Magnocellular mediated visual-spatial attention and reading ability

Kristofer Kinsey,[CA] Marina Rose,[1] Peter Hansen, Alex Richardson and John Stein

University Laboratory of Physiology, University of Oxford, Oxford; [1]School of Life and Health Sciences, Aston University, Birmingham, UK

[CA]Corresponding Author: kris.kinsey@physiol.ox.ac.uk

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This study explores the relationship between attentional processing mediated by visual magnocellular (MC) processing and reading ability. Reading ability in a group of primary school children was compared to performance on a visual cued coherent motion detection task. The results showed that a brief spatial cue was more effective in drawing attention either away or towards a visual target in the group of readers ranked in the upper 25% of the sample compared to lower ranked readers. Regression analysis showed a significant relationship between attentional processing and reading when the effects of age and intellectual ability were removed. Results suggested a stronger relationship between visual attentional and non-word reading compared to irregular word reading. *NeuroReport* 15:000–000 © 2004 Lippincott Williams & Wilkins.

Key words: Attention; Coherent motion; Magnocellular; Priming; Reading

INTRODUCTION

There is mounting evidence to suggest that neural processing associated with attention is an essential component to lexical decoding [1]. A significant proportion of the research that has lead to this hypothesis stems from studies of reading ability in developmental dyslexics. In such studies, good readers often demonstrate the ability to utilize attention in a quick and accurate fashion. In contrast, reading impaired individuals often demonstrate poor or sluggish attentional processing [2–6]. An extension of the hypothesis that reading impairment can stem from an attentional processing deficit is that the relationship may be mediated by a magnocellular (MC) processing deficit. Combined evidence from histological [7], behavioural [8,9] electrophysiological [10,11], and neuroimaging [12] research alike suggests that many developmental dyslexics suffer from a MC deficit. A recent neuronal model suggests that information carried in the MC system mediates visual attention, which in turn provides the control for processing including letter position encoding [1]. Under this hypothesis, attentional processing has a direct impact on reading ability. In the current study we explore this hypothesis using a novel approach.

The attention pathway: Attention has a neurological basis that includes the MC system and results in the biasing towards certain populations of neurons and suppression of others [1,13]. The MC pathway transmits retinal information to the primary visual cortex and has cells that respond particularly well to motion stimuli [14]. As information is transmitted through the MC layers in the lateral geniculate nucleus (LGN) and beyond the primary visual cortex, it passes into processing pathways commonly referred to as the ventral and dorsal processing streams. While MC information is transmitted to both pathways, dorsal stream processing stems primarily from the MC signal. Included in the dorsal processing stream is the middle-temporal (MT) region associated with motion perception [12] and the posterior parietal cortex (PPC) associated with spatial attention processing [14]. In the neuronal model of attention proposed by Vidyasagar [1], MC projections provide the information used by PPC to generate a spatial map of the visual field. This information is fed back to ventral processing regions to bind the more detailed lexical components, such as line orientation, carried in the parvocellular (PC) system. This in turn provides the letter position encoding necessary for reading.

Reading difficulties: Evidence for the relationship between visual attention, mediated by MC processing, and reading comes primarily from studies of individuals with reading difficulties. Hari *et al.* [5] reported that dyslexic subjects may suffer from what they described as sluggish attentional shifting. Similarly, Facoetti *et al.* [4] reported that dyslexics were unable to utilize brief exogenous visual spatial cues that automatically capture attention in non-disabled populations. Delays in attentional search tasks have also been found in dyslexics [6]. In addition to attentional deficits in dyslexics, there are many reports of MC processing impairments. Post-mortem histological examinations of the bottom two MC layers in the LGN show general disorganization and a 27% reduction of cell size in developmental dyslexic brains [7]. Functionally, dyslexics' performance on tasks that require MC processing is often poorer compared to age and ability matched controls. Such tasks include measures of coherent motion detection in random-dot kinematogram (RDK) [9] and sensitivity to rapid transient presentations of low contrast achromatic stimuli limited to low spatial frequencies [11].

Reading routes: Whilst reading appears to function as a unified process, it operates though a number of separate sub-processes such as decoding of visual features of words (orthography) and word sounds (phonology). According to the dual route cascading (DRC) model of reading [15], letters in text are initially identified in parallel, but subsequently processed serially from left to right in most languages. Grapheme to phoneme conversion follows in both a non-lexical rule guided route and a lexical route that utilizes a dictionary lookup procedure to identify the word as a whole. The DRC assumes that a novel non-word with regular pronunciation (i.e., flimp or slup) requires a rule based system for attaching phonemes to graphemes. This requires quick and accurate shifts of visual attention from one serial position to the other. Irregular word (i.e., pint or colonel) reading also requires a level of attentional processing, however, as the DRC model predicts, irregular word reading is done through a parallel process and demands less of an attentional load than does non-word reading. In this framework, the relative processing ability of the MC pathway may have a greater impact on lexical processing essential for phonological decoding due impoverished feedback information from the PPC controlling attention.

Current study: In the current study we have explored the relationship between reading, attention, and MC processing in a group of normally functioning children. Additionally, we explored the hypothesis that attentional processing, mediated by MC function, is more closely linked to non-word reading (processing in the phonological route) than to irregular word reading (processing in the direct route) defined by the DRC reading model. To do this we utilized a cueing task as a measure of attention processing. An exogenous visual cue was given to automatically draw attention to a spatial location without eye movements. It is assumed that such cues are processed by the MC pathway up through dorsal brain regions to the posterior parietal cortex where attention is automatically directed towards the cued location [4]. Detection of the target was manipulated by presenting either a valid or invalid visual-spatial cue. In this task, the target was coherent motion appearing in one of a set of four random-dot kinematogram (RDK) patches. It was expected that coherent motion detection thresholds would be modified by the different cueing conditions. Given a valid visual-spatial cue, participants were expected to show lower coherent motion detection thresholds, presumably due to increased target salience generated by the automatic orientation of attention to the correct location. Performance in this condition is assumed to reflect attentional and MC processing. Higher detection thresholds were expected in the invalid cue condition. Orientating attention to an incorrect location would subsequently force a serial search and comparatively decrease target saliency.

MATERIALS AND METHODS

Participants: After screening, the sample included 59 children (29 girls, 30 boys) between 8.9 and 11.8 years of age (107–141 months) and selected from four primary schools located in and around Oxford. All children were native English speakers, had normal or corrected to normal vision, and had no reported history of cognitive problems. Children with a general intellectual ability below the 50th percentile, as determined by scores on BAS matrices and similarities, were not included in this analysis. Participants' general reading ability as measured by the British Ability Scales (BAS) reading subsection and Test of Word Reading Efficiency (TOWRE) were within the normal range for their particular age group. This study was carried out in accordance with the guidelines of the Declaration of Helsinki.

Testing battery: Participants were assessed in a separate location from classes and given psychological tests of general verbal and non-verbal reasoning, tests of orthographic and phonological processing in addition to a MC based attentional processing task over two 30 min testing sessions. The Similarities and Matrices subtests from the British Abilities Scales Revised (BAS-R) were administered as tests of general cognitive ability. Participants also read out aloud from two lists consisting of either exception words or pronounceable non-words [16]. Thirty pronounceable non-words (e.g. bim) were presented in order to measure grapheme to phoneme conversion skills and 30 irregular words (e.g. island) to measure direct access to the mental lexicon.

Psychophysical measure: The task consisted of four separate patches each composed of 150 high luminance white dots, 1 pixel in size, moving at $7^{\circ}/s$ on a black background. The sizes of the patches were $10 \times 10^{\circ}$ of the viewing angle with 5° of separation. The percentage of coherently moving dots within a given trial was varied adaptively in response to a participant's ability to detect coherent motion (Fig. 1). The non-coherent dots moved randomly in a Brownian manner in the three distracter patches. In 2/3 of the trials a visual cue was given that correctly identified the location where the coherent motion would be found. In 1/3 of the trials an invalid cue was given that identified a location away from the target. An individual's threshold for detecting coherent motion was determined using a 3 dB up 1 dB down, two-alternative forced choice, staircase procedure [17]. Threshold estimates were determined by taking the geometric average of the last 6 of 8 reversal points. A series was presented once as a practice session. Final thresholds from the valid and invalid cue conditions were determined in a second series given. The children were told to look at the centre fixation cross throughout the experiment and to determine the direction of the coherently moving dots (rightwards or leftwards).

RESULTS

Log transformations were used to normalize the data. A paired samples *t*-test was conducted to evaluate the difference between the coherent motion detection thresholds related to the valid and invalid cue type. The results indicated that the mean detection threshold for detecting coherent motion was significantly reduced in the invalid cue condition ($t(58) = -5.20$, $p < 0.001$).

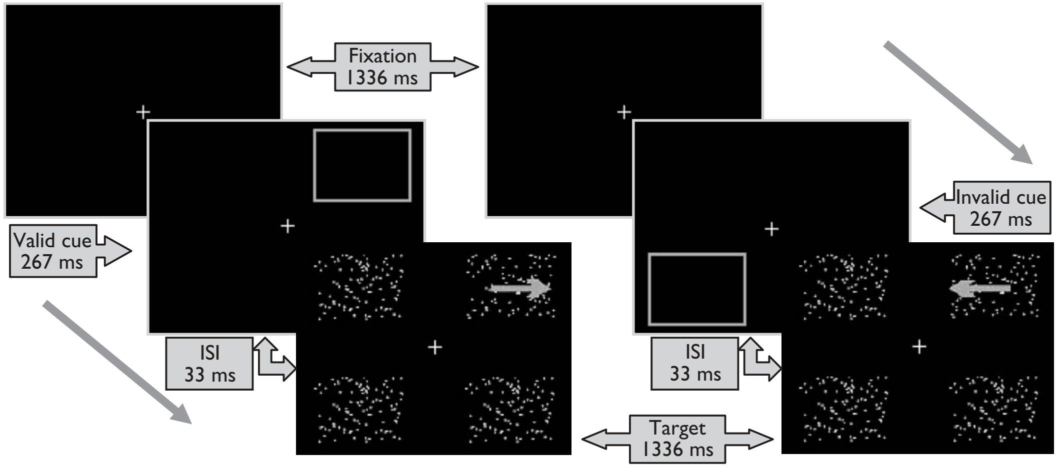

Fig. 1. Presentation sequences for both valid and invalid cue trials. Coherent motion for a given trial moved continuously rightward or leftward.

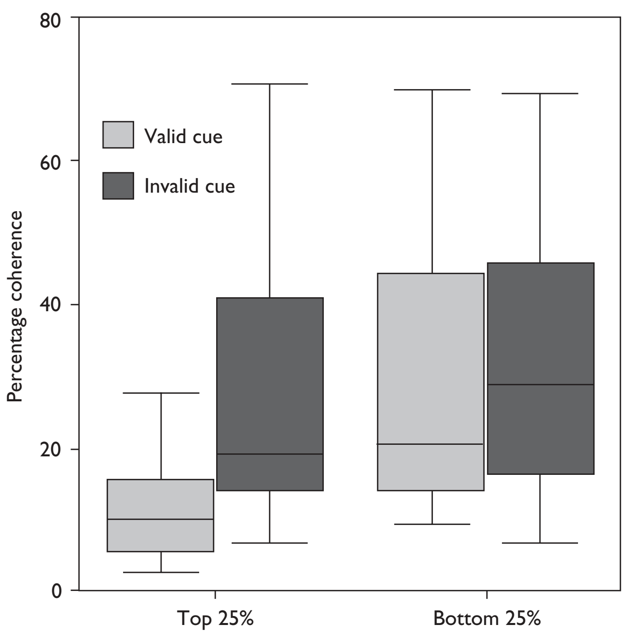

Fig. 2. Boxplot representation of untransformed means for valid and invalid spatial cues in the top and bottom 25% readers. Smaller numbers represent better coherent motion detection ability.

Reading groups: The sample was divided into two groups of children whose reading performance represented the upper and lower 25% of the sample. A two-way repeated-measures ANOVA using the Wilks' lambda criterion was conducted that considered reading group (upper and lower ranked readers) and spatial cue type (valid and invalid). A main effect for spatial cue type was found (F(1,28)=13.00, p=0.001, multivariate η^2=0.32). An interaction between spatial cue type and reading group was also found (F(1,28)=6.86, p=0.014, multivariate η^2=0.20). Paired t-tests showed there was a significant difference between the valid and invalid spatial cue types for the upper ranked readers (t(14)=−3.64, p=0.03). There was no difference between cue types for the lower ranked readers (Fig. 2).

Regression analyses: Hierarchical multiple regression analyses were conducted to explore the relationship between MC mediated attentional processing and reading ability. Because age showed a significant correlation with reading, in each model it was the first variable entered. To determine the unique covariance of the spatial cue type beyond intellectual capacity, coherent motion detection thresholds for valid cues, invalid cues, and the difference between the two cue types were entered into the three separate models last, resulting in a total of 6 regression models. For both non-word and irregular word reading, performance on the valid cue condition was significantly related to non-word reading (R^2 change=0.11, F(1,40)=5.26, p=0.03) and irregular word reading (R^2 change=0.08, F(1,40)=4.77, p=0.04). In addition, differential performance on the coherent motion detection task given the two cue types was significantly associated with non-word reading accuracy (R^2 change=0.12, F(1,40)=5.75, p=0.021).

DISCUSSION

The results demonstrated that coherent motion detection thresholds were significantly modified in the cueing paradigm. Overall, coherent motion detection thresholds were lower when a visual cue identified the correct location in space where the stimuli would be present. When a visual cue identified the incorrect location, thresholds were elevated. Importantly, the lower quartile in reading ability profited significantly less from the correct cueing condition than did readers in the highest quartile. In both the valid and invalid cueing conditions, lower ranked readers showed coherent motion thresholds similar to upper ranked readers in the invalid condition. These results suggest that less skilled readers tend to have poorer attentional processing capacities perhaps due to a weaker MC system.

Regression analyses were conducted to explore the relationship between specific reading ability and attentional processing controlling for both age and general intellectual ability. Results showed that a significant proportion of reading variance in both non-word and irregular word reading was associated with performance on the valid cueing condition. In addition, a significant relationship between non-word reading and the differential performance on the two cueing conditions was found. Irregular word reading did not show such a significant relationship to attentional processing. Overall, these data support the hypothesis that attentional processing may play a significant component in lexical decoding. The lexical processing associated with non-word and irregular word reading, however, may have different associations with attention.

The magnitude of the relationship between coherent motion or MC processing and reading ability found in the current study was similar to that reported by Talcott *et al.* [9]. In their study, visual coherent motion sensitivity accounted for a small but significant proportion of the variance in literacy skill (3%) after age and performance ability were controlled for. Poor performance on the visual task was associated with poor reading skill. Participants with non-verbal intelligence above the 50th percentile could detect motion with ~15% coherence. The task used in the current study utilized the same dot characteristics and thresholding procedure, but had four locations from which to identify the target. When the correct location of the target was identified in the valid cue condition, participants with general intelligence above the 50th percentile could also detect motion with ~15% coherence. However, this was only true for the higher ranked readers. Lower ranked readers required ~28% coherence to detect motion.

The finding that lower ranked readers did not utilize the exogenous attentional cue in the same manner as the upper ranked readers is consistent with reports from Facoetti *et al.* [4]. In their study, a visual cue highlighted the location where a single dot was to appear. For good readers, identifying the location of the dot was faster in the valid cue condition compared to an invalid condition. Poor readers, on the other hand, did not appear to utilize the cue and demonstrated equally delayed reaction times in both valid and invalid cueing conditions. When a longer stimulus onset asynchrony (SOA) was given between cue and target presentation, poor readers performed similarly to good readers [4,18]. This suggested that the speeded nature to which poor readers incorporate visual stimuli was impaired and supports the notion of a sluggish attentional system, as described by Hari and Renvall [5] in poor readers. One question raised by the similarities between the current study and that of Facoetti *et al.* [4] concerns the general importance of the dynamic stimuli to the overall results. The similarities suggest that the relationship between visual tasks and reading may be more dependent on an attentional component as opposed the specific stimuli characteristics.

What impact attentional processing difficulties may have on orthographic or phonological processing is an interesting question. According to the DRC model, non-word reading requires a serial processing strategy where a phonemic representation is constructed letter by letter. Reading irregular or high frequency words on the other hand is done in a more parallel processing whereby letters of a word are taken as a whole. It is possible then that decoding lexical information in the phonological route requires a greater attentional demand on visual-spatial processing compared to decoding in the direct route. The finding in the current study of a relationship between differential performance under the two attentional cueing conditions and non-word reading would appear to support this idea. The greater the differential performance between the valid and invalid cueing conditions is interpreted as representing a greater ability to incorporate rapidly presented visual information. Or in other words, the greater the difference between cueing conditions, the better attentional processing ability one has. The relationship therefore suggests that the better one's attentional processing ability, the better one is at non-word reading.

CONCLUSION

Further research on the relationship between specific components of reading and attentional processing are needed. While the data presented in the current study suggests that attentional processing may play an important role in reading, a more definitive investigation is needed. In future studies we will explore attention in a more parametric fashion across a larger range of reading abilities. The specific relationship between reading ability and motion processing compared to attentional processing will also be explored. Lastly, an auditory based paradigm matched to the visual task will be created to explore the possibility that the relationship between attention and lexical processing may extend to other modalities.

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