TEMPORAL AND SPATIAL PROCESSING IN READING DISABLED AND NORMAL CHILDREN

G.F. Eden¹, J.F. Stein¹, H.M. Wood² and F.B. Wood²

(¹University Laboratory of Physiology, Oxford, U.K.; ²Bowman Gray School of Medicine, Winston-Salem, N.C., U.S.A.)

ABSTRACT

The ability to process temporal and spatial visual stimuli was studied to investigate the role these functions play in the reading process. Previous studies of this type have often been confounded by memory involvement, or did not take into account the evidence which suggests a visual transient deficit in some dyslexics. Normal (n = 39), reading disabled (n = 26), and backward reading children (n = 12) were compared on a visual computer game, which consisted of a temporal and an analogous spatial dot counting task. Reading disabled children performed significantly worse than normal children on the Temporal Dot Task, but were only mildly impaired on the Spatial Dot Task. Backward readers were not significantly better than the reading disabled group on either task, suggesting that poor visual temporal processing is not specific to dyslexia. In a group of 93 children, a regression model including age, verbal IQ, phonological awareness, and visual temporal processing ability, predicted 73% of the variance of reading ability. The results suggest that dyslexics perform worse in tasks that require fast, sequential processing and that this impairment may be partially responsible for their reading difficulties.

INTRODUCTION

The ability to process temporal information accurately is an essential prerequisite for many aspects of learning. Auditory pattern that are perceived by the ear require accurate sequential perception in order to be understood and faithfully replicated in speech or writing. Further, auditory (or visual) pattern need to be processed accurately for memory storage, or their later retrieval may result in learning difficulties. Reading disability is an impairment where the standard of reading is lower than would be expected from the intellectual ability and educational background of a subject. The importance of phonological awareness, in which graphemes are translated to their corresponding phoneme during reading has long been known. "Phonological awareness" is often used as an umbrella term to describe abilities involved in grapheme/phoneme correspondence. It has been suggested by Stanovich (1988a) that phonological awareness should be reserved for the ability to make explicit verbal reports of phoneme-sized units, but for simplicity in this study we will be using the expression as a general term.

Phonological awareness was studied by Bruce (1964), who read out lists of words and asked children to repeat the words after a particular sound had been taken away. Liberman, Shankweiler, Fischer et al. (1974) devised a similar task,
in which mono- and poly-syllabic words were read to children, who in turn tapped out the number of phonemes and syllables of particular words. Both sets of experiments showed that phonological awareness developed a few years after normal children had begun to read and so the tasks were usually impossible for pre-readers. Since then a large body of evidence has shown that phonological ability predicts reading acquisition (Goswami, 1990; Stanovich, 1988b; Snowling and Rack, 1991). Bryant and Bradley found that a rhyme detection task was a very effective way to investigate phonological awareness. In one of their studies (Bradley and Bryant, 1978), reading disabled children were matched with reading-age matched controls. The tasks involved detecting rhyme, alliteration and producing rhyme. In all tasks the reading disabled older children were significantly worse than the younger control group. The alliteration task discriminated best between the two groups. Since the children were matched for reading level, Bradley and Bryant concluded that phonemic insensitivity was the cause of these children’s reading problems. Further experiments have confirmed that early ability to rhyme predict later reading and writing outcome (Lundberg, Oloffson and Wall, 1981; Fox and Routh, 1983) and that children who are taught to rhyme also improve their reading (Fox and Routh, 1976; Bradley and Bryant, 1983).

It might be thought that processing auditory information for speech is a temporal task, whereas reading words is purely a spatial task; but in fact reading involves the encoding of spatially arranged visual symbols as a temporal sequence from one fixation to the next. Temporal processing in reading disabled (RD) or dyslexic subjects has been investigated in terms of visuals and auditory temporal ordering. A well known study by Birch and Belmond (1964) integrated both the visual and auditory modalities to study differences of non-verbal intersensory ability in normal and reading disabled subjects. The study demonstrated that reading disabled subjects were worse than normals when asked to match one of three visual patterns to an auditory pattern of tapping sounds (the visual pattern consisted of horizontal rows of dots with varying spaces analogous to the intervals in the auditory pattern). Birch and Belmont suggested that dyslexic children had a problem with the integration of auditory and visual signals. However, further experiments demonstrated that dyslexic children were impaireed on both modalities when these were tested individually (Zurif and Carson, 1970). Therefore it was concluded that dyslexics have difficulties in dealing with temporal patterns within both the auditory and the visual modalities. Another study showed that in normal children visual temporal processing was less efficient than auditory temporal processing, which in turn was inferior to spatial temporal processing. Dyslexic children were worse than normals on all of these modalities (Willette and Early, 1985).

These studies and others (e.g., Reed, 1989; Zurif and Carson, 1970; Katz et al., 1981) employed tasks in which subjects were asked to remember the order of presentation of series of visual or auditory stimuli, and match it to another pattern. The results are variable, showing differences between normals and dyslexics in some cases, but not in others. In those experiments which showed dyslexics to be less able to reproduce temporal-order patterns, there are some limitations in interpreting the results. Given the nature of the tasks, that they
may have been verbally labeled, it is not clear to what extent the differences may have been confounded by memory. There is good evidence to believe that short term memory codes are phonologic and since dyslexia is often associated with poor short term memory and poor phonological awareness (Mann and Libermann, 1984), the poor performance seen in the dyslexic groups could be explained by the memory involvement required by the tasks.

Another problem with these studies was that the timing of the stimuli was not given enough attention. Due to technical problems, or reasons of study design, the interstimulus intervals for the visual task may have made the task too easy, so no differences were found between normals and dyslexics. RDs have been shown to be worse than normals at matching visual stimuli only if the exposure times were short (between 0.1 and 1.0 seconds) and the children were below 8 years of age (Lyle and Goyen, 1975; Willows, 1990). The age of subjects plays a crucial role in all visual studies (Fowler, Riddell and Stein, 1990). But for younger children it is now clear that rapidly represented stimuli are processed less accurately and more slowly by reading disabled than by normal children (Willows, 1990).

In the last two decades a large body of research has been carried out on the early processing of temporal sequences of visual stimuli. Once a stimulus has been removed from a subject's sight, an image of the stimulus is still apparent for a short time. This is called visual persistence; and it is thought to be caused by ongoing neural activity, which persists after the stimulus has ceased. The time course of visual persistence can be assessed by presenting two separate stimuli in close succession and assessing at which point the two stimuli are perceived as one. Such studies have demonstrated that reading disabled children had significantly longer separation thresholds (Stanley and Hall, 1973). These results were later confirmed by Lovegrove and Brown (1978) using spatial frequency analysis in the form of sinusoidal waveform gratings to investigate visual persistence. Lovegrove also found that the results varied with the nature of the grating: In adults the duration time of visible persistence increases as spatial frequency increases (as the gratings become less coarse). But Lovegrove and his colleagues found this increase to be less in reading disabled children compared to normal children (Lovegrove, Martin and Slaghuis, 1980). Therefore, at low spatial frequencies, reading disabled children exhibit longer visible persistence. Further, the contrast sensitivity of normal and reading disabled children was different, and the biggest effects were observed at low grating contrast (Martin and Lovegrove, 1984). Lovegrove and colleagues explain these differences in the framework of the sustained and transient channels of the visual pathway. These channels can be distinguished by their spatial frequency preference, their temporal properties and their contrast sensitivity (Kulikowski and Tolhurst, 1973). Since both contrast sensitivity and visible persistence varied in reading disabled children, Lovegrove and colleagues concluded that these children have disturbances in the transient system, which mediates global form, movement and temporal resolution. Experiments in which flicker thresholds were used to measure the efficiency of the transient system directly, also successfully differentiated normal and reading disabled children (Martin and Lovegrove, 1988).
The result of these recent studies have aroused new interest in visual temporal processing in dyslexic and they offer a physiological explanation for the problems observed in dyslexics. In the light of these findings, the present study therefore investigates the relationship between temporal and spatial ability in children and how it relates to their reading performance. Reading a word has both a spatial and a temporal dimension; it requires localization in space of letters by transferring the temporal order of foveal saccades into their spatial sequence. Therefore we administered both temporal and spatial processing tasks, which were free of verbal components, to dyslexic and normal children. The aim of the investigation was not to determine the separation time required by a subject to perceive two distinct images; this is around 30 msec for normal subjects, and so we used separation times well beyond this value. The aim was to see the effect of a sequential or simultaneous build-up on the visual system. The findings by Lovegrove and others would argue that this would be more taxing on the visual system of dyslexics than for normals.

To determine whether differences between these two groups are specific to dyslexic children, the reading disabled children were also compared to backward readers with lower IQ levels. Previous studies of the visual deficit hypothesis have been criticized for not using a reading-age match design. It has been argued that studies using reading-age matched controls are more precise in determining the cause of reading disability, and therefore deficits in dyslexics are not confused with problems resulting from reading disability (Bryant and Bradley, 1979). There are a number of objection to this argument (see Jackson and Butterfield, 1989), but the important point for the rejection of the reading-level match for the purpose of this study is that older children are likely to be at an advantage concerning visual tasks. The reading-age matched design would give the dyslexic children this age advantage and therefore it would no longer be a true comparison. Whilst a reading-age matched design may be useful for verbal material it is probably less important for these visual tests which do not involve printed words. The final objective of this study was to determine whether the performance of temporal and spatial visual tasks could predict reading ability in a population of children with a range of reading and IQ levels.

**Materials and Methods**

**Subjects**

A group of 39 normal children (N) were selected who demonstrated normal intelligence, between 85 and 115 on the Wechsler Intelligence Scale for Children — Revised (WISC-R: Wechsler, 1974), and a reading level in the normal range, between 85 and 115 on the Woodcock-Johnson standardized score (WJRSS), at 5th grade (Woodcock and Johnson, 1977). These children were selected from a larger epidemiological sample of normal (n = 485) 5th graders from the Learning Disability Project at the Bowman Gray School of Medicine, North Carolina (Felton, 1987; Felton and Wood, 1992).

A group of 26 reading disabled children (RD) were selected from a second epidemiological sample of poor reading (n = 295) children available from the same projects. The selection criteria for this RD group was the same as for the N group in terms of IQ level, but unlike the N group, their reading on the WJRSS was below 85.

A third group was chosen, also from the poor reading epidemiological sample, to provide
TABLE I
Profile of the 93 Subjects Studied

<table>
<thead>
<tr>
<th>Group</th>
<th>n</th>
<th>Chronological age (5th grade)</th>
<th>Reading age (5th grade)</th>
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<td>Mean</td>
<td>Range</td>
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<td>8.7-13.0</td>
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<td>7.2-9.0</td>
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<td>11.7 (0.19)</td>
<td>6.7-9.3</td>
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<td>9.0-18</td>
</tr>
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<td>10.2-12.6</td>
<td>11.3 (0.01)</td>
<td>6.7-18.0</td>
</tr>
</tbody>
</table>

a backward reading group (BR). These 12 BRs were reading below 85 on the WJRSS (like the RD group) but their IQ was also below 85 on the WISC-R. The RDs were compared to these backward readers, to see if reading disabled children have a specific deficit that is not found in children who read poorly for other reasons. By comparing the RD group to the BR group, we could determine whether the BR children's performance is a specific characteristic of being dyslexic or whether these features are present in other form of reading disorders (caused by low IQ). Dyslexic readers are worse at verbal tasks than backward readers, since these deficits are specific to dyslexics (Rutter and Yule, 1975). This discrepancy should therefore also be true for a visual task. The use of an IQ controlled experimental design has been criticized recently (Siegel 1989; Share, McGee, Mckenzie et al., 1987) because many verbal abilities are similar over a wide range of IQ levels. However, for the purpose of this study we have grouped the children according to their IQ, but we have not used a stringent discrepancy score between reading score and IQ level. This allowed us to include poor readers with low IQ, sometimes referred to as the “garden-variety poor reader” (Gough and Tunmer, 1986). The children were selected from a similar age range, but the reading disabled children were on average significantly older than the RDs (by 8 months).

Finally, a further aim of the study was to investigate the relationship between temporal visual tasks and reading ability by producing a regression model from a sample of children representing a variety of reading and IQ levels. Therefore a fourth group of children was selected to include children that did not meet any of the above criteria of the N, RD and BR group. This miscellaneous group (MIS) of 16 children mainly consisted of normal readers. They were included in order to fill the gaps between the other groups and extend the range of reading and IQ levels, providing a more representative population. The entire sample of 93 children was taken as a more representative sample to see if the effects hold true in a sample approaching a normal distribution. This group was only used to carry out correlations with other variables known to be associated with visuospatial performance or reading ability. These included sex, handedness, attention deficit disorder (ADD), memory, block design and phonological ability. Finally, these 93 children were used to produce a regression model, which predicted reading ability based on visual and phonological ability. The groups are represented in Table I.

Assessment Tests

General Intellectual Ability

The Wechsler Intelligence Scale for Children — Revised (Wechsler, 1974) was used to determine verbal IQ (WISCVIQ). This consisted of the following six subtests: information, similarities, arithmetic, vocabulary, comprehension and digit span. Another six subtests provided a composite score for performance IQ (WISCPIQ): picture completion, picture arrangement, block design, object assembly, coding and mazes. The scores were scaled for age and a calculated sum for WISCVIQ and WISCPIQ provided a full scale intellectual score (WISCFIQ).
Reading

Reading ability was assessed using the Woodcock-Johnson Psycho-Educational Battery (Woodcock and Johnson, 1977). The Woodcock-Johnson Reading cluster measured three reading skills which were converted into an age corrected standard score. It consists of word identification, word attack and passage comprehension therefore assessing sight word vocabulary, mono and polysyllabic nonword reading and passage comprehension, respectively.

Temporal and Spatial Dots

Small dots (they were actually squares) were counted by the children during brief presentation on the computer screen. The size of each dot was 0.3 degrees of visual angle at 30 cm viewing distance. There were two different types of presentation and these are summarized in Figure 1.

Temporal Dots. Dots were flashed one after the other in the same location, at the center of a 2 cm by 2 cm box. Each dot remained on the screen for 40 msec and the next dot in the sequence was presented after a random time interval ranging between 200 and 400 msec. The time interval was randomized to reduce the possibility of the child making use of a predictable, rhythmic pattern to help him/her obtain the answer. The time interval was long enough to ensure that under normal conditions no backward masking could occur. The child answered by pressing the relevant number on a touch screen. Between 3 to 8 dots were randomly presented in each trial and here were 12 trials at each dot number level giving each subject 72 trials to perform.

Spatial Dots. Here the same dots as used in the temporal task were presented, this time simultaneously. 3 to 8 dots were displayed, randomly scattered within a 20 cm by 16 cm frame, for 500 msec.

In summary, for the Spatial Dots the child had to count the dots in space whilst in the Temporal Dot task, s/he had to count the dots as they sequentially flashed up in the same area of the screen. For both the Temporal and Spatial Dots, results for each number of dots are presented here as correct answers (out of 12). Further, the time taken by the child to give this answer was recorded. Incorrect answers were divided into those where the child named fewer dots than were actually displayed, thereby underestimating the answer, or naming more dots than there really were, and so overestimating the dot count. Mean reaction times in both instances were recorded, at each numer of dot level. The results should yield

Fig. 1 - Diagrammatic representation of an instant of the Temporal and Spatial Dot Task.
information on how the child’s processing time related to his/her accuracy and how reaction
time varied as task difficulty increased.

Memory

Once visual information has been successfully taken in from a very brief presentation, it is then taken into short-term visual memory storage, before it can be passed into long-
term memory; here it can be called upon for later recognition and recall (Rayner and Pollatsek,
1989). As discussed in the introduction, previous results of temporal sequencing experiments
have been weakened because the effect of memory contraints were not separated out from the
effects of temporal order perception (for example Bakker, 1967). Whist the Temporal
and Spatial Dot tasks were designed to have minimal verbal memory involvement, a further
step was taken to control for this factor by analyzing the results using Digit Span from the
WISC-R as a covariate. The Digit Span test requires the child to repeat a random sequence of
numbers forwards and backwards. The result provide useful information about the child’s
memory abilities.

Sex and Handedness

Sex and handedness have shown to be associated with developmental language disorders
(Rutter and Yule, 1975). Both were therefore correlated with the results to determine if a
deficit in either of the visual tasks was associated with a particular sex or handedness.
Handedness was determined using the Edinburgh Test for handedness (Oldfield, 1971).
Children were classified as being either left or right handed.

Attention Deficit Disorder (ADD)

Felton and Wood (1989) have shown that Attention Deficit Disorder (ADD) plays a
complex role in reading ability and the relationship between the two visual tasks and ADD
was investigated in this study. The ADD portion of the Diagnostic Interview for Children
and Adolescents (DICA) by Herjancic (1983) was administered to a parent or guardian of
each child. This is a structured interview, yielding a standardized measure of ADD based
on the Diagnostic and Statistical Manual of Mental Disorder (DSM, 3rd ed.). A child was
classified as having ADD or no ADD.

Mathematics Skills

Since the Temporal and Spatial Dots involved counting or addition, the children’s
mathematics skills were assessed using the Woodcock-Johnson Math standardized score
(WJMSS). This measures the ability of calculation and applied problems.

Phonological Awareness

There is good evidence that phonological awareness is required for successful reading
(Bradley and Bryant, 1983). The Pig Latin Test (Olson, Wise, Conners et al., 1989) was
used to assess phonological ability, to investigate if children with good phonology also
performed well at the Temporal and Spatial Dot Task. In a previous study we found the
Pig Latin Test to be the strongest predictor of reading ability (Eden, Stein, Wood et al.,
1995). In the Pig Latin Test the order of sounds in words was reassembled by the child by
deleting the initial phoneme from a word, and placing it at the end of the word and then
adding “ay”. So “pig” was spoken as “igpay”. Correct answers, as well as the time to translate
27 words into Pig Latin at 5th grade were scored.

Procedure

For the achievement tests described above, children from the Bowman Gray Learning
Disability Study were tested individually at school. Their IQ and ADD data was collected
at 3rd grade, whilst all other data is the result from 5th grade testing. A few months after the school testing had been completed in 5th grade, the children carried out the Temporal and Spatial Dot Tasks as part of a test battery at Bowman Gray School of Medicine. Children with physical illness or clear neurological disorders were excluded from the study. A standard eye exam was administered by an independent ophthalmologist and orthoptist. All children entering the study had normal or corrected to normal vision and demonstrated no visual field deficits.

RESULTS

The following analysis was carried out: Differences in accuracy of Temporal Dot counting between the N (n = 39) and RD (n = 26) group were determined by multiple analysis of variance (MANOVA), with repeated measures across the number of dots (from 3 to 8 dots presented). Digit Span was entered as a covariate, to account for memory. The same analysis was then carried out for the Spatial Dot Task, i.e. a MANOVA with repeated measures across the number of dots, and with Digit Span entered as a covariate. In order to estimate if the children reported seeing more of fewer dots than were actually presented, a similar MANOVA was also applied to the data separating the number of over- or underestimated answers. We also analyzed the mean times take to arrive at the correct, over- or underestimated answer. The theory was that the reaction time may be related to the result. If for example a child reported seeing fewer dots than were presented to him, would he or she have responded in less time? This procedure was carried out separately for the Temporal and Spatial Dot data sets. Finally the above procedure was then repeated for the RD and BR (n = 12) group comparison.

A MANOVA (Group [N,RD] x Number of Dots [3,4,5,6,7,8]) was applied to the Temporal Dot Task with repeated measures across Number of Dots and with Digit Span entered as the covariate. The results revealed significant differences for Group (F = 4.77; d.f. = 1, 61; p < 0.0328). There was also a significant interaction of Number of Dots x Group (F = 2.4; d.f. = 5, 57; p < 0.0460). Figure 2 demonstrates how the reading disabled children had lower correct score (controlled for memory) than normals across all Number of Dots. This group difference was significant for 4 and 8 number of dots presented (t = 2.01, d.f. = 63, p < 0.0484; and t = 3.31, d.f. = 63, p < 0.0016, respectively). Figure 2 also illustrates the changes in score of the two groups, with increasing number of dots, as indicated by the MANOVA results.

A MANOVA on the Spatial Dot Task demonstrated that there were no significant differences between the Ns and RDs. There was a significant effect for Number of Dots (F = 12.8; d.f. = 5, 57; p < 0.0001) and a tendency towards significance on the interaction between Group and Number of Dots (F = 19.9, d.f. = 5, 57; p < 0.098). Figure 3 illustrates that performance in both groups decreased with increasing number of dots.

Backward readers did not differ from the RDs in the Temporal Dot Task and neither were there any interactions. Figure 2, however, shows that the BRs appear to improve their performance as the amount of dots presented increases, thereby demonstrating the opposite pattern of the Ns and RDs. On the Spatial
Dot Task, there were no significant differences except for Number of Dots (F=115.7; d.f. = 5, 30; p<0.0001). Figure 3 shows that the BRs follow the same pattern of decreased performance with increasing number of dots.

Incorrect Scores

MANOVAs were also performed on the number of scores underestimated at each level (Group [N,RD] × Number of Dots [3,4,5,6,7,8]; the same results were computed for the number of scores overestimated, to investigate a possible tendency for under- or overestimation in the N or RD groups. In both the Temporal and Spatial Dot Task there was never a simple effect of Group, but on all 4 MANOVAs (under- and over estimated in the Temporal and Spatial Dots) there was the expected significant effect for Number of Dots. These figures confirm the impression from Figure 2 and 3 that N and RD children increase their errors with increasing amounts of dots presented. However, they seem to have had an equal tendency to count too many or too few dots in both the Spatial and the Temporal Dot Tasks.

The BR again did not differ from the RDs in the number of dots they underestimated or overestimated. Here too there were significant effects on accuracy of performance as the number of dots increased (and surprisingly there was improvement with increasing rather than decreasing number of dots on the Temporal Dot Task, already described). Further, in the number of underestimated
Fig. 3 – Scores achieved by the Normal, Reading Disabled and Backward Readers on the Spatial Dot Task.

scores, there was an association between Number of Dots and Group in the Temporal (F = 2.6; d.f. = 5, 31; p < 0.0448) and Spatial Task (F = 2.7; d.f. = 5, 30; p < 0.0381). The BR group underestimated slightly, but not significantly more of their answers to the Spatial and Temporal Dot Tasks.

Reaction Time

The times for the subjects to respond were analyzed by MANOVA. For the Spatial and Temporal Dot Tasks there were no differences between the normal and reading disabled children in the time taken to respond correctly. There were also no significant changes in reaction time with increasing number of dots. For incorrect answers (that is under- or overestimating the answer) there were also no differences between the two groups in either tasks. The only significant result for time was the effect of Number of Dots (F = 5.4; d.f. = 5, 57; p < 0.0004) when Spatial Dots were underestimated. An increase in reaction time as the number of dots presented increased, was the typical picture for all responses in both the Temporal and the Spatial Task. However, with the exception of this last results, this effect did not have a significant impact on the outcome. Finally, comparing the BR with the RDs, there were no differences at all in reaction time between the groups in either task.

The relationship between reaction time and accuracy of score was assessed by Pearson's correlations for the N, RD and BR groups combined (n = 77). There
was no association between mean reaction time and mean correct score for the Temporal or Spatial Task. For incorrect scores there was only one significant correlation: mean number of overestimated answers with their mean reaction time in the Spatial Dot Task (r = -.34), which suggests that longer reaction times usually result in the wrong (in this case overestimated) answer.

In summary, the results demonstrate that reading disabled children are worse on the Temporal Dot Task compared to normals. BRs were no better than RDs on this test. There was no significant difference between normal, reading disabled and backward reading children on the Spatial Dot Task. Presentation of a series of dot stimuli in time, rather than space, appears to be more difficult for RDs. Generally, all children became worse in both tasks as the number of dots increased (with the exception of the BRs on the Temporal Dot Task). There were equal numbers of over- and underestimations amongst the mistakes. Reaction times did not differ between the groups. They also barely correlated with the difficulty of the task and did not seem to have affected the end result.

**Phonological Awareness**

Since children with dyslexia are known to have poor phonological awareness, we wanted to establish the interaction of phonological awareness and Temporal and Spatial Dot performance. We computed correlation with the results of the Pig Latin Test, measuring phonological awareness in 5th grade. To illustrate the power of this test in differentiating children with different reading abilities, a combined ANOVA on the Pig Latin correct score and the Pig Latin time score was performed and clearly differentiated the N and RD groups in 5th grade (F = 19.06; df. = 2, 60; p<0.0001). The RDs translated significantly less words correctly into Pig Latin [mean (SE): N = 16.26 (0.58), RD = 11.25 (0.88); t = -4.94, d.f. = 61, p<0.0] and took significantly more time to do so [mean (SE): N = 193.46 (8.65), RD = 366.63 (39.72); t = 5.3; d.f. = 61, p<0.0]. The BRs were not as good as the RDs, but a combined ANOVA on the Pig Latin correct score and the time to complete the task, demonstrated that these overall differences were not significant.

**Correlations**

Correlations of the mean performance on the Temporal and Spatial Dot Task were carried out on the entire sample of 93 children (Table II). Since these tests were carried out on a very selected sample, it was important to correlate them for a larger, more representative group. The aim was to see how far Dot Performance correlated with reading ability over a large range of reading and IQ levels. The Temporal Dot Task correlated with reading ability (r = .40), and at a more significant level than the Spatial Dot Task did (r = .28). The next highest correlation was between the Temporal Dots and mathematics (r = .34). Surprisingly, such a relationship did not emerge from the Spatial Tasks and mathematics, although one might think that mathematical skill would relate to both the Spatial and the Temporal Task. However, there was an even stronger
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<tr>
<th></th>
<th>Spatial dot mean</th>
<th>Temporal dot mean</th>
<th>Sex**</th>
<th>Hand**</th>
<th>ADD**</th>
<th>Pig latin correct (5th)</th>
<th>Pig latin time (5th)</th>
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<th>Maths (WMMSS) (5th)</th>
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</table>

Pearson's and Spearman's** Correlation Coefficients; p<0.05 * p<0.01.

correlation between mathematics and Pig Latin correct score (r = .62). ADD had a share of influence on the Temporal Task (r = -.28), as might be expected if the children had difficulties in attending the task. Sex and handedness however, did not. Performance of both the Spatial and Temporal Dot Task was related to phonological awareness, measured by the Pig Latin Test. Phonological awareness of course plays an important role in predicting reading outcome (r = .59). The correlation matrix suggests that performance on test of phonological ability may also be associated with visual temporal processing. Similarly the Temporal Dot Task was more closely associated with the verbal than the performance aspect of IQ. This may be the result of good readers being able to process fast verbal as well as fast temporal visual information. Spatial Dot performance however did correlate with Block Design and other aspects of performance IQ, as might be expected. Digit Span did account for some of the ability to perform the Temporal Task. However, it should be noted that the outcome of the analysis on the differences between normals and RDs on correct scores was not substantially altered when memory (Digit Span) was introduced as a covariant.

A regression model was computed to predict reading ability. All variables were entered in a step wise fashion in the following order and each variable made its own significant contribution: the model consisted of the phonological awareness measure Pig Latin Correct Score (48%), Verbal IQ (52%), Chronological Age (64%), and Temporal Dots (73%). This overall model accounted for 73% of the variance in reading ability. Since we were surprised by the strong associations between mathematical skill and the Temporal Dot Task as well as between mathematics skill and the Pig Latin test, a further model was computed. Mathematics skill was added to the above model and each variable continued to make a significant contribution and the model now predicted 77% of the variance. Since Pig Latin and Temporal Dot Task remained to make a strong contribution to this model in addition to the mathematical skill
involved, it seems fair to assume that the reading outcome can not be explained by mathematical ability.

**Discussion**

There is conflicting evidence in the literature about whether visual deficits, particularly related to temporal visual processing, contribute to reading disability. Some of the dispute results from poor study design and task selection. Our study was designed to minimize some of the confounding effects that have plagued temporal judgement tasks. Further it was intended to tap the functions of the visual system though to be abnormal based on the findings of Lovegrove, Martin and Slaghuis (1986).

Since there is a temporal as well as a spatial aspect to reading and previous findings have shown conflicting evidence on deficits in dyslexics performing temporal and visuospatial tasks, both aspects were studied. The result showed that dyslexic children were significantly worse than controls at processing temporally presented information but were only mildly impaired when the same kind of visual information was presented spatially. Backward readers performed at a level similar to reading disabled children, and therefore the deficit of temporal processing was not specific to dyslexic children. However, the backward reading group was also not better than the RDs at phonological awareness. Therefore the BRs may have had an IQ that was too low to make a realistic comparison. The results of the correlations showed that there was little relationship between gender or handedness with either the Temporal or the Spatial Dot Task. There was some correlation between ADD and the Temporal Dot Task (a positive ADD diagnosis indicated poorer performance). The correlation analysis also showed that the Temporal Dot Task may well play a role in predicting reading outcome. When the Temporal Dot Task was entered into a regression model along with chronological age, verbal IQ and phonological awareness, the model predicted 73% of the variance in reading ability.

**Visual Processing and Reading Disability**

Previous visual studies such as those by Lovegrove et al. (1986) have been able to differentiate dyslexic from normal children. These studies used low level visual processing stimuli which are thought to be processed in different channels of the visual system. Other studies, such as temporal order judgement paradigms discussed earlier, are much easier to perform in the laboratory, but they are more likely to tap other cognitive functions. The Temporal Dot task used in this study offers an alternative way to address the question of a visual temporal processing deficit. It successfully differentiated the normal and dyslexic group, predicted reading outcome in a larger sample, and the results can not be easily explained in terms of other verbal or memory skills.

The analogous Spatial Dot task, on the other hand, was performed only slightly worse by the dyslexic group. Earlier studies have demonstrated differences in other visual and visuospatial abilities in a sample chosen from
the same population (Eden et al., 1993) and in other reading disabled children (Solman and May, 1990). This raises the question why the Spatial Dot Task did not differentiate between these groups whereas the Temporal Dot Task did. The results suggest that it is not the spatial but the temporal aspect of reading that is responsible for the visual problems that some dyslexics have.

However, there are other alternative that ought to be considered. The inconsistency in the literature of visuospatial abnormalities in dyslexia may suggest that one visuospatial test may not tap the same abilities as another. Benton has argued that several visuospatial tests should be used to assess brain damaged patients, since the same tests are not always performed equally poorly by all patients suffering the same lesions (Benton, 1979). This could also apply to the case of dyslexia. There are other possible explanations. The visuospatial task in this study did to some degree differentiate normals from RDs when the number of stimuli the subject had to process increased. The Spatial Dot Task was designed to be analogous to the Temporal Dot Task, but it may have been too easy. With the presentation of four dots or fewer, a ceiling effect in the Spatial Dots may have prevented the normals from performing significantly better than the reading disabled children, though there did not appear to be a ceiling effect for larger number of dots. Nevertheless, using a larger number of dots might have taxed the system sufficiently to obtain greater differentiation between the N and RD group. Finally, the Spatial Dot Task may not have required the same visuospatial skills that other tests do that have shown dyslexics to perform poorly. Since the task was analogous to the Temporal Dot Task, children were processing dots in space as opposed to in sequence, but this may not have made enough visuospatial demand.

**The Transient Visual System and Reading Disability**

It has been postulated that poor visual temporal processing results from impaired operation of the visual transient system and this hinders reading. Lovegrove and colleagues have shown that 75% of their reading disabled children exhibit a sensory deficit demonstrated by greater visual persistence at low spatial frequencies (Lovegrove et al., 1980) and lower flicker fusion rates (Lovegrove et al., 1986). However, Lovegrove and his colleagues have found that RD children do not process differently to normals information involving the sustained subsystem, which mediates structural detail arrayed spatially. Therefore it has been postulated that only the fast processing transient pathway of visual perception, or magnocellular pathway, is abnormal in dyslexic subjects. Anatomical studies have revealed abnormalities in the magnocellular layers of the lateral geniculate nucleus of dyslexic brain, and physiological studies have demonstrated diminished evoked potentials at low contrast in dyslexic subjects (Livingstone et al., 1991). The way in which a deficit in the transient system may impede reading has been attributed to failure of transient-on-sustained inhibition (Breitmeyer and Ganz, 1976). Onset of transient activity terminates sustained activity and therefore helps to separate information encoded during a sequence of different eye fixations. If this information is not separated, individual may perceive overlapping letters. This could lead to visual confusion, and
children do complain of visual experiences during reading which indicate that they may have such problems (Eden et al., 1994).

We believe that the Temporal Dot Task was difficult for the dyslexics because here the subject is forced into a temporal perception rate which makes it more difficult than when the subject can monitor their own temporal sampling rate in space (within a limited time). If a subject suffers a deficit in speed of information processing, the following chain of events could arise: one of many sequential visual stimuli arrives at the visual system at a stage before the most recent information has been completely processed. Temporal Dot information that is being processed may in this case interfere with the discrimination of each individual dot as it is perceived. This may lead to incomplete or non-processing of the stimuli, and a bottleneck effect would cause a "information processing jam" on the following stimuli. Separation time between the dots in this study were well beyond the time periods required by normal and reading disabled subjects to perceive two stimuli. May et al. (1988) reported that the "stimulus onset asynchrony", which is the time required by a subject between two visually presented words in order to perceive them as two rather than one word was 44.5 msec for normally reading children compared to 83.4 msec required by the poor readers. The aim of our present study was not to test this critical time period itself, but the ability of children to take in sequential, continuous temporal information, as happens during reading. The results demonstrated that the RD children were less able to count longer temporal sequences accurately than normal children. This indicates that not only do short stimulus onset asynchrony (SOA) pose a problem for RD children in studies presenting two stimuli as described by May et al., but a number of sequential stimuli, even if somewhat stretched out in time, pose a problem for RD children.

The results of this study help to explain why previous studies have failed to show a deficit in dyslexics. For example Vellutino and colleague's (Vellutino, Steger and Pruzek, 1973; Vellutino, Steger, De Setto et al., 1975; Vellutino, Steger, Karman et al., 1975) negative findings might be explained by the fact that they were using long stimulus exposures, studied long term memory and used symbols that may well have been verbally loaded.

Transient processing is not peculiar to the visual system, but analogous systems are found in other sensory and motor regions. Tallal et al. (1980) showed that dyslexic children with concomitant oral language disabilities performed no differently to normal children in distinguishing linguistic and non-linguistic auditory stimuli, as long as they were presented slowly. When the same stimuli were presented rapidly, however, the dyslexics performed much worse than normal children. It has been postulated that these findings could be interpreted as a "transient" auditory processing deficit and this may be responsible for the phonological processing deficits repeatedly observed in dyslexics. Whilst the findings of a phonological deficit in dyslexics are very robust, an explanation for this deficit is not yet clearly established. However, the finding of temporal phonological and visual deficits may potentially be explained in the framework of a common temporal deficit. Perhaps a range systems with varying deficiencies of their temporal elements, may be responsible for the range of sensory, motor and cognitive deficits exhibited by reading disabled children. This would explain
the heterogeneity observed in the dyslexic population. However, much of this is still speculative. A deficit in visual temporal processing is only one of many problems found in some dyslexic children. One way in which a visual deficit could influence the reading process would be by preventing the uptake of crucial information required for the formation of spelling to sound correspondences. Studies looking at visual processing in dyslexics often find that there is a large overlap between children with visual deficits and phonological weakness (e.g. Lovegrove et al., 1989). This may suggest that visual deficits contribute to phonological errors. However it is not clear if both problems arise due to a common etiology or if one may be the result of the other.

**CONCLUSION**

The results of the present study demonstrate that reading disabled children were significantly different from normal children on temporal analysis of visual information. The difference was specific to the temporal aspect of visual processing, as no differences were found between these groups in an analogous spatial task. The results suggest that whilst dyslexia is primarily a phonological disorder, the ability to process rapid visual information is an additional deficit in these children and accounts for a significant portion of reading outcome.

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Guinevere Eden, D. Phil., Child Psychiatry Branch, NIMH, National Institutes of Health, 9000 Rockville Pike, Bethesda MD 20892, U.S.A.