in symmetrical patterns (Chen and Huang, 1999) may explain children's sensitivity to symmetry in Chinese in this study. Li (1964) found that Chinese 6 year olds perceived symmetrical parts in a character as one grapheme: when writing a character, they showed a tendency of first writing down the symmetrical parts in a character and then writing the remaining parts. Such perceptual wholeness of symmetrical parts may be especially conspicuous in high-complexity Chinese characters, which may partially explain why children were more likely to endorse high-complexity symmetrical stimuli as possible Chinese than low-complexity symmetrical stimuli in this study. Also, symmetrical parts contain similar or repetitive visual information. As reading involves mapping a visual form onto a spoken form, redundant information may facilitate perception of a symmetrical visual form and make linking it to a spoken form easier. This may explain why children in this study learned to read symmetrical characters better than asymmetrical ones.

Notably, learning to read asymmetrical characters, which necessitates analytic perception of sub-character components, uniquely predicted the 5-year-olds' Chinese word writing ability concurrently and longitudinally 2 years later. Learning to read asymmetrical characters may better tap the engagement of local

TABLE 3 Final model predicting Chinese word reading and Chinese word writing at Time 1 and Time 2 from character learning at Time 1.

Outcome and predictor	R^2	ΔR^2	ΔF	b	SE b	β	p value
Time 1 word reading							
Age	0.31	0.31	6.18*	0.51	0.31	0.40	0.118
IQ	–	–	–	0.01	0.04	0.03	0.899
Time 1 symmetrical character learning	0.39	0.08	1.60	0.00	0.29	0.00	0.999
Time 1 asymmetrical character learning	–	–	–	0.30	0.25	0.31	0.238
Time 1 word writing							
Age	0.42	0.42	9.61**	0.67	0.26	0.54*	0.015
IQ	–	–	–	−0.02	0.04	−0.13	0.519
Time 1 symmetrical character learning	0.57	0.16	4.54*	−0.00	0.23	−0.00	0.994
Time 1 asymmetrical character learning	–	–		0.42	0.21	0.44	0.052
Time 2 word reading							
Age	0.46	0.46	11.49***	−0.11	0.18	−0.09	0.536
IQ	–	–	–	0.08	0.02	0.40**	0.003
Time 1 word reading	0.83	0.37	56.19***	0.71	0.11	0.70***	0.000
Time 1 symmetrical character learning	0.84	0.01	0.74	−0.10	0.15	−0.11	0.501
Time 1 asymmetrical character learning	–	–	–	0.17	0.14	0.17	0.244
Time 2 word writing							
Age	0.67	0.67	27.71***	0.70	0.20	0.63**	0.002
IQ	–	–	–	0.04	0.03	0.24	0.125
Time 1 word writing	0.67	0.00	0.05	−0.18	0.14	−0.20	0.213
Time 1 symmetrical character learning	0.76	0.09	4.40*	−0.11	0.16	−0.13	0.498
Time 1 asymmetrical character learning	–	–	–	0.39	0.15	0.46*	0.017

$N = 30$. *$p < 0.05$, **$p < 0.01$, ***$p < 0.00$.

attention to components for greater precision than learning to read symmetrical characters and such precision is called for more in production (writing) than in recognition (reading). Thus, although symmetrical character learning was significantly correlated with Chinese word reading and word writing at both time points, it was not uniquely associated with them after age, IQ, and autoregressive effects were statistically controlled. From a novel perspective of symmetry sensitivity, this study contributes to current literature on the associations between breaking mirror invariance in print (such as shape orientation sensitivity) and literacy acquisition by showing that such link manifests not only in reading (Fernandes et al., 2016; Zhang et al., 2021) but more particularly in writing. This study also adds to the recent demonstrations by Fischer and Luxembourger (2022) of the difference between a recognition task (e.g., distinguishing between the reversible letters of b and d) and a writing task (e.g., reversing letters or digits in writing), the two tasks often considered as equivalent in the literature on mirror invariance but actually found to be at least partly independent processes (having a negative relationship between the two rates) in French 6 year olds. Future studies may further examine this issue with Chinese young children.

A limitation of the present study is that we were unable to disentangle visual-perceptual skill from orthographic knowledge that children might be using when making character decision or learning to read characters, despite the very low frequency of stimuli used. Future studies should use pseudocharacters and take identifiable subcomponents and configurations into consideration. Another limitation is the small sample size in each experiment despite the statistical adjustments we made before running association analyses. Future work should involve a larger sample with diverse language backgrounds to examine the generalizability of the symmetry effect across writing systems.

Despite the limitations, the present research provides novel evidence that young children are sensitive to symmetry in writing, but it is the analytic perception of sub-word units rather than pure sensitivity to perceptual symmetry that is significantly related to early literacy, particularly writing.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Tsinghua University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

LY and CM conceived of the presented idea and collaborated in analyzing the data and drafting the article. LY conducted the data collection. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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