SPATIAL LOAD FACTOR AS A PREDICTOR OF READING PERFORMANCE

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Abstract

This is an abbreviated report of a previously published study. It investigated whether there is a relationship between reading age and clinical optometric tests that have varying degrees of spatial loading in their design.

One hundred and twelve children aged 8 to 11 years were assessed using saccadic eye movement and rapid naming tasks with varying spatial loads. All were subtests of the Developmental Eye Movement test and the SeeRite Reading Diagnostic Program. Variability in load was achieved by comparing rapid naming of numerals versus the spatially loaded letters p, d, b, q; and by comparing the speed of reading numerals presented in increasingly complex arrays. Reading Age was assessed independently and results were analysed by Multiple Logistic Regression.

Spatially loaded naming tasks performed at speed exposed a Spatial Load Factor that clearly differentiates children at risk with reading.

Key Words

Developmental Eye Movement Test, learning disability, reading age, reading, rapid naming, saccades, SeeRite Reading Diagnostic Program, spatial load,

INTRODUCTION

This is an abbreviated version of a previously published study.[1] This investigation was designed to determine whether increasing spatial load within timed clinical optometric tests made the tests more predictive of reading performance compared to age. Spatial loading in this context is the demand on the vision system to process information about relative position and orientation of stimuli. Spatial load was deemed appropriate to test for several reasons: spatial awareness and visual attention have been shown to be important to saccadic eye movements[2-4] and during reading, attention has to be shifted from the phrase being fixated to the upcoming phrase or paragraph before the appropriate saccade can be made. Thus, we propose that the spatial demand of the task should be related to reading performance.

Also, people with dyslexia have been shown to perform worse than normal readers on tasks requiring fast, sequential processing of information.[5] Hence, processing speed, accuracy and task difficulty all relate to task performance.[6] When timed assessment procedures are carried out, a faster correct result implies mastery.[7,8]

The study's primary goal was to determine whether optometric testing could predict reading performance. Part of the study was a comparison between the commonly used Developmental Eye Movement test and the less commonly used SeeRite computerised test that assesses eye movement in more depth (see following test descriptions).

The purposes of the present paper are to provide readers with a synopsis of the original study's design and findings and to acquaint them with the computer based instrument.

METHODS

Subjects

Our experience and personal discussions with learning disability therapists suggest that most children have learned to read by 8 years old and that by 10 years old they should be reading with proficiency. Hence 8 and 10 year old children were used in this study. One hundred and twelve children were tested; 39 (34.8%) were male, 73 (65.2%) were female. Ages ranged from 7.8 to 11.3 years (mean 9.0 years). The unscreened group of students with no evident visual problems, as reported by school officials, came from three schools and a centre for learning disabled students. The schools were from a range of socio-economic regions across Sydney, Australia.

Visual Performance Tests

Two tests were performed: the Developmental Eye Movement test (DEM),[a] and components of the SeeRite Diagnostic Program (SRDP)[b]. Each subject was tested individually under ambient classroom lighting by the primary researcher. The tests were presented randomly, and all tests had a basis in rapid automatized naming (RAN). The spatial loading of each test is compared in Table 1.

Table 1 Summary of tests with respect to spatial loading				
TEST	**Sub-test**	**Test Description**	**Outcomes**	**Spatial Load**
Developmental Eye Movement Test (DEM)	Tests A and B	Rapid naming of numerals arranged in columns	Time taken (sec) reading 80 numerals in columns	Low
	Test C	Reading page of 80 numerals with errors factored in	Time taken (sec) reading 80 numerals in rows	High
	DEM Ratio	Calculation: C/A+B. For efficient readers the Ratio approaches 1		N/A
SeeRite Diagnostic Program (SeeRite)	RAN-numbers	Rapid naming of numerals presented singly	Minimum presentation speed for accuracy (sec)	Zero
	RAN-pdbq	Rapid naming of the high spatial load letters ‘p’, ‘d’, ‘b’, ‘q’. Letters are presented singly	Minimum presentation speed for accuracy (sec)	Zero: eye movement High: letter orientation
	Fixed Saccade	Predictive saccade: numerals presented alternately in 1 of 2 predetermined positions on screen. Presentation speed increased until too fast to be named.	Minimum presentation speed for accuracy (sec)	Low
	Random Saccade	4 to 6 numerals presented randomly along line. Presentation speed increased until too fast to be named.	Minimum presentation speed per numeral for accuracy (sec)	Low to Moderate
	Free Space (FS) Saccade	Reading page of numerals, only timing central 12 of 20 lines (60 numerals)*	Time (sec). “New Free Space” time adjusted for omissions/ re-reads etc	Very High
	Increase due to Free Space (IFS)	Calculation: New Free Space time minus equivalent Random saccade speed**		N/A

Table 1 Notes: **DEM C and FS tests are similar. The major difference is that reading of the first and last 4 lines of the FS is not timed, thereby raising the spatial demand*
***Increase due to FS = New FS – Equivalent Random,*
where New FS = time taken to read FS task, adjusted for errors, and
Equivalent Random = Random saccade time x 60
(Spatial loading as tabled is described in text with each test)

The DEM

Tests A & B of the DEM each contain two widely spaced vertical columns of twenty evenly placed numbers (total of 80 numbers). Because of the spacing, there is a relatively low level of spatial loading. Test C contains 80 randomly placed numbers in a horizontal display of 16 lines. This is a relatively greater level of spatial loading. The subject’s times to complete test A&B are recorded; the subject’s time to complete test C and number of errors are also recorded. The results are then compared to the test’s age norms. Thus, the DEM requires rapid automatic naming of a relatively low to a relatively higher level of spatial loading**.**

SeeRite© Diagnostic Program (SRDP)

We utilized the two subtests of the SRDP that are proposed to be a subtle test of the link between spatial awareness, speed and eye movements: Rapid Automatic Naming (RAN) and Free Space Eye Movements.

Five tasks, all presented on computer, were used with each one more spatially demanding than its precursor. The last task, the ‘Free Space’ test, most closely mimics reading as the subject is asked to ‘read’ a page of numbers set out in an array similar to that of words in a paragraph. The individual being tested is seated at approximately 50cm from the screen, and wears his habitual prescription. The tasks are:

1. ZERO SACCADE: RAN-numbers.
   This RAN task has no spatial load as there is a single numeral presented in the same position on the screen. The subject is asked to call out the numbers as fast as they can. The exposure time of the number is decreased in 0.1 Log steps until the subject cannot call the numbers accurately, that is when the presentation speed makes it impossible for the child to keep up. The same criteria to stop the test is used in the first four SeeRite tests.
2. ZERO SACCADE: RAN-pdbq.
   This RAN task is done using the lower case letters ‘p’, ‘d’, ‘b’, ‘q’. Again a single letter is presented in the same position on the screen and the subject calls out the letters as fast as possible. The exposure time of the letters is decreased until the subject cannot call them accurately. The letters used in this task are very spatially sensitive, so although the task of finding the letters has no spatial demand, that of identifying the letter has a relatively higher spatial load.
3. FIXED HORIZONTAL SACCADE
   Two numbers are serially presented on screen in one of two predetermined positions, separated horizontally by approximately 9 degrees. The subject is asked to call out the numbers as fast as they can. The rate of presentation is gradually increased until the subject is unable to call the numbers accurately. The result gives a measure of predic-

Table 2 Gender/Groups								
Gender / Groups	Below Average		Average		Above Average		Total	
	n	%	n	%	n	%	n	%
Females	7	41.2	21	65.6	45	71.4	73	65.2
Males	10	58.8	11	34.4	18	28.6	39	34.8
Total	17	100.0	32	100.0	63	100.0	112	100.0

tive saccade competence with a low spatial demand.

4. RANDOM HORIZONTAL SACCADE TASK IN DEFINED SPACE
   Sequences of 4, 5, or 6 numbers are serially presented along a fixed horizontal line in the center of the screen. They are presented in a left to right direction to simulate the reading eye movement pattern, but the spacing between the numbers is random. The first and last numbers in the line are presented in the same position on the screen each time, and are separated by approximately 16 degrees. The speed of presentation is gradually increased until the subject is unable to call the numbers out accurately. The time recorded is the first speed at which the numbers cannot be reliably called with accuracy. This task has a higher spatial load than the Fixed Saccade because although the subject has some idea of the position of the next number, the exact position or number of numerals along each line is variable.

5. FREE SPACE (FS) SACCADE
   The subject is timed reading a page of numbers from the computer screen. Five numbers are randomly spaced along each of twenty lines. This presents the greatest spatial demand of this series of tasks. The subject is only timed from the beginning of the fifth row of numbers to the end of the fifth row from the bottom of the page, 60 numerals in all. While this test is similar to the DEM-C, it represents a refinement of that test as performance is being measured where the spatial demand is highest. The timing starting and finishing points were specifically chosen following the repeated clinical observation that subjects reading the DEM array of numbers begin and end quickly and tend to slow down significantly and make errors in the middle section. We hypothesized that patients use the edge of the number array to help organize space thereby improving the speed and accuracy of the saccades. Whole lines or individual numbers that are skipped or re-read are noted, and calculated into the final score; this becomes the *New Free Space* score. For a full description of the calculations that the SRDP software produces is available in the original article.[1]

Reading Tests

Subjects had their reading comprehension age independently assessed by their schools using standardised tests: Neale Analysis of Reading Ability 3rd Edition 1999,[c] or ACER Progressive Achievement Tests in Reading 2nd Edition, or Woodcock Reading Mastery Tests – Revised 1998.[d] The subjects were ranked for the purpose of analysis into 'below average readers' (Stanine 1 to 3.65, N=17), 'average readers' (Stanine 3.66 to 5.45, N=32) and 'above average readers' (Stanine 5.46 to 9, N=63).

Synopsis of Results

SPSS v11[e] and STATA 7[f] were used for the statistical analysis.

We applied the Receiver-Operator Characteristic Curve (ROC) for the logistic regression. (See Appendix for a discussion of the ROC curve.) The results strongly indicate that:

1. Within the SeeRite protocol, the raw score for FS test is best as a test by itself for predicting below average readers (area under ROC 85.2), with the computed New FS very close (area under ROC 84.5). Test C of the DEM (area under ROC 82.8) is better than DEM Tests A+B (77.8).

2. The FS test and Ran pdbq together seem to better predict below average readers than FS test alone. These two tests together have an outstanding discriminatory power in predicting below average reading performance (area under ROC 93.5).

3. RAN pdbq (area under ROC 81.8) is significantly better at predicating below average readers than RAN numbers (area under ROC 67.8).

4. Spatial load alone predicts below average readers.

DISCUSSION

We had assumed from clinical experience that spatial awareness, i.e., the ability to maintain one's place when reading and make saccades in the appropriate direction of the appropriate length, should be coupled with the language component of reading if one is to be efficient.. This led to the coining of the term the Spatial-Load factor which was being tested by this study. We believe that the spatial load of text is in part responsible for the difficulty that some individuals have when reading. RAN procedures were included to ensure that automaticity of retrieval of the names of words or numerals was covered. The authors felt that this was necessary as speed of processing generally enhances function. The inclusion of the RAN pdbq test rather than only using RAN numbers loaded the spatial component of the testing further, as did the Free Space saccadic test. This decision was validated by the significant difference in predictive value of the two RAN tasks, the high spatial load letters being a much better predictor of reading age (RA) than numerals.

The FS subtest of the SRDP, the DEM C test, and to a slightly lesser extent the RAN pdbq, were significant in predicting below average readers. This reflects the combination of saccadic eye movements, spatial load and speed in the test design. (See Spatial Loading evaluation in Table 1.) These results were reflected in the area under the ROC curve which showed that the probability of these three tests discriminating between below average and average-above average readers was between 81.8-85.2%.

Nineteen percent of the sample had below average RA and this group scored significantly worse on the high-spatial load tasks. There was a clear distinction: if the subject could perform the more highly spatially loaded tasks well, their RA was at least average if not above.

As can be seen from Table 2 the study sample had approximately twice as many females as males. The males were more highly represented in the below average reader group (58%) and males made up 34% and 29% of the average and above average readers respectively. It is important to note that although three different reading tests were used due to students coming from four different schools, each of the tests was represented across the three reading performance groups. 29% of all subjects were tested on the Neale Analysis of Reading Ability, 24% on the Woodcock Reading Mastery Test, and 47% on the ACER Progressive Achievement Tests in Reading. Of the subjects who performed in the below average category, 43% had been tested on the Neale, 28.5% on the Woodcock, and 28.5% on the ACER. The distribution of below average readers over all tests was not significant (p>0.10) using the Chi^2 test.

An intriguing finding is that on all subtests the results for the average and above average RA groups was very similar, and significantly different from the below average group. The difference between the below average and the combined average and above average was greatest on the highly spatially loaded tests. This is either a reflection of the individuals studied and the small sample, *or an indication that once a child is spatially competent, their reading performance will outstrip a child with poor spatial competence, even if they are only considered average.* Note that the RA determined in this study was a comprehension age, not simply a word recognition test.

A limitation of the study was the small sample size, particularly of below average readers. This was a result of difficulty in recruiting subjects. There is scope for further research with stricter inclusion criteria and matched groups, but this current work indicates that the full SRDP may prove even more accurate in prediction of RA than the small portion used here.

CONCLUSION

Reading requires the ability to fixate on the phrase being read, enabling processing of information, while maintaining spatial awareness of the position of the next phrase or line where visual attention is to be directed**.** The subsequent saccadic eye movement has to be fast and accurate to ensure fluency. We postulated that there is a relationship between reading performance and the degree of spatial difficulty of a given task.

Clinical optometric testing of saccadic eye movements with spatially loaded naming tasks performed at speed, has uncovered a Spatial Load Factor which differentiates children at risk with reading. Timed tests of high spatial load tasks gave good evidence that spatial factors alone predict poor reading ability. The SRDP proved to be the most sensitive correlate of children's reading age, with the DEM very close behind.

It is suggested that helping to remediate poor spatial skills may have a direct effect on reading skills.

The authors have no financial or other interest in the tests utilized in this study.

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Appendix

The discriminatory ability of the developed model was reported using the Receiver-Operator-Characteristic curve (ROC curve) and its appropriate classification table. The ROC curve is a plot of the sensitivity and 1-specificity of the model at various probability values (0 to 1). The area under this curve gives the probability of determining the correct reading age group for any given case-control pair using the developed model. For what is considered to be an acceptable discrimination, the area under the ROC curve will be between 0.7 and 0.8. For an excellent discrimination the area will be between 0.80 and 0.90. For an outstanding discrimination the area will be >0.90. The classification table is a summary of the analysis after categorizing the subjects based on the estimated probability values into the cases and control groups using the best possible cutoff value that maximizes the correctly classified rates. The indices from the classification table are useful instruments in describing the discriminatory ability of the model.

Further information about the ROC curve can be obtained at: http://gim.unmc.edu/dxtests/ROC1.htm