Vision Research 67 (2012) 14–21

Contents lists available at SciVerse ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

# The relationship of global form and motion detection to reading fluency

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ARTICLE INFO

*Article history:*
Received 24 June 2011
Received in revised form 27 June 2012
Available online 6 July 2012

*Keywords:*
Reading fluency
Coherent motion
Glass patterns
Dorsal stream
Ventral stream

ABSTRACT

Visual motion processing in typical and atypical readers has suggested aspects of reading and motion processing share a common cortical network rooted in dorsal visual areas. Few studies have examined the relationship between reading performance and visual form processing, which is mediated by ventral cortical areas. We investigated whether reading fluency correlates with coherent motion detection thresholds in typically developing children using random dot kinematograms. As a comparison, we also evaluated the correlation between reading fluency and static form detection thresholds. Results show that both dorsal and ventral visual functions correlated with components of reading fluency, but that they have different developmental characteristics. Motion coherence thresholds correlated with reading rate and accuracy, which both improved with chronological age. Interestingly, when controlling for non-verbal abilities and age, reading accuracy significantly correlated with thresholds for coherent form detection but not coherent motion detection in typically developing children. Dorsal visual functions that mediate motion coherence seem to be related maturation of broad cognitive functions including non-verbal abilities and reading fluency. However, ventral visual functions that mediate form coherence seem to be specifically related to accurate reading in typically developing children.

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## 1. Introduction

A typical child is minimally exposed to over 500,000 words in school during the academic year,[1] yet the span and speed of reading develops slowly into late adolescence and adulthood (Kwon, Legge, & Dubbels, 2007). Reading is a complex process that involves many different parts of the brain (Roux et al., 2004; Schlaggar & McCandliss, 2007; Simos et al., 2002). It involves neural networks that mediate phonology, lexical and visual short-term memory, word formation and orthography, eye movements and attention (for review, see Dehaene, 2009). Thus, in order to successfully design reading intervention tools, it is important to understand specific mechanisms involved in several aspects of reading within a developmental perspective.

While much current reading research focuses primarily on phonological awareness, which is the ability to identify and manipulate the individual sounds that make up language (Fox & Routh, 1975; Shaywitz, 2003), non-phonological visual deficits have also been observed in disabled readers (Boets et al., 2011; Cornelissen et al., 1995; Witton et al., 1998). This has prompted investigation of the relationship between reading ability and dorsal and ventral visual stream function. While there is some indication that dorsal visual functions might be vulnerable to damage in development, generally coined as dorsal stream vulnerability hypothesis (e.g., Gunn et al., 2002), the application of this framework to reading remains debated (e.g., Spinelli et al., 1997).

The visual system is largely separated into the dorsal and ventral visual pathways, which are anatomically and functionally distinct (Livingstone & Hubel, 1988). As suggested by evidence from lesion studies (e.g., Vaina, 1994) and brain imaging (e.g., Haxby et al., 1991), dorsal stream functions process information about locations and movements, while ventral stream functions process about shapes and identities. The dorsal vulnerability framework in development posits that dorsal stream functions are more susceptible to damage in atypical development because they are more plastic in typical development than ventral stream functions (Braddick, Atkinson, & Wattam-Bell, 2003).

Two ways of measuring ventral and dorsal visual stream functioning are form and motion coherence thresholds, respectively. Few studies have examined the relationship of age to form and motion coherence within the context of reading ability. Because the developmental trajectories of form and motion detection have generally been demonstrated to mature after 6–7 years of age (Lewis et al., 2004; Parrish et al., 2005), which is also a critical age in reading development, examination of the dependence of motion and form coherence thresholds on age may help explain variation in findings of the relationship between dorsal and ventral visual function and reading in typical as well as atypical development. The

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[1] Assuming that children read 100 words per minute, and each book contained 1000 words. Reading three books a day corresponds to 15,000/week and 525,000 words in a school year of 35 weeks.

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http://dx.doi.org/10.1016/j.visres.2012.06.020

goals of the current study were to examine the relationship between reading abilities and dorsal and ventral stream visual functions, and to evaluate the dorsal stream "vulnerability" (or more exactly, plasticity) hypothesis in typically developing school-aged children.

### 1.1. Dorsal visual areas and reading ability

In studies of typically developing individuals, poor reading skills were associated with impaired performance on coherent motion detection and other dorsal stream tasks (Conlon, Sanders, & Zapart, 2004; Cornelissen et al., 1998a, 1998b). Similarly, many studies have reported poorer ability to detect motion for dyslexic participants than for typically developing controls (Cornelissen et al., 1998a, 1998b; Kevan & Pammer, 2008, 2009; Pellicano & Gibson, 2008; Talcott et al., 2000; Witton et al., 1998). Ben-Shachar et al. (2007) reported significant correlations in typically developing children between fMRI responsivity to various contrast levels of moving sinusoidal gratings in hMT+, a dorsal motion processing area (Koyama et al., 2005; Newsome & Pare, 1988), and standardized scores of reading skills, particularly phonological abilities. FMRI studies also showed reduced brain activation in hMT+ in dyslexic versus non-dyslexic participants to gratings at various contrasts (Demb, Boynton, & Heeger, 1997, 1998) and coherent motion stimuli (Eden et al., 1996). Collectively, findings from dyslexic and typically developing readers suggest a relationship between reading ability and motion processing mechanisms in the dorsal visual stream. We aimed to examine the relationship between age and reading abilities with respect to dorsal and ventral stream visual functions in typically developing school-aged children.

### 1.2. The involvement of ventral visual areas in reading

Visual areas in the ventral stream, such as V4, LOC, and IT, are responsible for processing shapes and objects. These ventral areas also respond to textural patterns (Ostwald et al., 2008). The recognition of letters (Flowers et al., 2004; see also Turkeltaub et al., 2008) and words (Buchel, Price, & Friston, 1998; Devlin et al., 2006; Turkeltaub et al., 2003) has been found to activate part of the occipitotemporal area (e.g., BA37) of ventral visual pathway, which demonstrates perceptual expertise for whole words (Bruno et al., 2008; Kronbichler et al., 2007; Nazir, Jacobs, & O'Regan, 1998) and has been coined the visual word form area (VWFA) or system.

The occipitotemporal area correlates with sight word efficiency in typically developing children (Ben-Shachar et al., 2011) and also seems to be impaired in dyslexic participants (Maurer et al., 2007; Shaywitz & Shaywitz, 2005; Shaywitz et al., 2002; van der Mark et al., 2009). Remarkably, however, the relationship between form coherence thresholds and reading disability has not been established (Kevan & Pammer, 2008, 2009; Tsermentseli, O'Brien, & Spencer, 2008; White et al., 2006).

In addition, while there have been numerous studies comparing typical (or other atypical) observers to dyslexics (Laycock et al., 2006; Tsermentseli et al., 2008) in dorsal and ventral visual tasks, there are only few studies that have evaluated these tasks in typically developing children in relation to reading skills (Ben-Shachar et al., 2011; Kevan & Pammer, 2008, 2009).

### 1.3. The current study

Here, we assessed correlations between performance on tasks that tap dorsal and ventral visual stream functioning and reading fluency in typically developing children. We specifically measured reading fluency, because it requires efficiency and accuracy in the early phonological decoding and orthographic recognition processes (Wolf & Katzir-Cohen, 2001). We measured motion and form coherence thresholds from well-matched motion and form stimuli from random dot kinematograms that tap dorsal (Newsome & Pare, 1988) and ventral (Ostwald et al., 2008) visual areas, respectively.

## 2. Methods

### 2.1. Participants

Participants included 40 typically developing school-aged children (mean chronological age = 9.06 years, *SD* = 2.36) recruited from the local community. They had no prior diagnosis of developmental disabilities[2] and were not receiving special education services at the school they attend. Children received compensation for their participation, as well as stickers and snacks for reinforcement during breaks between tasks. The University of South Carolina Institutional Review Board (IRB) approved this research.

### 2.2. Standardized tests

We used standardized tests commonly used by school psychologists in psychoeducational evaluations, including subtests from the *Woodcock-Johnson Tests of Cognitive Abilities, 3rd Edition* (WJ-III COG), and the *Gray Oral Reading Test, 4th Edition* (GORT-4). Non-verbal IQ (NVIQ) was assessed using the WJ-III COG Concept Formation and Visual Matching subtests, and reading fluency was measured with the GORT-4.

The WJ-III COG Concept Formation and Visual Matching subtests included tasks such as matching and solving geometric and verbal puzzles. The test material was presented visually, orally, or both, and participants were asked to respond verbally, by pointing, or by circling their responses. Raw scores were calculated from the number of correct and incorrect responses. The GORT-4 is an oral test of reading fluency and comprehension, though only fluency scores were calculated for the purposes of this study. We used Form A of the test for all participants. Participants were asked to read a series of increasingly difficult fiction and non-fiction passages aloud to the examiner, who timed their reading and marked any deviation from the passage as it is written as an error. Errors include repeating, omitting, inserting, or mispronouncing a word; skipping lines during reading; waiting for the word to be provided by the examiner (and only a specified number of words may be given per passage); or making any of these errors then self-correcting. The number of errors marked for each passage was summed into a raw accuracy score and combined with scores from other passages into a total accuracy score. The number of seconds taken to read each passage was recorded and combined with rate scores from the other passages into a total rate score. All standardized tests were conducted in a quiet room without the presence of parents. Statistical analyses were performed on raw scores.

### 2.3. Motion and form coherence tasks

Motion and form stimuli were presented on a Lacie 22″ monitor with a resolution of $800 \times 700$ and refresh rate of 72 Hz by a Power Macintosh G4 computer. The viewing distance was about 70 cm. Mean luminance was about 50 cd/m$^2$ and contrast was 90%. Coherent form (i.e. Glass patterns) and coherent motion stimuli consisted of random dot kinematograms covering a $23.33 \times 23.33$ deg$^2$ with

[2] Forty-seven children were originally recruited in this study, but data from seven children were excluded in the analysis due to inattention during the study (*n* = 3) or prior indication of ADHD (*n* = 1), sensory integration disorder (*n* = 1), Asperger Syndrome (*n* = 1) or reading disability (*n* = 1). Three children included in our sample were in Kindergarten, who read independently for at least 6 months.

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