Australian Journal of Learning Disabilities
Volume 10 Number 2 2005, pp. 51 - 62

Efficacy of the Cellfield Intervention for reading difficulties: An integrated computer-based approach targeting deficits associated with dyslexia

Lee-Ann Prideaux[a], Kerry A. Marsh[a] and Dimitri Caplygin[b]
[a] *Griffith University,* [b]*Cellfield Pty limited*

Abstract
Despite contemporary research on dyslexia moving toward multi-deficit hypotheses, intervention studies tend to focus on specific causal mechanisms. The Cellfield Intervention, which involves computer-based activities designed to remediate multiple deficits concurrently, is evaluated in the present paper. Participants were 262 Australian school children (187 males, 75 females; mean age 11.05) who undertook the ten intervention sessions at the Cellfield Clinic in 26 mean days between pre- and post- test, during a 24 month period. Pre- and post-intervention data were collected using the Wide Range Achievement Test, the Woodcock Reading Mastery Tests – Revised, the Neale Analysis of Reading Ability, and ocular assessments. Significant gains ($p < .05$) were made in all three sets of dependent measures analyzed (i.e., reading-related skills, oral reading proficiency, and ocular measures) providing some support for the efficacy of an integrated approach to the treatment of reading difficulties.

There has been considerable conjecture in the literature as to the causes of dyslexia with a swing away from postulates concerning a single underlying factor, to recent conjecture about the possible interplay of a combination of etiologies (e.g., Bishop, Carlyon, Deeks, & Bishop, 1999; Ramus, 2001; Wolf, Miller, & Donnelly, 2000). Despite theory moving toward more complex and multifaceted explanations, intervention studies have generally focused upon a single underlying factor. Hence, much research effort concerning intervention for dyslexia has been directed toward the amelioration of specific reading deficits, reflecting an assumption that either visual (Clisby, Fowler, Hebb, Walters, Southcott, & Stein, 2000) or phonological (Gillon, 2000) impairments are central causal mechanisms.

The Cellfield Intervention evaluated in the present paper is aimed at remediating multiple causes of dyslexia by targeting several deficits concurrently including phonological, visual, and visual to phonological processing. It was assumed that if participants made gains in the measures of reading-related skills taken prior to and following the Cellfield Intervention of greater significance than what would be expected from current practice, this study would provide some support for a double deficit or even a multi-deficit causal hypothesis.

A deficiency in visual processing, labeled "word blindness", was originally thought to be the reason a small proportion of the population has trouble learning to read (Hinshelwood, 1917, cited in Miles & Miles, 1991). Various theoretical explanations have since been proffered. These include the phonological theory, the cerebellar theory and the magnocellular theory (Ramus, Rosen, Dakin, Day, Castellote, White, & Frith, 2003).

Each of these theories highlights different aspects of dyslexia. The phonological theory centres upon a cognitive deficit in phonological awareness. That is, one's ability to perceive and manipulate the sounds of spoken language, believed to underlie reading (Castles & Coltheart, 2004).

Cerebellar theorists focus on the role of a mildly dysfunctional cerebellum in the acquisition of phonological skill and reading proficiency (Fawcett & Nicolson, 1999). Research supporting this theory has demonstrated that skills related to the cerebellum such as balance, motor co-ordination, postural stability and automatization are deficient amongst dyslexic samples (e.g., Nicolson & Fawcett, 1990; Levinson, 1988). These theorists contend that the range of deficits associated with dyslexia (including poor speech articulation, insufficient automatization of reading tasks, difficulties in cognitive information processing and motor skills) occur "as a result of cerebellar abnormality" (Nicolson, Fawcett, & Dean, 2001, p. 509).

The magnocellular theory accentuates both auditory and visual temporal processing deficits, which are presumed to result from a slight impairment of neural pathways involving large magno cells (Stein & Talcott, 1999). These cells specialize in the detection of rapidly

Correspondence: Dimitri Caplygin, Cellfield Pty Ltd, PO Box 580, Southport, MDC Qld 4215
Email: dimmitri@bigpond.com

ISSN 1324-8928
Published by Learning Difficulties Australia

presented stimuli, transmitting transient visual input about location and shape (Lovegrove, 1999) as well as transient auditory input detecting changes in acoustic frequencies (Stein & Walsh, 1997).

Dyslexia has thus come to be defined as a "neurodevelopmental problem" (Stein, Richardson, & Fowler, 2000, p. 164) characterized by difficulties in reading accuracy and fluency, word recognition, spelling and decoding (Lyon, Shaywitz, & Shaywitz, 2003). The body of knowledge that has been accrued to elucidate this learning disability has built up via the use of a variety of methodologies ranging from psychometric tests to physiological measures. Firstly, for example, Lyon, Shaywitz and Shaywitz (2003) review research demonstrating the neural basis of dyslexia reporting on studies that use psychophysical tests, postmortem brain specimens, brain morphometry and diffusion tensor MRI imaging. Secondly, substantial evidence for the relationship between phonological awareness tasks and reading ability has been provided via the use of psychometric testing (Castles & Coltheart, 2004). However, in their review of this literature, Castles and Coltheart point out that "no single study has conclusively established ... a causal link between phonological awareness and literacy acquisition" (p. 101).

Finally, studies employing orthoptic measures have attested to the specific ocular motor control deficits experienced by dyslexics compared to normal readers. Stein, Richardson and Fowler (2000), review several findings showing the inferior binocular vergence control and unstable fixation in dyslexic samples. Moreover, Talcott et al. (2000) used a combination of sensory psychophysic and psychometric tests to examine the influence of dynamic visual and auditory detection on reading performance. They concluded that vision and audition may have separate effects on readers' orthographic and phonological skills.

In conjunction with these various lines of investigation reporting on the characteristics and purported causes of dyslexia, attempts to remedy specific deficiencies in impaired readers have been studied. For instance, reading fluency was targetted with an intervention designed to assist naming-speed deficits (Wolf, Miller, Donnelly, 2000). Although a comprehensive description of the intervention and a clear rationale for its inception based on the double deficit hypothesis was provided (i.e., phonological and processing-speed deficits), this intervention was not statistically evaluated. In another example of intervention research, the efficacy of an exercise based intervention was assessed (Reynolds, Nicolson, & Hambly, 2003). This intervention involved a course of visuomotor activities designed to ameliorate the motor control problems of dyslexics. This intervention was found to have significant benefits for participants in the intervention group compared to controls.

Furthermore, strategies to treat the visual processing problems that dyslexics experience have been investigated. In one such study (Clisby et al., 2000) a large sample of children (N = 297) with reading difficulties was given particular coloured lens to use when reading to determine if it made small print clearer for them, or monocular occlusion (patching) if they had unfixed ocular dominance. Other participants were given binocular vergence exercises or pursuit tracking exercises depending on their specific visual deficits. This study demonstrated that such interventions were effective by showing considerable gains in reading age for participants.

Regardless of the particular area of deficit being targeted in intervention studies, it has been established that the majority of children who participate can be helped and the challenge now is to discover "the best method, or combination of methods ... to eliminate reading failure in children" (Torgesen, 2000, p. 63).

The Cellfield Intervention

Given that training in discrete processes has been shown to assist those with reading difficulties, the Cellfield Intervention set out to integrate computer-based tasks requiring visual, auditory and phonological processing to see if more substantial impact could be achieved over a broader range of the deficits related to reading impairment. The intervention comprises ten one-hour sessions, each consisting of ten exercises. Some of these target phonological processing, requiring the concurrent activation of visual and auditory processing. Other exercises involve decoding and encoding activities using tasks such as finding text embedded in continuous random text without spacing. Motion graphics designed to stimulate the magnocellular pathways and other visual exercises requiring eye/hand coordination are also incorporated into each session.

Various fields of investigation influenced the development of this intervention. Firstly, an understanding of the neurophysiology of the transient vision system (Hart, 1992) guided the motion graphics design which is superimposed onto the letters, words and sentences presented on screen at all times. The motion graphics consist of contrasting edges of varying orientations, dimensions and varying directions of motion. These were designed to enhance the transient (moving) vision of subjects and to achieve enhancements in eye movement control, in working memory, sequencing, peripheral vision and in visual persistence. By also behaving as a moving mask, the enhancement of transient vision sought was through the stimulation of cells in the transient vision areas of the brain. The stimulation was intended to be triggered by the motion graphics, which were designed to match the excitation characteristics of the numerous receptive cell types in the magnocellular pathways and the motion centers of the visual cortex. In the early stages of the Cellfield Intervention, the motion graphics are translucent, enabling the words and sentences to be seen through the motion graphics. Progressively, the motion graphics become more opaque until words and sentences can only be read in between the gaps of the motion graphics. The intention of the motion graphics and also of the underlying tasks to be performed, is to make the Cellfield Intervention progressively more difficult but manageable. The intervention is also designed to be inherently motivating and to elicit an optimal cognitive focus. The motion graphics design was also biased towards improving eye tracking, strengthening orthographic visualization, and improving working memory.

Much of the Intervention design was influenced by researchers who showed differences in the brains of poor readers compared to non-impaired readers. More specifically, anatomical evidence for impaired neural development in the visual system (e.g., Galaburda & Livingstone, 1993; Livingstone, Rosen, Drislane, & Galaburda, 1991) and brain scanning evidence for under-activation in the angular gyrus (e.g., Shaywitz, 1998) highlighted the need to enhance auditory, visual, and visual to auditory processing. Thus, letters, words and sentences that are presented on screen correspond to aural tasks presented through earphones. There are no auditory exercises, which are presented without their corresponding visual forms. About 30% of the intervention time of each session involves matching rhymes, from a choice of four alternatives. The target rhyme is presented visually and aurally for the first five sessions and then only aurally for the last five sessions. All target rhymes are presented in a recorded Australian voice of neutral accent, which breaks the target rhyme into its phonemes. The target rhyme is electronically 'stretched' to increase the time available to recognize the first letter (onset) and the differences between phonemes and sound segments, whilst preserving the way the word sounds as much as possible. This process seeks to alter auditory temporal characteristics whilst preserving its spectral characteristics. The degree of electronic 'stretch', (temporal characteristics), is automatically reduced in steps until target rhymes are as normal speech for the last two sessions.

Each intervention session also includes an exercise using 'Pidgin English', an exercise involving embedded text and an exercise for homophones. Short non-verbal exercises also appear periodically in all sessions increasing in difficulty as the sessions progress. This part of the intervention was influenced by the work of experts pointing toward the role of visual and phonological factors in developmental dyslexia (e.g., Castles & Coltheart, 1993; Stein & Walsh, 1997). Added to this was the influence of Ehri's (1998) educational research stressing the importance of grapheme-phoneme conversion and sound segmentation ability.

It should be noted that although research by Lovegrove (1999) on spatial frequency analysis was influential, some of his laboratory findings seemed to be counter to what was perceived in regard to the Cellfield Intervention. (Spatial frequency refers to whether the moving stripes in a vision study are widely spaced or finely spaced. The stripes can be mounted on a rotating disk, which produces motion that can be mathematically defined as being sinusoidal). Lovegrove's findings demonstrated that, based on sinusoidal motion with respect to transient and sustained subsystems, the magnocellular pathways only appeared to be engaged at very low spatial frequencies. However, for the Cellfield Intervention, which is based on a linear motion system, the most demanding screens with respect to transient vision, seemed to be foregrounds with fine spacing (high spatial frequency) presented at higher speeds (higher temporal frequency). The Cellfield Intervention sessions were therefore designed with a progressive increase in spatial and temporal frequency in the belief that this would progressively increase the load on the magnocellular pathways and the extra striate middle temporal region of the visual cortex, (the brain centre most responsible for transient vision), at the same time placing higher demands on visual focus, eye tracking, on language processing and on eye/hand coordination.

Eye movement control has also been linked to reading problems through deficits in fixation stability, Stein, Richardson and Fowler (2000). This refers to an inability to align both eyes so that their centre of vision coincides exactly with the fovea, a small point inside each eye where vision is most sharp. Those with an inability to achieve this alignment are said to have 'fixation eccentricity'. Those who are able to achieve this alignment but not hold a steady focus are said to have 'fixation instability'. Some have a deficit in both.

Subjects in this study who displayed visual fixation instability or visual fixation eccentricity during the Cellfield pre-intervention orthoptic examination, underwent an orthoptic procedure during intervention that included the use of red lens filtering for some of the sessions, and an initial covering of one eye (monocular occlusion) for some of the initial sessions. Various studies of the visual problems associated with dyslexia and the benefits of monocular occlusion guided this aspect of the treatment (e.g., Clisby et al., 2000; Stein, Richardson, & Fowler, 2000; Stein & Talcott, 1999

The purpose of the present study was to provide a preliminary report on the efficacy of the Cellfield Intervention based on pre- and post-intervention data collected from all school aged individuals who undertook the ten sessions in a mean of 26 days, during a 24-month period. Measures of reading related skills (i.e., word reading, spelling, word attack, and cloze technique) and reading proficiency (i.e., reading speed, accuracy and comprehension) were employed to gauge whether this combination of computer-based exercises derived from contemporary theory could assist a clinical sample experiencing reading difficulties. Unlike other interventions that tend to focus on one area of deficit, it was not possible to assess the efficacy of any one aspect of the Cellfield Intervention due to its integrative nature. Nevertheless, it is our contention that, in line with the literature, the multiple deficits associated with dyslexia should be examined concurrently and thus, should be treated concurrently. It was hypothesised that the young people who undertook the Cellfield Intervention during 2002/2003 would show significant gains in reading related measures taken immediately following the 10 intervention sessions in comparison with those taken prior to intervention.

Method

Participants

Participants were 262 Australian school children (187 males, 75 females) who undertook intervention at the Cellfield Clinic at some time during a 24-month period. They ranged in age from 7 to 17 with a mean age of 11.05. The majority of participants completed the pre assessment, the 10 intervention sessions, and the post assessment within a one month period, with the mean number of days between pre-test and post-test being 26. Average verbal IQ (as measured by Slosson, 1989); see Instruments), was 92.39 (SD 12.58) with the sample categorised as 3% mild mental handicap, 10% borderline, 24.5% below average, 48% average, 9% above average and 1.5% high, according to the Slosson manual. Just over half of the sample (51%) was identified as being at risk of dyslexia using the Dyslexia Screening Test (Fawcett & Nicholson 1996).

Materials

The Cellfield Intervention software was loaded into personal computers of high-level graphics processing specification, with optical mice for good eye-hand control. These were set apart on large desks located in a quiet room. An adjustable office chair was placed before each computer. The monitors were 17 inch with flat-screens. Foot rests were provided to ensure an ergonomically correct seating position for participants and a set of high fidelity earphones was connected to each computer.

Instruments

Parallel forms of a battery of individual tests were employed in the pre- and post-assessment of all participants. These widely used psychological instruments were selected to provide reliable information about participants' performance in reading-related skills and oral reading proficiency. Scores were also generated from the visual assessment conducted during the pre- and post-tests. A test of verbal IQ and a screening test for dyslexia were administered at the pre-test.

Descriptive Measures. The Slosson Intelligence Test-Revised (SIT-R); (Slosson, 1998) is a brief measure of verbal intelligence consisting of 187 items, which are presented in increasing levels of difficulty in oral form. A total standard score by age level is calculated (mean = 100, SD = 16). Calibrated norms approximate the Wechsler Intelligence Scale for Children-III (Wechsler, 1991). The SIT-R served a dual purpose in the present study. Total standard scores were used as a covariate to control for baseline intelligence at the pre-test for one of the analyses. These scores were also used to group students on ability level, as recommended by the SIT-R manual, to provide an accurate description of the sample in terms of verbal IQ levels.

Satisfactory validity data are reported in the manual. Concurrent validity is indicated by the Pearson's product-moment correlation coefficient of $r = .83$ between the SIT-R and WISC-III Verbal IQ. Internal reliability appears robust with a strong split-half correlation of .97 using the Spearman-Brown correction and overall reliability of .96 using the Kuder-Richardson 20 coefficient.

The Dyslexia Screening Test (DST) (Fawcett & Nicolson, 1996) provides a measure of susceptibility for dyslexia along with a profile of the degree to which respondents display deficits in the particular areas associated with this disorder. The 11 sub-tests screen for receptive and expressive language, phonological processing, fluency in naming and reading, working memory, handwriting, and motor skills. Raw scores for each test are converted to "At Risk Index" scores, which are based upon the stanine scale (mean = 5, SD = 1.96). An overall "At Risk" quotient (ARQ) is calculated. An ARQ of one or greater, is interpreted as strong evidence for the child being at high risk of dyslexia.

Reading-Related Skills Measures. The Wide Range Achievement Test3 (WRAT3) (Wilkinson, 1993) was used to assess basic reading and spelling skills while controlling for the effects of comprehension. The WRAT is a widely used and well-normed instrument (Gregory, 2004). It provides measures of the relative performance of participants in relation to their same aged peers. Derived scores utilized in the present study were standard scores with a mean of 100 and standard deviation (SD) of 15 and grade norms.

The WRAT3 Reading sub-test requires respondents to read words aloud, progressing in level of difficulty from initial items like "see" to more complex words such as "protuberance". The Spelling sub-test requires respondents to write words that increase in level of difficulty from items such as "cut" to "assiduous". Internal reliability co-efficients range from .88 for the eight-year-old normative sample to .90 for 13 year olds.

The Woodcock Reading Mastery Tests - Revised (WRMT-R) (Woodcock, 1998) assess a variety of reading-related abilities. This instrument is a revised version of the original test published in 1973 with updated and expanded normative data taken from a large representative sample of school children in America (N = 6,089). For the purpose of the current test battery, the 'Word Attack' and 'Passage Comprehension' sub-tests were administered to gain a measure of participants' ability to use phonic decoding skills and to comprehend passages of text. Both measures provided derived scores of grade and age equivalents, and standard scores (mean = 100, SD = 15).

The 'Word Attack' sub-test consists of 45 nonsense words arranged in order of difficulty to assess the respondent's ability to pronounce the array of phonemes in the English language. The Passage Comprehension sub-test involves a cloze technique whereby respondents are required to read either a sentence or short passage and determine the appropriate missing word to complete it. The items contained in the test booklet, are formulated so that sound comprehension and knowledge of the appropriate vocabulary need to be applied in order to reach a correct response.

Internal split-half (odd and even items) reliability with the Spearman-Brown correction for the Word Attack sub-test is reported at .91 for Grade 3 children (8 year olds) and .89 for Grade 5 (10 year olds). For Passage Comprehension these figures are .92 and .73 respectively.

Oral Reading Proficiency. The third edition of the Neale Analysis of Reading Ability (Neale, 1999) was used to test reading speed, accuracy and comprehension. Sound validity and reliability evidence is reported in the manual. Internal consistency coefficients across grades two to seven for rate and accuracy are strong (KR 21 .91 to .94) and moderately strong for comprehension (KR 21 .85 to .96).

The Neale consists of a series of passages arranged in increasing levels of difficulty. Errors are recorded as the respondent reads aloud (i.e., mispronunciations, substitutions, refusals, additions, omissions, reversals and exceptions). The time taken to read each passage and the number of correct answers to oral comprehension questions are also recorded. Accuracy raw scores for each passage are calculated by deducting the number of errors from the permissible number of errors. The comprehension raw score is simply the number of correct answers for each passage read. Reading rate is the number of words read correctly divided by the total time taken (in seconds) and then multiplied by 60.

Ocular Measures. An experienced orthoptist provided ratings of participants' visual performance in relation to foveal alignment, foveal stability and contrast sensitivity, using a 'Heine' visuoscope, with concentric viewing rings and a central fovea viewing 'star'.

A score for each eye was recorded prior to and following the Cellfield Intervention. For foveal alignment, a score of zero was recorded if the axis of vision was centred on the fovea. If the axis of vision was at about the edge of the fovea, a score of one was given. If well away from the fovea, a score of two was recorded. For foveal stability, zero represented no discernable movement. One represented movement from the centre to about the edge of the fovea, or its equivalent. Two represented movement from centre to well away from the fovea, or its equivalent. Similarly, zero was assigned for contrast sensitivity within the normal range, one for slightly outside the normal range and two for well outside the normal range (i.e., a defect).

Procedure

Prior to beginning treatment, parents provided details concerning their child's developmental, medical and educational history. They also answered questions concerning their child's central auditory processing abilities. The information provided, along with the child's position within the family and any family history of learning difficulties was then discussed with a registered psychologist during an intake interview.

The psychologist engaged in a process of behavioural observation throughout the testing so that qualitative observations could be used to support scores and/or highlight any possible contributing factors for further consideration. A visual assessment took place in a different room at a specified point during the battery of psychological tests to give the children a break.

A qualified orthoptist, trained in the diagnosis and management of eye movement disorders and visual function, conducted several short procedures to determine if there were any specific weaknesses in each client's visual performance. Whether saccades (i.e., problematic "eye tracking") and/or strabismus ("turned eye" problems) were present was also scrutinized during this part of the testing process.

It should be noted that the psychologists ($N = 4$) who undertook this testing were not employed by the Cellfield organization, but contracted their services on an independent basis. Hence, they provided impartial advice concerning the suitability of the child for the Cellfield program given their profile of results. Alternate recommendations included intensive speech therapy, hearing assessment and occupational therapy. In the latter cases, parents were provided with the relevant referrals so that immediate action could ensue.

Following the completion of the ten sessions, a post-test was arranged. Parallel forms of the tests were administered by the registered psychologist at this time (i.e., the WRAT3, the Woodcock and the Neale tests) and a follow-up visual assessment was performed by the orthoptist. Immediate overall feedback was provided to parents following the post-assessment and formal reports were sent.

Results

Extensive screening of all pre-test and post-test data was undertaken to detect problems with skew and kurtosis and to locate any data input errors. Extreme data points were investigated separately and removed where appropriate. No transformations were required to meet the assumption of normality once this screening process was complete and the investigation of homogeneity of variance revealed no violations to this assumption. Scatter diagrams for each bivariate pair of continuous dependent variables were also inspected and demonstrated no violations concerning linearity. Equal variance-covariance matrices were also observed.

Parallel forms of the Wide Range Achievement Test3 (WRAT3), the Woodcock Reading Mastery Tests-Revised (WRMT-R) and the Neale Analysis of Reading Ability test were randomly assigned to the pre- and post-test administration. Hence, differences in outcomes according to the form used were examined. In all instances, there was no significant difference between forms used. That is, those who were given the Blue WRAT3 form at the pre-test and then the Tan form at the post-test made similar gains as those who were tested using the Tan form first and then the Blue form second. Likewise, it made no difference whether participants were administered the WRMT-R Blue form and then the Red form or visa-versa and there was no difference in outcomes for the group who were given the Neale Yellow form followed by the Green form compared to those who did them in the reverse order.

However, there was a significant interaction between time tested and the form administered for the WRAT3 Reading sub-test: $F(1, 260) = 16.02$, $p < .001$ and for the Neale measure of Reading rate: $F(1, 260) = 11.21$, $p = .001$. Pre-test means for WRAT3 Reading forms (Blue 82.44, Tan 81.31) and Neale Reading rate forms (Yellow 55.04, Green 54.11) and the 95% confidence intervals (WRAT3 Blue 79.33 to 85.56, Tan 79.60 to 83.03; Neale Yellow 51.68 to 58.40, Green 48.00 to 60.21) demonstrated pre-test scores were not dependent on the form used and thus the interactions were not deemed problematic for subsequent analyses as they involved post-test scores only. Those who were administered the WRAT3 Blue form at post-test had higher reading scores than those who were given the Tan form at post-test (Blue 90.68, Tan 87.69). In the case of the Neale Reading rate test, those who used the green form at the post-test read slower than those who used the yellow form at post-test (Yellow 50.51, Green 43.97).

Results are presented in three sections in accordance with the type of dependent variables (DVs) utilised to evaluate the efficacy of the Cellfield Intervention. In the first section, standard scores (mean = 100 & SD = 15) obtained from the four measures of reading-related skills were analysed concurrently using multivariate analysis of variance. In the second section, oral reading proficiency was assessed using the three measures obtained from the Neale Analysis of Reading Ability test. These three DVs were analysed via separate *t*-tests. In the third section, the ocular measures were assessed using a series of chi-square analyses.

Reading-Related Skills

The impact of the Cellfield Intervention on reading-related skills was assessed using the standard scores derived from the WRAT3 Reading and Spelling sub-tests (WR & WS) and the WRMT-R Word Attack and Passage Comprehension sub-tests (WA & PC).

Correlations conducted on the measures of reading-related skills revealed significant positive relationships between all four DVs (see Table 1). Tolerance values were inspected as a check for multi-colinearity and were deemed acceptable. Mahalanobis distance scores were obtained and using a chi square statistic of .001 with three degrees of freedom to generate a cut-off score, three multivariate outliers were revealed. These three students' data were removed one by one and analyses were run with and without their scores revealing no effect on the results. All three cases were thus retained.

To assess the effect of the Cellfield Intervention on reading-related skills, a repeated measures MANOVA

Table 1
Pearson Product-Moment Correlations of Pre-Test Reading-Related Skills Data and Verbal IQ, 2-tail Significance

	WR	WS	WA	PC	Verbal IQ
WRAT Reading (WR)	--	.73*	.72*	.68*	.33*
WRAT Spelling (WS)		--	.71*	.68*	.33*
WRMT-R Word Attack (WA)			--	.60*	.28*
WRMT-R Passage Comprehension (PC)				--	.40*
Verbal IQ as measured by Slosson					--

Note: * = $p < .01$

was conducted comparing standard scores recorded prior to and following treatment. The dependent variables were the two WRAT subscale scores, Reading and Spelling (WR & WS), and the two WRMT-R subscale scores, Word Attack and Passage Comprehension (WA & PC). The within-groups variable was Time with two levels, Pre-test and Post-test. Table 2 presents means, standard deviations and 95% confidence intervals for the four DVs according to testing time.

There was a significant multivariate main effect for Time, $F(1, 261) = 270.96$, $p < .001$ and there were significant univariate effects for all DVs: WR, $F(1, 261) = 353.43$, $p < .001$; WS, $F(1, 261) = 69.70$, $p < .001$, WA, $F(1, 261) = 708.93$, $p < .001$, and PC, $F(1, 261) = 277.79$, $p < .001$. Cohen's d statistics were calculated to explicate the practical importance of these findings. These were "computed by dividing the difference of the two means by the pooled standard deviation" (p. 587) as described by Fidler and Thompson (2001). The effect sizes ranged from .30 for WS, .62 for PC, .68 for WR to 1.01 for WA, which denotes a large standardized effect (Cohen, 1988).

The same DVs were entered into a second MANOVA, this time with the dyslexia screening data used as a between subjects variable, to determine if these significant gains would be influenced by whether participants were identified as being at risk of dyslexia or not. The significant main effect was retained: $F(1, 259) = 270.93$, $p < .001$ as were the significant univariate effects: WR, $F(1, 259) = 357.26$, $p < .001$; WS, $F(1, 259) = 69.78$, $p < .001$, WA, $F(1, 259) = 700.84$, $p < .001$, and PC, $F(1, 259) = 274.06$, $p < .001$. There was no effect for interaction but a significant between subjects effect was found: $F(1, 259) = 120.16$, $p < .001$. Inspection of the profile plots showed that, while those identified as being at risk of dyslexia recorded lower scores on all DVs compared to their non-dyslexic peers at both the pre and post testing times, these students made the same relative gains across all DVs. That is, parallel profiles were in evidence demonstrating a similar pattern of gains were made by both groups of students (i.e., at risk of dyslexia or not).

A multivariate analysis of covariance (MANCOVA) was conducted to further examine the effect of the Cellfield Intervention on reading-related measures but with pretreatment differences in verbal IQ adjusted (see Table 1 for correlations and Table 3 for summary statistics). This MANCOVA showed a significant multivariate main effect for Time $F(1, 250) = 3.67$, $p = .006$ with the effect of verbal IQ removed. Significant univariate effects for WR, $F(1, 250) = 4.10$, $p = .044$; WA, $F(1, 250) = 8.52$, $p = .004$, and PC, $F(1, 250) = 4.53$, $p = .034$ were observed and effect sizes ranged from .62 for PC, .70 for WR and 1.01 for WA. Thus, similar results were achieved for three of the four reading-related DVs with or without verbal IQ entered as a covariate, although the univariate effect for WS found in the initial MANOVA was not upheld in the MANCOVA.

Using the normative data provided by the WRAT, the significant gain made in the Reading without context subscale scores (WR) equated to an average increase of approximately one grade level (1.1) during the one month of intervention. Students on average were performing at the equivalent of a grade three reading level prior to intervention and at a grade four level post-treatment. Grade norm increments for the WRMT-R Word Attack (WA) and Passage Comprehension (PC) subscales were observed at gains of two and one and a half grades respectively. On average, students extended their word attack skills from the equivalent of an average grade three level to a grade five level following the one month of intervention and their comprehension skills changed on average from a grade three level to a mid year five

Table 2
Summary Statistics for the Four Reading-Related Skills Dependent Variables by Testing Time

Variables	Testing Time	Mean ($N = 262$)	SD	95% Confidence Interval Lower Bound	Upper Bound
WRAT Reading (WR)	Pre-test	81.58	12.35	80.07	83.08
	Post-test	89.98	12.19	88.50	91.46
WRAT Spelling (WS)	Pre-test	81.35	10.25	80.10	82.60
	Post-test	84.43	10.04	83.21	85.65
WRMT-R Word Attack (WA)	Pre-test	88.21	9.23	87.09	89.34
	Post-test	97.70	9.57	96.54	98.86
WRMT-R Passage Comp (PC)	Pre-test	83.96	10.96	82.63	85.30
	Post-test	90.52	10.22	89.28	91.76

Table 3
Summary Statistics for the Four Reading-Related Skills Dependent Variables by Testing Time Evaluated with Verbal IQ as the Covariate

Variables	Testing Time	Mean ($N = 262$)	SD	95% Confidence Interval Lower Bound	Upper Bound
WRAT Reading (WR)	Pre-test	81.45	12.33	80.00	82.90
	Post-test	90.06	12.21	88.64	91.48
WRAT Spelling (WS)	Pre-test	81.47	10.33	80.26	82.68
	Post-test	84.39	10.04	83.21	85.58
WRMT-R Word Attack (WA)	Pre-test	88.22	9.26	87.12	89.33
	Post-test	97.66	9.60	96.52	98.80
WRMT-R Passage Comp (PC)	Pre-test	83.93	10.78	82.71	85.16
	Post-test	90.40	9.88	89.30	91.51

level after the intervention. The age norms provided by the WRMT-R showed 23 months increase in word attack ability for the one month treated and 12 months gain per the month of intervention in passage comprehension scores.

Oral Reading Proficiency

Three related samples t-tests were conducted to assess changes in oral reading proficiency. The Neale Analysis of Reading Ability subscale raw scores of Reading Rate (NR), Accuracy (NA) and Comprehension (NC) were the three dependent measures used. A Bonferroni correction of .02 was applied to control for Type 1 errors. Table 4 presents summary statistics for these analyses.

A significant decrease in reading rate was observed in NR scores from pre-test to post-test: $t(261) = 9.70, p < .001$ whereas accuracy and comprehension scores significantly increased following the Cellfield Intervention. For the NA analysis $t(261) = -19.24$, $p < .001$ was observed and for the NC analysis $t(261) = -17.74$, $p < .001$. These results indicate that students made a speed accuracy trade-off meaning that a significantly slower reading rate was employed in order to read significantly more accurately and with significantly better comprehension following the treatment. Standardised effects were calculated at $d = .39$ for NR, $d = .46$ for NA and $d = .52$ for NC.

Ocular Measures

Ocular measures of foveal position (FP), foveal stability (FS) and contrast sensitivity (CS) recorded for each eye were used in a series of chi-square tests to assess if there were any changes in these visual assessments following the Cellfield treatment. Recordings of zero represented normal FP, FS and CS while recordings of one meant the measures taken were abnormal. That is, off centre FP, unsteady FS and CS outside the normal range. Since there were very few recordings (frequency range 1 to 8, mean = 1.5) made in the worst category (i.e., FP way off centre, FS very unsteady, or a CS defect), this category was collapsed with the non-normal category. Frequency data are presented in Table 5.

The six chi-square tests showed that post-test frequencies for the optic measures differed significantly compared with expected frequencies based upon the pre-test recordings. For FP left eye x^2 (1) = 22.31, $p < .001$; for *FP* right eye x^2 (1) = 41.15, $p < .001$; FS left eye x^2 (1) = 110.92, $p < .001$; for FS right eye x^2 (1) = 99.32, $p < .001$; for CS left eye x^2 (1) = 46.15, $p < .001$; and for CS in the right eye x^2 (1) = 52.25, $p < .001$. In all instances, less recordings than expected were made in the non-normal category and significantly more than expected were made in the normal category at the post-test. Thus, a significant number of participants whose foveal position, stability and contrast sensitivity were registered as being outside the normal range prior to intervention were appraised as being within the normal range following intervention.

Table 4
Summary Statistics for the Three Oral Reading Proficiency Dependent Variables by Testing Time

		$N = 262$		95% Confidence Interval of the Difference	
Variables	Testing Time	Mean	SD	Lower Bound	Upper Bound
Neale Reading Rate (NR)	Pre-test	54.82	24.17	7.44	11.23
	Post-test	45.49	23.44		
Neale Accuracy (NA)	Pre-test	32.32	19.07	-10.63	-8.66
	Post-test	41.97	22.44		
Neale Comprehension (NC)	Pre-test	14.40	8.67	-4.27	-17.74
	Post-test	19.20	9.83		

Table 5
Frequency Data for Optic Measures Recorded for Right and Left Eyes

		$N = 222$			
		Pre-Test		Post-Test	
Measures	Eye Tested	Normal	Non-Normal	Normal	Non-Normal
Foveal Position	Left Eye	195	27	218	4
	Right Eye	184	38	220	2
Foveal Stability	Left Eye	123	99	201	21
	Right Eye	120	102	194	28
Contrast Sensitivity	Left Eye	179	43	219	3
	Right Eye	175	47	219	3

Discussion

This study provides preliminary support for the efficacy of the Cellfield Intervention. The results show that this combination of computer-based exercises derived from contemporary theory has a positive impact on reading-related skills, oral reading proficiency, and ocular measures in the clinical sample assessed. While it is not possible to make inferences with regard to specific aspects of the intervention, the data provide evidence for the benefits participants have experienced as a result of their exposure to its integrated format. Hence, the conjecture over double or even multi-deficit hypotheses of dyslexia and our contention that intervention should reflect this by adopting a multi-deficit focus appear germane.

Word attack skills showed the greatest gains following the Cellfield Intervention with a strong effect (d = 1.01) recorded whether verbal IQ pre-intervention scores were adjusted or not. This means that regardless of one's verbal IQ level, participants' ability to pronounce phonemes was markedly enhanced following intervention. This represents an accelerated gain of 23 months or an advance of two entire grade levels for the duration of intervention. Given that over half the participants took two weeks or less to complete the ten sessions and two thirds of participants completed them in less than one month, this is indeed an extraordinary result. To put this into perspective, intervention studies tend to report reading age gains of 2 months per 1 month of intervention as being noteworthy since this "is twice what might be expected of normal readers" (Clisby et al., 2000, p. 12). In the present study, word attack skills improved 23 times per 1 month of intervention.

The improvement in reading words without context was also of practical significance given the moderate effect size recorded whether verbal IQ was taken into consideration (d = .7) or not (d = .68). Likewise, scores on passage comprehension using the cloze technique demonstrated meaningful gains following the Cellfield Intervention with or without verbal IQ controlled for (d = .62). These two results correspond to normative data gains of one grade level and 12 months age increase respectively over the ten sessions. Once again this represents markedly accelerated gains compared to the literature wherein an increase of three months over two months of treatment has been reported as "creditable ... for students whose history of reading is below the normal trajectory of development" (Le Fevre, Moore, & Wilkinson, 2003, p. 45). Finally, although spelling skills showed a modest improvement at the post-test (d = .3), this gain was not found to be significant when differences in pre-treatment verbal IQ were considered.

It should be noted that the improvements made in all reading-related skills were similar for those participants who were identified as being at risk of dyslexia and for those who were not. Hence, this integrated approach (or some components of it) to the amelioration of reading difficulties appears to result in significant gains in reading-related skills for students with profound reading difficulties as well as for those with less severe deficits.

In terms of oral reading in context, results again demonstrated significant improvements. Students read more proficiently after the Cellfield Intervention as reflected by a decrease in reading rate (d = .39) accompanied by elevated scores for reading accuracy (d = .46) and comprehension (d = .52). Observational records showed that prior to treatment, the principal reading strategy employed was to guess unknown words based on their first letter(s) or their similarity to familiar words. Students were also observed to substitute and/or leave words out at the pre-test. Conversely, during post-intervention assessment, participants were observed to slow down and actively sound out and break down words in an effort to decode them. The reduced reading rate was also attributable to an engagement in more self-corrective behaviour, which demonstrated that students were gaining more meaning from what they were reading. The gains in reading related skills and oral proficiency reported in this study appear large enough to question the likelihood that they could be attributed to regression to the mean, to a Hawthorne effect, or to placebo effects.

In addition to the benefits students experienced in terms of reading-related skills and oral reading proficiency, results pertaining to the ocular measures taken prior to and following the Cellfield Intervention were also encouraging with regard to the efficacy of this integrated approach. Ninety per cent of those who were assessed as having a foveal position off centre at the pre-test were found to have a corrected foveal position at post-test. The chi-square results, averaged across left and right eye recordings, showed that participants were 12 times more likely to be assessed as having a centred foveal position at post-test than at pre-test. Foveal stability also improved with 65% of those with recordings of instability prior to intervention having readings within the normal range after intervention. Participants were seven times more likely to be assessed as having normal foveal stability after treatment than before. Thirdly, contrast sensitivity also significantly improved with 93% of those evaluated as being outside the normal range being assessed as exhibiting normal levels of contrast sensitivity after treatment. Odds ratios for this result demonstrated that participants were 19 times more likely to be given a normal contrast sensitivity rating at post-intervention than at pre-intervention.

Notwithstanding these impressive results, there are several limitations to this study that should be taken into consideration. Firstly, a convenience sample of those seeking intervention for reading difficulties was employed. Thus, the generalizability of these results is uncertain. The students who undertook the Cellfield treatment during the span of this study may be peculiar to the population of Australian students who experience difficulty learning to read. The Cellfield Intervention is a commercial venture that requires a certain monetary investment on behalf of parents and thus the participants in the present study's sample may be representative of those who have reading difficulties but who have the financial resources to support attempts to ameliorate their predicament. It is recommended that future research independent of the Cellfield Clinic, be devoted to the evaluation of this intervention amongst a wider and more representative sample of Australian students who require assistance with reading difficulties.

Further research is also needed to establish the long term benefits of the Cellfield Intervention. Perhaps future studies could examine whether ongoing learning support with, for instance, one-on-one phonological awareness lessons, could augment the gains made immediately following this intensive computer-based treatment. Moreover, anecdotal evidence suggests that if teachers are supportive of the benefits of the Cellfield Intervention, their students tend to make more positive incremental gains as opposed to those under the influence of teachers who view the intervention as placebo-like. Again, this would need to be assessed systematically to determine if such effects were indeed plausible.

Another consideration for future research is the possible impact of gains in self-esteem or self-efficacy for reading as a result of the Cellfield Intervention. Clinicians who dealt first hand with the students in the present study reported that participants typically exhibited reduced motivation and even reported physical stress at the initial two or three sessions. By about the middle sessions of intervention, motivation usually improved with enhanced competence. By the end of the ten sessions, motivation and self confidence tended to be high. It may be pertinent in future to attempt to determine whether levels of esteem, efficacy and/or motivation have substantial impact upon intervention outcomes. Thus, measures of these person-centred variables could be analysed in conjunction with reading-related measures in future research studies.

Finally, the limitations of the scales used to assess the Cellfield Intervention should be noted. First, Australian normative data was only available for the Neale-3. The WRAT-3 and WRMT were both normed on American populations, whilst the DST was normed on a British population. Consequently, caution should be taken when comparing to other populations. Second, the WRAT-3 does not provide reading age equivalencies, which restricts interpretation and comparison to a same-age population. This is of particular concern in relation to wide age ranges within each classroom group, as well as State differences in Year level structure (i.e., Queensland and Western Australia do not have a preparatory year). Third, there are no norms or interpretive information available for children above primary school level for the Neale-3. Further, reading age comparisons for primary school students are not provided in excess of 13-years, prohibiting a reading age comparison for children who excel for their age. Finally, qualitative observations of outcomes for the DST suggest that the ceiling limits may be too low at the upper end for each normative age group leading to the possibility of false negatives (children who are found to be in the not at risk range, but should be). This appears to be particularly pertinent for the timed reading and spelling tasks, and the timed nonsense passage task.

This paper provides an initial evaluation of the efficacy of the Cellfield Intervention for reading difficulties. It has highlighted the need for an integrated approach to the amelioration of reading difficulties via a computer-based series of sessions that incorporate research findings concerning the multiple causes of dyslexia. It is hoped that the results reported herein will prompt theorists and practioners to examine the Cellfield Intervention with intense scrutiny and critically investigate its contribution to the field. In addition, it is our aim to encourage teachers to view this intervention as a welcome adjunct to their practice. We believe that the Cellfield Intervention represents a beneficial approach to the rapid amelioration of visual and auditory magnocellular-related deficits of students experiencing reading difficulties, but one which nonetheless requires teachers' professional and ongoing follow-up assistance post-treatment.

References

Bishop, D. V. M., Carlyon, R. P., Deeks, J. M., & Bishop, S. J. (1999). Auditory temporal processing impairment: Neither necessary nor sufficient for causing language impairment in children. *Journal of Speech, Language and Hearing Research, 42*, 1295-1310.

Castles, A., & Coltheart, M. (1993). Varieties of developmental dyslexia. *Cognition, 47*, 149-180.

Castles, A., & Coltheart, M. (2004). Is there a causal link from phonological awareness to success in learning to read? *Cognition, 91*, 77-111.

Clisby, C., Fowler, M. S., Hebb, G. S., Walters, J., Southcott, P., & Stein, J. F. (2000). Outcome of treatment of visual problems in children with reading difficulties. *Professional Association of Teachers in Special Situations Bulletin*, 9-14.

Ehri, L. C. (1998). Research on learning to read and spell: A personal-historical perspective. *Scientific Studies of Reading*, 2(2), 97-114.

Fawcett, A. J., & Nicolson, R. I. (1999). Performance of dyslexic children on cerebellar and cognitive tests. *Journal of Motor Behavior*, *31*(1), 68-7 8.

Fawcett, A. J., & Nicolson, R. I. (1996). *The Dyslexia Screening Test: Manual.* The Psychological Corporation: London.

Gillon, G. T. (2000). The efficacy of phonological awareness intervention for children with spoken language impairment. *Language, Speech, and Hearing Services in Schools, 31,* 126-141.

Hart, W. M. Jr. (1992). *Adler's physiology of the eye* (9th ed.). St. Louis: Mosby-Year Book, Inc.

Le Fevre, D. M., Moore, D. W., & Wilkinson, I. A. G. (2003). Tape-assisted reciprocal teaching: Cognitive bootstrapping for poor decoders. *British Journal of Educational Psychology, 73,* 37-58.

Levinson, H. N. (1988). The cerebellar-vestibular basis of learning disabilities in children, adolescents and adults: Hypothesis and study. *Perceptual and Motor Skills, 67,* 983-1006.

Lovegrove, W. (1999, July). *Visual information processing in dyslexics* (Professorial Lecture). Griffith University, Nathan Campus, Brisbane.

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). Defining dyslexia, comorbidity, teachers' knowledge of language and reading. *Annals of Dyslexia, 53,* 1-14.

Miles, T. R., & Miles, E. (1991). *Dyslexia a hundred years on.* Philadelphia: Open University Press.

Neale, M. D. (1999). *Neale Analysis of Reading Ability:* Manual (3rd ed.). Australian Council for Educational Research: Melbourne, Australia.

Nicolson, R. I., & Fawcett, A. J. (1990). Automaticity: A new framework for dyslexia research. *Cognition, 35,* 159-182.

Nicolson, R. I., Fawcett, A. J., & Dean, P. (2001). Developmental dyslexia: The cerebellar deficit hypothesis. *Trends in Neurosciences, 24*(9), 508-511.

Ramus, F. (2001). Talk of two theories. *Nature,* 412, 393-395.

Ramus, F., Rosen, S., Dakin, S. C., Day, B. L., Castellote, J. M., White, S., & Frith, U. (2003). Theories of developmental dyslexia: insights from a multiple case study of dyslexic adults. *Brain, 126,* 841-865.

Reynolds, D., Nicolson, R. I., & Hambly, H. (2003). Evaluation of an exercise-based treatment for children with reading difficulties. *Dyslexia, 9,* 48-71.

Shaywitz, S. E. (1998). Current concepts: Dyslexia. *The New England Journal of Medicine, 338*(5), 307-312.

Slosson, R. L. (2002). *Slosson Intelligence Test for Children & Adults 3rd Revision: Technical Manual.* Slosson Educational Publications: New York.

Stein, J. F., Richardson, A. J., & Fowler, M. S. (2000). Monocular occlusion can improve binocular control and reading in dyslexics. *Brain, 123,* 164-170.

Stein, J., & Talcott, J. (1999). Impaired neuronal timing in developmental dyslexia - The magnocellular hypothesis. *Dyslexia, 5,* 59-77.

Stein, J., & Walsh, V. (1997). To see but not to read: The magnocellular theory of dyslexia. *Trends in Neurosciences, 20*(4), 147-152.

Talcott, J. B., Witton, C., McLean, M. F., Rees, A., Green, G. R., & Stein, J. F. (2000). Dynamic sensory sensitivity and children's word decoding skills. *PNAS, 97*(6), 2952-2957.

Torgesen, J. K. (2000). Individual differences in response to early interventions in reading: The lingering problem of treatment resisters. *Learning Disabilities Research & Practice,* 15(1), 55-64.

Wechsler, D. (1991). *Manual for the Wechsler Intelligence Scale for Children-III.* San Antonio, TX: Psychological Corporation.

Wilkinson, G. S. (1993). *Wide Range Achievement Test: Administration Manual Third Edition.* Wide Range: Delaware, USA.

Wolf, M., Miller, L., & Donnelly, K. (2000). Retrieval, automaticity, vocabulary elaboration, orthography (RAVE-O): A comprehensive, fluency-based reading intervention program. *Journal of Learning Disabilities, 33*(4), 375-386.

Woodcock, R. W. (1998). *Woodcock Reading Mastery Tests – Revised: Examiner's Manual.* American Guidance Service: Minnnesota, USA.