

# Is There a Common Linkage Among Reading Comprehension, Visual Attention, and Magnocellular Processing?

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## Abstract

The authors examined the relationships between reading comprehension, visual attention, and magnocellular processing in 42 Grade 7 students. The goal was to quantify the sensitivity of visual attention and magnocellular visual processing as concomitants of poor reading comprehension in the absence of either vision therapy or cognitive intervention. Nineteen good readers ( $M$  = grade equivalent of 11.2) and 23 poor readers ( $M$  = grade equivalent of 3.5) were identified. Participants were tested for visual attention skills (*Cognitive Assessment System: CAS*) and magnocellular integrity (Coherent Motion Threshold: CM). Individual and combined correlations of dependent variables with reading were significant at the 0.01 level. When combined, the two tests (CAS + CM) accounted for 61% of the variance in reading comprehension. Logistic regression analysis measured sensitivity of the two diagnostic tests. Attention tests correctly classified 95.7% of poor readers, and coherent motion correctly classified 78.3% of poor readers. When the data were combined, 91.3% of poor readers were correctly classified. The research reinforces the notion that a common linkage exists between reading comprehension, visual attention, and magnocellular processing. Diagnostic test batteries for students who have been identified as reading disabled should include magnocellular and visual attention tests. Procedures to diagnose and ameliorate these disabilities are discussed.

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Reading disability (RD) is a widespread disorder that shapes the educational development of 15% of elementary and middle school children (Shaywitz, 1998). During the past 2 decades, investigators have associated numerous visual characteristics with RD. For example, Lovegrove, Martin, and Slaghuis (1986) reported deficits in the magnocellular, but not the parvocellular visual system in 75% of individuals with RD. Recent research has confirmed the importance of motion sensitivity (Eden et al., 1996; Solan, Hansen, Shelley-Tremblay, & Ficarra, 2003; Solan, Shelley-Tremblay, Hansen, & Larson, 2004; Talcott, Hansen, Asoku, & Stein, 2000) and temporal visual attention therapy in ameliorating reading comprehension disabilities (Solan, Shelley-Tremblay, Ficarra, Silverman, & Larson, 2003). This study examines some of the remaining uncertainties. Because there

has been no universal agreement on how to define visual attention or its characteristics, it is difficult to answer the following question: To what extent is magnocellular (M-cell) visual processing influenced by visual attention in above- and below-average readers? Furthermore, it would be valuable to know the sensitivities of M-cell visual processing and visual attention skills in predicting changes in the reading comprehension performance of students with RD and with no disabilities (ND). Although mild anomalies in the neurophysiology of the M-cell system are inevitable, the thrust of this study presumes the absence of significant neuropathology in the participants. The diagnostic regimen uses a neurocognitive approach to quantify a visual functional disorder. Our previous research has demonstrated that visual attention skills are malleable, and improvement with therapy appears to

have a salutary effect on reading comprehension (Solan, Shelley-Tremblay, et al., 2003; Solan et al., 2004); but the linkage between M-cell processing and visual attention requires further verification. The primary purpose of this study has been to quantify the sensitivity of visual attention and magnocellular visual processing as concomitants of poor reading comprehension in the absence of either vision therapy or cognitive intervention.

Two visual processing pathways, the *magnocellular* and *parvocellular*, originate in the retinal ganglion cells. They are usually referred to as M-cells and P-cells respectively. For the purposes of this research, we are primarily concerned with M-cells, as they have specific characteristics that are frequently associated with reading skills. M-cells typically are sensitive to short wavelengths, visual motion, high temporal frequencies, and low spatial frequen-

cies (Lovegrove et al., 1986). En route to the visual cortex and the extrastriate areas in the brain, M-cells are influenced by associated inputs such as visual attention (Bassi & Lehmkuhle, 1990; Sherman & Koch, 1986).

Indeed, visual attention may have a complex and reciprocal relationship with magnocellular functioning (Vidyasagar, 2005). Cheng, Eysel, and Vidyasagar (2004) presented evidence that the magnocellular system may be critically involved in the operation of visual attention during the type of serial, visual search that underlies typical reading. These authors adapted the Treisman (Treisman & Gelade, 1980) feature versus conjunction search paradigm using visual stimulus arrays with either isoluminant or non-isoluminant stimuli to selectively stimulate the parvo- or magnocellular systems, respectively. They found that the attention-demanding conjunction search was significantly aided by the presence of luminance contrast compared to the isoluminant condition. This finding demonstrated that when the M-cell system was allowed to operate normally, it uniquely facilitated rapid, attention-demanding, serial scanning of the stimuli. Based on these and related findings, Vidyasagar (2005) proposed that M-cell dysfunction can be a contributing cause of dyslexia. When the M-cell system malfunctions, there is a disruption of the sequential gating of information coming into the primary visual cortex, and a concomitant disturbance in the orderly processing of letter identity information by the ventral visual pathway. In the present context, visual attention refers to mental processing by which an individual selectively focuses on particular stimuli while inhibiting responses to competing stimuli (Naglieri & Das, 1997).

M-cell sensitivity to visual motion may be measured with a coherent motion (CM) threshold program in the form of a *random dot kinematogram* (RDK), as shown in Figure 1. Eden et al. (1996) demonstrated that CM threshold was significantly correlated with cortical activation in the middle

temporal (MT) area. The MT area, a part of the dorsal visual stream, is important in the processing of visual motion. Coherent motion threshold, by itself, does not provide a measure of MT area function, nor is it intended to localize the source of a processing deficit. In a prior study with Grade 6 children, Solan, Hansen, et al. (2003) reported that above-average readers could recognize visual motion when just 4.61% of the dots appeared to be moving to and fro laterally in a field of 150 moving dots, whereas the below-average readers required 9.17% ( $p < 0.001$ ). The reading comprehension of the RD cohort was retested after a 7-month hiatus. Sixteen of the 20 below-average readers participated and received 15 weekly sessions of temporal vision processing therapy. Although there was no mean improvement in reading during the 7-month hiatus, the temporal vision therapy resulted in significant improvements in reading comprehension and M-cell sensitivity, as measured with the *Gates-MacGinitie Reading Tests* (GMRT<sup>®</sup>) Reading Comprehension test (MacGinitie & MacGinitie, 1989) and the *Coherent Motion Threshold Test*, respectively (Solan et al., 2004).

In the present context, *visual attention* refers to mental processing by which an individual selectively focuses on particular stimuli while inhibiting responses to competing stimuli (Naglieri & Das, 1997). Moores, Laiti, and Chelazzi (2003) also supported the notion that in some models of visual selective attention, corresponding neural representations compete for perceptual awareness. Visual attention implicates visual processing and embraces accuracy and automaticity. Steinman, Steinman, and Garzia (1998) investigated the spatial-temporal characteristics of visual attention experimentally in individuals with RD. They concluded that M-cell pathway deficits in RD are manifested as a visual attention abnormality with direct implications to the reading task. In typical readers, the loci of fixation and attention are initially coincident. That is,

the direction of gaze and the direction of attention are identical in space. According to Henderson (1992) and Clark (1999), programming of a saccade (eye movement) to the *next* target location is initiated when processing of the fovea input has been completed, and visual attention shifts to the right parafovea location—an area of low spatial frequencies. Ordinarily, this reorientation in visual attention drives the next saccade to the new fixation point, as the low spatial frequencies serve as an M-cell stimulant (Hoffman & Subramaniam, 1995). Oculomotor readiness depends on this shift in attention to drive the saccade. Fortunately, in some children with RD who have M-cell deficits, this condition may be ameliorated with temporal (Solan et al., 2004) and spatial vision therapy (Faceotti, Paganoni, Turatto, Marzola, & Mascetti, 2000). A prior controlled study quantified the influence of visual attention therapy on the reading comprehension of 30 Grade 6 children with moderate reading disabilities (RD) in the absence of specific reading remediation. After 12 one-hour sessions, the 15 participants who received attention therapy showed statistically significant improvement in reading comprehension ( $p < .05$ ) compared to the control group, who manifested no change in reading (Solan, Shelley-Tremblay, et al., 2003).

Sergeant (1996) viewed attention from an information processing point of view by distinguishing selective from sustained attention. The latter relates to the (in)ability of an individual to maintain performance over time—a behavioral characteristic that is prominent in children with RD. Therapy programs should stress arousal, activation, and vigilance (Halperin, 1996; Solan, Shelley-Tremblay, et al., 2003). In these individuals, it is prudent to perform a vision evaluation that includes binocular vision and accommodation (visual focusing) tests, because anomalies in these functions may be contributing to the reading problem.

Attention may be thought of as the catalyst that links perception with

cognition. McConkie, Reddix, and Zola (1992) postulated a strong distinction between perceptual processes that make information available from the visible text stimulus and cognitive processes that use the information in language processing. This study seeks to clarify the extent to which attention is related to the rapid visual processing indexed by the RDK, which is necessary for fluent reading and ultimately for comprehension.

## Method

### Participants

Forty-two students were preliminarily identified as good and poor readers from the results of school-administered, standardized reading tests given at the end of the previous school year. Nineteen participants (10 boys and 9 girls) were identified as good readers (no disabilities; ND), and 23 (13 boys and 10 girls) were identified as poor readers (reading disabilities; RD). All were attending Grade 7 standard academic classes at a New York City public middle school. Although records were not available, it is probable that each of the poor readers had received abundant small-group supplementary instruction in phonics and comprehension. That the mean age of the ND group was 11.5 years ( $SD = 0.3$ ) compared to 11.9 years ( $SD = 0.7$ ) for the RD group suggests the absence of widespread retention in grade or significant variations in IQ (see Note 1). The school serves a mixed middle class population consisting of European American, Asian American, Hispanic, and African American families. There were no further restrictions to participate in the research, providing that the child and parents signed the informed consent letter mailed to the home. This research program was approved by the College's Institutional Review Board and the Proposal Review Committee of the New York City Board of Education. The investigators completed the CITI human research ethics program. A

vision screening, performed on each child, revealed mild vision problems such as distance acuity slightly below 20/20 or near-point of convergence beyond four inches in 16 of the 42 participants. A notice that recommended a complete eye examination was sent to parents.

### Measures

**Reading.** The *Gates-MacGinitie Reading Tests* (GMRT; MacGinitie & MacGinitie, 1989) Reading Comprehension subtest (Level 5/6, Form K) was administered to the 42 students and reviewed by the investigators early in the new school year. Standardized directions, including a 35-min time limit, were observed precisely in the administration of the Reading Comprehension test. Each student was asked to answer 48 multiple choice items that queried main ideas, reasoning, vocabulary in context, and drawing conclusions. That is, the test measured the student's ability to read and understand passages of prose. Some of the questions required an understanding based on explicitly stated information; others required an understanding based on information that was only implicit. As shown in Table 1, the raw scores were converted to grade equivalent (GE) scores, percentiles, and normal curve equivalent (NCE) scores for Grade 7 (see Note 2). The 19 good read-

ers scored between the 70th and the 99th percentile ( $\geq 0.5 SD$  above the mean). Their mean score was GE 11.2 (mean percentile = 85). The 23 poor readers scored between the 30th and 5th percentiles ( $\geq 0.5 SD$  below the mean). Their mean score was GE 3.5, about 1  $SD$  below average (mean percentile = 14). Overall, the good readers averaged 1  $SD$  above the mean, whereas the poor readers averaged 1  $SD$  below the mean. No specific tests for word attack skills were administered.

**Coherent Motion.** Each of the 42 participants (ND and RD) was tested for coherent motion (CM) under semi-dark (mesopic) illumination conditions. A Dell Laptop Computer (Model PP02) was placed on a table at a viewing distance of 18 inches (45 cm) directly in front of each student. The student observed two rectangular patches of dots on the screen, side by side (see Figure 1). Each frame of the random dot kinematogram subtended a  $10 \times 14$  degree visual angle, separated by 5 degrees, with 150 high-luminance ( $131.0 \text{ cd m}^2$ ) white dots presented on a nominal black background for 2.3 seconds per trial.

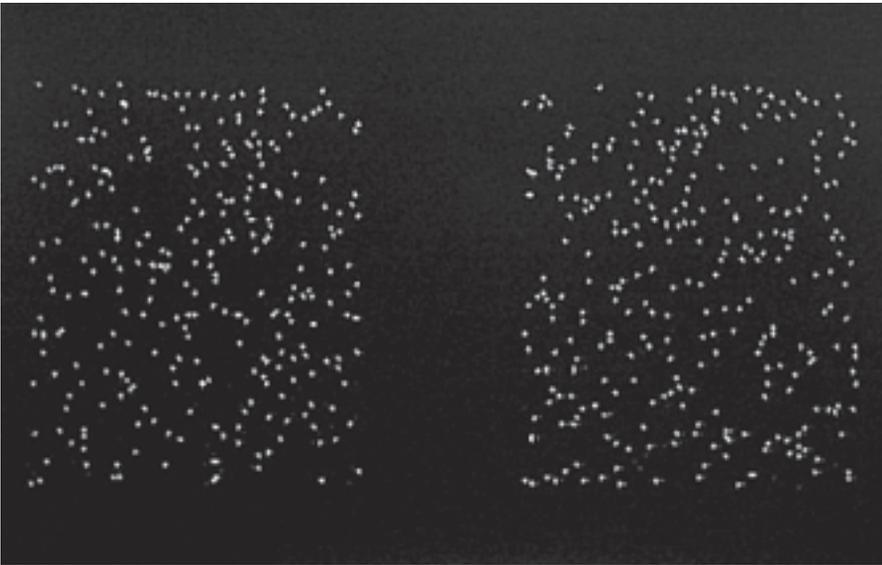
The rectangular patches were 100 pixels wide by 150 pixels high on an LCD screen of  $1024 \times 768$  pixels resolution. Once seated, the participants were monitored closely by the tester to

**TABLE 1**  
Means, Medians, and Standard Deviations of Descriptive Statistics for Participants With and Without Reading Disabilities

Measure	Score	ND <sup>a</sup>			RD <sup>b</sup>			<i>p</i>
		<i>M</i>	<i>Mdn</i>	<i>SD</i>	<i>M</i>	<i>Mdn</i>	<i>SD</i>	
SCM	RS	4.76	4.63	1.37	7.68	6.99	2.91	.001 <sup>c</sup>
CAS	SS	38.79	40.00	7.60	28.30	29.00	4.12	.001 <sup>c</sup>
GMRT	NCE	74.68	73.00	11.69	27.43	27.00	8.19	.001 <sup>d</sup>

Note. RD = students with reading disabilities (poor readers); ND = students with no disabilities (good readers); CM = *Coherent Motion Threshold Test* (Solan et al., 2004); RS = raw score (percentage); CAS = *Cognitive Assessment System* (Naglieri & Das, 1997), Attention subtest; SS = sum of scaled scores ( $M = 10$ ,  $SD = 3$ ); GMRT = *Gates-MacGinitie Reading Tests* (MacGinitie & MacGinitie, 1989), Reading Comprehension subtest; NCE = normal curve equivalent score.

<sup>a</sup> $n = 19$ . <sup>b</sup> $n = 23$ . <sup>c</sup>Mann-Whitney *U*. <sup>d</sup>ANOVA.



**FIGURE 1.** Example of random dot kinematogram (RDK) for coherent motion test.

avoid any gross body movements that would appreciably change the visual angle of the stimuli on the participant's retina. In one of the patches, a varying percentage of the dots appeared to move horizontally to and fro. The remaining noise dots had the same speed but varied directions and moved randomly in a Brownian fashion. In the other patch, all dots were noise dots and appeared to move with random Brownian motion. Important, each dot had a fixed lifetime of only 3 animation frames (100 ms), so the judgment about which patch had coherently moving dots in it could not be made by tracking any single dot alone.

Prior to actual testing, demonstration stimuli were used to illustrate coherent motion. Students then ran through a two-alternative forced-choice (2AFC) paradigm. On successive trials, coherent motion would appear randomly in either the left or the right rectangular patch. After each display period, the student selected the designated key on the left or right side of the keyboard to indicate their preference for which patch the coherent motion was in. A weighted 1-up-1-down staircase method of limits procedure (Kaernbach, 1991) was used, in which 10 reversals were required for trial termi-

nation. Incorrect responses led to an increase in the percentage of coherently moving dots by a factor of 1.41; correct responses led to a decrease in the percentage by a factor of 1.12. After two runs of the staircase series (Trial 1 and Trial 2) the testing was concluded, and the two threshold estimates were averaged together. Each participant's threshold was defined as the geometric mean of the percentage coherence score for the last 8 of 10 reversals (see Talcott, Hansen, Assoku, & Stein, 2000, for a detailed description). The percentage coherence score was calculated as the number of non-noise dots that appeared to move coherently together on the horizontal axis divided by the total number of dots in the patch (150 in this case), corrected for the finite dot lifetime. Thresholds were corrected for finite dot lifetimes so that in the case where all dots were moving coherently, and each dot had a lifetime of four frames, this was described as 75% coherence.

Because the test used a forced-choice procedure and the stimuli varied unpredictably in each rectangle, a degree of guessing was permitted at low coherence values. Therefore, individuals with better motion sensitivity (ND group) would have a lower detec-

tion threshold, as they would require a smaller percentage of the dots to be moving to perceive coherent motion, whereas the opposite would be true for RD participants with a poorer coherent motion detection threshold.

**Attention Tests.** The visual attention processing assessment consists of the three subtests that comprise the attention scales in the *Cognitive Assessment System* (CAS; Naglieri & Das, 1997): Expressive Attention, Number Detection, and Receptive Attention. The standardized directions and extensive normative data were followed precisely as prescribed in the CAS administration and scoring manual for ages 8 to 17 years. Each of the subtests was administered individually to all the participants by one of the three examiners. The three attention subtests not only provide developmental measures of visual attention and the ability to shift attention, but they also quantify the individual's potential to avoid responding to habitual stimuli while responding to another feature. That is, the tests assess how well the child responds to relevant stimuli while being challenged with irrelevant stimuli.

The Expressive Attention subtest—the only verbal response test—uses variations in color as distractions and is similar to the *Stroop Test* (Stroop, 1935). For example, after completing suitable orientation that included color and word recognition, the word *green* is shown printed in blue, and the child is expected to respond *blue* (i.e., the color of the stimulus, not the word). The Number Detection subtest is a timed paper-and-pencil test that also measures the ability to shift attention and resistance to distraction. The child is required to underline certain numbers that appear in regular typeface and others that appear in outlined typeface. Similarly, the Receptive Attention subtest matches letters according to physical similarity (*t* and *t*) and lexical similarity (*t* and *T*). In each of these two timed tests, the child must work from left to right and from top to bottom and may not recheck the page

upon completion. The timed test scoring is based on (a) number of correct minus number of incorrect responses and (b) time to complete the test. Therefore, the attention quotient represents the combined effects of accuracy and automaticity—that is, correctness as well as speed of response.

For the current investigation, we employed the publisher's procedures to calculate individual subtest scaled scores normed for each child's age. The CAS scaled scores had a mean of 10 and standard deviation of 3. We then aggregated the subtest scaled scores through simple summation to produce the sum of scaled scores (SS).

## Results

Descriptive statistics for ND and RD groups are profiled in Table 1. The three variables, CM (raw scores), CAS Attention (sum of scaled scores), and GMRT (normal curve equivalents), represent different aspects of visual processing, and in each, good readers performed significantly better than poor readers ( $p < .001$ ). The results were confirmed with a MANOVA analysis with the single between-groups variable of group (ND vs. RD) on the combined dependent measures. The combined effects of group on CM, CAS (SS), and GMRT (NCE) were all significant,  $F(3, 38) = 599.56$ ,  $p < .001$ , partial  $\eta^2 = .979$  (see Note 3). Individual, univariate ANOVAs demonstrated that much of this effect was due to the a priori diagnostic measure of GMRT (NCE) score,  $F(1, 40) = 236.079$ ,  $p < .001$ , partial  $\eta^2 = .855$ . Univariate analyses for the measures of CM,  $F(1, 40) = 16.02$ ,  $p < .001$ , partial  $\eta^2 = .286$ ; and CAS (SS),  $F(1, 40) = 32.40$ ,  $p < .001$ , partial  $\eta^2 = .448$ , indicated that large, significant differences existed between the groups on the experimental dependent measures as well. Because CM and CAS (SS) are significantly correlated (see later), an additional ANCOVA was performed on the CM scores with the between-groups factor of Group, and the covariate of CAS (SS). This

**TABLE 2**  
Correlations Among Primary Dependent Variables for All Participants

Measure	CM	CAS (SS)	GM (NCE)
CM			
Pearson correlation	—	-.409	-.450
$p$ (2-tailed)		.007	.003
CAS (SS)			
Pearson correlation	-.409	—	.766
$p$ (2-tailed)	.007	.000	
GM (NCE)			
Pearson correlation	-.450	.766	—
$p$ (2-tailed)	.003	.000	

Note.  $N = 42$ . CM = Coherent Motion Threshold Test (Solan et al., 2004); RS = raw score (percentage); CAS = Cognitive Assessment System (Naglieri & Das, 1997), Attention subtest; SS = sum of scaled scores; GMRT = Gates-MacGinitie Reading Tests (MacGinitie & MacGinitie, 1989), Reading Comprehension subtest; NCE = normal curve equivalent score.

analysis demonstrated that even when controlling for the variance in CAS (SS) scores, CM was still significantly different between the ND and RD groups,  $F(1, 39) = 6.777$ ,  $p = .013$ .

Because mean data can obscure important relationships among continuous variables, the interrelationships between these variables were examined (see Table 2). Visual attention (CAS SS) correlated significantly with both reading comprehension ( $r = .766$ ,  $p = .01$ ) and coherent motion threshold ( $r = .409$ ,  $p = .01$ ). Visual attention accounted for 59% of the variance in reading comprehension (see Note 4). Twenty percent of the variance in reading comprehension was explained by coherent motion ( $r = .450$ ,  $p = .01$ ). A multiple regression correlation statistic was obtained to measure the combined relationship of visual attention and coherent motion with reading comprehension. The combined effects of the two tests yielded a multiple  $R = .78$  ( $R^2 = .61$ ). That is, variations in visual attention and coherent motion threshold accounted for 61% of the variance in reading comprehension. Consequently, it is reasonable to expect that children who exhibit M-cell and visual attention developmental delays may be helped with visual processing therapy to ameliorate these learning-related vision disorders (Bender, 1958;

Solan, Shelley-Tremblay, et al., 2003; Solan et al., 2004). To assess the unique variance accounted for by the CM scores in predicting GMRT (NCE), while controlling for the variance shared by the CAS (SS), partial correlations were computed. The partial correlation coefficient for CM was not significant (partial  $r = -.232$ ,  $p = .144$ ), an indication that when the common variance in CM and CAS (SS) scores are taken into account, CM loses its ability to predict GMRT (NCE) scores at above the chance level. In contrast, when controlling for the variance shared by CM, the CAS (SS) partial correlation was significant (partial  $r = .714$ ,  $p < .001$ ).

*Sensitivity* is the ability to correctly classify participants according to the disorder of interest (e.g., poor reading), particularly in the case of a dichotomous outcome such as ND versus RD. *Specificity* is the ability to correctly identify individuals who do not have the disorder of interest. Logistic regression analysis of the attention scores (CAS SS) revealed that 95.7% of the poor readers (sensitivity) and 68.4% of the good readers (specificity) were correctly classified as poor or good readers, respectively. Overall, the percentage correctly classified by the CAS (SS) scales was 83.3% (see Table 3A). This analysis suggests that

visual attention may be a useful tool, a priori, to differentiate RD from ND groups, as this measure classified individuals at a rate significantly greater than chance, Wald's  $\chi^2(1, N = 42) = 8.907; p = .003$  (see Table 3B). In a similar analysis of the CM scores, a sensitivity of 78.3% and a specificity of 73.7% were obtained (see Table 4A). Overall, CM classified 76.2% of all participants correctly, Wald's  $\chi^2(1, N = 42) = 8.991; p = .003$  (see Table 4B). When the predictive effects of attention (CAS) and coherent motion were combined, 91.3% of the poor readers and 84% of good readers were correctly classified (see Table 5A). Overall 88.1% of all participants were correctly classified Wald  $\chi^2(1) = 8.991, p = .003, n = 42$  (see Table 5B).

The CAS (SS) is very sensitive in classifying poor readers; its specificity—the ability to correctly identify good readers—is less precise (95.7% vs. 68.4%,

respectively). CM testing, on the other hand, was less sensitive in classifying poor readers, albeit the findings for sensitivity and specificity were similar. In general, as sensitivity improves, specificity decreases.

## Discussion

Prior studies have suggested that deficits in coherent motion threshold and visual attention are frequently associated with RD (Solan et al., 2004; Solan, Hansen, et al., 2003; Solan, Shelley-Tremblay, et al., 2003). Some children experience visual processing disabilities in both neurocognitive functions; therefore, it is diagnostically prudent to determine their combined effects on reading comprehension. Moreover, an awareness of their interrelationship could be valuable in rendering more effective treatment of the disorders.

In this study, no special effort has been made to limit the participants to individuals with moderately reading disabilities (16th to 31st percentile) as in our previous M-cell and attention research studies that related to diagnosis and vision therapy (Solan, Hansen, et al., 2003; Solan, Shelley-Tremblay, et al., 2003; Solan et al., 2004). Our current analyses compare the effect of specific and combined contributions of M-cell and visual attention processing skills in children identified as good (ND) and poor (RD) readers. Although visual attention appears to influence the mechanism by which the brain recovers phonemes and associates them with visually presented orthography, the specifics of this processing remain

elusive (Eden & Moats, 2002; Solan, Shelley-Tremblay, et al., 2003).

The participants were originally classified according to reading comprehension; nevertheless, visual attention (scaled scores) and coherent motion (raw scores) also showed statistically significant group differences (see Table 1). This difference remained significant for CM scores even when variations in CAS (SS) were accounted for in an ANCOVA model. Because mean data can obscure important relationships between continuous variables, examining the intercorrelations of these variables was a concern (see Table 3). The percentage of variance ( $r^2 \times 100$ ) between attention (as measured with CAS) and reading is robust (59%). That is, 59% of the variance in reading comprehension can be accounted for by parallel changes in visual attention. To a lesser extent, but statistically significant, variations in coherent motion alone account for 20% of the variance in reading comprehension and 17% of the variance with attention ( $p < .01$ ). A partial correlation analysis revealed that CM accounted uniquely for only 5.4% ( $-.232$  squared) of the variance, a nonsignificant result. The results tend to support Skottun's (2005) point of view that although a magnocellular deficit may be a contributing factor to RD, it is not necessarily a direct cause. That the M-cell pathway is sensitive to visual motion is indisputable. Our previous research has indicated that therapeutic procedures to improve temporal visual processing skills appeared to have a salutary effect on magnocellular processing and reading comprehension, even though we provided no reading instruction per se. (Solan et al., 2004).

To obtain the linkage of reading comprehension with visual attention and M-cell visual processing, logistic regression analyses were performed on the individual and combined coherent motion and attention scores. Grouping variables were good and poor readers. Poor reading was the disorder of interest. Sensitivity was measured with individual and combined data. A

**TABLE 3A**

Regression Analysis: Ability of Visual Attention (CAS) to Predict Group Membership

Group observed	Predicted		% correct
	ND	RD	
ND	13	6	68.4
RD	1	22	95.7
Overall %			83.3

Note. Cut value = .500. ND = no disabilities (good readers); RD = reading disabilities (poor readers); CAS = Cognitive Assessment System, Attention subtest (Naglieri & Das, 1997), sum of scaled scores.

**TABLE 3B**

Regression Analysis: Wald's Chi-Square Test for CAS to Predict Group (ND vs. RD)

Parameter	B	SE	Wald $\chi^2(1)$	p	Exp(B)
Step 1 <sup>a</sup>	-0.325	0	8.907	.003	0.723
Constant	10.729	3.474	9.536	.002	45638.904

Note. ND = no disabilities (good readers); RD = reading disabilities (poor readers); CAS = Cognitive Assessment System, Attention subtest (Naglieri & Das, 1997), sum of scaled scores.

<sup>a</sup>Variable entered on Step 1: CAS.

remarkable finding is that attention testing (CAS SS) correctly classified 68.4% of good readers and 95.7% of poor readers. Although CAS (SS) failed to classify accurately 32% of good readers, it should be noted that sometimes there is a trade-off between sensitivity and specificity. When dealing with clinical entities, it may be preferable to employ an instrument that correctly identifies the disorder of interest, even at the expense of some false positive identifications. Coherent motion (CM) threshold correctly classified 74% of good readers and 78% of poor readers. When attention testing and coherent motion threshold were combined, the outcome was impressive: 84% of good readers and 91% of poor readers were correctly classified. These statistics lend further support to the notion that visual attention and visual temporal processing contribute to reading ability.

We agree with Stein and Walsh (1997), who hypothesized that RD may result from a generalized temporal processing disorder that involves phonological, visual, and motor deficits. Individuals with RD may be unable to process incoming sensory information rapidly in any domain. In their recent study that evaluated the effect of temporal vision processing therapy with Grade 6 children with RD, Solan et al. (2004) reported statistically significant improvements in reading comprehension ( $p < .001$ ), coherent motion threshold (M-cell sensitivity;  $p < .01$ ), oral reading ( $p < .020$ ), and pseudoword reading ( $p < .001$ ) after sixteen 45-min sessions.

Yet it would be naïve to suggest that we are dealing with a unitary deficit. At the very least, Wolf's (1999) double-deficit hypothesis, which involves sight words and phonological deficits and their effect on reading fluency and prosody, is worthy of consideration. The reader is reminded, however, that the purpose of this study was to examine the linkage of vision processing and reading comprehension in the absence of specific cognitive and metalinguistic intervention.

These interrelations are supported by the observations reported in functional magnetic resonance imaging (fMRI) studies (Eden et al. 1996; Temple et al., 2003). An examination of Eden et al.'s study of participants with dyslexia confirms that the brain is not completely compartmentalized into verbal and visual processing areas, but rather "their joint appearance in dyslexia may be due to the presence of

an underlying deficit in systems that have in common the processing of temporal properties of stimuli" (p. 69). Temple et al. observed increased fMRI activity following temporal processing therapy in the bilateral anterior cingulate gyrus, a region associated with increased attention. The left inferior temporal gyrus, an area suggested to be associated with visual processing, also showed improvements immediately after auditory remediation. Furthermore, Temple et al. reported (but did not identify) several sources of evidence that visual orthography is mapped onto phonological knowledge in left temporoparietal cortex, "and this mapping is impoverished in many children with dyslexia" (p. 2864). Temple et al.'s fMRI observations may explain some of the improvements we have measured following visual temporal processing therapy in our earlier study (Solan et al., 2004).

Although visual motion sensitivity and visual attention have been stressed in this research, it is not our intent to diminish the value of correcting phonological awareness and language processing deficits in treating children with RD. As visual and auditory processing is enhanced with temporal processing, effective behavioral remediation to improve reading and language performance should include visual temporal processing, just as Stein and Walsh (1997) hypothesized. Abundant fMRI evidence supports the notion that the two systems, auditory and visual processing, are not mutually exclusive. Current research in brain imaging not only has provided a neurophysiological basis for Stein and Walsh's temporal processing hypothesis, but has also advanced the implementation of research-validated treatment for RD. In this preliminary study, logistic regression analyses supported the notion that a strong linkage exists between reading comprehension and the two visual processing variables of coherent motion and visual attention. These two tests, individually and combined, not only contribute to classifying poor readers with a high degree of

TABLE 4A

Regression Analysis: Ability of CM to Predict Experimental Group Membership

Group Observed	Predicted		% correct
	ND	RD	
ND	14	5	73.7
RD	5	18	78.3
Overall %			76.2

Note. Cut value = .500. ND = no disabilities (good readers); RD = reading disabilities (poor readers); CM = *Coherent Motion Threshold Test* (Solan et al., 2004), raw score.

TABLE 4B

Regression Analysis: Wald's Chi-Square Test for CM to Predict Group (ND vs. RD)

Parameter	B	SE	Wald $\chi^2(1)$	p	Exp(B)
Step 1 <sup>a</sup>	0.866	0.289	8.991	.003	2.378
Constant	-4.907	1.682	8.514	.004	0.007

Note. ND = no disabilities (good readers); RD = reading disabilities (poor readers); CM = *Coherent Motion Threshold Test* (Solan et al., 2004), raw score.

<sup>a</sup>Variable entered on Step 1: CM.

sensitivity, but also identified good readers with acceptable specificity.

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#### AUTHORS' NOTES

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#### NOTES

1. IQ testing is not permitted in New York City public schools except in special circumstances.
2. Although grade equivalent scores are informative and easily understood, they may not represent equal units of measurement. Therefore, normal curve equivalent (NCE) scores were obtained for parametric tests

involving GMRT scores in Tables 1 and 3. NCE scores were produced using the scaled score to NCE conversion tables from the scoring manual.

3. Partial  $\eta^2$  is a common measure of effect size—a statistic that quantifies the size of the effect of the experimental variable. Partial  $\eta^2$  is calculated as follows:  $\text{partial } \eta^2 = \frac{(df_{\text{treatment}})(F)}{[(df_{\text{treatment}})(F) + df_{\text{within}}]}$
4. The percentage of variance was calculated as  $r^2 \times 100$ .

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**TABLE 5A**  
Regression Analysis: Combined Ability of CAS and CM to Predict Group Membership

Group observed	Predicted		% correct
	ND	RD	
ND	16	3	84.2
RD	2	21	91.3
Overall %			88.1

Note. Cut value = .500. ND = no disabilities (good readers); RD = reading disabilities (poor readers); CAS = Cognitive Assessment System, Attention subtest (Naglieri & Das, 1997), sum of scaled scores; CM = Coherent Motion Threshold Test (Solan et al., 2004), raw score.

**TABLE 5B**  
Regression Analysis: Wald's Chi-Square Test for CM and CAS Combined to Predict Group (ND vs. RD)

Parameter	B	SE	Wald $\chi^2(1)$	p	Exp(B)
Step 1 <sup>a</sup>	0.866	0.289	8.991	.003	2.378
Constant	-4.907	1.682	8.514	.004	0.007

Note. ND = no disabilities (good readers); RD = reading disabilities (poor readers); CAS = Cognitive Assessment System, Attention subtest (Naglieri & Das, 1997), sum of scaled scores; CM = Coherent Motion Threshold Test (Solan et al., 2004), raw score.

<sup>a</sup>Variables entered on Step 1: CM + CAS.

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