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# A Perceptual Learning Deficit in Chinese Developmental Dyslexia as Revealed by Visual Texture Discrimination Training

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Learning to read involves discriminating between different written forms and establishing connections with phonology and semantics. This process may be partially built upon visual perceptual learning, during which the ability to process the attributes of visual stimuli progressively improves with practice. The present study investigated to what extent Chinese children with developmental dyslexia have deficits in perceptual learning by using a texture discrimination task, in which participants were asked to discriminate the orientation of target bars. Experiment 1 demonstrated that, when all of the participants started with the same correlated with their performance in Chinese character recognition. These findings suggest that deficits in visual perceptual processing and learning might, in part, underpin difficulty in reading Chinese. Copyright © 2014 John Wiley & Sons, Ltd.

**Keywords:** developmental dyslexia; perceptual learning; texture discrimination; Chinese

## INTRODUCTION

Efficient reading involves automatically recognizing printed symbols, and accessing associated phonological and semantic information, after repeated exposure to written materials. However, individuals with developmental dyslexia fail to achieve this

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*Correspondence to: Xiangzhi Meng and Xiaolin Zhou, Department of Psychology, Peking University, Beijing, 100871, China. E-mail: mengxzh@pku.edu.cn; xz104@pku.edu.cn automaticity in reading, even after extensive reading practice (Nicolson & Fawcett, 1990; Nicolson & Fawcett, 2007). Two major frameworks have been presented to account for the origin and mechanisms of developmental dyslexia. The first, the linguistic framework hypothesis, postulates that deficits in accessing and manipulating phonological information account for developmental dyslexia (Ramus *et al.*, 2003; Studdert-Kennedy, 1997; Studdert-Kennedy & Mody, 1995; Wagner & Torgesen, 1987). The second, the nonlinguistic framework hypothesis, proposes that phonological and other deficits at the linguistic level may stem from more fundamental deficits in sensory information processing, including acoustic–auditory, auditory temporal processing (Frith, 1996; Tallal, 1980; Tallal, Merzenich, Miller, & Jenkins, 1998; Walker, Hall, Klein, & Phillips, 2006; Witton *et al.*, 1998) and visual perceptual processing (Goswami *et al.*, 2010; Stefanics *et al.*, 2011; Stein, 1994; Stein & Walsh, 1997; Vidyasagar & Pammer, 2009).

Another important line of research has addressed the dynamic learning process in individuals with developmental dyslexia. This stream of research has found that people suffering from dyslexia have difficulty with paired-association learning (Li *et al.*, 2009; Mayringer & Wimmer, 2000; Messbauer & de Jong, 2003; Vellutino, Steger, DeSetto, & Phillips, 1975) and procedural learning (Nicolson & Fawcett, 2007; Nicolson, Fawcett, Brooks, & Needle, 2010). Researchers have also found strong evidence of an association of dyslexia with difficulties in implicit learning in motor sequence (Gabay, Schiff, & Vakil, 2012a, 2012b; Howard, Howard, Japikse, & Edend, 2006; Menghini *et al.*, 2006; Stoodley, Harrison, & Stein, 2006; Stoodley, Ray, Jack, & Stein, 2008; Vicari *et al.*, 2003, 2005, except for Rüsseler, Gerth, & Münte, 2006, and Kelly, Griffiths, & Frith, 2002) and in linguistic rules (Gabay *et al.*, 2012b; Boada & Pennington, 2006; Pothos & Kirk, 2004; and Folia *et al.*, 2008, for a review, except for Rüsseler *et al.*, 2006), even in cases when their explicit learning is intact (Vicari *et al.*, 2003, 2005). These implicit sequence learning deficits have been commonly attributed to the failure of automaticity in skill learning, which are associated with selective deficits in the fronto-striatal-cerebellar circuits (Howard *et al.*, 2004; Howard *et al.*, 2006; Nicolson, Fawcett, & Dean, 2001; Stoodley *et al.*, 2008).

Notably, the majority of studies on implicit procedural learning in people with dyslexia, including those cited earlier, have focused on dyslexia in terms of an abstract, rule-based, implicit knowledge based on experiences (Folia *et al.*, 2008). The question thus remains as to whether people with dyslexia have a deficit only in abstract, rule-based, implicit knowledge settings (Banai & Yifat, 2012; Oganian & Ahissar, 2012) or a deficit also in basic perceptual learning of concrete skills. Perceptual learning is evidenced by an improvement of perceptual performance as a function of training (Gibson, 1969). This improvement in performance results from an increase in sensory sensitivity, induced by repetitive exposure to various experiences (Karni & Sagi, 1991). A study by Censor, Sagi and Cohen (2012) examined previous evidence supporting the notion that perceptual and motor procedural learning skills in humans exhibit similar properties. The authors proposed that a common general mechanism for learning in humans may exist across several sensory domains. Given that people with dyslexia have a deficit in implicit motor sequence learning, it is plausible that they may also have a deficit in perceptual learning. In support of this assertion, findings from longitudinal studies have revealed that infants' habituation and dishabituation speeds can, to a degree, predict their later intellectual development and academic achievement (Kavšek, 2004; Rose, Feldman, Jankoeski, & Rossem, 2012). The findings of such studies have indicated a relationship between perceptual learning and cognitive learning. Habituation is the process whereby infants decrease their attention to repeatedly presented stimuli (e.g. a circle), whereas dishabituation is the process whereby infants increase their attention to stimuli with a single-feature change (e.g. a circle changing into a triangle). The processes involved in habituation and dishabituation include stimulus encoding, storage and retrieval, which are the basic processes of perceptual learning. If an individual's early perceptual learning abilities are associated with later information processing abilities and academic learning, it is then hypothesized that an association between perceptual learning and higher-order learning may exist.

To the best of our knowledge, except for studies on auditory temporal learning (Merzenich *et al.*, 1996; Tallal *et al.*, 1998; Temple *et al.*, 2003), no previous study has directly compared the properties and time course of perceptual learning between individuals with dyslexia and typically developing children. Tallal and colleagues (Tallal *et al.*, 1998; Merzenich *et al.*, 1996; Temple *et al.*, 2003) argued that dyslexic people have a deficit in auditory temporal processing, which can be ameliorated by stretching the auditory stimuli to make them more individually adaptive. Compared with learning English (the alphabetic scripts), learning to read Chinese (the logographic system) may demand more from the reader on visual-orthographic processes in lexical processing (Zhou & Marslen-Wilson, 1999, 2000). It is also the case that visual-orthographic processes may play a more important role in learning to read and reading impairment in Chinese than in English (Li *et al.*, 2009; Meng *et al.*, 2011). Previous studies did reveal positive associations between visual skills and Chinese character recognition (Chung *et al.*, 2008; Ho *et al.*, 2004; Huang & Hanley, 1995; Luo *et al.*, 2013; McBride-Chang & Chang, 1995; Meng *et al.*, 2002; Meng *et al.*, 2011; Siok & Fletcher, 2001). Given the relatively important role of visual processing in Chinese reading development, the present study will specifically investigate to what extent Chinese-speaking children with dyslexia would show deficits in visual perceptual learning and whether these deficits are related to their performance in linguistic tasks.

Perceptual learning has been found in various visual tasks involving basic visual features, such as motion direction (Ball & Sekuler, 1987), spatial phase (Fahle, 1994), hyperacuity (Schoups, Vogels, & Orban, 1995), orientation discrimination (Vogels & Orban, 1985) and texture discrimination (Karni & Sagi, 1991). Among these psychophysical paradigms, the texture discrimination task (TDT) is one of the most intensively studied. In this task, a frame of texture stimuli is presented, followed by a mask frame. Participants are typically asked to search for singleton stimuli in the texture and perform a particular task (e.g. orientation discrimination) towards these imperative stimuli (Figure 1). Recent neuroimaging studies utilizing TDT have shown that changes in the primary visual cortex (V1) might underpin perceptual learning in adults (Karni & Sagi, 1991; Schwartz, Maquet, & Frith, 2002; Yotsumoto, Watanabe, & Sasaki, 2008). On the other hand, top-down influences exerted on V1 from later visual processing stages (Hupe *et al.*, 1998; Mehta, Ulbert, & Schroeder, 2000) or from fronto-parietal attention networks (Schwartz *et al.*, 2004; Song *et al.*, 2007) have also been detected with perceptual learning. In the present study, we applied TDT to Chinese school children with dyslexia and a matched control group.

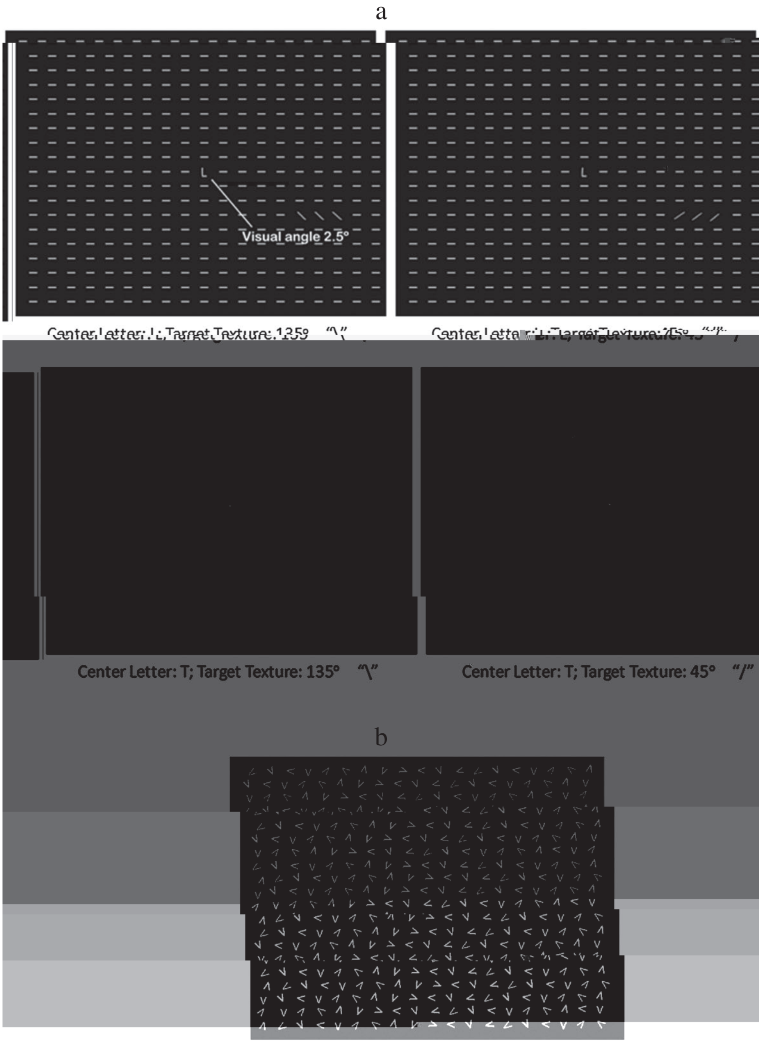

Figure 1. Experimental stimuli displays. [a] TDT stimuli frame and [b] mask frame.

## METHODS

### Participants

In this study, 38 Chinese-speaking children, 19 with dyslexia and 19 typical readers, in grades four, five and six, were selected according to the procedures described in the following text. None of the participants had a history of neurological disease or psychiatric disorders. In particular, the DSM-IV ADHD Scale (American Psychiatric Association, 1994) was used to exclude children with ADHD. All of the participants were right-handed and had normal or corrected-to-normal vision. Informed consent was obtained from each participant and his or her parents. This study was approved by the Ethics Committee of the Department of Psychology, Peking University.

Within each group, 10 were assigned to Experiment 1 and nine to Experiment 2. Participant screening was based on a Chinese written vocabulary test and reading fluency test (see in the following text and in Table 1).

### Pretests

*The Standardized Chinese Character Recognition Test* (Wang & Tao, 1996) involved 210 characters, divided into 10 groups on the basis of reading difficulty level. Participants were asked to write down a compound word on the basis of a constituent morpheme provided on the sheet. Performance was measured by the total number of correct characters (morphemes) that the participants could utilize in word compositions. Participants had to know morpheme combination rules to form a compound word. The scores from this test formed the index of the participants' Chinese character recognition performance.

*The Reading Fluency Test* was composed of 95 sentences. Each sentence was paired with five multiple-choice pictures. Participants were asked to read each sentence and select, from five pictures, the one that best illustrated the meaning of the sentence. Children were encouraged to complete as many paragraphs as possible within a 10-min period. The total number of sentences that the participants could understand determined the performance score. This task required rapid retrieval and retention of lexical information and construction of sentential representation.

Additionally, *Raven's Standard Progressive Matrices* were used to measure the children's nonverbal IQ. Scoring procedures were based on the Chinese norm (Zhang & Wang, 1985).

Children were placed in the group of dyslexia if their scores on the character recognition test were at least 1.5 grades below the norm and if reading fluency test scores were lower than the mean scores of their grades. Additionally, they had typically developed IQ. The chronological age-matched and grade-matched control children were selected from among their peers. Similar procedures for recruiting children with dyslexia or with reading impairment were implemented by previous studies (Meng, Tian, Jian, & Zhou, 2007; Shu, Chang, Wu, & Liu, 2006; Siok, Perfetti, Jin, & Tan, 2004; Siok *et al*., 2008).

### Materials

The stimuli in the current study in the texture discrimination task (Karni & Sagi, 1991) were white on a uniform black background and appeared on a 17-in. coloured monitor at a 57 cm viewing distance (Figure 1). The resolution of the monitor was set at 1024 × 768 pixels, and the frame rate was 85 Hz.

The stimulus was a texture display made of 19 × 19 high-contrast horizontal line segments, covering an area with a 17.53° × 13.32° visual angle. The lines were 0.44° × 0.08° and spaced 0.55 d spa° apart. The targets consisted of three adjacent diagonal bars (135°, '\' or 45°, '/'; Figure 1), which were presented in the lower-left visual quadrant (the fourth quadrant), at 2.5° of the visual angle from fixation. A rotated letter 'T' or 'L' (tilted 2.5°–5°) appeared as a fixation in the centre of the whole screen. A mask was made of 19 × 19 randomly oriented V-shaped patterns, and the display size was the same as the stimulus display.

Table 1. Characteristics of the participants, with standard deviation in parentheses

| | Two groups of participants | | | | Subgroup of Experiment 1 | | | | Subgroup of Experiment 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dyslexia group ($n = 19$, 11 men) | Control group ($n = 19$, seven men) | $F$ | $P$ | Dyslexia group ($n = 10$, eight men) | Control group ($n = 10$, five men) | $F$ | $P$ | Dyslexia group ($n = 9$, three men) | Control group ($n = 9$, two men) | $F$ | $P$ |
| Age | 116.74<br>(10.99) | 116.91<br>(11.60) | 0.006 | >0.1 | 117.84<br>(9.12) | 117.60<br>(12.61) | 0.001 | >0.1 | 115.64<br>(7.51) | 116.21<br>(4.44) | 0.04 | >0.1 |
| Raven | 70.00<br>(18.93) | 80.52<br>(14.33) | 3.73 | >0.1 | 67<br>(22.14) | 78<br>(17.51) | 1.52 | >0.1 | 73.33<br>(15.21) | 83.33<br>(10.0) | 2.72 | >0.1 |
| Reading fluency | 32.21<br>(7.09) | 43.47<br>(7.14) | 24.06 | <0.001 | 34.3<br>(6.83) | 46.6<br>(8.12) | 13.42 | <0.01 | 30.11<br>(7.08) | 40.33<br>(4.12) | 14.01 | <0.001 |
| Chinese character recognition | 1455.33<br>(470.31) | 2393.82<br>(665.71) | 25.13 | <0.001 | 1472.92<br>(430.42) | 2846.74<br>(501.61) | 26.39 | <0.001 | 1102.41<br>(151.85) | 1888.32<br>(412.74) | 28.74 | <0.001 |

Age is depicted by mean months for the dyslexic and control groups. The Raven scores are mean percentiles for the dyslexic and control groups. For reading fluency, the numbers represent means of items that the dyslexic and control groups answered correctly. For Chinese character recognition, the numbers are the numbers of characters that children could use correctly in word composition.

### Procedures

The procedure of each trial is as follows. First, a white cross was presented at the centre of the black background screen for 250 ms, followed by a 300 ms blank screen, and then the stimuli were displayed for 12 ms. After an interval of stimulus-to-mask onset asynchrony (SOA, which may vary according to experimental design), the masking was shown for 100 ms, and then the participants judged the central letter and target texture. That is, the participants first determined whether the central letter was T or L (to determine whether or not the participants were able to see the centre) and then judged the orientation of target texture (45° '/' or 135° '\'; Figure 1). The response was deemed correct when judgments on both the letter and the target texture were correct. There was no feedback, and the reaction time was not limited.

## EXPERIMENT 1

To the best of our knowledge, there has been no systematic study on the perceptual learning of developmental dyslexia in the texture discrimination task; hence, there are no agreed-upon conclusions regarding whether or not adults and children use the same initial threshold SOA in TDT. The first experiment set the initial value of threshold SOA, the same as in the classic TDT studies at 300 ms (Karni & Sagi, 1991; Schwartz *et al.*, 2002; Yotsumoto *et al.*, 2008).

Before the experiment, all participants went through eight practice sessions. The SOA of practice sessions started from 1000 ms, so that the participants could have enough time to see the stimuli clearly and learn how to respond.

In the formal experiment, participants were administered five sessions of training over five successive days. Each session included five blocks with 40 trials each. After each block, participants took a short break. If the response accuracy was beyond 80% in a block, the SOA of the next block was reduced by 23 ms; otherwise, the SOA was increased by 23 ms in the next block.

### Results

During the training sessions, all of the participants evidenced stable and high-level accuracy on the central letter (T/L) discrimination task (group of dyslexia, 91.83%; control group, 92.88%), suggesting that the participants viewed the fixation well during the experiment.

The threshold SOAs for the two groups of children in five sessions were averaged separately. Learning curves depicted the learning progress of the two groups of children (Figure 2). The curves showed that threshold SOA in the control group decreased from the initial 300 to 55 ms at the final session. In contrast, the mean threshold SOA in the group of dyslexia was 293 ms at the final session. The mean threshold SOA of the two groups in the five sessions was submitted to a mixed-design ANOVA with group as a between-subjects factor and learning sessions as a within-subjects factor. The main effect of group was significant [$F(1, 18) = 32.42$, $p < 0.0001$], indicating that the group of dyslexia ($m = 328$ ms) had significantly higher threshold SOA than the control group ($M = 154$ ms). The main effect of training sessions was also significant [$F(4, 72) = 28.58$, $p < 0.0001$]. The interaction between group of participants and training session was also significant [$F(4, 72) = 14.33$, $p < 0.0001$]. Further intra-group pairwise comparisons observed significant learning effects in the first four sessions of training (ps $<$

at 600 ms. If the response for one trial was correct, then SOA of the next trial was decreased by 58 ms; otherwise, it was increased by 58 ms. For each participant, the average SOA of the last 20 trials was set as his or her initial threshold SOA.

Then, each participant underwent five sessions of training on five consecutive days, with one session per day. Each session included five blocks with 40 trials each. In each block, there were fi had similar learning patterns across five sessions of perceptual learning. Further intragroup *post hoc*

(300 ms), Chinese children with dyslexia did not achieve as high of a perceptual

Consistently, research on the neural basis of visual perceptual learning has supported the aforementioned observation. Gibson (1963, p. 29) defined perceptual learning as '[any] relatively permanent and consistent change in the perception of a stimulus array, following practice or experience with this array'. The mainstream view suggests that cortical changes occurring in the early visual cortex, such as the primary visual cortex, (V1) underlie behavioural changes in visual perceptual learning (Karni & Sagi, 1991; Pourtois, Rauss, Vuilleumier, & Schwartz, 2008; Schoups, Vogels, Qian, & Orban, 2001; Schwartz *et al.*, 2002; Walker, Stickgold, Jolesz, & Yoo, 2005; Yotsumoto *et al.*, 2008). However, recent psychophysical studies have also suggested that perceptual improvements might be related to changes outside of the visual cortices (Zhang & Li, 2010; Zhang, Xiao, *et al.*, 2010; Zhang, Zhang, *et al.*, 2010): Perceptual learning could be a result of refinement of processing in the decision-making and attentional systems. This idea is supported by neuroimaging studies showing that only the activity pattern in the anterior cingulate cortex tracks changes during perceptual learning (Kahnt, Grueschow, Speck, & Haynes, 2011).

For developmental dyslexia, it has been proposed that defects may exist anywhere along the dorsal visual stream (Vidyasagar & Pammer, 2009), and the deficits at different levels of the magnocellular pathway are associated with impaired performance in different aspects of reading (Kevan & Pammer, 2008). The higher threshold SOAs for children with reading impairment observed in the present study might, in fact, be indicative of deficiency in higher-level visual cortex or in the neural network responsible for top-down control, including attention and decision-making. Although such deficiency can be compensated, to some extent, by extensive training, the results of Experiment 2 suggested that deficits in basic perceptual processing may not be completely reversed.

Of particular importance are the implications of the present findings for educational curriculum design and reading remediation for developmental dyslexia. A comparison of the results from Experiment 1 (fixed SOA) and Experiment 2 (adaptive SOA) clearly shows that it is difficult to produce a learning effect if the training or learning programme does not fit the learners' current level of processing. The 'resister', who cannot benefit from traditional intervention reported in previous literature (Fuchs & Fuchs, 2006; Troia & Whitney, 2003) may

Experiment 2. These findings revealed that children with dyslexia can benefit from long-term repetitive training, even though they may not catch up with controls. Meanwhile, the dissociation between the courses of perceptual learning in the aforementioned two cases, and the much-wider standard deviation in the group of dyslexia than in the control group (Figure 3), implies inter-group variability among dyslexia-affected children.

Taken together, the present study observed a link between visual perceptual learning and Chinese reading and suggested that deficits in visual perceptual processing and learning might, in part, underpin difficulty in reading Chinese. However, the following additional questions are raised from this preliminary observation. First, because we know that visual perceptual learning involves various visual features, the generalization of the present findings needs to be verified with more participants and varieties of visual perceptual learning tasks (Lin, Wang, & Meng, 2013). Second, the nature, correlation or causality, of the relationship between visual perceptual learning and Chinese reading has also yet to be clarified with longitudinal design and training study. Third, the underlying mechanisms between visual perceptual learning and reading also need to be explored in depth.

## CONFLICT OF INTEREST

None.

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