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Unspoken knowledge: kindergarteners are sensitive to patterns in Chinese pinyin before formally learning it

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**ABSTRACT**

Do young children extract patterns from print to which they are naturally exposed but only in a limited way? This study investigated Chinese kindergarteners' sensitivity to regularities in pinyin, an alphabetic coding system for non-alphabetic Chinese characters to which kindergarteners have limited exposure and little motivation for learning. Sixty 4- and 5-year-olds from Beijing took a pinyin decision task and a pinyin learning task and were assessed on Chinese word reading, Chinese word writing, and non-verbal IQ. Sensitivity to letter patterns in pinyin spellings and sensitivity to letter-sound correspondences in pinyin syllables appeared in 5-year-olds. After statistically controlling for age and IQ, sensitivity to letter-sound correspondences in pinyin syllables explained 4% additional variance in Chinese word reading and 7% additional variance in Chinese word writing. This study contributes novel evidence to statistical learning in early literacy, demonstrating that children are adept at pattern recognition in print even under limited conditions.

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**KEYWORDS**

Statistical learning; early literacy; kindergartener; Chinese; pinyin

**Introduction**

Do young children extract patterns from print under natural conditions? Young children, before receiving formal instruction, detect patterns in spellings and spelling-sound connections in print that they see frequently in their own homes, kindergartens, and daily environments (e.g. Bowman & Treiman, 2002, 2008; Pollo, Kessler, & Treiman, 2009; Treiman & Kessler, 2004; Wright & Ehri, 2007; Yin & McBride, 2015). Such knowledge is thought to come from statistical learning (Perruchet & Pacton, 2006; Saffran, Aslin, & Newport, 1996), a capacity to detect regularities in associations among items in the environment. There is increasing evidence that a capacity for statistical learning is associated with proficiency in language (e.g. Conway, Bauernschmidt, Huang, & Pisoni, 2010; Kidd, 2012), which contains rich statistical structures, and in literacy (e.g. Arciuli & Simpson, 2012), which may be affected by discovery of probabilistic patterns in spellings and spelling-pronunciation correspondences and boosted linguistic resources such as vocabulary (Evans, Saffran, & Robe-Torres, 2009).

However, in most systems that have thus far been studied, there is a relatively clear and straightforward utility to the learning (e.g. learning one's native language or even learning to read). Moreover, the target of learning is typically clear and motivating (e.g. one's native language). Little empirical evidence shows whether statistical learning of patterns from print also occurs when conditions are limited, e.g. when exposure is not primary and motivation is not immediate. In this article we report a study that tested Chinese kindergarteners' sensitivity to patterns in pinyin, an alphabetic coding system for Chinese characters for which children have limited exposure and little motivation to learn in kindergarten, and the relationship between such sensitivity and literacy abilities.

Findings from laboratories show that statistical learning is automatic on the one hand (e.g. Fiser & Aslin, 2002; Olson & Chun, 2001; Saffran, Newport, Aslin, Tunick, & Barrueco, 1997) and requires selective attention on the other (e.g. Tanaka, Kiyokawa, Yamada, Dienes, & Shigemasu, 2008; Toro, Sinnett, & Soto-Faraco, 2005; Turk-Browne, Junge, & Scholl, 2005). Statistical learning seems to occur through mere exposure to stimuli because it has frequently been reported that the participants had no intention to extract the statistical structure from the stimuli (watching or listening to) and were completely unaware that the structure was being learned, despite the fact that it fuelled their familiarity judgments (e.g. Fiser & Aslin, 2002) or speeded up their subsequent visual performance in search tasks (e.g. Olson & Chun, 2001). For example, Saffran et al. (1997) reported...
effective speech segmentation based on statistical learning in both adults and children while they were performing an unrelated drawing task. Statistical learning also appears to be not entirely automatic; some attention is needed for it to occur. For example, Toro et al. (2005) found that after passively listening to streams of artificial speech, participants successfully extracted the statistical regularities between syllables. However, diverted attention (doing a concurrent task) led to a dramatic impairment in performance, reflecting the fact that statistical learning is seriously compromised when attentional resources are depleted. In Turk-Browne et al. (2005), participants viewed geometric shapes in red or green colour appearing at different temporal sequences, as attention was manipulated by the researchers. Robust statistical learning of the shapes that had been attended to was observed in even the most demanding conditions, but no hint of statistical learning was found from unattended shapes in any condition. According to Turk-Browne et al. (2005), statistical learning both is and is not automatic. Observers do not pick up statistical structure in a reflexive and premature manner (e.g. as a product of mere exposure); rather, selective attention is required in this process despite lack of direct awareness of the observer. In Saffran et al. (1997), as Turk-Browne et al. (2005) reasoned, statistical learning happened despite the fact that the observers’ attention was not explicitly directed towards the stimuli because that task did not require attentional selection between competing stimuli (indeed, that task was not intended to manipulate selective attention).

Evidence of statistical learning from the natural environment but in limited conditions will better “push the envelope” of the concept of statistical learning. Chinese pinyin, which is a literacy tool but does not constitute reading itself, represents a unique opportunity for such investigation.

Pinyin is an alphabetic coding system using 26 Roman letters and 4 tone marks to represent the pronunciation of Chinese characters. Chinese is a morphosyllabic language in which each character represents a syllable and a morpheme rather than a phoneme. A change in the tone in which a syllable is pronounced alters both the sound and the meaning of a word (e.g. 妈 mā mother vs. 马 mǎ horse). In young Chinese children, tone awareness (Shu, Peng, & McBride-Chang, 2008) as well as syllable awareness (McBride-Chang & Ho, 2000) are good indicators of reading variability. In Mainland China, mastering pinyin is taken as an important early step for literacy learning of Chinese (e.g. McBride-Chang et al., 2012).

Certain patterns exist in pinyin. In terms of spelling, the average length of pinyin is 3.23 letters (range = 1–6), with the three-letter pattern being the most common, comprising about 43% of the pinyin spellings for school Chinese (Shu, Chen, Anderson, Wu, & Xuan, 2003). In three-letter pinyin spellings, the number of consonant letters does not exceed two, e.g. bei and lan. Three-consonant letter strings (three consonant letters in a row) do not exist in pinyin (e.g. plq). In terms of spelling–sound correspondence, pinyin is largely consistent at the onset-rime level. Pinyin consists of 21 onsets and 35 rimes. The pronunciation of the pinyin syllable can be reliably assembled from the sounds of its onset and rime (some rimes can stand alone as syllables such as ai, en, o), which bear consistent correspondence to their spellings. For example, in pinyin, the rime spelling in is pronounced /in/ in all syllables (e.g. jin and lin) and the onset spelling k is pronounced /k/ in all syllables (e.g. kai and ken).

In Mainland China, children are not explicitly taught pinyin until Grade 1, but they are exposed to pinyin much earlier than Grade 1, though in a limited manner. The limited nature of pinyin exposure is reflected in two ways. First, in books intended for kindergarteners, pinyin is commonly seen but secondarily printed – in smaller size and above each character to indicate its pronunciation, e.g. 火星人 (火 xīng rén, the Martian). Second, pinyin is seldom taught in kindergartens and rarely mentioned by adults at home. The official early education policy in China (Ministry of Education, 2001) states that the goal of early literacy education is to foster children’s ability to construct meaning and express ideas, rather than training decoding skills. In public kindergartens managed by the government, especially in big cities, pinyin is seldom explicitly taught. For example, in Beijing, 83% of the 152 kindergartens in Haidian district are public kindergartens, of which 79% are “Category-1” kindergartens where state policies are strictly observed (Haidian District People’s Government, 2011). Pinyin is also rarely mentioned by adults at home. In an unpublished survey we conducted prior to the study (as a part of a longitudinal project in which the authors were PI’s), 98% of over 200 kindergarten teachers and parents in Beijing said that they seldom mention pinyin while reading to children. The adults were concerned that early discussion of pinyin with children may negatively impact their initial understanding of Chinese and may even interfere with children’s future learning of English which uses the same alphabet but has different letter names and letter sounds.

In the current study, we tested the hypothesis that despite the fact that Chinese kindergarteners are exposed to pinyin only in limited quantities and they have relatively little motivation to learn, these children nevertheless develop sensitivity to letter patterns in pinyin spellings and to letter-sound correspondences in
pinyin syllables. Furthermore, such sensitivity is significantly related to their literacy abilities in Chinese. This hypothesis was based on four considerations.

First, as reviewed earlier, learning of statistical regularities occurs with mere exposure, even if one has no intention to learn and is unaware of the knowledge being learned. Chinese kindergarteners are exposed to pinyin through children’s books, which constitutes the basis for statistical learning to take place.

Second, as reviewed earlier, statistical learning may require selective attention and may operate only over objects or events that are important to us (Turk-Browne et al., 2005). It is possible that due to the special features of pinyin in children’s books — printed in smaller size and above each character (e.g. 火星人), which is different from what they see in other print environments such as food packages and newspapers where there is no pinyin annotation above the characters, children may pay implicit attention to pinyin on children’s books when being read to by adults or experimenting with reading by themselves, trying to understand what they are seeing. This provides a further possibility for statistical learning to occur.

Third, Chinese kindergarteners, before formally learning to read and write, develop sensitivity to regularities in written Chinese (e.g. Ho, Yau, & Au, 2003; Tong & McBride, 2014; Yin & McBride, 2015), and such sensitivity is longitudinally associated with Chinese literacy skills (Yin & McBride, 2015). Yin and McBride (2015), for example, found that in a character learning task, the 4-year-old Chinese performed better when phonetic cues were available (e.g. 下/人) than when phonetic cues were not available (e.g. 下/米), and the 5-year-olds performed better when radicals in the stimuli were positioned legally (e.g. 山) than when they were positioned illegally (e.g. 岳). Such sensitivities demonstrate that Chinese kindergarteners can detect statistical patterns in Chinese characters without being taught explicitly. The same may hold true for pinyin.

Finally, knowledge about pinyin is significantly related to literacy skills in Chinese (e.g. Ding, Liu, McBride, & Zhang, 2015; Lin et al., 2010; Pan et al., 2011; Siok & Fletcher, 2001). For example, pinyin invented spelling was uniquely predictive of Chinese word reading 12 months later in 6-year-old Chinese children (Lin et al., 2010), and pinyin invented spelling measured at age 6 independently predicted Chinese reading at ages 8 and 10 (Pan et al., 2011). Moreover, a pinyin invented spelling task was found to differentiate readers with and without reading difficulties better than did a typical phonological awareness task in school-aged Chinese children (Ding et al., 2015). In the current study, we tested younger children in kindergarten and tapped their sensitivity to the patterns in pinyin; we further examined the relationship between this early pinyin sensitivity and literacy skills in Chinese. Detection of patterns in pinyin spellings and pinyin spelling-sound correspondence reflects, on the one hand, a general ability of abstracting statistical regularities from oral and written languages, which has been shown by a substantial body of research to be related to the ability of learning to read (e.g. Arciuli & Monaghan, 2009; Harm & Seidenberg, 1999) and spell (e.g. Deacon, Conrad, & Pacton, 2008; Treiman & Kessler, 2006), and on the other, enhanced phonological sensitivity, which is one of the cognitive cores in learning to read Chinese (McBride & Wang, 2015).

We used a pinyin decision task to tap children's sensitivity to the letter patterns in pinyin spellings. We asked children to make decisions on whether a visually-presented 3-letter spelling was a possible pinyin representation. Two types of stimuli were constructed: legal spellings that contain one or two consonant letters (e.g. pao or ben) and illegal spellings that contain three consonant letters only (e.g. plq). If children are sensitive to the letter patterns in pinyin spellings, they would be more likely to endorse as correct spellings those that are legal than those that are illegal. This task was conceptualised to tap orthographic understanding implicitly.

We additionally used a pinyin learning task adapted from the word learning paradigm (Ehri & Wilce, 1985; Treiman & Rodriguez, 1999; Wright & Ehri, 2007) to tap children’s implicit knowledge about the letter-sound correspondences in pinyin syllables. In this task, children were taught to read novel pinyin spellings in four conditions differing in level of letter-sound correspondence: the onset-and-rime condition in which letter-sound correspondence occurs in both the onset and rime levels, the onset-only condition in which correspondence occurs only at the onset level, the rime-only condition in which correspondence occurs only in the rime segment of the syllable, and a no-correspondence condition in which no correspondence exists in any position. If children have developed the insight that pinyin spellings represent the sounds they hear, they would learn better when such letter-sound correspondences are available than when they are not available. If they possess the segmentation skills to recognise onset and rime in the syllable and use the phonetic cues contained in these positions to remember pinyin spellings, they would learn better when letter-sound correspondences are available at both the onset and rime (where more phonological cues are available) levels than when they are available only in one position. This task was conceptualised as primarily tapping phonological skills.

We also assessed children’s word reading and word writing ability in Chinese. Given that Chinese literacy ability was significantly associated with the ability to
detect patterns in written Chinese in the 5-year-olds (e.g. Yin & McBride, 2015) and pinyin knowledge in the 6-year-olds (e.g. Lin et al., 2010; Pan et al., 2011) in previous studies, we expected that early sensitivity to patterns in pinyin would significantly relate to Chinese literacy skills in the current study.

Method

Participants

Sixty monolingual Mandarin Chinese-speaking children (33 girls) from a public kindergarten in a middle-class area in Beijing participated. They were 30 K2 children and 30 K3 children, with a mean age of 4 years and 7 months and 5 years and 6 months, respectively. In Mainland China, most kindergartens, as the one from which the children were drawn in the present study, are separate schools with three levels (K1, K2, and K3) starting from 3 years of age. Parental consent was obtained from all participants before the study. The kindergarten follows official early education policy in China and does not provide formal literacy instruction. Children have a rich print environment and a lot of opportunities to be read to or to explore books by themselves. Teachers do not teach characters or pinyin but will help if children ask in this school. The average level of mother education of the participants was 17.12 years (with 16 years equivalent to a college degree). According to the parent survey, no child had known developmental, speech, or hearing problems and no child attended after-school classes to learn Chinese, pinyin, or English.

Procedure

In the first semester of the school year, children completed five tasks over a period of three weeks. All tasks were individually administered by trained graduate students in a quiet reading room. Half of the children were given the pinyin decision task in the first week and the pinyin learning task in the second, and the other half were administered the pinyin learning task in the first week and the pinyin decision task in the second. For each pinyin task children typically spent 20–30 min with a 5-minute break in the middle. In the third week, children were assessed on Chinese word reading, Chinese word writing, and non-verbal IQ, each of which lasted 10–20 min, and the order of tasks was randomised across children.

Tasks

Pinyin decision

Children were presented with three-letter spelling configurations and were asked to make a decision (i.e. yes or no) as to whether it was a possible pinyin representation of a word (The experimenter asked: “Is this possible in pinyin?”). When children were not sure, the experimenter provided encouragement to make a guess but did not explain what pinyin was (The experimenter would say: “If you don’t know, that is very natural and does not matter because nobody taught us this, right? Just do your best to make a guess.”). The spelling was printed on a white card using lower case letters and Songti font as pinyin often appears in children’s books. The card was presented to each child one at a time. The spellings were constructed in two conditions: legal and illegal. Table 1 shows the sample stimuli. The legal spellings contained one consonant letter in the onset with either two vowel letters in the rime (e.g. pei) or one vowel letter plus one consonant letter in the rime (e.g. ban), both of which are common spellings in pinyin. The illegal spellings contained three consonant letters only (e.g. plq and hmg). There were 40 items for each type, totalling 80 items in the task. The presentation of items was randomised across children. The internal consistency reliability for this task was .93.

Since there is no official or published pinyin letter frequency information in modern Chinese, to test the possible effect of letter frequency, we did a random sampling analysis in which we randomly selected 10,000 pinyin words from three types of pinyin-annotated books intended for young children in Mainland China, namely, storybooks, nursery rhymes, and classic poems, and we calculated the frequency of each letter in the 30,106 pinyin letters contained. The average pinyin letter frequency was .04 (range = .01–.14), with vowel letters ($M = .10$) being more frequent than consonant letters ($M = .02$), $p = .000$. We then obtained a spelling frequency value by averaging the frequencies of the three letters in each spelling stimulus. Considering that vowel letters are more frequent than consonant letters, we calculated two types of spelling frequency value, with and without vowel letters included, and tested them separately in subsequent analyses.

Because in conventional pinyin spellings tone marks appear and only appear above a vowel letter, to avoid

Table 1. Sample stimuli used in pinyin decision task.

<table>
<thead>
<tr>
<th>Letter pattern condition</th>
<th>Legal</th>
<th>Illegal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>pan</td>
<td>plq</td>
</tr>
<tr>
<td></td>
<td>mei</td>
<td>kdt</td>
</tr>
<tr>
<td></td>
<td>lao</td>
<td>bmf</td>
</tr>
<tr>
<td></td>
<td>xin</td>
<td>sgr</td>
</tr>
<tr>
<td></td>
<td>zao</td>
<td>cjh</td>
</tr>
</tbody>
</table>
Table 2. Sample stimuli used in pinyin learning task.

<table>
<thead>
<tr>
<th>Onset-and-rime</th>
<th>Onset-only</th>
<th>Rime-only</th>
<th>No-correspondence</th>
<th>Pronunciation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ban</td>
<td>bei</td>
<td>gan</td>
<td>pks</td>
<td>/bän/</td>
</tr>
<tr>
<td>lei</td>
<td>lan</td>
<td>mei</td>
<td>mhy</td>
<td>/lei/</td>
</tr>
<tr>
<td>fen</td>
<td>fai</td>
<td>sen</td>
<td>dqz</td>
<td>/fen/</td>
</tr>
<tr>
<td>kun</td>
<td>kai</td>
<td>lun</td>
<td>rei</td>
<td>/kän/</td>
</tr>
<tr>
<td>mai</td>
<td>men</td>
<td>kai</td>
<td>bor</td>
<td>/mäi/</td>
</tr>
</tbody>
</table>

possible cue effect, tone marks were not included in the stimuli.

**Pinyin learning**

Children were taught to pronounce the 3-letter novel pinyin spellings based on four conditions: the onset-and-rime condition in which letter-sound correspondence occurs in both the onset and rime levels (e.g. /pän/ for pán), the onset-only condition in which correspondence occurs only at the onset segment of the syllable (e.g. /pän/ for pei), the rime-only condition in which correspondence occurs only in the rime segment of the syllable (e.g. /pän/ for kan), and a no-correspondence condition in which no correspondence exists in any position (e.g. /pän/ for nrb). Four sets of stimuli, each consisting of 5 items, were constructed for each condition. Table 2 shows the examples of stimuli and pronunciations used in this task. The pronunciations were orally familiar to children of this age, and the four tones were balanced across conditions. The task consisted of a demonstration phase and up to 8 testing trials. In the demonstration phase, the experimenter said the child would learn to read some pinyin. The experimenter then presented the child with a stimulus card and provided its pronunciation, running her finger under the stimulus for emphasis. This procedure was repeated for all five stimuli in the set with the order randomised for each child. In the testing trial phase, the experimenter showed the child each stimulus in the set and asked whether the child remembered its pronunciation. If the child responded correctly, the experimenter would praise him or her; if not, the experimenter would provide the correct answer. All five stimuli in the set were tested in a random order for each trial. Subsequent testing trials were conducted in the same manner. Testing trials continued until the child achieved the criterion of responding correctly to all five items on two consecutive trials. The order of condition and the number of sets were balanced across children. The internal consistency reliability for this task was .98.

**Chinese word reading**

This task was given to assess children’s early reading ability (Lin et al., 2010; Wang, Yin, & McBride, 2015).

Children were asked to read aloud 50 Chinese single-character words presented in order of increasing difficulty. Testing was discontinued when children failed to read 10 characters consecutively. One point was given for each correctly read item and the maximum score was 50. The internal consistency reliability for this task was .97.

**Chinese word writing**

This task was given to assess children’s early writing skills (Wang et al., 2015; Yin & McBride, 2015). Children were asked to write 3 single-character words and 7 two-character words. The words were orally familiar to children and selected from popular kindergarten storybooks and primary school textbooks. The experimenter read each word twice, putting it in a sentence each time, and then asked the child to try his or her best to write the target word. One point was given for each correctly written character and the maximum score was 17. The internal consistency reliability for this task was .79.

**Non-verbal IQ**

Sets A and B of Raven’s Standard Progressive Matrices (Raven, Court, & Raven, 1996) were used to measure children’s nonverbal IQ. The maximum score was 24. The internal consistency reliability for this task was .83.

**Results**

Table 3 shows children’s performances in the tasks in each grade level. We first looked at children’s sensitivity to letter patterns in pinyin spellings tapped in the pinyin decision task and their sensitivity to letter-sound correspondences in pinyin syllables tapped in the pinyin learning task. We then examined the relationship between these sensitivities in pinyin and literacy skills in Chinese.

**Sensitivity to letter patterns in pinyin spellings**

In the pinyin decision task, the K2 children’s mean accuracy was at chance level (.50), \( t (2399) = -0.12, p = .903, d = -0.005 \), but the K3 children’s mean accuracy was significantly higher than chance, \( t (2399) = 8.07, p = .000, d = .033 \). Task order (pinyin learning task preceding pinyin decision task vs. pinyin learning task following pinyin decision task) was not significant, \( F (1, 4798) = 0.42, p = .518 \) for the whole sample and \( F (1, 2398) = 0.02, p = .881 \) and \( F (1, 2398) = 2.83, p = .093 \) for the K2 and K3 children, respectively. Given that half of the items in the task were legal and half of them were illegal, these results suggest that the K3 children were more likely to endorse as correct pinyin spellings that were legal than those
Table 3. Mean performance (standard deviation) in the tasks for each grade level.

<table>
<thead>
<tr>
<th>Tasks</th>
<th>K2 (N = 30)</th>
<th>Range</th>
<th>K3 (N = 30)</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (year)</td>
<td>4.62 (0.28)</td>
<td>4.00–5.00</td>
<td>5.52 (0.30)</td>
<td>5.00–5.98</td>
</tr>
<tr>
<td>Raven’s (raw score)</td>
<td>11.80 (3.91)</td>
<td>3–19</td>
<td>15.43 (4.08)</td>
<td>8–23</td>
</tr>
<tr>
<td>Chinese word reading</td>
<td>2.83 (5.54)</td>
<td>0–26</td>
<td>19.20 (12.52)</td>
<td>0–40</td>
</tr>
<tr>
<td>Chinese word writing</td>
<td>1.30 (1.32)</td>
<td>0–4</td>
<td>3.40 (2.51)</td>
<td>0–10</td>
</tr>
<tr>
<td>Pinyin decision</td>
<td>0.50 (0.50)</td>
<td>0–1</td>
<td>0.58 (0.49)*</td>
<td>0–1</td>
</tr>
<tr>
<td>Pinyin learning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset-and-rime condition</td>
<td>0.33 (0.47)**</td>
<td>0–1.00</td>
<td>0.65 (0.48)**</td>
<td>0–1.00</td>
</tr>
<tr>
<td>Onset-only condition</td>
<td>0.34 (0.48)**</td>
<td>0–1.00</td>
<td>0.62 (0.49)**</td>
<td>0–1.00</td>
</tr>
<tr>
<td>Rime-only condition</td>
<td>0.37 (0.48)**</td>
<td>0–1.00</td>
<td>0.61 (0.49)**</td>
<td>0–1.00</td>
</tr>
<tr>
<td>No-correspondence condition</td>
<td>0.35 (0.48)**</td>
<td>0–1.00</td>
<td>0.52 (0.50)</td>
<td>0–1.00</td>
</tr>
</tbody>
</table>

Note: Mean percentage correct was compared with chance level (50%) for the pinyin decision task and the pinyin learning task. ***p < .001.

Table 4. Fixed-effect coefficients (standard errors) predicting pinyin reading from letter-sound correspondence condition (upper portion) and trial (lower portion), respectively, for each grade level.

<table>
<thead>
<tr>
<th>Model term</th>
<th>K2</th>
<th>K3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>-0.71 (2.00)</td>
<td>0.09 (2.05)</td>
</tr>
<tr>
<td>Onset and rime correspondence</td>
<td>-0.13 (0.09)</td>
<td>0.63 (0.09)**</td>
</tr>
<tr>
<td>Onset correspondence</td>
<td>-0.04 (0.09)</td>
<td>0.51 (0.09)**</td>
</tr>
<tr>
<td>Rime correspondence</td>
<td>0.07 (0.09)</td>
<td>0.43 (0.09)**</td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.03 (1.96)</td>
<td>1.67 (1.93)</td>
</tr>
<tr>
<td>Trial 1</td>
<td>-1.73 (0.14)**</td>
<td>-2.85 (0.15)**</td>
</tr>
<tr>
<td>Trial 2</td>
<td>-1.37 (0.14)**</td>
<td>-2.08 (0.14)**</td>
</tr>
<tr>
<td>Trial 3</td>
<td>-1.09 (0.13)**</td>
<td>-1.49 (0.14)**</td>
</tr>
<tr>
<td>Trial 4</td>
<td>-0.77 (0.13)**</td>
<td>-1.05 (0.14)**</td>
</tr>
<tr>
<td>Trial 5</td>
<td>-0.51 (0.13)**</td>
<td>-0.75 (0.14)**</td>
</tr>
<tr>
<td>Trial 6</td>
<td>-0.38 (0.13)**</td>
<td>-0.55 (0.15)**</td>
</tr>
<tr>
<td>Trial 7</td>
<td>0.06 (0.25)</td>
<td>-0.30 (0.15)*</td>
</tr>
</tbody>
</table>

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

that were illegal, indicating that sensitivity to letter patterns in pinyin spellings emerges from K3 at age 5.

To rule out the possibility that the K3 children’s discrimination was based on letter frequency or letter category (vowel letter or consonant letter), rather than letter pattern, we conducted an ANCOVA on pinyin decision performance for each grade level, using spelling frequency, with and without vowel letter included, respectively, as a covariate and letter pattern legality as the independent variable. Results showed that for the K2 children, letter pattern legality was not significant using any type of spelling frequency, ps > .08. For the K3 children, letter pattern legality was significant in both cases, F (1, 77) = 4.01, p = .049 when using the spelling frequency calculated with both vowel and consonant letters included, and F (1, 77) = 20.72, p = .000 when using the spelling frequency calculated with only consonant letters included. These results suggest that the K3 children’s sensitivity to the letter patterns in pinyin spellings appears to have been at least somewhat independent of the frequency or category of the letters involved.

Sensitivity to letter-sound correspondences in pinyin syllables

For the pinyin learning task, the average percent of correct reading of the K2 children was significantly lower than chance level on all conditions, ps = .000, but that of the K3 children was significantly higher than chance when letter-sound correspondence was available, ps = .000, than when it was not available.

The generalised linear mixed modelling (GLMM) procedure in IBM SPSS Version 20 was used to analyse the data of pinyin learning. As an extension of generalised linear modelling (e.g. logistic regression), GLMM allows for the linear predictors containing random effects in addition to the fixed effects. It also allows response variables from different distributions, such as binary responses. In the models we built, the dependent variable was the binary response of pinyin reading (correct vs. incorrect). We selected binary logistic regression for target distribution and entered children and items as random effects. The fixed effects included task order (pinyin learning task preceding pinyin decision task vs. pinyin learning task following pinyin decision task), grade level (K2 vs. K3), letter-sound correspondence condition (onset-and-rime, onset-only, rime-only, and no-correspondence), and trial (1–8). All interactions were included in the models.

The final model that fit best the observed performance in the pinyin learning task had an overall correct-classification rate of 73.5% (observed versus predicted values by the model), F (106, 9493) = 9.06, p = .000. The main effect of task order was not significant, p = .704. The main effects of grade level, letter-sound correspondence condition, and trial were all significant, ps = .000. The K3 children learned better than the K2 children, children learned better in conditions where letter-sound correspondence was available, and children improved across trials, ps = .000. Significant two-way interactions were found between the grade level and letter-sound correspondence conditions, F (3, 9493) = 14.04, p = .000, and between grade level and trial, F (7, 9493) = 7.19, p = .000. No other interaction was significant. To better
understand these interactions, separate generalised linear mixed modelling was conducted for each grade level using letter-sound correspondence condition and trial as the fixed effects, respectively. Table 4 displays the fixed-effects coefficients. Figure 1 illustrates these interactions.

The effect of the letter-sound correspondence condition was significant for the K3 children, $F(3, 4796) = 18.70, p = .000$, but not significant for the K2 children, $p = .194$. Pairwise comparison analyses showed that the K3 children learned significantly more poorly in the no-correspondence condition than in all the other three conditions where letter-sound correspondence information was available, $t(4796) > 4.84, ps = .000$. The K3 children also learned significantly better when letter-sound correspondence was available in both onset and rime than when it was available only in rime, $t(4796) = 2.16, p = .031$. No other significant difference was observed. The effect of trial was significant for both the K2 children and the K3 children, $F(7, 4792) = 34.41, p = .000$ and $F(7, 4792) = 84.77, p = .000$, respectively. However, the K3 children made bigger between-trial improvements than the K2 children, especially in the first 4 trials, and they made a significant improvement even in the last trial (trial 7 to 8), $t(4796) = -2.87, p = .005$, whereas the K2 children did not. We further examined the number of trials taken by children in each grade and in each condition before reaching criterion (i.e. responding correctly to all five items on two consecutive trials). For the K2 children, only 3 children in each condition reached criterion, with the average number of trials taken before reaching criterion ranging between 6.33 in the onsets-only condition and 7.33 in the no-correspondence condition. In contrast, for the K3 children, 16 children in the onset-and-rime condition, 13 children in the onset-only condition, 13 children in the rime-only condition, and only 6 children in the no-correspondence condition reached criterion, with the average number of trials taken before reaching criterion ranging between 5.3 in the onset-and-rime condition and 6.33 in the no-correspondence condition. Furthermore, of the K3 children who reached criterion, 31% and 38% in the onset-and-rime condition and onset-only condition, respectively, did so within the first 4 trials, whereas 0% in the no-correspondence condition reached criterion within the first 4 trials. These results indicate that K3 children learned better and faster when letter-sound correspondence was available than when it was not available.

Overall, the results of the pinyin learning task demonstrate that Chinese children develop sensitivity to the letter-sound correspondences in pinyin from K3 at age 5 and they make use of such correspondences in learning to read new pinyin syllables.

**Relationship between pinyin sensitivity and Chinese literacy skills**

How is early sensitivity to pinyin related to literacy skills in Chinese? Correlational analyses showed that children’s mean accuracy in the pinyin decision, which taps sensitivity to letter patterns in pinyin spelling, or early orthographic sensitivity, was not significantly correlated with Chinese word reading, Chinese word writing, age, or IQ ($rs = .03$ to $.23, ps > .08$). Children’s mean percent of correct reading in pinyin learning, which taps sensitivity to letter-sound correspondences in a pinyin syllable, was significantly correlated with Chinese word reading,
Table 5. Results of the final model predicting Chinese word reading and Chinese word writing, respectively, from pinyin learning performance.

<table>
<thead>
<tr>
<th>Outcome and predictor</th>
<th>$R^2$</th>
<th>$\Delta R^2$</th>
<th>$\Delta F$</th>
<th>$B$</th>
<th>SE</th>
<th>$b$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chinese word reading</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.48</td>
<td>.48</td>
<td>25.72***</td>
<td>9.63</td>
<td>.28</td>
<td>.43**</td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td></td>
<td>.45</td>
<td>3.53</td>
<td>.35</td>
<td>.15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset and rime</td>
<td>.52</td>
<td>.04</td>
<td>4.95*</td>
<td>12.79</td>
<td>5.75</td>
<td>.26*</td>
<td></td>
</tr>
<tr>
<td>correspondence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chinese word writing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td>.41</td>
<td>.41</td>
<td>17.69***</td>
<td>1.19</td>
<td>.51</td>
<td>.30*</td>
<td></td>
</tr>
<tr>
<td>IQ</td>
<td></td>
<td>.13</td>
<td>1.69</td>
<td>.06</td>
<td>.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rime-only correspondence</td>
<td>.48</td>
<td>.07</td>
<td>7.28**</td>
<td>2.85</td>
<td>1.06</td>
<td>.31**</td>
<td></td>
</tr>
</tbody>
</table>

Note: $N = 60$.

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

Chinese word writing, age, and IQ in all four conditions ($rs = .36$ to .58, $ps < .006$).

To better understand the relationship between sensitivity to letter-sound correspondences in pinyin syllable and literacy skills in Chinese, stepwise regression analyses were conducted for Chinese word reading and Chinese word writing, respectively, with age and IQ entered in Step 1 and pinyin learning in four conditions entered in Step 2. Table 5 shows the results of the final models. For Chinese word reading, pinyin learning in the onset-and-rime condition, which taps children’s sensitivity to the connections between the pronunciation of pinyin syllable and the phonetic cues contained in its onset and/or rime, accounted for 4% additional variance after statistically controlling for age and IQ, $p < .05$; all the other three conditions were not significant in the final model, $ps > .29$. For Chinese word writing, pinyin learning in the rime-only condition, which reflects children’s onset-rime segmentation skills as well as sensitivity to the phonological link between written and spoken pinyin, explained 7% additional variance after having statistically controlled for age and IQ, $p < .01$; all the other three conditions were not significant in the final model, $ps > .36$. These results indicate that the Chinese 4-and 5-year-olds’ sensitivity to the letter-sound correspondences in given pinyin syllables is significantly associated with Chinese literacy skills, independent of age and IQ.

Discussion

Most statistical learning that has thus far been studied in natural settings (e.g. language learning or learning to read) involves sufficient exposure of the target and a relatively clear and straightforward unity to the learning (e.g. learning one’s native language). There is little empirical evidence showing whether statistical learning also occurs in natural environments in which conditions are limited, e.g. insufficient exposure and little motivation to learn. The current study contributed to this research by examining whether Chinese 4- and 5-year-old kindergarteners develop sensitivity to the regularities in pinyin, an alphabetic coding system representing the pronunciation of non-alphabetic Chinese, to which children are exposed only in a very limited way and for which children have little motivation to learn in the kindergarten years. We found that Chinese 5-year-olds who had received no formal literacy instruction demonstrated sensitivity to both the letter patterns in pinyin spellings and the letter-sound correspondences in pinyin syllables, reflecting the fact that statistical learning happens despite the limited conditions. Furthermore, sensitivity to the letter-sound correspondences in pinyin was significantly associated with Chinese word reading and writing abilities after having statistically controlled for the effects of age and IQ.

The uniqueness of this study is partly in our focus on pinyin, which is a literacy tool but does not constitute reading itself. In Mainland China, mastering pinyin is taken as an important early step for literacy learning of Chinese (e.g. McBride-Chang et al., 2012). However, in other cultures, notably Hong Kong (Taiwan has a different literacy tool for learning of Chinese called Zhuyin-Fuhao), there is no such intermediary tool used for teaching Chinese. Thus, our focus is not on statistical learning of a skill that is clearly of independent value for all learners, such as language learning or learning to read. Instead, our focus was on statistical learning of a skill that is helpful for facilitating the valued ability of Chinese character recognition but is not itself a main learning goal. Our focus was on statistical learning of a tool for literacy development, a kind of mediator between no knowledge of how to read and solid mastery of Chinese character recognition.

To a certain extent, mastery of the Roman alphabet has this function in English. Knowing the letters of the alphabet does not constitute reading. At the same time, failing to learn the letter names or sounds of the alphabet is strongly associated with failing to learn to read. Pinyin learning goes beyond learning the letters to learning what patterns of letter configurations are and are not acceptable. The system is relatively comprehensive, but it is not reading itself.

Pinyin represents a unique opportunity to delve into the limits of statistical learning. Unlike the primary motivation that learning one’s native language presents or even the motivation of learning to read, learning patterns of pinyin is not particularly motivating in kindergartens. That might be important because perhaps children’s interest in paying attention to pinyin is limited. At the same time, the idea that exposure to a system produces pattern recognition even under such limited conditions
is interesting in “pushing the envelope” on the concept of statistical learning. Our focus on pinyin highlights the fact that children tend to be quite adept at pattern recognition even for patterns that are less immediately important for adaptation to one’s environment.

Sensitivity to the legality of letter patterns in pinyin spellings found in the 5-year-olds in our study fits nicely with similar reports from previous studies with older beginning readers of alphabetic languages, but our finding serves as stronger evidence for statistical learning because pinyin represents a set of patterns to which children receive limited exposure (e.g. English: Cassar & Treiman, 1997; Treiman, 1993; Wright & Ehri, 2007; Finnish: Lehtonen & Bryant, 2005; French: Pacton, Sobaco, Fayol, & Treiman, 2013). For example, when U.S. late kindergarteners and first graders were asked to choose from nonword pairs items that they thought looked like English words, they correctly chose nonwords with final doublets (e.g. baff) as more word-like than nonwords with initial doublets (e.g. bbaft) (Cassar & Treiman, 1997). Similarly, in our study, when the Chinese 5-year-olds were asked to decide whether an item was a possible pinyin word, they chose conventional spellings with one or two consonants (e.g. bei or pan) as more pinyin-like than illegal spellings with three consecutive consonant letters, which do not exist in pinyin (e.g. plq).

Sensitivity to the letter-sound correspondences in pinyin syllables found in the 5-year-olds in this study reflects the fact that children pay selective attention to pinyin while being read to, although they have no intention of learning pinyin or awareness of learning it. This finding also supports evidence for the universal phonological principle of reading (Perfetti & Tan, 1998; Perfetti, Zhang, & Berent, 1992; Ziegler et al., 2011), which states that phonological activation is involved in recognising printed words across all writing systems, and adds to the research showing that phonological processes are involved in the earliest stage of children’s reading (Ehri & Wilce, 1985; Rack, Hulme, Snowling, & Wightman, 1994). For example, in the study by Rack et al. (1994), 5-year-old English-speaking children who were taught to associate printed three- or four-letter abbreviations with spoken words found the phonetic-cue words (e.g. bzn for the word basin) easier to learn than the control-cue words (e.g. bfn for the word basin) and they learned words with relatively direct correspondence between letters and sounds more easily than words with less obvious letter-sound correspondences. Chinese 5-year-olds in our study learned pinyin syllables that contained letter-sound correspondences better and faster than those who did not, and better when letter-sound correspondences were available in two positions than when they were available in one position. This demonstrates that Chinese 5-year-olds are not exclusively logographic learners who use rote memory to connect pinyin spellings and sounds. Rather, they search for structure and make use of the overlap between sounds of the pinyin syllable and sounds of its onset or and/or rime to establish a connection between written pinyin and spoken pinyin. This sort of learning mechanism was described in the connectionist models of learning to read (Seidenberg & McClelland, 1989) and is well-evidenced in alphabetic language-speaking children learning to read native languages (e.g. Ehri & Wilce, 1985; Rack et al., 1994). Our study contributed to these findings with evidence from non-alphabetic language speaking children in learning an alphabetic coding system which is reading-like but does not constitute reading itself in Chinese.

A significant association was found between sensitivity to spelling-sound correspondences in pinyin and Chinese literacy abilities in our study. This was consistent with previous studies showing a significant relationship between pinyin knowledge and Chinese literacy in older children with and without reading difficulties (Ding et al., 2015; Lin et al., 2010; Pan et al., 2011; Siok & Fletcher, 2001). In children’s books pinyin and Chinese characters are often paired together. Pinyin is not reading but it is very much reading-like – patterns related to pinyin mimic those of reading. In a study with 6-year-old Chinese kindergarteners (McBride-Chang et al., 2012), maternal mediation of pinyin explained unique variance in Chinese word reading concurrently and a year later, after controlling for children’s age and non-verbal IQ. Our study provided evidence from younger children using a learning task to tap the earliest implicit knowledge of pinyin.

In the present study, pinyin learning in the rime-only condition but not in the onset-only condition explained unique variance in Chinese word writing. This might be explained by the developmental differences of rime awareness and onset awareness in young children. Shu et al. (2008) found that for Chinese children, syllable awareness and rime awareness increased gradually and steadily across ages 3–6 years, whereas phoneme onset awareness did not differ from chance levels at ages 3–5 years but increased to 70% correct in the first grade when children received pinyin instruction. Their findings suggest that the development of syllable awareness and rime awareness may depend primarily on maturational age, which is in line with other findings on English (Goswami & Bryant, 1990; Treiman & Zukowski, 1991), whereas the development of phoneme onset awareness may be related more to schooling, which was also reported in studies of English (e.g. Castles & Coltheart, 2004).
One might also expect a significant relationship between sensitivity to letter patterns in pinyin spellings and Chinese literacy skills, given findings from previous research that the ability of detecting statistical patterns in written language is significantly related to reading and writing skills in children. We did not observe such a relationship in this study, which might be due to the limited exposure of pinyin at the ages of 4 and 5 since sensitivity to conventional letter patterns in pinyin was found to be only significantly correlated with age in this study. It might be that a significant link between the two was still developing at the time the children were tested, and future longitudinal studies may better investigate this. Perhaps the phonological aspects of pinyin become clearer earlier than do the orthographic aspects of it.

There were some limitations in the present study. First, we did not have an exact measure of pinyin exposure in the study. Our finding that the Chinese 5-year-olds were sensitive to the patterns in pinyin spellings before they were formally taught pinyin provides promising but not direct evidence for statistical learning. Future research with a systematic measure of pinyin exposure in kindergarten years and rigorous statistical analysis of written pinyin, as was done with written Chinese (Tong & McBride, 2014), may better address this issue. Second, because we sought to tap children’s earliest implicit sensitivity to patterns in pinyin before they had a conscious intention to learn or awareness of what was learned, we did not explain to them what pinyin was during the tasks. This left a possibility that some children’s poor performance might have been due to a lack of understanding of what pinyin is. Future studies may include an assessment of pinyin knowledge and examine how explicit pinyin knowledge relates to sensitivity to regularities in pinyin. Third, the data in stepwise regression analyses were the K2 and K3 combined samples, so in our results, we cannot compare the role of statistical learning in different grades. Future studies may include an assessment of pinyin knowledge and examine the relationship between explicit pinyin knowledge and pinyin pattern sensitivity. Finally, we tested children in a “Category-1” public kindergarten in a middle-class neighbourhood in Beijing where, as in most first-tier government-funded kindergartens in Mainland China, official policies are well observed and no explicit literacy instruction developed sensitivity to the letter patterns and the letter-sound correspondences in pinyin from the Grade 1 syllabus is conducted (Yang & Cao, 2010). Findings of our study may not be generalisable to children in such settings. Future studies may examine kindergarteners from varied regions and SES backgrounds.

To summarise, our study revealed that despite the limited and secondary exposure of pinyin, Chinese young children who had not received formal literacy instruction developed sensitivity to the letter patterns and the letter-sound correspondences in pinyin from age 5, and such sensitivity was significantly related to Chinese literacy ability. These findings highlight the general nature of implicit statistical learning in early literacy development and demonstrate that children tend to be quite adept at pattern recognition in print, even under limited conditions.

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