Spatial load factor in prediction of reading performance

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Abstract

This study investigated whether there is a relationship between reading age and clinical optometric tests that have varying degrees of spatial loading in their design. Spatial loading in this context is the demand on the visual system to process information about the relative position and orientation of stimuli. A total of 112 children aged 8–11 years were assessed using saccadic eye movement and rapid naming tasks with varying spatial loads. All were subtests of Garzia's Developmental Eye Movement test and Liubinas' SeeRite Reading Diagnostic Programme. Variability in load was achieved by comparing rapid naming of numerals vs 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 Loading Factor which clearly differentiates children at risk with reading.

Keywords: learning disability, rapid naming, reading, reading age, saccades, spatial load

Introduction

This study was designed to determine whether increasing spatial load within timed clinical optometric tests made the tests more predictive of reading performance compared with age. Spatial loading in this context is the demand on the visual system to process information about relative position and orientation of stimuli. Spatial load was deemed interesting to test because spatial awareness and visual attention have been shown to be important to saccadic eye movements (Bullmore *et al.*, 1996; Clark, 1999; Michael *et al.*, 2001) and when reading, attention has to be shifted from the phrase being fixated to the upcoming phrase before the appropriate saccade can be made, hence the spatial demand of the task should correlate to reading performance.

The concept is supported by the common thread tying together visual attention, perceptual span, spatial processing, saccadic eye movements and reading on both neurological and performance levels (McConkie and Rayner, 1975; McConkie and Rayner, 1976; Rayner *et al.*, 1980; Pollatsek *et al.*, 1981; Underwood and McConkie, 1985; Rayner, 1986; Findlay and Kapoula, 1992; Fischer and Biscaldi, 1999).

Electrophysiological studies show a strong link between the many regions of the brain that process space and direct eye movements with those that process language, demonstrating the complexity of the neural processes involved in the act of reading and comprehension (Stowe *et al.*, 1998; Di Salle *et al.*, 1999; Helenius *et al.*, 1999; Handy and Mangun, 2000). Functional Magnetic Resonance Imaging studies show links between the cortical sites used in eye movement control, visuo-spatial attention, and language in humans (Chelazzi *et al.*, 1995; Just *et al.*, 1996; Berman *et al.*, 1999; Carpenter *et al.*, 1999; Keller *et al.*, 2001). The parietal region has been shown to be associated with visual attention shifts accompanied by saccadic eye movements (Heide and Kompf, 1998; Berman *et al.*, 1999; Coslett, 1999). Vidyasagar (1999) has proposed that during reading, an attentional spotlight, such as the one believed to be used in serial search, is used during each fixation. He claims that when learning to read, shifting of attention has to be trained to result in a spatially sequential rather than random search.

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People with dyslexia have been shown to perform worse than normal readers on tasks requiring fast, sequential processing of information (Hari *et al*., 1999). Hence, processing speed, accuracy and task difficulty all relate to task performance (Eden *et al*., 1995). When timed assessment procedures are carried out, a faster correct result implies mastery (Johnson, 1992; Binder, 1996). The inclusion of timed tests in the study addresses this factor.

The integration of visual, auditory, and motor information all affect the ease with which people learn to read. Stein and Walsh (1997) state: 'The evidence is consistent with an increasingly sophisticated account of dyslexia that does not single out either phonological, or visual, or motor deficits. Rather, temporal processing in all three systems seems to be impaired. Dyslexics may be unable to process fast incoming sensory information adequately in any domain'.

The primate vision system has been shown to have two distinct pathways: the magnocellular and parvocellular pathways. The M-cells are responsible for transmitting achromatic information of low spatial frequency, high temporal frequency, and high motion sensitivity. P-cells are responsive to colour, high spatial frequencies and low temporal frequencies.

Anatomically, the M pathway includes the retinal ganglion cells that project to the M layers of the LGN of the thalamus, the M-layer LGN cells that project to primary visual cortex, level 4B of VI and the thick stripes of V2, and the VI cells that project to the extrastriate area MT and adjacent motion sensitive area MT+ (Ross *et al*., 1996; Demb *et al*., 1998). The M pathway then proceeds to the posterior parietal cortex. Subcortically, there exists a clear anatomical segregation between the outputs from M and P retinal ganglion cells (Cornelissen *et al*., 1998). Steinman and Steinman (1998) have demonstrated that the M pathway provides a more robust input into visual attention than does the P pathway, although there is some cross-talk between the two streams beyond the LGN (Burr *et al*., 1994). Using flicker matching (M processing) and brightness matching (P processing) techniques, Floyd *et al*. (2004), were able to show that poor and normal readers could be differentiated on the basis of M-cell vs P-cell functioning.

The most direct evidence of the implication of the visual M-cell pathway in reading disability and dyslexia comes from anatomical and visually evoked potential studies carried out by Livingstone *et al*. (1991). Their histological studies of dyslexic brains showed disorganization, variability and significant shrinkage of cells in the subcortical M-cell layers of the LGN, but not in the P-cell layers. Stein (2001) claims that the M system is responsible for timing events when reading, signalling to eye movement control centres if the image slips off the fovea and resulting in high motion sensitivity when functioning normally. Vidyasagar (2004) suggests that focussing visual attention is reliant on having intact M-cell input which provides information on the location of objects that is necessary for the parietal cortex to make its dynamic spatial map.

In summary, research from a wide range of clinical and academic sources is convergent in its findings that reading is a complex outcome from multi-sensory input which is mediated by complex brain networks. Eye movements, spatial processing, attention, and speed of processing have been shown to be relevant to efficient reading. This suggested the hypothesis that performance on tests which combined these skills could correlate to reading competence.

This study compared the results of the widely used Developmental Eye Movement (DEM) test with those of subtests of the new SeeRite Reading Diagnostic Programme, a computer based test which tests rapid naming and saccadic speed with varying spatial load. Rapid automatised naming (RAN) procedures were included as it is the automaticity of retrieval of the names of words or numerals rather than knowledge of names that has been shown to be predictive of reading ability (Peachey, 1991; Meyer *et al*., 1998).

Methods

Subjects

Experience and personal discussions with Learning Disability therapists suggest that most children have learnt to read by 8 years old and that by 10 years old they should be reading with proficiency (Streff, 1998). Hence this study tested the hypothesis on 8 and 10 year old children: 112 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 came from three schools and a centre for learning disabled students. The schools were from a range of socio-economic regions across Sydney. The project was approved by the Human Research Ethics Committee of the University of NSW (HREC no. 00096). A Consent Form approved by the Committee was filled out for each subject by their parent/guardian.

Visual performance tests

Two tests were performed: the DEM test, and the SeeRite Diagnostic Programme (SRDP). Each subject was tested individually under ambient classroom lighting. The tests were presented randomly.

Developmental Eye Movement test (Garzia et al.*, 1990).* The DEM is a test of saccadic eye movement efficiency. The tests are printed on A4 size cards which the subjects hold as they would a book.

The first part of the DEM requires the subject to read aloud four columns of numerals as fast as possible. Two columns, each with 20 numerals are presented on test A, and two similar columns on test B. The time for reading all 80 numerals is recorded. This is a RAN task of low spatial demand: the columns are widely separated on each sheet and the subject has to move their eyes down the columns rather than in a horizontal saccade.

Test C is more spatially demanding as the 80 numerals are presented on a single page in a horizontal array of 16 lines. The spacing between the five numbers in each line is random. The subjects are instructed to read aloud the numbers along the lines 'just like reading a book'. Note is taken if whole lines or individual numbers are skipped or re-read. Allowance for this is calculated into the final score.

The DEM Ratio is calculated by dividing the time taken to read the horizontally arrayed numbers by the time taken to read the vertically aligned numbers. With increasing proficiency this ratio approaches 1. That is, it is expected that a more proficient reader will not be markedly slowed down by the increased spatial demand of Test C.

DEM ratio = time taken to read the horizontally arrayed numbers (test result C)/time taken to read the vertically aligned numbers (test result A + B)

For more detail on the theoretical basis and application of this test, the reader is referred to standard texts such as Griffin *et al.* (2002) and Rouse (1994).

SeeRite© Diagnostic Programme (Liubinas, 2000). This study utilised the two subtests of the SRDP that are proposed to be a subtle test of the link between spatial awareness, speed and eye movement: rapid naming and free space eye movements. RAN tasks are used as a means to assess the impact of varying spatial loads on what superficially seems to be an assessment of saccadic eye movements.

Five tasks, all presented on computer, were used with each one more spatially difficult 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. In all five tasks the numerals to be read are the same size. 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.

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. 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 four 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 high spatial load.

3 Fixed horizontal saccade task

Numbers are presented on screen in one of two predetermined positions, separated horizontally by approximately 9°. The subject is asked to call out the numbers as fast as they can. The numbers are initially presented at the RAN-numbers speed determined previously. The rate of presentation is again gradually increased until the subject is unable to call the numbers accurately.

This task involves a slightly higher spatial load than the initial RAN-numbers as it forces the subject to change fixation from a target that appears in a known position to another, also in a known position. The result gives a measure of predictive saccade competence with a low spatial demand.

4 Random horizontal saccade task in defined space

Sequences of four, five, or six numbers appear along a fixed horizontal line in the centre 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°. The subject is asked to call out the numbers as fast as possible. As with the Fixed Saccade task, the numbers are initially presented at the RAN-numbers speed. 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. The score records the exposure time of a single number.

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 SeeRite© 'Free space' saccade

The subject is timed reading a page of numbers from the computer screen. Five numbers are randomly spaced along each of 20 lines. This presents the greatest spatial demand of this series of tasks, as the subject has to maintain accurate eye position on the numerals being read whilst maintaining place on the page. That is, the subject has to organise space within the array of numbers to allow accurate saccades. 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. It was proposed that patients use the edge of the number array to help organise space thereby improving the speed and accuracy of the saccades. Whole lines or individual numbers that are skipped or re-read are taken note of and calculated into the final score, the New Free Space score.

The SeeRite© software calculates two results that provide a gauge of performance beyond the raw score of time taken for the various tasks. The first is the Equivalent Random score. It takes the result of the Random Horizontal Saccade test and multiplies it by 60. This gives the time it would take to call out 60 numbers, the number in the Free Space (FS) task. The second calculation is the Increase Due to Free Space time, which is the difference between the New Free Space time and the Equivalent Random time. The result is a reflection of the difficulty of maintaining function under a higher spatial demand.

$$\text{Increase due to FS} = \text{New FS} - \text{equivalent random},$$

where

$$\text{New FS} = \text{time taken to read FS task, adjusted for errors}$$

$$\text{Equivalent Random} = \text{Random Saccade time} \times 60$$

For example, a subject takes 59 s to read the middle 60 numerals of the FS test and makes no errors, so the New FS time remains at 59 s. The random saccade result is 0.43 s presentation speed. The equivalent random score is $0.43 \times 60 = 25.8$ s. Hence the increase due to FS is 59–25.8 = 33.2 s. That is, it takes 33.2 s longer to read the 60 numerals in a paragraph array than would be predicted by simple calculation.

See *Table 1* for a description of the tests, the outcomes, and their relative spatial loads.

Reading ages

Subjects had their reading comprehension age independently assessed by their schools using standardised

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 (s) reading 80 numerals in columns	Low
	Test C	Reading page of 80 numerals	Time taken (s) reading 80 numerals in rows	High
	DEM ratio	Calculation: C/A + B. For efficient readers the Ratio approaches 1		N/A
SeeRite Diagnostic Programme (SeeRite)	RAN-numbers	Rapid naming of numerals presented singly	Minimum presentation speed for accuracy (s)	Zero
	RAN-pdbq	Rapid naming of the high spatial load letters 'p', 'd', 'b', 'q'. Letters are presented singly	Minimum presentation speed for accuracy (s)	Zero: eye movement High: letter orientation
	Fixed saccade	Predictive saccade: numerals presented alternately in one of two predetermined positions on screen. Presentation speed increased until too fast to be named	Minimum presentation speed for accuracy (s)	Low
	Random saccade	Four to six numerals presented randomly along line. Presentation speed increased until too fast to be named	Minimum presentation speed per numeral for accuracy (s)	Low to moderate
	Free space (FS) saccade	Reading page of numerals, only timing central 12 of 20 lines (60 numerals)*	Time (s). '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

*DEM-C and FS tests are similar. The major difference is that reading of the first and last four lines of the FS is not timed, thereby raising the spatial demand.

Table 2. Stanine ranks for reading age (RA)

RA Stanine groups	n (%)	Mean (S.D.)	Minimum	Maximum
RA Stanine ranks				
Below average	17 (15.2)	2.7 (0.7)	1.6	3.6
Average	32 (28.6)	4.6 (0.5)	3.7	5.4
Above average	63 (56.3)	7.2 (0.9)	5.5	8.5
Total	112 (100.0)	5.8 (1.9)	1.6	8.5

tests: *Neale Analysis of Reading Ability*, 3rd Edition 1999 (ACER Press, Camberwell, Victoria, Australia), or *ACER Progressive Achievement Tests in Reading*, 2nd Edition, or *Woodcock Reading Mastery Tests*, revised 1998 (American Guidance Service Inc., Circle Pines, MN, USA). The subjects were ranked for the purpose of analysis into 'below average readers' (Stanine 1–3.65, $n = 17$), 'average readers' (Stanine 3.66–5.45, $n = 32$) and 'above average readers' (Stanine 5.46–9, $n = 63$). *Table 2* shows the rankings used. *Figure 1* shows the comparison of percentile ranks and stanines with standard deviations and areas under the normal curve.

Statistics

For the purpose of data analysis the stanine reading age (RA) ranks were grouped as described above. The data analyses were performed to obtain the factors predictive of below average RAs. Univariable analyses using ANOVA preceded multivariable analyses. Multiple comparisons were performed using Tukey's adjustment. Each variable's contribution in predicting below average RA was assessed using the log likelihood statistics and area under the receiver operating characteristic (ROC) curve from univariable logistic regression. Multivariable models for the SeeRite and DEM tests were developed using variables within each respective test. The stepwise backward followed by forward method was used for model building, with the significance of the log likelihood ratio statistic as the criteria. Goodness of fit of the developed model was assessed using the Hosmer–Lemeshow test. Area under the ROC curve determined the discriminatory ability of the model. Factors identified from the model were considered significant at $p \leq 0.05$. SPSS v11 and STATA 7 were used for the statistical analysis.

Results

ANOVA results showed that each test was highly significant in discriminating between below average/average/above average RA to the level of $p < 0.004$ (*Table 3*). This result did not discriminate between the tests so further investigation was done using multivariate analysis.

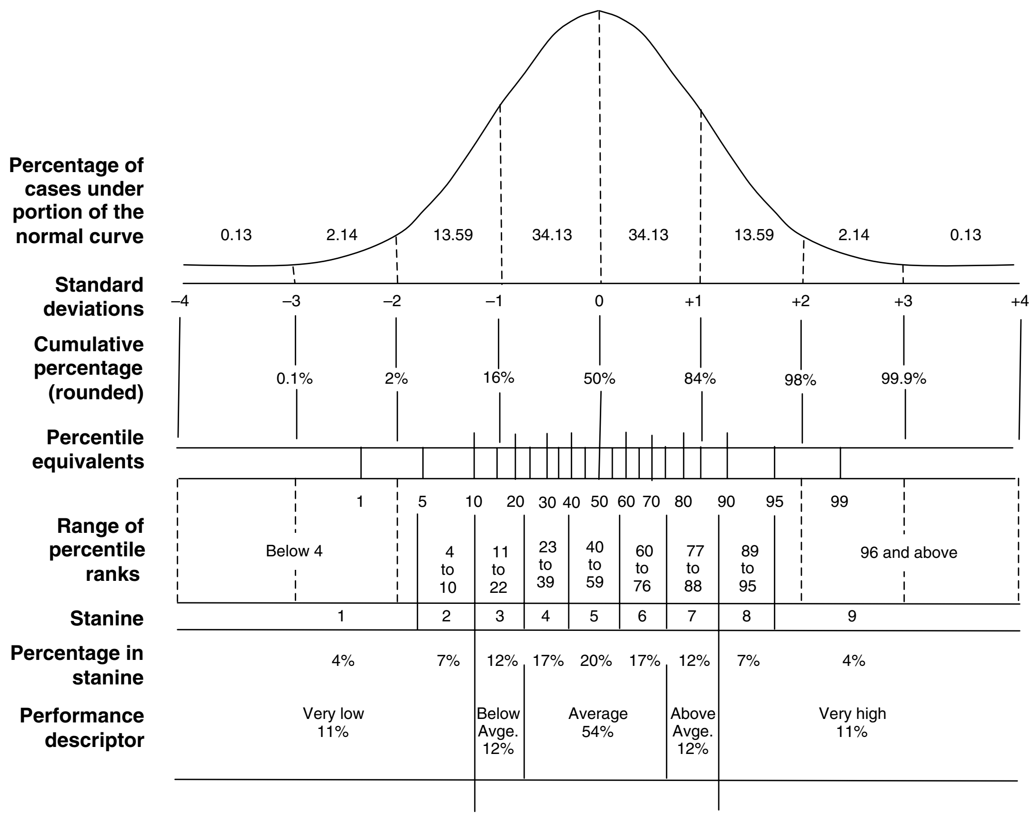

Figure 1. Comparison of percentile ranks and stanines with standard deviations and areas under the normal curve.

Table 3. Univariate analysis of variance comparing Stanine groups

					Multiple comparisons (Tukey)		
Variables	**Stanine groups**	***n***	**Mean (S.D.)**	**ANOVA**	**Below average**	**Average**	**Above average**
RAN numbers	Below average	17	0.43 (0.11)	0.001		0.001	0.007
	Average	32	0.36 (0.05)		0.001		0.421
	Above average	63	0.38 (0.05)		0.007	0.421	
RAN pdbq	Below average	17	1.12 (0.70)	<0.001		<0.001	<0.001
	Average	32	0.60 (0.11)		<0.001		0.869
	Above average	63	0.63 (0.12)		<0.001	0.869	
Fixed	Below average	17	0.51 (0.12)	<0.001		<0.001	<0.001
	Average	32	0.40 (0.06)		<0.001		0.995
	Above average	63	0.40 (0.06)		<0.001	0.995	
Random	Below average	17	0.54 (0.13)	<0.001		<0.001	<0.001
	Average	32	0.42 (0.08)		<0.001		0.919
	Above average	63	0.43 (0.07)		<0.001	0.919	
FS	Below average	17	89.76 (31.02)	<0.001		<0.001	<0.001
	Average	32	58.04 (22.51)		<0.001		0.698
	Above average	62	54.50 (14.17)		<0.001	0.698	
New FS	Below average	17	90.18 (31.01)	<0.001		<0.001	<0.001
	Average	32	59.13 (23.40)		<0.001		0.641
	Above average	62	55.12 (14.60)		<0.001	0.641	
Equivalent Rand	Below average	17	32.51 (7.96)	<0.001		<0.001	<0.001
	Average	32	25.33 (4.75)		<0.001		0.976
	Above average	63	25.57 (4.49)		<0.001	0.976	
Increase due to FS	Below average	17	57.67 (28.90)	<0.001		<0.001	<0.001
	Average	32	33.87 (21.20)		<0.001		0.546
	Above average	62	29.62 (12.71)		<0.001	0.546	
DEM A + B	Below average	17	58.47 (16.47)	<0.001		<0.001	<0.001
	Average	31	42.26 (9.47)		<0.001		0.881
	Above average	63	43.41 (9.77)		<0.001	0.881	
DEM-C	Below average	17	80.24 (25.64)	<0.001		<0.001	<0.001
	Average	31	53.94 (14.91)		<0.001		0.880
	Above average	63	52.24 (13.17)		<0.001	0.880	

From the Univariate Analysis it is very clear that there is no difference between average and above average readers' results on the tests used. Age was tested for significance in the logistic regression. It was not significant. Hence for multivariate analysis the average and above average readers were combined together to determine factors predicting below average readers, and all ages were combined (*Table 4*).

From the logistic regression it is clear that:

(1) Within the SeeRite protocol, the raw score FS 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) FS and RAN pdbq together seem to better predict below average readers than FS alone.

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

(4) Spatial load alone predicts below average readers.

Discussion

The authors and Liubinas had assumed from clinical experience that spatial awareness, in this context the ability to maintain place when reading and make saccades in the appropriate direction of the appropriate length, is coupled with the language component of reading, the decoding of symbols into sounds and hence words. This led them to the coining of the term the Spatial–Load factor which was being tested by this study. 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 FS 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 RA than numerals. Tests A and B of the DEM are also a

Table 4. Logistic regression predicting below average RA compared with average and above average RA

Variables	Univariable analysis			Multivariable analysis									
	Log likelihood	Overall *p*-value	ROC	Beta	S.E.	*p*-Value	Log likelihood	Overall *p*-value	ROC	Goodness of fit *p*-value	Sensitivity	Specificity	Correctly classified rate
SeeRite Diagnostic Programme													
RAN nos	−42.73	0.002	67.8				−26	<0.001	91.1	0.623	76.5	84	82.9
RAN pdbq	−32.82	<0.001	81.8	5.34	2.42	0.027							
Fixed	−35.91	<0.001	78.5										
Random	−37.07	<0.001	76.5										
FS	−33.91	<0.001	85.2	0.06	0.02	0.001							
New FS	−34.71	<0.001	84.5										
Equivalent rand	−37.12	<0.001	76.6										
Increase due to FS	−37.57	<0.001	81										
Developmental Eye Movement Test													
DEM A + B	−37.14	<0.001	77.8				−33.78	<0.001	82.8	0.636	70.6	76.6	75.7
DEM-C	−33.78	<0.001	82.8	0.08	0.02	<0.001							
DEM ratio	−46.75	0.215	56										

RAN task. As all the numbers are printed on the page and therefore available to the visual field, there is a low level of spatial awareness in the DEM task. This made it a better predictor of RA (ROC 77.8) than the singly presented RAN numbers (ROC 67.8), but neither were as predictive as RAN pdbq (ROC 81.8).

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 and 85.2%.

The RAN pdbq is designed to find the speed at which the subject can confidently name highly spatially loaded letters. Developmentally, reversals are normal in Kindergarten and grade 1, but reversals seen in children over 7 years old are indicative of the need for intervention. Due to this developmental trend, it seemed likely that the RAN pdbq test would be significant in the target age groups, and it was.

Of the sample, 19% had below average RA and this is approximately the proportion found in the general population. Even so, 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.

The results of the FS test and the DEM-C were similar, although the FS performed slightly better. This is not surprising as both tests are very similar: the result being the time taken to read a 'paragraph' of 60 and 80 numerals respectively. The FS is more challenging as the numerals being timed are the central 12 lines of the 20 lines being read, whereas in the DEM-C all 16 lines are timed, tending to allow faster times at the start and finish for those reliant on the edges of the paragraph for orientation.

FS or DEM-C plus RAN pdbq might be better in predicting poor readers than either alone, but future studies are needed to prove this.

The SRDP uses a number of calculations in its programme: new FS, equivalent random, IFS. From the results of this study, it would appear that the new FS may be the only necessary one. As with the DEM-C, allowance has to be made for lines and/or letters skipped or re-read. This gives the new FS result which is appropriate to use rather than, say, a time which may seem fast, but is not so when allowance has been made for skipping three lines. In the logistic regression it can be seen that the new FS is very similar to the raw FS score for prediction of below average readers. The increase due to FS result appears to be less significant but still has >80% area under ROC.

Table 5. Gender/groups

Gender/ groups	Below average	Average	Above average	Total
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)

Values are given as *n* (%).

With respect to the practicalities of using the two tests clinically, the DEM is simpler, as the child is handed the test pages whilst seated in the consulting room chair and timed reading the various sub-tests. This could be seen as performing using a more normal reading posture, although use of computers is obviously on the rise. The FS is a part of the SRDP which is a computerised test, so the child has to move to the computer, or vice versa. The SRDP could be done by an Optometric Assistant as the programme records the results automatically. The benefit in using the SRDP is that it includes a broad diagnostic battery of tests (of which only a small number were used in this study) that probe other visual skills related to reading, for example: accuracy of capture of visual information, speed of capture, and visual–auditory matching. So, given time, using the SeeRite protocol provides more information on visual information processing style and function.

As can be seen from *Table 5* the study population 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. A total of 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-squared test.

An intriguing finding is that on every subtest 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 (*Table 3*). 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. Comprehension generally involves the ability to visualise, a skill requiring spatial abilities.

One difficulty with this 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.

An implication from this study is that helping to remediate poor spatial skills may have a direct effect on reading skill. Clinically this is seen when therapy is designed around activities such as body awareness, motor planning, space and height matching and peripheral awareness. These activities are used to develop a sense of how individuals relate to their own spatial world. Activities using parquetry blocks help develop visualization and spatial awareness, particularly when imagining shapes flipped or rotated. Tracking and saccadic eye movement therapy helps to fine tune the visual attention and spatial awareness needed for the accurate efficient eye movements needed during, for example, reading.

Conclusion

Reading requires the ability to fixate on the phrase being read, enabling processing of information, whilst maintaining spatial awareness of the position of the next phrase or line to direct the eyes to. The subsequent saccadic eye movement has to be fast and accurate to ensure fluency. It was postulated that there should be a correlation 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 clearly showed that spatial factors alone predict poor reading ability. The SRDP proved to be the most sensitive correlate of children's RA, with the DEM test very close behind.

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

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