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Children with Low Literacy and Poor Stereoacuity: An Evaluation of Complex Interventions in a Community-Based Randomized Trial

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ABSTRACT

Purpose: **To assess, among children with low literacy and poor stereoacuity, the efficacy of two intervention programs on child vision and education compared to a control program.** ***Methods:*** **Eighty-eight children aged 8 to 13 years who had reading problems, and demonstrated poor stereoacuity as measured by the Titmus stereocircle test (>100 seconds arc) or computerized assessment were randomized to one of two intervention programs: Lawson vision or Phono-Graphix, or a control group: Parental Literacy Support. Vision (Lang test, visual acuity, convergence insufficiency symptom survey) and education assessments (Woodcock Reading Mastery Tests–Revised) were conducted at baseline, intervention end (10 weeks), and 36 weeks. Analysis used intention to treat multi-level models.** ***Results:*** **Compared to the parental literacy support group, convergence insufficiency symptoms were reduced 36 weeks post-randomization amongst those receiving the Lawson orthoptic intervention (mean difference −5.55; 95% confidence interval (CI): −11.1 to −0.05, P < 0.05). Stereoacuity, measured by the Lang test, improved for both the Lawson and Phono-Graphix interventions compared to the parental literacy support group (−1.01; 95% CI: −1.6 to −0.4, P = 0.001, and −0.77; 95% CI: −1.4 to −0.2, P = 0.01). At the 36 week follow-up assessment, word identification had also improved for the Lawson and Phono-Graphix groups but other educational outcomes did not improve.** ***Conclusion:*** **A formal randomized control trial was feasible in this setting. Intervention among children with poor stereoacuity and low literacy produced small improvements in stereopsis and convergence insufficiency symptom scores. Further randomized control trials should be conducted to clarify the role of orthoptic intervention on literacy in selected child populations.**

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INTRODUCTION

Low literacy has long-term adverse consequences.[1,2] Some children with low literacy have adequate intelligence, visual acuity and opportunity to learn, yet experience reading difficulties. This is known as developmental dyslexia.[3] The causes of dyslexia are still controversial. The phonological theory of dyslexia argues that most children with dyslexia have problems with phonological processing,[4] leading to a range of programs aimed at teaching children to connect sounds with letters or groups of letters.[5]

However, reading disability, including dyslexia, is becoming increasingly recognized to be a spectrum of heterogeneous conditions. In particular, one other factor that may contribute to reading disability is poor binocular vision.[6] Both scanning text and depth perception require good binocular visual coordination.[7–9] Studies of dyslexic children have found deficits in binocular vision.[10] In particular, poor stereoacuity—problems with assessing depth from disparate binocular images—has been identified as a marker for reading difficulties in kindergarten and first grade children of average intelligence.[11,12] Visual convergence insufficiency—the inability to initiate and sustain convergence—leads to symptoms such as blurred or moving visual images during reading. These symptoms have been found to be highly predictive for convergence insufficiency.[13] Vision therapy aimed at improving visual skills has been proposed for the treatment of poor stereoacuity,[14–16] although the efficacy of such therapies remains controversial.[17] Orthoptic exercises are commonly prescribed as a treatment for convergence insufficiency[18] or reading difficulties. Although few would argue that vision problems can interfere with reading and learning, what is not apparent is the extent to which visual problems represent an underlying cause of reading disability. In 2009, a critical evaluation of the evidence supporting the practice of behaviour vision therapy concluded that vision therapy cannot be considered as an evidence based treatment for reading or learning disorders because RCTs investigating the benefits of vision therapy in reading/learning are lacking.[19]

We focussed on children with poor stereopsis among those with low literacy because stereopsis is highly feasible to screen in the school setting. This allowed the selection of a more homogeneous subgroup of poor readers than is often utilized for population-based studies of low literacy.

We aimed to test the hypothesis that, for children with low literacy and poor stereoacuity, an orthoptic program improves both stereoacuity and convergence insufficiency symptoms, thus impacting positively on reading ability and other educational outcomes.

METHODS

Recruitment and trial sample

Subjects were recruited for the trial by two methods (Fig. 1). The first method was school-based. During June 2005–October 2006, children attending participating schools (84 of the 85 schools approached) in the Greater Hobart area who were below the 10th percentile for literacy, based on the national literacy benchmark standards for Grade three,[20] were invited to attend a school screening. The second recruitment method was community advertising for children with reading difficulty. Stereoacuity was assessed using both the Titmus stereocircles test[21] and computerized tests (*CityVision Screener for Schools*[22]). Eligibility for the trial was based on a stereoacuity of worse than 100 seconds of arc by the Titmus stereocircles test, or failure of the stereoacuity component in the computerized assessment (123 seconds of arc). Previously, mean stereoacuity for 6–12 year old children in a large sample was 25 (SD 10) seconds of arc.[23] Children were excluded if their screening results were not technically satisfactory, or the child had epilepsy or cerebral palsy.

Randomization and masking procedures

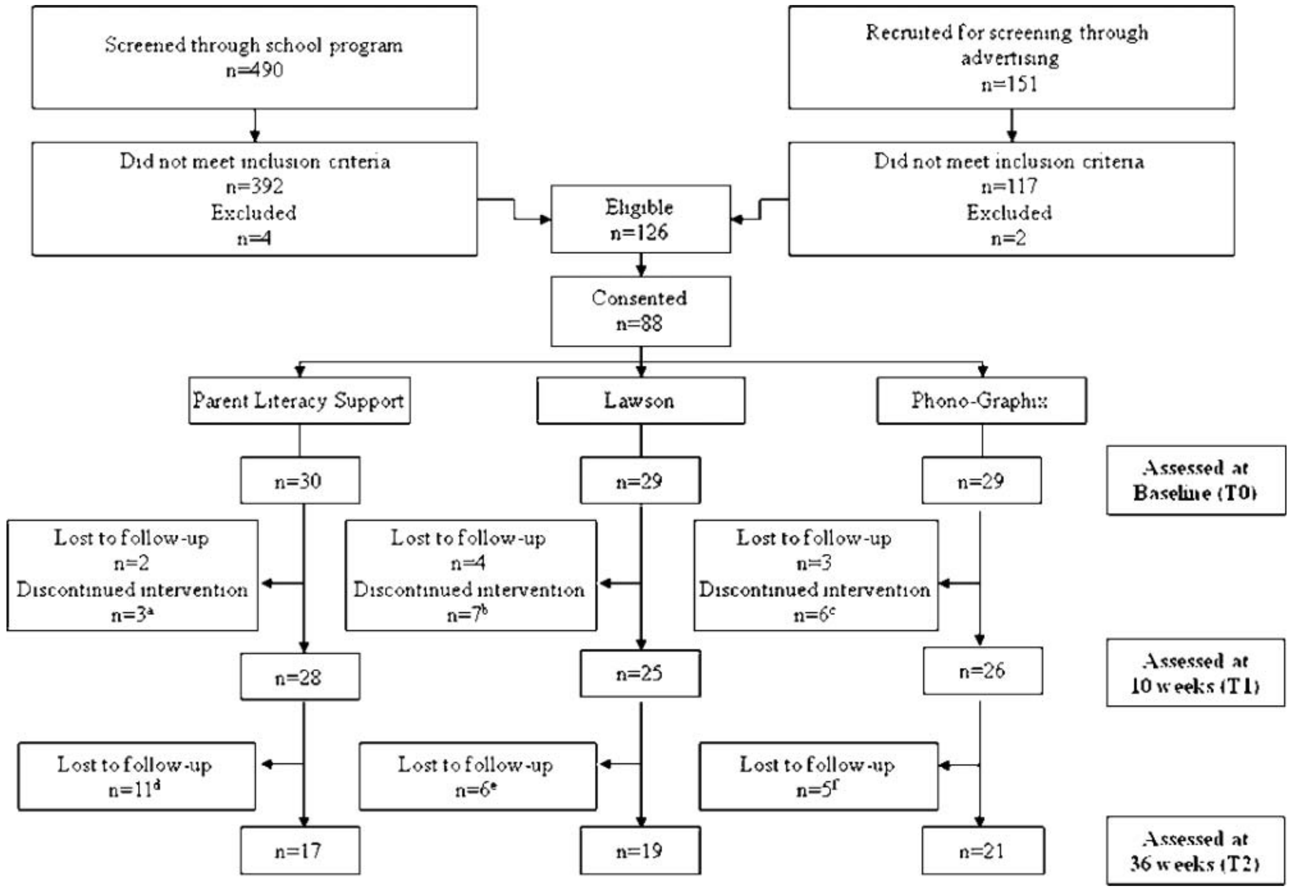
Block randomization used size 20 blocks derived by computerized random number generating functions by an independent statistician. Sequentially numbered envelopes were used by a staff member to assign the children to an intervention. All assessors and the statistical analyst were masked. The interventions began in June 2006 and follow-up was completed by July 2007.

The trial was performed according to the guidelines of the Declaration of Helsinki. Ethics approval for the trial was obtained from both the Human Research Ethics Committee of the University of Tasmania and the Departmental Consultation Research Committee. The trial was registered with the Australian Clinical Trial Network in 2006 (ACTRN012606000245594). Parents/guardians of the eligible children were contacted by phone and the trial was explained to them in detail. On arrival at the pre-assessments parents/guardians were also given an information sheet detailing what the trial involved and written consent was given before the assessments began.

Trial programs

Each child was randomized to receive one of three programs—the Lawson orthoptic program, an adapted Phono-Graphix program, or the control parental literacy support program. Each program required 1 hour of homework to be completed every night, and all programs involved some remedial reading and spelling exercises. The programs are described in detail below.

Children allocated to the Lawson program received 10 one-hour sessions one-on-one with a trained project officer at weekly intervals. The sessions were based around the use of the Lawson Anti-Suppression Device (LASD),[15] a screen with a light source that has rotating gratings. During the 10 sessions, the child completed transparencies covering sequences, basic sounds, left to right orientation, spelling and visual memory. As the sessions progressed, the gratings became finer. Filters, patches and lenses were used as follows. In session one, a black patch was worn on the dominant eye and a red filter on the non-dominant eye. In sessions two, three and four a red filter was used on the dominant eye and no patch on the non-dominant eye. In sessions five and six a red filter was used for the dominant eye and lenses + or −1 or 2 diopters (D) were used on both eyes. In session seven and eight, only lenses + or −3 D were worn on both eyes. Children were otherwise permitted to wear previously prescribed glasses. Homework of orthoptic exercises included watching black and white television wearing an eye patch, fixation and tracking exercises and pencil push-ups. Remedial reading and spelling was also recommended. The written homework was checked at the start of each session and compliance with the orthoptic exercises was self reported. This program has previously been associated with improved stereoacuity and reading skills in a before-after intervention study.[15]



Note 1 Reasons for loss [a]house burnt down (1), parent diagnosed with cancer (1), child did not want to continue (1). [b]moved away (2), child illness (3), wanted a different intervention (1), child did not want to continue (1). [c]mother ill (1), child did not want to continue (4), family issues (1). [d]did not want to be assessed (8), lost to follow-up (3). [e]did not want to be assessed (2), lost to follow-up (4). [f] did not want to be assessed (4), lost to follow-up (1).

Note 2 Allocation was to either Parent Literacy Support, Lawson Phono-Graphix. Follow-up occurred 10 weeks and 36 weeks post intervention and analysis incorporated both 10 week and 36 week outcomes.

Figure 1. Flowchart of participants through the trial.

Children allocated to the Phono-Graphix program received 10 one-hour sessions one-on-one with a trained project officer at weekly intervals. Children were taught how to blend sound pictures together for reading and to separate them for spelling using phonetic sectioning and training and color phrase cards as described in http://www.readamerica.net/. The program has previously been associated with improved brain activation and reading skills among a sample of eight children[24] and improved reading in two assessments.[25,26] The program involved one hour of homework per night, consisting of reading tasks and other phonetic work.

The control program consisted of a parental literacy support program developed in consultation with the Institute of Inclusive Learning, University of Tasmania. This program was partly based on the approach used in the Ease program[27] and a spelling program.[28] The parental literacy support program was designed to take approximately one hour per day but weekly sessions with a Project Officer did not occur.

Outcome measures

Children were individually assessed immediately prior to randomization (T_0), 10 weeks later on termination of the interventions (T_1), and 36 weeks post-randomization (T_2). Vision, visual processing skills, and educational outcomes were assessed at each time point and the child and parent(s) were asked to complete a questionnaire. The parent questionnaire asked about issues that could affect the child's performance such as if the child was currently ill or taking any medication, if there had been any major changes at home or at school in the previous two weeks, and how many hours of sleep the child had the night before testing. In addition, compliance with homework and session attendance was recorded. At the 10 week and 36 week follow-up assessments, parents were asked about their perceptions of the intervention their child was allocated to and whether they believed it had improved their child's ability and enthusiasm. At each follow-up assessment, the children were also asked about their perceptions of the intervention.

Table 1. Baseline characteristics of randomized intervention groups

Characteristic n (%) or mean [SD]	Parental literacy support (n = 30)		Lawson (n = 29)		Phono-Graphix (n = 29)	
Male	16	(53.3%)	20	(69.0%)	16	(55.2%)
Age yrs – mean [SD]	11.5	[1.2]	11.0	[1.4]	10.8	[1.3]
IQ for age:*						
Intellectually impaired	9	(31.0%)	7	(24.1%)	11	(37.9%)
Definitely below average	8	(27.6%)	7	(24.1%)	3	(10.3%)
Below average	6	(20.7%)	6	(20.7%)	5	(17.2%)
Average	6	(20.7%)	8	(27.6%)	8	(27.6%)
Above average	0	(0.0%)	1	(3.4%)	1	(3.4%)
Definitely above average	0	(0.0%)	0	(0.0%)	1	(3.4%)
SES disadvantage index–mean (SD)	918.0	(86.9)	947.6	(94.5)	943.1	(93.4)

*intellectually impaired (≤5th percentiles for age); definitely below average in intellectual capacity (>5th to ≤10th percentiles for age); below average (>10th to ≤25th percentiles for age); average (>25th to <75th percentiles for age); above average (75th to <90th percentiles for age); and definitely above average in intellectual capacity (≥90th to <95th percentile for age).
SD = standard deviation; SES = socioeconomic status.

At T_0 the untimed version of the Raven Standard Progressive Matrices Test was used to assess child IQ.[29] Using age group specific population norms,[29] child IQ was categorized into six groups by percentiles for age outlined in Table 1. Postcode of residence was used to determine socioeconomic status using SEIFA (Socio-Economic Index For Australia) scores.[30]

Primary outcomes—vision

The total score from the convergence insufficiency symptom survey (CISS) was used to assess symptoms such as words moving or blurring on the page. Children who wore glasses for reading were asked to answer the questions thinking about when they wore their glasses. The 15 questions in the survey were read to the child who was asked to choose one of the following response options for each question: never (0); not very often (1); sometimes (2); fairly often (3) and always (4). The numerical score allocated to each response is indicated in parentheses above. Summing the 15 scores gives a total convergence insufficiency score ranging from 0 to 60, with higher scores indicating higher insufficiency.[13] This measure has been demonstrated to have good reliability, with an intraclass correlation of 0.8 and high sensitivity and specificity.[13]

Stereoacuity was assessed using the Titmus stereocircles and the Lang test,[21] with the child wearing their prescribed glasses during testing. The Titmus stereocircle test card was held at eye level 40 cm away from the child, who was wearing polarized glasses. Testing stopped once the child gave two consecutive incorrect answers on two consecutive thresholds. The stereocircle test results were used to place each child in one of nine graded categories (seconds of arc): 1 = better than 40, 2 = better than 60 not 40, 3 = better than 80 not 60, 4 = better than 100 not 80, 5 = better than 140 not 100, 6 = better than 200 not 140, 7 = better than 400 not 200, 8 = better than 800 not 400, 9 = worse than 800. The border for each category reflects that they passed the test at the score immediately below but not the next test. For example a child passing the 60 seconds of arc but not the 40 seconds of arc test is categorized into category two. The Lang I Stereocard contains three shapes: a cat (1200 seconds of arc), a star (600 seconds of arc) and a car (550 seconds of arc), The card was held at eye level 40 cm away from the child and the test was conducted using red/green glasses, to possibly further reduce displacement clue conditions. The Lang test results were graded into four categories (seconds of arc) 1 = better than 550, 2 = better than 600 but not 550, 3 = better than 1200 but not 600, 4 = worse than 1200. An incorrect response was cited as fail at that level. For both stereoacuity tests, higher categories represent worse stereoacuity.

Secondary outcomes—visual processing

Two tests were used to assess visual processing and eye movement: the Visual Attention Span (VAS) and the Developmental Eye Movement (DEM) test. A child's VAS is defined as the number of letters that a child can process and recall in one glance.[31] A computerized assessment of the VAS was used.[31,32] The number of correct answers was summed to provide a VAS overall score ranging from 0 to 50. A higher VAS score indicates better performance.

The Developmental Eye Movement (DEM) test assesses ocular motor function, adjusting for automaticity of reading performance.[33] The ratio of the adjusted horizontal time to the sum of the two vertical times was used to measure ocular motor function, with ratios closer to one indicating better function.[33] Failure of the DEM ratio has been shown to identify 90% of subjects with symptomatic occulomotor dysfunction.[34] Test-retest reliability for the DEM test has been reported to be high in the school setting with vertical time having an Intraclass correlation coefficient (ICC) of 0.96 (95% CI: 0.93, 0.97); horizontal time ICC 0.92 (95% CI: 0.87, 0.95).

Secondary outcomes—educational outcomes

The educational outcomes used were the Rate of Reading test, the Copying test, and a subset of the Woodcock Reading Mastery Tests—Revised (WRMT-R). The Rate of Reading test[35,36] consists of short non-contextual passages of words that are easily recognized by young children. For the Copying test, the error-adjusted time taken to complete a sentence (time*42/characters actually copied) was calculated. From the WRMT-R the letter identification, word identification, word attack and passage comprehension subtests were used. These measure rate of reading, accuracy and comprehension and have been used widely in previous research.[37−39] Raw scores from these tests were converted into W-scores, as defined by the manual.[40]

Statistical analysis

An intention-to-treat approach was used to analyze the data. We originally calculated that a trial of 300 children with 100 in each group would provide 80% power to detect an absolute risk reduction of 0.20 for each intervention compared with the parental literacy support group (control group), assuming a significance level of 5%. We recruited only a third of this target sample which resulted in low power for simple comparisons of outcomes at each assessment time-point. Therefore, multilevel models were used to assess the interventions, allowing for correlation between outcomes repeatedly measured on the same child. In these models, the follow-up assessment (T_1 or T_2), and intervention group were both entered as main (categorical) effects, with an interaction between the two and a random effect for the child. Adjustment for baseline values and covariates that were imbalanced at baseline was also undertaken in order to increase the precision of the models. The parental literacy support group was used as the 'Reference' group. Wald test P-values, assessing the joint effect of the intervention groups, were derived separately for each of the two follow-up assessments.

A log transformation was applied to these outcomes with positively skewed distributions before analyzing as described above. Results from these analyses are therefore presented as estimated ratios of geometric means, rather than differences in means. Where a small amount of baseline data was missing (<3 values) for a covariate that appeared imbalanced between intervention groups, the values were imputed using a single imputation model. Multiple imputation models were performed as a sensitivity analysis to assess the impact of missing data, assuming that data were missing at random. The effect of compliance with the randomized intervention was assessed by adjustment for the number of sessions attended and other tuition received. Similar models were fitted to assess the effect of technical issues, such as the child forgetting to wear prescribed glasses on the day of testing. Chi-squared tests were used to compare parent and child perceptions across trial programs. No correction was made for multiple testing, but all comparisons made have been reported.[41] All analyses were conducted using STATA 10.0 (Statacorp 2007: Statistical Software: Release 10, College Station, TX).

RESULTS

General features

From an initial screened sample of 641 children, 126 met the selection criteria. Of these, 88 (72%) consented and were randomized (Fig. 1). From these 88 children, 9 were lost before

Table 2. Outcome measures at baseline by randomised intervention group

Characteristic	Parental literacy support (n = 30)		Lawson (n = 29)		Phono-Graphix (n = 29)	
	Mean (SD)/Median [Q1 to Q3]					
			Vision			
CISS total score	25.0	(10.6)	28.3	(13.5)	23.5	(13.6)
Stereocircles category score	4.3	(3.0)	4.6	(3.5)	5.5	(3.1)
Lang test category score	2.5	(1.4)	2.2	(1.4)	2.8	(1.4)
			Visual processing			
VAS total score	37.3	(4.7)	33.7	(5.1)	34.1	(6.8)
DEM test:						
Ratio	1.4	[1.3 to 1.6]	1.4	[1.3 to 1.6]	1.4	[1.2 to 1.5]
Errors	7	[2 to 10]	6	[1 to 15]	9	[3 to 13]
			Education			
Rate of reading test	83.5	(26.1)	79.2	(22.8)	75.7	(21.2)
Copying test:						
Adjusted time	0.9	[0.6 to 1.0]	0.8	[0.6 to 1.4]	1	[0.8 to 1.2]
Errors	2	[1 to 3]	2	[1 to 4]	2	[1 to 5]
WRMT-R test standard scores:						
Letter identification	72.8	(5.4)	73.4	(6.7)	73.8	(8.6)
Word identification	81.1	(8.7)	82.4	(11.9)	82.7	(10.9)
Word attack	88.5	(7.5)	87.2	(11.4)	88.1	(10.0)
Passage comprehension	78.7	(9.6)	79.3	(12.8)	80.5	(10.2)

CISS = convergence insufficiency symptom survey, VAS = visual attention span, DEM = developmental eye movement, WRMT-R Woodcock reading mastery test–revised.

the 10 week assessment (10%) and a further 22 were lost before the 36 week assessment (25%). Children participating in the trial ranged in age from 8 to 14 with a mean age of 11.1 (SD 1.3). The sample was predominantly male (59%, 52/88) and less than 30% of children in each program were classified as having average or above average intelligence. Due to small sample size, some baseline characteristics were not completely balanced after randomization (see Table 1). However, the proportion of children failing the stereocircle test >100 seconds of arc was similar across the three programs. Baseline vision, visual processing and educational variables are summarized in Table 2. The mean CISS scores in each program ranged from 23.5 to 28.3, well above the cut-off of ≥16 that has been reported to be highly predictive of convergence insuffficiency.[13] The WRMT-R results indicated that the average scores were below age referenced norms.[40]

The Woodcock standard scores are standardized scores which have a mean (SD) of 100 (15) in the general population. The sample mean scores at baseline all lie between 73 and 93, with standard deviations between 4 and 12.5, indicating that the sample is more homogenous than expected and that they perform more poorly than expected, based on population norms. This is probably due to the lower IQ scores observed in the sample.

Intention-to-treat multilevel analysis

The distribution of vision, visual processing and educational variables at baseline are shown in Table 2 and the follow-up assessments are summarized in Table 3. The estimated mean differences (or ratios of geometric means) and 95% confidence intervals are shown in Table 4. Models were adjusted for sex, age, socio-economic disadvantage (SEIFA) and IQ-for-age. Five missing covariate values were imputed. By the 36 week follow-up, both the Lawson and Phono-Graphix groups were associated with a larger improvement in stereoacuity, as measured by the Lang test (Table 4). In addition, the Lawson group, but not the Phono-Graphix group, was associated with a reduction in CISS scores (Table 4). The magnitude of the estimated reduction in

Table 3. Outcome measures at the 10 week (T1) and 36 week (T2) follow-up assessments by randomised intervention group

Characteristic [a]		Parental literacy support (n = 28,17)[b]		Lawson (n = 25,19)[b]		Phono-Graphix (n = 26,21)[b]		P value
				Mean (SD) / Median [Q1 to Q3]				
				Vision				
CISS total score[L]	T1	23.6	(9.3)	25.9	(11.0)	22.3	(13.3)	0.98
	T2	23.0	(8.2)	20.8	(10.0)	23.1	(15.3)	0.06
Stereocircle category score[L]	T1	3.8	(2.9)	3.3	(3.4)	5.1	(3.2)	0.16
	T2	2.8	(2.8)	3.0	(3.1)	4.6	(3.1)	0.33
Lang category score[L]	T1	2.5	(1.4)	1.8	(1.3)	2.7	(1.4)	0.32
	T2	3.0	(1.4)	1.6	(1.0)	2.4	(1.5)	0.002
				Visual processing				
VAS total score[H]	T1	38.6	(4.5)	36.8	(4.7)	35.4	(4.6)	0.60
	T2	37.4	(5.7)	38.4	(5.3)	37.6	(3.8)	0.19
DEM test:								
Ratio (Horiz/Vertical)[L]	T1	1.3	[1.2 to 1.5]	1.5	[1.2 to 1.6]	1.4	[1.2 to 1.5]	0.49
	T2	1.3	[1.2 to 1.4]	1.3	[1.2 to 1.4]	1.4	[1.2 to 1.5]	0.92
Errors[L]	T1	3.5	[0 to 9.5]	5	[1 to 11]	5	[1 to 19]	0.63
	T2	5	[1 to 10]	2	[1 to 6]	5	[2 to 14]	0.81
				Education				
Rate of reading test[H]	T1	86.2	(24.9)	84.9	(23.9)	84.1	(21.2)	0.39
	T2	93.4	(26.5)	87.6	(24.4)	91.2	(21.2)	0.15
Copying test:								
Adjusted time[L]	T1	0.7	[0.6 to 1.0]	0.8	[0.6 to 1.0]	0.9	[0.7 to 1.2]	0.48
	T2	0.9	[0.7 to 1.0]	0.8	[0.6 to 1.0]	0.9	[0.8 to 1.3]	0.09
WRMT-R test standard scores:								
Letter identification[H]	T1	73.6	(4.2)	74.3	(6.8)	75.3	(6.8)	0.82
	T2	73.2	(4.7)	72.1	(5.4)	73.5	(6.6)	0.13
Word identification[H]	T1	81.9	(8.7)	85.2	(9.9)	85.0	(11.5)	0.22
	T2	80.7	(9.0)	88.8	(8.7)	86.0	(12.0)	0.11
Word attack[H]	T1	89.5	(8.3)	89.0	(12.4)	92.6	(10.1)	0.01
	T2	89.3	(12.7)	96.6	(11.8)	93.8	(12.0)	0.17
Passage comprehension[H]	T1	80.7	(9.1)	85.5	(11.3)	84.2	(11.4)	0.36
	T2	78.5	(8.8)	86.3	(9.2)	82.5	(10.5)	0.36

[a] beneficial direction of scale is indicated by superscripts H (higher is better) and L (lower is better).
[b] ($n = n_1, n_2$) are the sample sizes at time T1 (n_1) and time T2 (n_2).
CISS = convergence insufficiency symptom survey, VAS = visual attention span, DEM = developmental eye movement, WRMT-R Woodcock reading mastery test–revised.

Table 4. The estimated effect of the Lawson and Phono-Graphix interventions compared to parental literacy support on vision, visual processing and educational outcomes at 10 week (T1) and 36 week (T2) follow-up assessments

Characteristic[a]		Ref.	Lawson		Phono-Graphix	
			Mean difference (95% CI)			
			Vision			
CISS total score[L]	T1	0	0.28	(−4.4, 5.0)	0.46	(−4.4, 5.3)
	T2	0	−5.55	(−11.1, −0.05)	0.58	(−4.9, 6.1)
Stereocircle category score[L]	T1	0	−0.59	(−1.8, 0.6)	0.69	(−0.6, 2.0)
	T2	0	0.58	(−0.8, 2.0)	1.11	(−0.3, 2.6)
Lang category score[L]	T1	0	−0.30	(−0.8, 0.2)	0.09	(−0.4, 0.6)
	T2	0	−1.01	(−1.6, −0.4)	−0.77	(−1.4, −0.2)
			Visual processing			
VAS total score[H]	T1	0	0.17	(−1.8, 2.1)	−0.79	(−2.8, 1.2)
	T2	0	1.89	(−0.2, 4.0)	1.47	(−0.7, 3.6)
DEM test						
Ratio (Horiz/Vertical)[H]	T1	1	1.04	(1.0, 1.1)	0.99	(0.9, 1.1)
	T2	1	1.00	(0.9, 1.1)	1.02	(0.9, 1.1)
Errors[L]	T1	1	1.17	(0.6, 2.2)	1.38	(0.7, 2.7)
	T2	1	0.86	(0.4, 1.8)	1.08	(0.5, 2.3)
			Education			
Rate of reading test[H]	T1	0	0.02	(-6.4, 6.4)	4.12	(−2.5, 10.7)
	T2	0	−4.92	(−12.1, 2.2)	2.07	(−5.2, 9.3)
Copying test						
Adjusted time[L]	T1	1	0.96	(0.8, 1.1)	1.04	(0.9, 1.2)
	T2	1	0.95	(0.8, 1.1)	1.12	(1.0, 1.3)
WRMT-R test standard scores:						
Letter identification[H]	T1	0	−0.58	(−2.4, 1.2)	−0.27	(−2.1, 1.6)
	T2	0	−2.21	(−4.4, −0.1)	−1.27	(−3.4, 0.9)
Word identification[H]	T1	0	0.06	(−1.9, 2.0)	1.59	(−0.4, 3.6)
	T2	0	2.35	(0.1, 4.6)	1.74	(−0.5, 4.0)
Word attack[H]	T1	0	−1.25	(−4.4, 1.9)	3.59	(0.4, 6.8)
	T2	0	2.98	(−0.7, 6.7)	3.17	(−0.5, 6.9)
Passage comprehension[H]	T1	0	2.01	(−0.8, 4.9)	1.43	(−1.5, 4.4)
	T2	0	2.20	(−1.1, 5.5)	0.32	(−3.0, 3.6)

[a] beneficial direction of scale is indicated by superscripts H (higher is better) and L (lower is better).
CISS = convergence insufficiency symptom survey, VAS = visual attention span, DEM = developmental eye movement, WRMT-R Woodcock reading mastery test–revised.

the Lawson group was approximately 10% of the range of the CISS score. These changes in stereoacuity and CISS scores over time are reflected in Fig. 2 which shows the means of these variables at each assessment. Some differences in reading mastery were observed but there were no marked differences in visual processing (Table 4). At the 36 week follow-up assessment, both the Lawson and Phono-Graphix groups performed better than the parental literacy support program with regard to word identification but the Lawson program children performed less well on letter identification (Fig. 3).

Because stereopsis may be influenced by changes in visual acuity we conducted further analysis. Both interventions were significantly associated with an improved Lang score with a similar magnitude of effect to Table 3 after adjustment for acuity and acuity change (logMAR score of worse eye) or after adjustment for usual glasses and change in need for glasses.

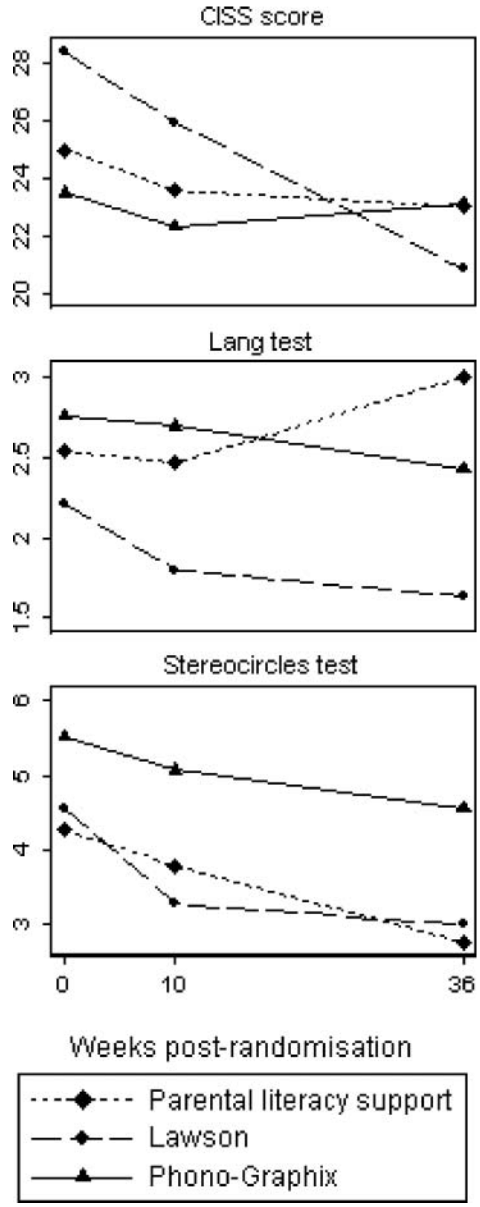
Further adjustment for child session attendance, parental attendance at session, homework completed or additional educational therapies did not alter the findings. Sensitivity analyses investigating the effect of imputing the five missing covariate values, and multiple imputation models accounting for dropouts did not substantially alter the results. There was no evidence that other technical issues such as test assessor had any affect on these results.

Parent and child perceptions post-intervention

The Lawson and Phono-Graphix programs were reported by parents to have increased the child's interest in reading (Table 5). From the child's perspective, while the differences between the intervention groups were not significant, it should be noted that over 50% of children in the Lawson and Phono-Graphix programs considered their reading to be 'much better' in comparison with only 30% of those in the parental literacy support program.

DISCUSSION

This study compared the effect of two interventions with a control group on stereoacuity, convergence insufficiency, visual



Note: For estimated intervention effect of each program compared to parental literacy support, see Table 4.

[a] For all three measures, lower indicates better function

CISS = convergence insufficiency symptom survey.

Figure 2. Mean scores for stereoacuity and the convergence insufficiency symptom survey at the three assessments by randomized intervention group.

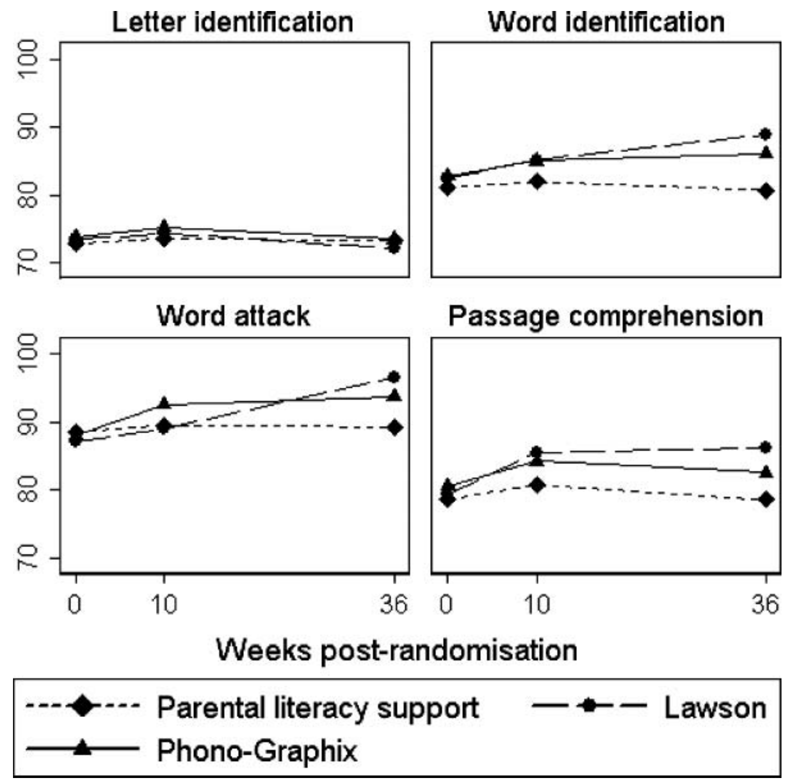
Table 5. Parental and child perceptions of the three interventions at the 36 week assessment

Characteristic n (%) or mean (SD)	Parental literacy support (n = 17)		Lawson (n = 19)		Phono-Graphix (n = 21)	
Parent perceptions						
How has your child's interest in reading changed?						
A lot more interested	0	(0.0%)	6	(35.3%)	10	(47.6%)
Slightly more interested	7	(41.2%)	9	(52.9%)	4	(19.0%)
No change	10	(58.8%)	2	(11.8%)	6	(28.6%)
Slightly less interested	0	(0.0%)	0	(0.0%)	1	(4.8%)
A lot less interested	0	(0.0%)	0	(0.0%)	0	(0.0%)
						P = 0.005
How has your child's confidence in school changed?*						
A lot more confident	1	(5.9%)	7	(41.2%)	9	(42.9%)
Slightly more confident	9	(52.9%)	7	(41.2%)	6	(28.6%)
No change	7	(41.2%)	3	(17.6%)	6	(28.6%)
Slightly less confident	0	(0.0%)	0	(0.0%)	0	(0.0%)
A lot less confident	0	(0.0%)	0	(0.0%)	0	(0.0%)
						P = 0.09
How has the amount of time your child spends reading for pleasure changed?†						
A lot more	2	(11.8%)	6	(33.3%)	9	(42.9%)
Slightly more	6	(35.3%)	8	(44.4%)	5	(23.8%)
No change	9	(52.9%)	4	(22.2%)	6	(28.6%)
Slightly less	0	(0.0%)	0	(0.0%)	1	(4.8%)
						P = 0.19
Time spent reading for pleasure						
Hours per week	1.3	(1.0)	2.2	(1.7)	2.3	(2.0)
						P = 0.18
Child perceptions						
How has the program helped your reading?						
Much worse	0	(0.0%)	0	(0.0%)	0	(0.0%)
Slightly worse	0	(0.0%)	0	(0.0%)	0	(0.0%)
No change	3	(17.6%)	2	(10.5%)	6	(28.6%)
Slightly better	9	(52.9%)	7	(36.8%)	4	(19.0%)
Much better	5	(29.4%)	10	(52.6%)	11	(52.4%)
						P = 0.18
Has the program helped with school?						
Yes	9	(52.9%)	10	(52.6%)	9	(42.9%)
No	3	(17.6%)	2	(10.5%)	2	(9.5%)
Don't know	5	(29.4%)	7	(36.8%)	10	(47.6%)
						P = 0.80

*Lawson n = 17, †Lawson n = 18, SD = standard deviation.

processing and reading among children with poor stereoacuity and low literacy. The main study finding was that the orthoptic Lawson program improved child vision in terms of stereoacuity and symptoms of convergence insufficiency in comparison with parental literacy support. The Phono-Graphix program was associated with improved stereoacuity, but not convergence insufficiency symptoms. Both the Lawson and the Phono-Graphix programs performed better than the parental literacy support program in relation to word identification within the Woodcock reading mastery test but other educational benefits at 36 weeks were not evident and indeed there was some evidence that the parental literacy support group performed better in terms of the letter identification sub-test. This lack of consistent educational improvement despite apparent improvements in stereoacuity may reflect the relatively short follow-up period of only 36 weeks post-randomization in this trial or that other factors, rather than this degree of improvement in stereoacuity, are more important determinants of educational outcomes.

In previous vision therapy, Scheiman reported a statistically and clinically significant reduction in CISS score from 32.1 ± 7.9 to 9.5 ± 8.2 ($P < 0.001$), after a 12 week intervention[42] as did the Convergence Insufficient Treatment Trial with base-in prisms in reading glasses—31.6 to 16.5 and 28.4 to 17.5 for the placebo glasses.[18] The placebo vision therapy/orthoptics group had a small but clinically insignificant decrease from 30.7 ± 10.6 to 24.2 ± 11.9 ($P = 0.04$), whereas the pencil push up



Note: For estimated intervention effect of each program compared to parental literacy support, see Table 4.

[a] All four scores have a population mean of 100 and standard deviation of 15. Higher values indicate better performance.

Figure 3. Mean scores for the Woodcock standard scores at the three assessments by randomized intervention group.

group had neither a statistical nor clinically significant change in the symptom score (29.3 ± 5.4 to 25.9 ± 7.3; $P = 0.24$).[18]

A strength of this study was that it involved population-based recruitment of children with low literacy. Thus, the findings are more generalizable to children with low literacy and poor stereoacuity than past work based on small and highly selected groups of children with reading disability. In addition, our population-based intervention used the randomized control trial (RCT) design with masking of assessors and analyst to intervention status. Neither the Lawson nor the Phono-Graphix therapies have previously been evaluated using the RCT design.[15,24] Due to the nature of the intervention, families could not be fully masked but were informed that each intervention had some evidence of efficacy. Since the child's perception of the intervention at the 36 week follow-up assessment did not differ significantly across the three programs, the child-reported CISS score should not be greatly affected by bias related to perceived worth of the intervention. The other primary outcome, stereoacuity, was measured objectively by a masked assessor. The Lawson and Phono-Graphix programs had a greater impact on stereoacuity as assessed by the Lang rather than Titmus test. This may reflect the greater emphasis on differentiating more severe stereoacuity problems with the Titmus stereocircles test—seven out of nine stereocircles categories fall within the best Lang category. Alternatively, the Lang test has less problems with monocular or lateral displacement than the Titmus stereocircles test[43] and this may be important where repeated outcomes (and thus training effects) could occur as in this trial. The repeated measures randomized control trial analysis means that each child was compared to self and all received the same number of Lang test repeats, so memorization of the test is unlikely to explain the differences observed. Further the color conditions for the conduct of the Lang test were standardized across trial arms and could not have contributed to differences. However, as in all complex interventions, it is difficult to evaluate the subcomponents of the Lawson or Phono-Graphix programs that were efficacious and to rule out elements such as encouragement leading to increased child effort.

The study had limited statistical power. This was due to the lower than expected recruitment from the population-based school screening study and to the lower than expected prevalence of poor stereoacuity (17% with a stereocircle test of worse than 100 seconds of arc) among the school-based sample of children with low literacy.

Another problem was that a majority of trial participants had a lower than average IQ and thus may not have been as likely to respond to intervention, particularly in terms of educational outcome, as would children with higher natural ability. We were unable to examine the association between poor stereoacuity and reading outcomes after stratification for child intelligence due to small sample size, but previous work indicates this association may be more evident in children of normal intelligence.[11] After extensive consultation at the trial design phase, it was considered unethical to conduct a school-based intervention to improve reading but exclude those with reading disability limited to lower IQ. Consistent with this view, a 2009 review of the education of the dyslexic child[19] has stated that it is not valid to assume that discrepant children (poor reading relative to IQ) require instructional strategies that differ from low-achieving non-discrepant children, particularly as the two groups resemble each other on reading measures, development and differences to able readers. This RCT was designed to implement interventions within a school setting. What are required now are RCTs studying neurobiological outcomes among discrepant poor readers with poor stereopsis in response to vision therapy. This neurobiological dimension has been assessed in RCTs assessing phonological deficits by functional magnetic resonance imaging for small groups of poor readers of normal IQ. The reasons for poor stereopsis (eg, amblyopia) were not further delineated in this population-based study and finer stratification of eligible children by specific ocular conditions derived from a full clinical ophthalmological assessment may have provided a more appropriate population for a RCT than the school-based screening methods used have allowed. It should also be taken into account that the children had high CISS scores at baseline ranging from a mean of 23.5 to 28.3 and the beneficial reduction associated with the Lawson program was in the order of 6 points of magnitude thus, as shown in Fig. 2, most of the children remained above a CISS score of 16 at follow-up. A CISS score of $\geq$16 has been reported to have a sensitivity of 95.7% and specificity of 87.5% for abnormal binocular vision.[13] Thus, although there may have been an improvement in convergence insufficiency symptom scores, the children still had relatively high CISS scores in all programs at 36 weeks. This may also have contributed to the null finding with regard to educational improvement.

Although educational trials of different teaching methods for reading exist,[44] there are currently no trials investigating therapies for children with low literacy summarized within the Cochrane database of systematic review. The extremely poor scientific and educational evidence base for efficacy and correctly targeted interventions for children with poor literacy contrasts starkly with the immense costs of low literacy.[2] Pediatric developmental research related to poor vision and literacy is a neglected area. A recent review on education of the dyslexic child did not mention vision problems.[45] This study clearly demonstrates that it is feasible to conduct RCTs to evaluate alternative interventions for children with low literacy, taking into account comorbid conditions such as low stereoacuity. Further trials of visual therapy and reading should include a neurological component and utlize a carefully ophthalmologically phenotyped group of children with poor stereopsis. It is important to note that low child literacy, even among children with dyslexia, represents a set of disability subgroups, not a single entity.[46] There is an urgent need to more precisely define types of low literacy and rigorously evaluate appropriate interventions for children with low literacy due to differing causes.

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A-LP, KS, DB, AC, TD and JK designed the study. KS, JB and NO conducted the fieldwork, AC provided paedriatric advice, JK provided opthalmological advice and DB and AJ provided educational advice. EW conducted the statistical analyses and was involved in the interpretation with A-LP, KS, TD and JK. All authors provided input and approval for the final draft. A-LP is the guarantor.

DECLARATION OF INTEREST

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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