Ann. of Dyslexia (2011) 61:161–176
DOI 10.1007/s11881-010-0049-2

Dynamic visual perception and reading development in Chinese school children

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Received: 19 September 2007 / Accepted: 19 November 2010 / Published online: 15 January 2011

Abstract The development of reading skills may depend to a certain extent on the development of basic visual perception. The magnocellular theory of developmental dyslexia assumes that deficits in the magnocellular pathway, indicated by less sensitivity in perceiving dynamic sensory stimuli, are responsible for a proportion of reading difficulties experienced by dyslexics. Using a task that measures coherent motion detection threshold, this study examined the relationship between dynamic visual perception and reading development in Chinese children. Experiment 1 compared the performance of 27 dyslexics and their age- and IQ-matched controls in the coherent motion detection task and in a static pattern perception task. Results showed that only in the former task did the dyslexics have a significantly higher threshold than the controls, suggesting that Chinese dyslexics, like some of their Western counterparts, may have deficits in magnocellular pathway. Experiment 2 examined whether dynamic visual processing affects specific cognitive processes in reading. One hundred fifth-grade children were tested on visual perception and reading-related tasks. Regression analyses found that the motion detection threshold accounted for 11% and 12%, respectively, variance in the speed of orthographic similarity judgment and in the accuracy of picture naming after IQ and vocabulary size were controlled. The static pattern detection threshold could not account for any variance. It is concluded that reading development in Chinese depends to a certain extent on the development of dynamic visual perception and its underlying neural pathway and that the impact of visual development can be specifically related to orthographic processing in reading Chinese.

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Keywords Chinese · De elopmental d sle ia · D namic is al perception · Magnocell lar path a · Orthographic processing

Introduction

Reading de elopment req ires that children link lang age's spoken form and meaning ith its ritten s mbols. St dies ha e sho n that phonological and orthographic skills are highl important to reading acq isition and de elopment (Wagner, Torgesen, & Rashotte, 1994). Longit dinal and training st dies demonstrate that phonological abilit can predict and ma pla a ca sal role in children's literac de elopment (Bradle & Br ant, 1978, 1983, 1985; L ndberg, Frost, & Peterson, 1988), as do orthographic skills (see McBride-Chang, 2004 for a re ie). S bstantial e idence also demonstrates that deficits in phonological and orthographic processing pla a direct role in reading fail re (e.g. Br ck, 1992; Manis, C stodio, & S es lski, 1993; Stano ich, Siegel, Gottardo, Chiappe, & Sidh , 1997). D sle ic children, for e ample, ma ha e problems ith phonological manip lation, phonological encoding, and phonological memor (Bradle & Br ant, 1978; Frith, 1981).

A large n mber of st dies on de elopmental d sle ia s ggest that, besides ling istic factors, deficits in is al and a ditor processing ma also ca se reading impairment. A partic lar theor , the magnocell lar theor (Lo egro e, Bo ling, Badcock, & Black ood, 1980; Stein, 1994; Stein & Walsh, 1997; Stein & Talcott, 1999; Stein, Richardson, & Fo ler, 2000; Demb, Bo nton, Best, & Heeger, 1998; Witton, Talcott, Hansen, Richardson, Griffiths, Rees, Stein, & Green, 1998; Talcott, Witton, McLean, Hansen, Rees, Green, & Stein, 2000), s ggests that reading impairment is associated to some e tent ith deficits in magnocell lar path a , hich projects onto the MT/V5 comple located at the temporal–occipital–parietal j nction in the brain. This path a is partic larl sensiti e to is al information of lo spatial freq enc and high temporal resol tion (see Boden & Giaschi, 2007 for a re ie), incl ding spatial locali ation, mo ement and depth perception (Goodale & Milner, 1992). The parietal–temporal regions (MT area) of the magnocell lar path a are in ol ed in percei ing stim li of global motion (Vaina, Lema , Bienfang, Choi, & Naka ama, 1990; Cheng, F jita, Kanno, Mi ra, & Tanaka, 1995; Zeki, Watson, L eck, Friston, Kennard, & Fracko iak, 1991). It has been proposed that defects ma e ist an here along the dorsal stream (Vid assagar & Pammer, 2009), and deficits at different le els of magnocell lar path a are associated ith impaired performance in different aspects of reading (Ke an & Pammer, 2008). Deficits ithin the is al s stem co ld be the core deficit in d sle ia, hereas phonological deficits might be onl an effect rather than a ca se (Vid assagar & Pammer, 2009; La cock & Cre ther, 2008).

This magnocell lar theor is s pported b se eral lines of st dies (see Stein & Walsh, 1997; Boden and Giaschi, 2007; La cock & Cre ther, 2008, for re ie s). For e ample, presentation of d namicall mo ing stim li to d sle ics failed to prod ce the same task-related brain acti ation in the MT/V5 comple as normal controls (Eden, VanMeter, R mse , Maisog, Woods, & Zeffiro, 1996). D sle ics are less sensiti e to is al coherent motion than matched controls (Witton et al., 1998; Talcott et al., 2000; Hansen, Stein, Orde, Winter, & Talcott, 2001; Pellicano & Gibson, 2008; Conlon, Sanders, & Zapart, 2004; Conlon, Sanders, & Wright, 2009). This diffic lt in coherent motion perception ma hinder the abilit to e tract letter position information d ring earl stages of is al print anal sis (Cornelissen & Hansen, 1998; Cornelissen, Hansen, H tton, E angelino , & Stein, 1998). D sle ic children ma ha e a range of problems ith is al search (Vid asagar & Pammer, 1999; Casco & Pr netti, 1996) and is al–

spatial attention (Casco & Prunetti, 1996; Facoetti, Paganoni, Turatto, Marzola, & Mascetti, 2000; Facoetti, Trussardi, Ruffino, et al., 2010; Hari, Valta, & Uutela, 1999; Bosse, Tainturier, & Valdois, 2007). In the lexical decision task, adult readers with good motion detection skills respond significantly faster than individuals with poor motion detection skills (Levy, Walsh, & Lavidor, 2010). Moreover, several longitudinal studies and training studies implicated the dorsal magnocellular pathway in reading development (Kevan & Pammer, 2008, 2009; Boets, Wouters, van Wieringen et al., 2006; Hood & Conlon, 2004; Fischer & Hartnegg, 2000).

However, evidence contradicting the magnocellular pathway theory of dyslexia has also been collected. For example, measures that are supposed to be sensitive to the functions of the magnocellular pathway, including contrast sensitivity (Williams, Stuart, Castles, & McAnally, 2003) and global motion sensitivity (Edwards, Giaschi, Dougherty, Edgell, Bjornson, Lyons, et al., 2004; Huslander, Talcott, Witton, DeFries, Pennington, Wadsworth, Willcut, & Olson, 2004; Reid, Szczerbinski, Iskierka-Kasperek, & Hansen, 2007), did not show significant differences between the dyslexics and their controls in some of the studies. Moreover, since visual deficits, when present, are only identified in a small subgroup of adult (Ramus, Rosen, Dakin, Day, Catelotte, White, & Frith, 2003) and child (White, Milne, Rosen, Hansen, Swettenham, Frith, & Ramus, 2006) dyslexics, it could be argued that the magnocellular pathway deficit is associated with but is not essential to the development of dyslexia (Ramus, 2004). Under this line of reasoning, the deficit is considered ancillary to the more fundamental phonological deficits, which are present in 50% of dyslexic children (White et al., 2006).

The purpose of the present study was to investigate to what extent developmental dyslexia and reading development in Chinese depend on the development of dynamic visual perception and its neural substrates. Compared with alphabetic scripts, the logographic writing system used in Chinese may rely more on visual–orthographic processes in lexical processing (Zhou & Marslen-Wilson, 1999, 2000), and hence any contribution from the magnocellular pathway deficit to dyslexia could be more easily revealed through testing Chinese dyslexic children. In Chinese, the basic orthographic units, the characters, correspond directly to morphemic meanings and to syllables in the spoken language. Because spoken Mandarin has only 1,200 syllables but over 5,000 commonly used morphemes (Zhou, 1978), there exist a great many homophonic morphemes and homophonic characters. Homophonic characters may or may not share graphical forms. For example, 因 (because of) and 阴 (negative) have the same pronunciation, /yin1/, but their visual forms are different; 诚 (honest) and 城 (city) share the pronunciation, /cheng2/, and part of the visual forms (i.e., the radical 成, /cheng2/, success, which is a meaningful character by itself). Orthographically similar characters, on the other hand, may or may nohathese-369.(i)1lla, poucationreu0.3(,)T5/F121Tf.90200.9(/)311.3188.(r).2945Tm also shown that phonological skill is an important factor in Chinese reading development and dyslexia (Shu, Chen, Anderson, Wu, & Xuan, 2003; Siok & Fletcher, 2001; McBride-Chang & Ho, 2000; Ho & Bryant, 1997). Findings concerning general visual skills in the development of Chinese reading, however, are less consistent, with some studies observing positive associations between visual skills and Chinese character recognition (Huang & Hanley, 1995; McBride-Chang & Chang, 1995; Siok & Fletcher, 2001; Meng, Zhou, Zeng, Kong, & Zhuang, 2002; Ho et al., 2004; Chung, McBride-Chang, Wong, Cheung, Penney, & Ho, 2008) and other studies finding no such association (Ho, 1997; Hu & Catts, 1998; Huang & Hanley, 1997; McBride-Chang & Ho, 2000). A possible reason for this discrepancy is that tasks used to measure visual skills in the aforementioned studies involve mostly higher level cognitive processing and are not sensitive enough to lower level visual processes that rely on the magnocellular pathway.

In this study, we employed coherent motion detection, a task that has been proven to be sensitive to the functions of magnocellular pathway (Hansen, 2001; Conlon et al., 2009). Two patches of randomly moving white dots are presented on the left and right sides of screen, with one patch having a certain percentage of dots moving coherently. Participants have to judge which patch has such coherently moving dots. The percentage of these dots is varied adaptively to determine the participants' detection threshold. Using this task, Talcott et al. (2000) found that English children's sensitivity to dynamic visual stimuli is related to their literacy skills. Visual motion sensitivity can explain independent variance in orthographic skill, but not in phonological ability. Witton et al. (1998) found that dyslexic individuals are less sensitive to dynamic stimuli, with higher threshold in detecting the coherent motion. We also obtained evidence in a preliminary study showing that dynamic visual perception may be related to orthographic processing in Chinese (Meng et al., 2002). In this study, we more systematically investigated the relations between dynamic visual perception and reading development in Chinese. Experiment 1 was conducted to examine whether Chinese dyslexics have the same deficits in detecting coherent motion as their English counterparts. If Chinese dyslexics have deficits in the functions of magnocellular pathway, they will show reduced sensitivity to dynamic coherent motion compared with controls. Experiment 2 was designed to examine more specifically what aspects of cognitive processes in reading Chinese might be related to dynamic visual processing. To achieve this, we tested 100 randomly selected normal school children with both the visual perception tasks and a number of reading-related tasks and conducted regression analyses to determine possible predictive contributions of the coherent motion detection task to the reading-related measures.

Experiment 1

Method

Participants

Twenty-seven dyslexic children and 27 controls participated in the study. These two groups of children were matched on chronological age and nonverbal IQ (see Table 1). The 27 dyslexics were screened from a pool of 420 school children, with the percentage of incidence at 6.43%. The psychometric screening tests, which were administered in groups, are described below. This study was approved by the Academic Committee of the Department of Psychology, Peking University.

Psychometric tests

Raven's Standard Progressive Matrices were used to measure children's nonverbal IQ. There were five sets of 12 items each in the test. Each item consisted of a target matrix with one missing part. Children were asked to select, from six to eight alternatives, the part that best completed the matrix. Scoring procedures were based on the Chinese norm (Zhang & Wang, 1985).

A number of reading tests were administered, with three of them modeled after the Hong Kong test of specific learning difficulties in reading and writing (Ho, Chan, Tsang, & Lee, 2000). In the Chinese word reading test, children were asked to read aloud 150 Chinese two-character words in order of increasing difficulty. The test was discontinued when the child failed consecutively to read 15 words. The 1-min reading test consisted of 90 two-

The reading fluency test was a reading comprehension test which had 95 sentences, each sentence paired with five picture choices. Participants were asked to read each sentence and select from the five pictures the one that best reflected the meaning of the sentence. Children were encouraged to complete as many paragraphs as possible within a 10-min time period. The performance was measured by the total number of sentences the participants could understand. Rapid retrieval and retention of lexical information and construction of sentential representation are needed to complete the task.

The phonological awareness test used the oddball paradigm (Bradley & Bryant, 1978) in which participants were asked to pick out a phonologically odd item from four items. Three blocks of stimuli were tested, each having 20 quartets of items, with the oddity on either onset, rime, or lexical tone. Items were presented orally, and participants indicated on the answering sheet which spoken syllable was an odd one. The percentage of correct answers was taken as the measure of each participant's phonological awareness performance. This test was to measure participants' sensitivity to the phonological structure of Chinese syllables (morphemes).

Visual perception tasks

Two psychophysic tests, a coherent motion detection test and a static visual pattern detection test (Talcott et al., 2000; Witton et al., 1998), were administered to the two groups of children. In the coherent motion detection task, two patches of randomly moving white dots were presented on the left and right sides of screen with dark background. One patch had a certain percentage of dots moving coherently leftward and rightward. Participants had to judge which patch had such coherently moving dots. The percentage of these dots was varied adaptively to decide participants' detection threshold. In the static pattern detection task, two patches of static dots were also presented on the screen, with one patch having a certain percentage of dots forming a circle. Participants had to indicate which patch had such a circle. The procedural details of the two tasks can be found in Witton et al. (1998) and Talcott et al. (2000).

Results and discussion

Table 1 lists the means of the two groups of children in age, IQ, reading-related tests, and visual perception tests. It is clear from this table that compared with normal controls, dyslexics showed significant deficits in all the reading-related tests. More importantly, dyslexics had a higher threshold in the coherent motion detection test, but not in the static pattern perception test, suggesting that Chinese dyslexics have specific deficits in perceiving dynamic visual information. This dissociation between dyslexics' performance on dynamic and static visual perception suggests further that Chinese dyslexic children may have deficits in the magnocellular pathway.

Additionally, the number of individuals that were classified as dyslexic but did not perform worse than the mean of the controls in the dynamic motion detection task was nine, about 32% of the total number of dyslexics; meanwhile, the number of individuals from the control group that performed below the dyslexic mean was four, about 14% of the total number of controls. A deviance analysis (Ramus et al., 2003) was also conducted to identify individuals having dynamic visual perception deficit. Fourteen of 27 dyslexic children (about 52%), three of 27 controls (13%), whose performance was outside ±1.65 SD of control means were identified. These results showed that approximately half of the dyslexic children had a dynamic motion detection deficit.

Experiment 2

Experiment 1 suggested that there is apparent relationship between poor performance in reading Chinese and deficits in dynamic visual perception and possibly its neural substrates. The purpose of Experiment 2 was to investigate whether the impact of dynamic visual perception on reading Chinese can be related to certain cognitive processes in reading Chinese. Specifically, we wanted to examine whether perception of dynamic visual information has specific impact upon orthographic processing in reading Chinese, as suggested by Meng et al. (2002).

Method

Participants

One hundred fifth-grade children from a primary school in Beijing were tested on a number of linguistic and visual perception tasks. These children were randomly selected, and hence their reading skills ranged from excellent to poor.

Psychometric and visual perception tests

A battery of linguistic and visual perception tests were administered. The two visual perception tasks and the written vocabulary, reading fluency, and phonological awareness tests were the same as in Experiment 1. In addition, this experiment tested participants with three on-line tasks: character naming, orthographic similarity judgment, and picture naming. The written vocabulary test, reading fluency test, and phonological awareness test were administered in groups. Character naming, orthographic similarity judgment, picture naming, and visual perception tests were administered individually in a quiet room.

In the character-naming task, 100 characters were presented one by one on the screen, and participants were asked to name the characters into a microphone as quickly and as accurately as possible. Each character was presented for 400 ms (Meng, 2000). Naming latencies were recorded by the DMDX system (Forster & Forster, 2003), and naming errors were recorded by an experimenter. The characters were all complex characters, each composed of a semantic radical and phonetic radical (Zhou & Marslen-Wilson, 1999). According to whether the whole character was pronounced in the same way as its phonetic radical, a character could be categorized as “regular” or “irregular.” For example, the character 球 (/qiu2/, ball) is regular, with the phonetic radical 求 (to ask) having the same pronunciation as the whole character; the character 滑 (/hua2/, slippery) is irregular, with the phonetic radical 骨 (/gu3/, bone) having a different pronunciation. There were 50 regular and 50 irregular characters, with half of each group being of relatively high-frequency (109/per million) and half of low-frequency (20/per million). This composition of stimuli was to present participants with a representative sample of characters that readers would encounter in school. It also allowed us to check the regularity and frequency effects in character naming.

In the orthographic similarity judgment task, children had to judge whether a pair of consecutively presented characters were orthographically similar. Orthographic similarity was defined in the way that simple characters had similar visual form (e.g., 甲 /jia3/, first and 龟/gui1/, turtle) and complex characters contained the same radicals (e.g., 徒 /tu2/, apprentice and 陡 /dou3/, steep). For each pair, the first character was presented for 400 ms, followed by a 100-ms blank interval. The second character was presented for 400 ms, and participants were asked to make “yes” or “no” judgment as quickly and as accurately as possible.

Previous studies have shown that orthographic, phonological, and semantic information is sufficiently activated in reading Chinese with this type of time interval between the two characters (see, for example, Zhou & Marslen-Wilson, 2000), and the present results also showed that readers were capable of completing this task without making many errors (see Table 3). There were 120 pairs of characters, witho6ii6h0eiin32.9yb(s)-222.2((e)16.2(s)13.6ps)0(o)1.6(u)

no-.222.9((e)16.2(s)13.6ps)0(o)1.6(u)14.8(er)19.3(.o-.2226(E(a)162(c)11.(h)8(o6.8(or)19.3(ou)1.6p

er-30169mhion0(h)8918.1(a)11.(dh)8919.83h0

anlse,

Table 2 Correlation matrix between various measures in Experiment 2

	1	2	3	4	5	6	7	8	9	10	11	12
RAV		0.24*	0.21*	0.27**	0.04	−0.35**	0.12	−0.18	0.02	−0.20*	−0.00	−0.09
VOC			0.36**	0.50**	−0.18	−0.05	−0.23*	−0.13	−0.34**	−0.35**	0.02	−0.16
FLU				0.25*	−0.28**	0.04	−0.28**	−0.02	−0.40**	−0.16	−0.07	0.04
PHO					−0.20*	−0.26**	−0.11	−0.29**	−0.13	−0.30**	−0.16	−0.29*
ORT_RT						0.07	0.26**	0.19	0.37**	0.00	0.03	0.36**
ORT_ER							−0.15	0.36**	0.04	0.12	−0.00	0.21*
PIC_RT								−0.03	0.67**	−0.10	−0.02	−0.16
PIC_ER									0.00	0.52**	0.11	0.36**
CHA_RT										0.07	−0.10	−0.00
CHA_ER											−0.11	0.17
STA												0.28**
MOT												

RAV Raven Standard Progressive Matrices, VOC vocabulary, FLU reading fluency, PHO phonological awareness, ORT_RT orthographic similarity judgment latency, ORT_ER orthographic similarity judgment error rate, PIC_RT picture-naming latency, PIC_ER picture-naming error rate, CHA_RT character-naming latency, CHA_ER character-naming error rate, STA static pattern detection, MOT coherent motion detection

*$p<0.05$; **$p<0.01$

Table 3 Paired t tests for character and picture frequency effects and for character regularity effect in response time and error rate, with standard deviation in parenthesis

Variable_1	Means	Variable_2	Means	T	p
ORT_L_RT	683 (142)ms	ORT_H_RT	660 (133)ms	4.96	<0.001
ORT_L_ER	0.06 (0.05)	ORT_H_ER	0.054 (0.05)	1.11	>0.1
PIC_L_RT	874 (134)ms	PIC_H_RT	816 (119)ms	11.85	<0.001
PIC_L_ER	0.04 (0.05)	PIC_H_ER	0.02 (0.03)	4.53	<0.001
REG_RT	719 (161)ms	IREG_RT	804 (189)ms	−18	<0.001
REG_ER	0.04 (0.06)	IREG_ER	0.08 (0.09)	−6.9	<0.001
CHA_L_RT	804 (194)ms	CHA_H_RT	719 (156)ms	12	<0.001
CHA_L_ER	0.10 (0.09)	CHA_H_ER	0.06 (0.06)	7.12	<0.001

ORT_L_RT orthographic similarity judgment reaction time for low-frequency characters, ORT_H_RT orthographic similarity judgment reaction time for high-frequency characters, ORT_L_ER orthographic similarity judgment error rate for low-frequency characters, ORT_H_ER orthographic similarity judgment error rate for high-frequency characters, PIC_L_RT picture-naming latency for low-frequency objects, PIC_H_RT picture-naming latency for high-frequency objects, PIC_L_ER picture-naming error rate for low-frequency objects, PIC_H_ER picture-naming error rate for high-frequency objects, REG_RT naming latency for regular characters, IREG_RT naming latency for irregular characters, REG_ER naming error rate for regular characters, IREG_ER naming error rate for irregular characters, CHA_L_RT naming latency for low-frequency characters, CHA_H_RT naming latency for high-frequency characters, CHA_L_ER naming error rate for low-frequency characters, CHA_H_ER naming error rate for high-frequency characters

and the error rate in orthographic similarity judgment was significant for low-frequency characters ($r=0.29$, $p<0.01$), but not for high-frequency characters ($r=0.05$, $p>0.1$) when the characters were grouped according to their frequencies.

Furthermore, hierarchical regression analyses showed that the coherent motion detection threshold could also account for 12% of the variance in picture-naming error rate after nonverbal IQ and vocabulary size were controlled (Table 6; see also Meng et al., 2002 for a similar pattern). Regression analyses did not find significant contributions of coherent motion threshold to other linguistic measures.

We believe that both orthographic similarity judgment and picture-naming tap into speeded visual form analysis, which may rely partly on the magnocellular pathway.

General discussion

The main purpose of this study was to investigate to what extent developmental dyslexia and reading development in Chinese depend on the development of dynamic visual

Table 4 Hierarchical regression predicting the speed of orthographic similarity judgment

Dependent variable	Independent variables	R^2	$R_{ch}{}^2$	F
ORT_RT	RAV	0.002	0.002	0.69
	VOC	0.03	0.03	0.09
	CHA_RT	0.14	0.11	0.001
	PHO	0.18	0.04	0.045
	MOT	0.30	0.11	0.002

Table 5 Hierarchical regression predicting the speed of orthographic similarity judgment

Dependent variable	Independent variables	R^2	R_{ch}^2	F
ORT_L_ER	RAV	0.08	0.08	0.007
	VOC	0.081	0.001	0.78
	CHA_ER	0.11	0.02	0.32
	PHO	0.19	0.09	0.035
	MOT	0.23	0.04	0.042

perception and its neural substrates. Experiment 1 found that the Chinese dyslexic group had a higher threshold in detecting coherent motion than normal controls did. Further deviance analysis showed that about 52% of the dyslexic children, as opposed to only 13% of the controls, had dynamic visual perception deficits, suggesting that substantial amount of Chinese dyslexics are impaired in dynamic visual perception, a function of the magnocellular pathway. Moreover, the regression analyses in Experiment 2 showed that dynamic visual perception threshold could account for 11%, 12%, and 4% of the variance in, respectively, the speed of orthographic similarity judgment, the error rate in picture naming, and the error rate in orthographic similarity judgment for low-frequency characters after IQ and vocabulary were controlled. These results demonstrate that the impact of dynamic visual perception on Chinese reading could be related specifically to orthographic processing and hence provide evidence for a link between dynamic visual processing and the development of reading skills in Chinese.

Note that the prevalence of dyslexic children having dynamic visual perception deficit in the present study (52%) was higher than the percentage reported for English counterparts (30% in Conlon et al., 2009, or even less in Ramus et al., 2003). This difference may result from the logographic nature of Chinese writing system, in which the reader relies more heavily on visual–orthographic route in lexical access (Zhou & Marslen-Wilson., 1999, 2000) and in learning to read (Huang & Hanley, 1994; Leck, Weeks, & Chen, 1995; Tzeng & Wang, 1983; Meng, Jian, Shu, Tian, & Zhou, 2008). The present findings suggest that although dynamic visual perception and its underlying neural substrates are important in learning to read across different writing systems, the extent of its impact upon reading development and developmental dyslexia may depend partly on the role of orthography in lexical processing for a particular writing system.

Findings in the present study are consistent with Witton et al. (1998) who demonstrated that English dyslexic adults have lower sensitivity to dynamic sensory information than normal controls, and with Talcott et al. (2000) who found that after controlling for intelligence and overall reading ability, for normal children, dynamic motion sensitivity explains independent variance in orthographic skill but not phonological ability, while auditory sensitivity in frequency modulation explains independent variance in phonological skill but not in orthographic skill. These results suggest that there are common

Table 6 Hierarchical regression predicting the picture-naming error rate

Dependent Variable	Independent variables	R^2	R_{ch}^2	F
PIC_ER	RAV	0.32	0.03	0.09
	VOC	0.04	0.01	0.36
	MOT	0.17	0.12	0.003

underlying causes of development dyslexia across different cultures and different writing systems, and deficits in the magnocellular pathway is one of them.

Stein and Talcott (1999) suggested that accurate visual coding is needed to identify a word and to retrieve the correct pronunciation of that word. Eden, Van Meter, Rumsey, and Zeffiro (1996

To summarize, by using a coherent motion detection task that taps into the functions of the magnocellular pathway, the present study demonstrates that a large proportion (over 50%) of Chinese dyslexic children have deficits in dynamic visual perception and that this deficit affects specific cognitive processes in reading. Thus, reading development in Chinese depends to a certain extent on the development of dynamic visual perception and its underlying neural pathway, and the impact of visual development can be specifically related to orthographic processing in reading Chinese characters.

Acknowledgment This study was supported by grants from the Natural Science Foundation of China (30770712, 30970889) and a research grant from The Joint PekingU-PolyU Center for Child Development and Learning. We thank the anonymous reviewers for their constructive comments and suggestions.

References

Ben-Shachar, M., Dougherty, R. F., Deutsch, G. K., & Wandell, B. A. (2007). Contrast responsivity in MT+ correlates with phonological awareness and reading measures in children. Neuroimage, 37, 1396–1406.

Boden, C., & Giaschi, D. (2007). M-stream deficits and reading-related visual processes in developmental dyslexia. Psychological Bulletin, 133, 346–366.

Boets, B., Wouters, J., van Wieringen, A., et al. (2006). Auditory temporal information processing in preschool children at family risk for dyslexia: Relations with phonological abilities and developing literacy skills. Brain and Language, 97, 64–79.

Borsting, E., Ridder, W. H., III, Dideck, K., Kelley, C., Matsui, L., & Motoyama, J. (1996). The presence of a magnocellular deficit depends on the type of dyslexia. Vision Research, 36, 1047–1053.

Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. Cognition, 104, 198–203.

Bradley, L. L., & Brayant, P. (1978). Difficulties in auditory organization as a possible cause of reading backwardness. Nature, 271, 746–747.

Bradley, L. L., & Brayant, P. (1983). Categorizing sounds and learning to read: A causal connexion. Nature, 301, 419.

Bradley, L. L., & Brayant, P. (1985). Rhyme and reason in reading and spelling. Ann Arbor: University of Michigan Press.

Bruck, M. (1992). Persistence of dyslexics' phonological deficits. Developmental Psychology, 28, 874–886.

Casco, C., & Prunetti, E. (1996). Visual search of good and poor readers: effects with targets having single and combined features. Perceptual Motor Skills, 82, 1155–1167.

Cheng, K., Fujita, H., Kanno, I., Miura, S., & Tanaka, K. (1995). Human cortical regions activated by wide-field visual motion: an H2(15)O PET study. Journal of Neurophysiology, 74, 413–427.

Chung, K. K. H., McBride-Chang, C., Wong, S. W. L., Cheung, H., Penney, T. B., & Ho, C. (2008). The role of visual and auditory temporal processing for Chinese children with developmental dyslexia. Annals of Dyslexia, 58, 15–35.

Conlon, E., Sanders, M., & Zapart, S. (2004). Temporal processing in poor adult readers. Neuropsychologia, 42, 142–157.

Conlon, E. G., Sanders, M. A., & Wright, C. M. (2009). Relationships between global motion and global form processing, practice, cognitive and visual processing in adults with dyslexia or visual discomfort. Neuropsychologia, 47, 907–915.

Cornelissen, P., & Hansen, P. (1998). Motion detection, letter position encoding, and single word reading. Annals of Dyslexia, 48, 155–188.

Cornelissen, P., Hansen, P., Hutton, J., Evangelinou, V., & Stein, J. F. (1998). Magnocellular visual function and children's single word reading. Vision Research, 38, 471–482.

Demb, J. B., Boynton, G. M., Best, M., & Heeger, D. (1998). Psychophysical evidence for a magnocellular deficit in dyslexia. Vision research, 38, 1555–1559.

Eden, G. F., Van Meter, J. W., Rumsey, J. M., & Zeffiro, T. A. (1996). The visual deficit theory of developmental dyslexia. Neuroimage, 4, S108–S117.

Eden, G. F., Van Meter, J. W., Rumsey, J. M., Maisog, J., Woods, R., & Zeffiro, T. A. (1996). Abnormal processing of visual motion in dyslexia revealed by functional brain imaging. Nature, 382, 66–69.

Edwards, V. T., Giaschi, D. E., Dougherty, R. F., Edgell, D., Bjornson, B. H., Lyons, C., et al. (2004). Psychophysical indexes of temporal processing abnormalities in children with developmental dyslexia. Developmental Neuropsychology, 25, 321–354.

Facoetti, A., Paganoni, P., Turatto, M., Marzola, V., & Mascetti, G. G. (2000). Visual–spatial attention in developmental dyslexia. Cortex, 36, 109–123.

Facoetti, A., Trussardi, A. N., Ruffino, M., et al. (2010). Multisensory spatial attention deficits are predictive of phonological decoding skills in developmental dyslexia. Journal of Cognitive Neuroscience, 22, 1011–1025.

Fischer, B., & Hartnegg, K. (2000). Effects of visual training on saccade control in dyslexia. Perception, 29, 531–542.

Forster, I. K., & Forster, C. J. (2003). DMDX: A Windows display program with millisecond accuracy. Behavior Research Methods, Instruments, & Computers, 35, 116–124.

Frith, U. (1981). Experimental approaches to developmental dyslexia: An introduction. Psychological Research, 43, 97–109.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. Trends in Neuroscience, 15, 20–25.

Hansen, P. C. (2001). Global form and global motion processing programs. London: Department of Physiology, Oxford University.

Hansen, P. C., Stein, J. F., Orde, S. R., Winter, J. L., & Talcott, J. B. (2001). Are dyslexics' visual deficits limited to measures of dorsal stream function? NeuroReport, 12, 1527–1530.

Hari, R., Valta, M., & Uutela, K. (1999). Prolonged attentional dwell time in dyslexic adults. Neuroscience Letters, 271, 202–204.

Ho, C. (1997). The importance of phonological awareness and verbal short-term memory to children's success in learning to read Chinese. Psychologia, 40, 211–219.

Ho, C., & Bryant, P. (1997). Phonological skills are important in learning to read Chinese. Developmental Psychology, 33, 946–951.

Ho, C., Chan, D., Lee, S., Tsang, S., & Luan, V. (2004). Cognitive profiling and preliminary subtyping in Chinese developmental dyslexia. Cognition, 91, 43–75.

Ho, C., Chan, D., Tsang, S., & Lee, S. (2000). The Hong Kong test of specific learning-difficulties in reading and writing (HKT-SpLD), August (Researchth ed.). Hong Kong: Hong Kong Specific Learning Difficulties Research Team.

Hood, M., & Conlon, E. (2004). Visual and auditory temporal processing and early reading development. Dyslexia, 10, 234–252.

Hu, C. F., & Catts, H. W. (1998). The role of phonological processing in early reading ability: what we can learn from Chinese. Scientific Studies of Reading, 2, 55–79.

Huang, H. S., & Hanley, J. R. (1994). Phonological awareness and visual skills in learning to read Chinese and English. Cognition, 54, 73–98.

Huang, H. S., & Hanley, J. R. (1995). Phonological awareness and visual skills in learning to read Chinese and English. Cognition, 54, 73–98.

Huang, H. S., & Hanley, J. R. (1997). A longitudinal study of phonological awareness, visual skills and Chinese reading acquisition among first graders in Taiwan. International Journal of Behavioral Development, 20(2), 249–268.

Hulslander, J., Talcott, J., Witton, C., DeFries, J., Pennington, B., Wadsworth, S., et al. (2004). Sensory processing, reading, IQ, and attention. Journal of Experimental Child Psychology, 88, 274–295.

Johnson, A., Bruno, A., Watanabe, J., Quansah, B., Patel, N., Dakin, S., et al. (2008). Visually-based temporal distortion in dyslexia. Vision Research, 48, 1852–1858.

Kevan, A., & Pammer, K. (2008). Visual processing deficits in preliterate children at familial risk for dyslexia. Vision Research, 48, 2835–2839.

Kevan, A., & Pammer, K. (2009). Predicting early reading skills from pre-reading measures of dorsal stream functioning. Neuropsychologia, 47, 3174–3181.

Laycock, R., & Crewther, S. G. (2008). Towards an understanding of the role of the magnocellular advantage in fluent reading. Neuroscience & Biobehavioral Reviews, 32(8), 1494–1506.

Leck, K. J., Weekes, B. S., & Chen, M. J. (1995). Visual and phonological pathways to the lexicon: evidence from Chinese readers. Memory & Cognition, 23, 468–476.

Levy, T., Walsh, V., & Lavidor, M. (2010). Dorsal stream modulation of visual word recognition in skilled readers. Vision Research, 50, 883–888.

Lovegrove, W. J., Bowling, A., Badcock, D., & Blackwood, M. (1980). Specific reading disability: Differences in contrast sensitivity as a function of spatial frequency. Science, 210, 439–440.

Lundberg, I., Frost, J., & Petersen, O. (1988). Effects of an extensive program for stimulating phonological awareness in preschool children. Reading Research Quarterly, 23, 263–284.
Manis, F. R., Custodio, R., & Szeszulski, P. A. (1993). Development of phonological and orthographic skill: a two-year longitudinal study of dyslexic children. Journal of Experimental Child Psychology, 56, 64–86.
McBride-Chang, C. (2004). Children's literacy development. London: Arnold.
McBride-Chang, C., & Chang, L. (1995). Memory, print exposure, and metacognition: components of reading in Chinese children. International Journal of Psychology, 30(5), 607–616.
McBride-Chang, C., & Ho, C. (2000). Developmental issues in Chinese children's character acquisition. Journal of Educational Psychology, 92, 50–55.
Meng, X. (2000). The lexical representation and processing in Chinese-speaking developmental dyslexia. Doctoral dissertation: Beijing Normal University.
Meng, X., Zhou, X., Zeng, B., Kong, R., & Zhuang, J. (2002). Visual perceptual skills and reading abilities in Chinese-speaking children (in Chinese). Acta Psychologica Sinica, 34(1), 16–22.
Meng, X., Tian, X., Jian, J., & Zhou, X. (2007). Orthographic and phonological processing in Chinese dyslexic children: An ERP study on sentence reading. Brain Research, 1179, 119–130.
Meng, X., Jian, J., Shu, H., Tian, X., & Zhou, X. (2008). ERP correlates of the development of orthographical and phonological processing during Chinese sentence reading. Brain Research, 1219, 91–102.
Pellicano, E., & Gibson, L. Y. (2008). Investigating the functional integrity of the dorsal visual pathway in autism and dyslexia. Neuropsychologia, 46, 2593–2596.
Ramus, F. (2004). Neurobiology of dyslexia? A reinterpretation of the data. Trends in Neurosciences, 27, 720–726.
Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Catelotte, J. M., White, S., et al. (2003). Theories of developmental dyslexia: Insights from a multiple case study of dyslexic adults. Brain, 126, 841–8[illegible]5.
Reid, A. A., Szczerbinski, M., Iskierka-Kasperek, E., & Hansen, P. (2007). Cognitive profiles of [illegible]dult developmental dyslexics: Theoretical implications. Dyslexia, 13, 1–24.
Ridder, W. H., Borsting, E., & Banton, T. (2001). All developmental dyslexia subtypes display an ele[illegible]ted motion coherence threshold. Optometry and Vision Science, 78, 510–517.
Shu, H., Cheng, Y. S., & Zhang, H. C. (1989). The naming consistency, familiarity, represent[illegible]ion consistency and visual complexity of 235 pictures (in Chinese). Acta Psychologica Sinica, 21(4), [illegible]89–396.
Shu, H., Chen, X., Anderson, R. C., Wu, N., & Xuan, X. (2003). Properties of school Chinese: implica[illegible]ons for learning to read. Child Development, 74(1), 27–48.
Siok, W. T., & Fletcher, P. (2001). The role of phonological awareness and visual–orthographic ski[illegible] in Chinese reading acquisition. Developmental Psychology, 37(6), 886–899.
Slaghuis, W. L., & Lovegrove, W. J. (1985). Spatial-frequency-dependent visible persistence and sp[illegible]ific reading disability. Brain and Cognition, 4, 219–240.
Slaghuis, W. L., & Ryan, J. F. (1999). Spatio-temporal contrast sensitivity, coherent motion, and [illegible]ble persistence in developmental dyslexia. Vision Research, 39, 651–668.
Song, H., Zhang, H., & Shu, H. (1995). The role of phonology and orthography and its developm[illegible] in Chinese reading. Acta Psychologica Sinica, 27, 139–141.
Stanovich, K. E., Siegel, L. S., Gottardo, A., Chiappe, P., & Sidhu, R. (1997). Subtypes of develop[illegible]ntal dyslexia: differences in phonological and orthographic coding. In B. Blachman (Ed.), Foundat[illegible] of reading acquisition and dyslexia (pp. 115–142). London: Lawrence Erlbaum.
Stein, J. F. (1994). A visual defect in dyslexics? In A. Fawcett & R. Nicolson (Eds.), Dyslexia in ch[illegible]en: Multidisciplinary perspectives (pp. 137–156). Hemel Hempstead: Harvester Wheatsheaf.
Stein, J. F., & Talcott, J. (1999). Impaired neuronal timing in developmental dyslexia—The magno[illegible]ular hypothesis. Dyslexia, 5, 59–77.
Stein, J. F., & Walsh, V. (1997). To see but not to read: the magnocellular theory of dyslexia. T[illegible] in Neurological Science, 20, 147–152.
Stein, J. F., Richardson, A. J., & Fowler, M. S. (2000). Monocular occlusion can improve binocular [illegible]trol and reading in dyslexics. Brain, 123, 164–170.
Stevenson, H. W., Stigler, J. W., Lucker, G. W., Hsu, C. C., & Kitamura, S. (1982). Reading disabi[illegible] the case of Chinese, Japanese and English. Child Development, 53, 1164–1181.
Talcott, J. B., Hansen, P. C., Willis-Owen, C., McKinnell, I. W., Richardson, A. J., & Stein, J. F[illegible]98). Visual magnocellular impairment in adult developmental dyslexics. Neuro-Opthalmology, 20, [illegible]201.
Talcott, T. B., Witton, C., McLean, M. F., Hansen, P. C., Rees, A., Green, G. G. R., et al. (2000). [illegible]amic sensory sensitivity and children's word decoding skills. Proceedings of the National Ac[illegible]y of Sciences, 97, 2952–2957.

Tzeng, O. J. L., & Wang, W. S. Y. (1983). The first two R's. Scientific American, 71, 238–243.
Vaina, L. M., Lemay, M., Bienfang, D. C., Choi, A. Y., & Nakayama, K. (1990). Intact "biological motion" and "structure from motion" perception in a patient with impaired motion mechanisms: A case study. Visual Neuroscience, 5, 353–369.
Vidyasagar, T. R., & Pammer, K. (1999). Impaired visual search in dyslexia relates to the role of the magnocellular pathway in attention. Neuroreport, 10, 1283–1287.
Vidyassagar, T. R., & Pammer, K. (2009). Dyslexia: A deficit in visual–spatial attention, not in phonological processing. Trends in Cognitive Sciences, 14, 57–63.
Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading-related phonological processing abilities: New evidence of bidirectional causality from a latent variable longitudinal study. Developmental Psychology, 30, 73–87.
Wang, X. L., & Tao, B. P. (1996). The scale and assessment of vocabulary for primary school (in Chinese). Shanghai: Shanghai Educational.
White, S., Milne, E., Rosen, S., Hansen, P., Swettenham, J., Frith, U., et al. (2006). The role of sensorimotor impairments in dyslexia: A multiple case study of dyslexic children. Developmental Science, 9, 237–269.
Williams, M. J., Stuart, G. W., Castles, A., & McAnally, K. I. (2003). Contrast sensitivity in subgroups of developmental dyslexia. Vision Research, 43, 467–477.
Witton, C., Talcott, J. B., Hansen, P. C., Richardson, A. J., Griffiths, T. D., Rees, A., et al. (1998). Sensitivity to dynamic auditory and visual stimuli predicts nonword reading ability in both dyslexic and normal readers. Current Biology, 8, 791–797.
Zeki, S., Watson, J. D. G., Lueck, C. J., Friston, K. J., Kennard, C., & Frackowiak, R. S. J. (1991). A direct demonstration of functional specialization in human visual cortex. The Journal of Neuroscience, 11, 641–649.
Zhang, H. C., & Wang, X. P. (1985). Raven standard progressive matrices: Chinese city revision. Beijing: The National Revision Collaborative Group.
Zhang, C. F., Zhang, J. H., Chang, S., Zhou, J., & Yin, R. (1998). A study of cognitive profiles of Chinese learners' reading disabilities. Acta Psychologica Sinica (in Chinese), 30, 50–55.
Zhou, Y. G. (1978). To what degree are the 'phonetics' of present-day Chinese characters still phonetic? (in Chinese) Zhongguo Yuwen, 146, 172–177.
Zhou, X., & Marslen-Wilson, W. (1999). Phonology, orthography, and lexical semantic activation in reading Chinese. Journal of Memory and Language, 41, 579–606.
Zhou, X., & Marslen-Wilson, W. (2000). The relative time course of semantic and phonological activation in reading Chinese. Journal of Experimental Psychology: Learning, Memory, and Cognition, 26, 1245–1265.