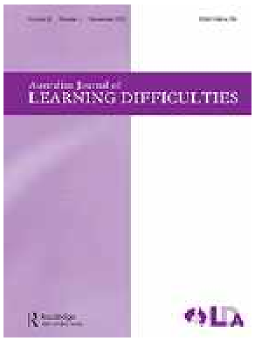

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A longitudinal study of the efficacy of the Cellfield reading intervention in a South African context

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ABSTRACT
The Cellfield reading intervention is based on the multi-deficit theory of reading difficulties and addresses several foundation skills of reading simultaneously. Existing research has confirmed that the Cellfield intervention leads to improvement in reading skill directly following the intervention, but little data exist to determine the long-term efficacy of Cellfield. The present study investigated the long-term efficacy of the Cellfield intervention in a group of South African children. Fifty-two struggling readers were assessed via two standardised tests (Woodcock Reading Mastery Tests and Gray Oral Reading Test). Of the 52 readers, 41 underwent the Cellfield intervention, while 11 did not. Children were assessed on six reading variables before the intervention and directly following the intervention (treatment group). Both groups were re-assessed on the same variables at least a year after the intervention ended. Statistical analyses showed that advances in the treatment group directly after the intervention were maintained in the long term.

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Introduction

Worldwide, many children struggle to acquire age-appropriate reading levels in the expected time frame, risking academic failure (Meeks, Madelaine, & Stephenson, 2020; UNESCO Institute of statistics, 2015; World Bank, 2016). This is also true in the South African context, where large scale national assessments suggest that many learners don't reach their literacy milestones, such as knowing the letters of the alphabet at the end of Grade 1, and reading with understanding at the end of Grade 3 (Spaull, 2016, 2023; Van der Berg, 2015). Research suggests that reasons for literacy delays include poverty, overcrowded classrooms, underdeveloped pre-literacy skills, language barriers, poor instruction, mismanaged schools, underqualified teachers and learning difficulties (Howie et al., 2017; Spaull & Pretorius, 2019). For a subset of struggling readers, weak reading skills may be caused by developmental disorders – within the group of children with learning difficulty in reading, around 10% of the population will be diagnosed with dyslexia (also referred to as Specific Learning Difficulty in Reading, the recommended term in the fifth

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revised edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V)). For these children, the difficulty tends to be more severe, is persistent, and contrasts with other areas of academic achievement in that they have average, to above average IQ. The debate about which struggling readers should be diagnosed as dyslexic continues, as reading difficulties present in various ways, and weak readers have mixed profiles in terms of their difficulties. Shaywitz (2005, p. 139) suggests that a wide range of factors should be considered when diagnosing dyslexia and says that there is "no single test score that ensures diagnosis of dyslexia. It is the overall picture that matters". What has been clearly established though is that teaching methods and interventions designed for dyslexic students are effective for most weak readers, regardless of their diagnosis. According to Ramus (2014), existing evidence suggests that explicit phonics-based intervention programmes, that are both intensive and systematic, are effective (albeit moderately) in the remediation of heterogeneous groups of poor readers.

In the South African context, many children grow up in high-poverty contexts and perform below expected levels in reading (Spaull, 2023), yet few of these children will officially be diagnosed as reading disabled. Establishing the long-lasting effectiveness of interventions that were traditionally developed for dyslexic readers could thus be meaningful for struggling readers in this context. The present study investigated the long-term efficacy of the dyslexia intervention programme, Cellfield, in a group of South African children identified as struggling readers, where the underlying reason for the learning difficulty has not been clearly established for every participant. The reading deficits in the present sample were most likely heterogeneous, falling into three quadrants of Gough and Tunmer's (1986) Simple View of Reading, namely weak decoding, weak comprehending and co-morbid. We therefore deemed that the term "reading disabled" is more appropriate to use with the current sample. In the sections that follow, we briefly describe the theory that underlies Cellfield, as well as the structure of the intervention.

The multiple-deficit theory of reading difficulties

The complex nature of reading acquisition relies on multiple levels of skill that interact simultaneously (Pennington et al., 2012; Ring & Black, 2018). Potential difficulties can surface because of a deficit in phonological, cerebellar, auditory, and/or visual processing. Traditionally, several theories, including the phonological deficit hypothesis (hypothesizing that weak decoding is caused by inadequate phonological processing skills), the cerebellar deficit theory (attributing difficulty in reading skills to a deviation in the cerebellum, which impacts on the ability to automatize skills) and the magnocellular theory (postulating a dysfunction in either the visual or auditory magnocellular system) attempted to explain reading failure as a result of single deficit, in a specific area.

From a theoretical perspective, the challenge is that deficits associated with specific reading disorder do not occur in a consistent or predictable manner. Visual or auditory difficulties can occur without phonological impairment, rapid naming deficits can occur in the absence of phonological impairment, some children can read irregular words but not pseudowords, and so on. Single deficit theories cannot explain this, nor that co-morbidity can occur with other disorders such as Specific Language Impairment or Attention Deficit and Hyperactivity Disorder (Pennington, 2006; Van Bergen, van der Leij, & de Jong, 2014). In contrast, the multiple-deficit theory can explain the heterogeneous nature of reading disorder, accounts for the continuous nature of difficulties and clarifies the existence of co-morbidity amongst associated disorders (de Jong & van Bergen, 2017; Snowling, Hulme, & Nation, 2020; Tschentscher, Ruisinger, Blank, Diaz, & Kriegstein, 2019; Van Bergen et al. 2014). Ring and Black (2018) support the multi-deficit model of reading and argue that poor reading may stem from a number of risk factors beyond diminished phonological awareness skills. Whilst the multi-deficit model is more realistic in terms of multiple symptoms presenting in children struggling with reading, it does complicate the process of making decisions about instructional practices and remediation for children who don't progress in reading skill in the expected timeframe. In addressing this complication, Protopapas (2019) suggests that since there is now broad agreement that reading skill depends on the development of multiple skills on multiple levels, it is also makes sense that assessment and remedial efforts are focused directly on the pre-requisites that determine reading development. Since the visual, auditory, phonological and motor skills, as well as working memory skills associated with reading often are not activated simultaneously in the brain of an impaired reader (Christodoulou et al., 2014; Shaywitz, 2005; Waldie, Wilson, Roberts, & Moreau, 2017), it makes sense to design interventions that address this. Cellfield is an example of a multifaceted intervention, as it simultaneously remediates *multiple* skills that could be impaired. This contrasts with most reading interventions that target *specific* difficulties i.e. either auditory, visual or motor deficits.

The Cellfield intervention

In line with research that shows that concentrated interventions are more effective than drawn out interventions (Solis, Miciak, Vaughn, & Fletcher, 2014; Wolff, 2011), Cellfield consists of ten 1-h computerized sessions, conducted by a licensed practitioner over a two- to three-week period. Each of the ten sessions includes exercises which target phonological awareness, visual and auditory processing, ocular/motor skills, orthographic skills, working memory, coding, and decoding skills. For the most part, letters, words or sentences that are presented visually have corresponding aural input. This stimulates visual-auditory neural pathways that are activated in proficient reading. The Cellfield intervention contains five levels of difficulty. The pre-assessment determines which level will be used so that the participant works in a band that is challenging but achievable.

The letter-sound association task reinforces grapheme–phoneme associations. The rhyming task presents a target word, broken into its phonemes. Four rhyming words are then presented, and the participant is required to select the target word. For the initial sessions, the word is acoustically modified with a "stretch" to enable the struggling reader to hear the individual sounds that comprise the word. This stretch is reduced over the sessions until normal speech speed in the last two sessions. Letter sounds that are close in sound, for example, /f/,/th/and/v/ or those easily confused (/b/and/d/) are presented in a rhyming set. In this way, auditory discrimination skills, correct grapheme representation, and phonological awareness skills are addressed. The homophone task presents a homophone set and a sentence for selection of the appropriate homophone option. For example, the homophone pair *blue* and *blew* is presented with a corresponding aural sentence: *We painted our boat blue*. The participant is required to select the appropriate option. The added semantic aspect of this task stimulates the simultaneous activation of neural areas that process visual, auditory, orthographic and semantic information.

Embedded text exercises strengthen phonological awareness and demand high levels of attention and working memory. A target phrase is presented visually and aurally, then removed. The participant is required to hold the phrase in working memory and then scan for the target words that are embedded in moving text, select the appropriate words, and paste them onto the correct line. The phrases increase in length and complexity depending on the level and the session, for example, *the thin pin* to *it is faster to travel by plane*. By integrating moving text, eye movement control is also addressed.

The decoding and encoding exercises require the candidate to code a set of words into pseudowords and then decode pseudowords back into words. The decoded/coded word must then be held in working memory and the target word retrieved from rows of words that are scrolling across the screen. This decoding exercise is a phoneme manipulation task that is similar in concept to "Pig Latin". Manipulating the words demands high cognitive effort and good working memory, with the ability to pay attention to, discriminate recall and manipulate sounds at the word level (Hester & Hudson, 2004; Strattman & Hodson, 2005). Additionally, pseudoword reading requires good phoneme-grapheme knowledge and high levels of phonological processing.

In the embedded text and decoding exercises, the candidate is required to scan through moving text to identify and select the target word within a limited time. This encourages extending visual span. While the causal impact of visual span on reading is debated, much research has been done to show that there is a correlation between reading and visual attention span (Bosse, Tainturier, & Valdois, 2007; van den Boer & de Jong, 2018; Zoubrinetzky, Bielle, Valdois, & Kroesbergen, 2014).

Between each of the exercise groupings, a mosaic exercise provides a break from the "reading exercises", and at the same time enhances spatial skills, pattern recognition, retention of visual information, scanning and eye/hand motor control. Motion graphics and dots that appear and disappear are superimposed over all exercises, which stimulate the magnocellular pathways and provide enhancement of the control of eye movement, peripheral vision and visual persistence. The use of motion graphics and dots that appear and disappear are also believed to improve working memory and sequencing skills (Prideaux, Marsh, & Caplygin, 2005). The motion graphics are translucent in the early sessions, gradually becoming more opaque, until they are solid. For children who display visual fixation instability or eccentricity during the pre-Cellfield visual examination, red lens filtering is integrated into some of the sessions.

Cellfield allocates scores for each exercise and participants earn "smiley faces", which provides immediate positive feedback and motivates children to improve their own scores from the previous session. Additionally, since Cellfield is a computerised programme, it is presented in gaming style, with scoring, time limitations, novelty and challenges embedded in the programme to keep the reader engaged and motivated. Intense intervention, repetition, and stimulation have been shown to result in changes to neural pathways (Fälth, Gustafson, Tjus, Heimann, & Svensson, 2013; Feuerstein, Falik, & Feuerstein, 2013; Frijters et al., 2017; Van Gorp, Segers, & Verhoeven, 2016).

Although Cellfield was originally designed for dyslexia, it has been shown to improve reading for all weak readers, not only those diagnosed with dyslexia (Prideaux, Marsh, & Caplygin, 2005). Existing studies have shown the improvement of reading skills immediately following the Cellfield intervention, but, to our knowledge, no formal research has been done to assess whether gains are retained in the long term. To address this gap, the aim of the present study was to answer the following questions:

- What are the long-term outcomes of the Cellfield intervention in a South African context?
- How does the development of reading skills in children who underwent the Cellfield intervention compare, over time, to reading development in children (with reading difficulties) who have not received the Cellfield intervention?

Methodology

The present study employed a longitudinal quasi-experimental design. Ethical clearance for the study was obtained from the University of South Africa College of Human Sciences Research Ethics Review Committee. Informed consent and assent forms were signed by parents and children respectively, giving the researcher permission for the data collected in the testing to be used for the research. In addition, permission was obtained from parents to use secondary data (i.e. the baseline assessment and assessment immediately following the intervention, which was conducted prior to the onset of the current study).

Participants

The sample consisted of 52 children (33 males) who experienced reading difficulties and who were referred for reading intervention via their various schools, educational psychologists or other professionals. The participants had an age range of 7:3 to 16:3. All children attended schools that used English as a medium of instruction. The 52 participants all exhibited significant impairment in reading, as reflected on the baseline assessments, which were done between September 2016 and July 2019. For this study, the criterion of "significant impairment" were children that scored 12 months or more behind their age-appropriate level in one or more of the following subtests: Word Attack (as measured on the Woodcock Reading Mastery Test); Reading Rate (as measured on the Gray Oral Reading Test); Comprehension (as measured on the Gray Oral Reading Test).

Forty-one children (treatment group) completed the Cellfield intervention following the baseline assessment, while 11 children (control group) did not proceed with the intervention, due to financial constraints, time commitments or the parents felt that they were not significantly behind and that the cost of the intervention programme was not justified. Children that proceeded with the intervention completed ten 1-h sessions over a two- to three-week period. Some of the children in the control group received once a week 45-min remedial sessions in the reading centre.

Procedure

At the start of 2020, 104 parents of children who had been assessed in the centre, a year or more prior to the onset of the study, were invited to participate in the research. Fifty-two families agreed to participate, of which 41 children had undergone Cellfield. Eleven of the 52 children had not undergone Cellfield but also consented to participate in the study and be tested to determine changes in their reading skills from the baseline assessment point.

Due to COVID lockdown restrictions which were in place during 2020, assessments were mostly conducted online. A suitable time was arranged, and parents assisted with remote computer access if required for younger children. When lockdown restrictions were eased, participants were assessed in person.

Instruments

Standardised reading assessment instruments (the Woodcock Reading Mastery Test (WRMT) and the Gray Oral Reading Test (GORT)) were used to assess reading development across six areas of reading. Validity and reliability data are reported in the manuals. Although the assessments were normed on samples in the United States of America, norms were deemed to be applicable for the current sample, considering the majority of the participants were English home language speakers, and schooled at private schools where the curriculum is often aligned to international curricula. A questionnaire, custom-designed by the researcher, was used to gather additional information from the participants such as biographical information, previous history of difficulties and any regular therapies or medication used.

Woodcock Reading Mastery Test – Revised (WRMT-R)

The WRMT-R (Woodcock, 1998) is a psycho-educational instrument that measures encoding and decoding skills which are needed to acquire basic reading skills. For all subtests, a ceiling is reached when the individual answers six consecutive items incorrectly and all items on a test page are administered. Correct responses are score with one, and incorrect response (or failure to respond) with zero. The number of correct responses constitutes the raw score. The WRMT-R has parallel tests (Form G and Form H) to facilitate re-testing before and after intervention. The Word Identification, Word Attack and Passage Comprehension subtests of the WRMT-R were administered in this study. The Word Identification test (maximum raw score: 106) requires the individual to read aloud a list of words in isolation. The test is a measure of sight-word vocabulary, i.e. it measures how well an individual can recognise known words. The words are arranged in order of increasing difficulty from *is* to *zeitgeist*. The Word Attack test (maximum raw score 45) requires the child to read aloud nonsense words of increasing difficulty, such as *pog* and *straced*. The test is widely accepted as an indicator of decoding ability. Indirectly, it measures phonological processing ability, as it measures an individual's ability to apply phonic and structural analysis skills to unfamiliar words. The Passage Comprehension test (max raw score 68) measures an individual's ability to study a short passage, usually two to three sentences long, and to supply a key word missing from the passage. A correct response demonstrates the subject's understanding, not only of the sentence with the missing word, but the entire passage. This is a silent reading exercise (only the missing word is presented aloud to the tester). The first third of the items contain a picture related to the text which presents a cue for the answer. The remainder of the items are text only.

Gray Oral Reading Test 4 and Test 5 (GORT-4 and GORT-5)

The GORT-4 (Wiederholt & Bryant, 2001) is a measure of oral reading ability, assessing both reading fluency (speed and accuracy) and reading comprehension. It consists of 14 passages of increasing length and difficulty, starting with a five-sentence story. Each passage has five questions related to the text. Basal and ceiling levels are established by using a conversion table, provided on the answer booklet, which translate scores into a score between zero and five. The GORT-4 has parallel tests (Form A and Form B) to facilitate re-testing before and after intervention.

The Reading Rate, Reading Accuracy and Comprehension sub-tests were administered in the present study. In the Reading Rate test, each of the passages is read aloud by the child and the time, in seconds, is recorded. The time is converted to a point score between zero and five, where five is the best and zero is the worst score. A discontinuation score is a score of one point. In the Accuracy test, the number of errors is recorded. The total number of errors is converted to a point score, resulting in a score between zero and five (with five as the best score). A discontinuation score for accuracy is a score of one point. In the Comprehension test, following the reading of each passage, the child has to answer five questions, without referring back to the text. The score is the total number of correct answers out of five. The test is discontinued when the child answers two or fewer questions correctly.

GORT-5 (Wiederholt & Bryant, 2012) is an updated version of the GORT-4. There are 16 separate stories which increase in length and difficulty. The procedure for testing is the same as for GORT-4. The questions on the updated version are open ended as opposed to multiple choice (as in GORT-4). Additional feature changes of the GORT-5 are new normative data, an extended age range and additional reliability and validity studies added. Because of the extended period of data collection, both versions of the GORT were used in this study (the GORT-5 was acquired by the first author, and subsequently used for assessment before the inception of the longitudinal study). Children that were originally assessed with the GORT-4 at the baseline test, were assessed with the GORT-4 at all subsequent measurement points. Similarly, children assessed on GORT-5 at the baseline test were tested using the same test on all assessments.

Overview of assessments

Secondary data from the baseline and post Cellfield assessments were available for the treatment group. For the control group, as there was no intervention, there was no midline assessment. Table 1 provides an overview of how the assessment forms were administered:

Table 1. Testing procedure for the treatment and control groups.

	WRMT-R	GORT 4/5
Treatment group		
Baseline (before Cellfield intervention):	Form G	Form A
Conducted between 11.2014–07.2019, secondary data		
Post-test (directly after Cellfield intervention):	Form H	Form B
Conducted between 02.2015–08,2019, secondary data		
Delayed post-test (minimum of 12 months after Cellfield intervention):	Form G	Form A
Conducted between 03.2020–09.2020		
Control group		
Baseline:	Form G	Form A
Conducted between 09.2016–07.2019, secondary data		
Delayed post-test:	Form H	Form B
Conducted between 03.2020–09.2020		

It is important to note that the time difference between the assessment points was not even. On average, there was 1.5 months between the baseline and the immediate post-test, while 27.8 months passed between the post-test and the delayed post-test.

Data analysis

During the initial data processing, raw scores from the assessments were converted to standard scores and age-equivalent measures were recorded in spreadsheets to calculate the means for each subtest and group. Jamovi V1.2.27 and IBM SPSS (Version 28) were used for data analysis. For all inferential analyses, the independent variable was the Cellfield intervention, and the dependent variables were the six reading measures, namely Word Identification, Word Attack and Passage Comprehension (WRMT), and Rate, Accuracy and Comprehension (GORT). A Shapiro–Wilk test indicated that the data violated the assumption of normality in both the treatment group and the control group on several variables. Given the non-normal distribution of the data, and the small sample size of the control group, non-parametric tests (the Friedman, Kruskal-Wallis and Wilcoxon tests) were deemed appropriate to determine statistical significance of differences within and between groups. Since we opted not to run a repeated measures multivariate analyses, we acknowledge that our data analysis plan limits our interpretation of the findings. Although we can compare the treatment and control groups, we will not be reporting the interaction between time and group, and thus we cannot statistically confirm that group differences are due to an intervention effect.

Results

The descriptive statistics (mean standard scores) for the treatment and control groups are provided in Table 2. Standard scores are based on a norming sample, where a score of 100 indicates an appropriate score for the participant's age on the three Woodcock Reading Mastery Test subtests, and a score of 10 indicates an age-appropriate score on the three Gray Oral Reading test subtests.

The short- and long-term efficacy of the Cellfield intervention in a South African context

To assess the immediate gains in reading skill following the Cellfield intervention, as well as gains over time in the treatment group, all six dependent variables were considered at the three testing points (baseline, post-test and delayed post-test). The results of the Friedman test and Durbin-Conover pairwise comparisons are shown in Table 3.

The Friedman tests confirmed that, for each variable, there was a significant improvement from the baseline test to the post-test. Likewise, the statistics suggested that there were significant improvements in all variables from the baseline assessments to the delayed post-test assessments. Only Reading Rate significantly improved significantly from the post-test to the delayed post-test. Effect sizes (Kendall's W) for the observed differences from the baseline to the post-test and from the baseline to the delayed post-test were calculated, and are presented in Table 4.

Table 2. Descriptive statistics: Standard Scores per variable for treatment and control groups.

	Group	WI Base Std Score	WI Post Std Score	WI Delay Std Score	WA Base Std score	WA Post Std Score	WA Delay std score	PC Base std score	PC Post Std Score	PC Delay Std Score	Rate Base Std Score	Rate Post Std Score	Rate Delay Std Score	Acc Base Std Score	Acc Post Std Score	Acc Delay Std score	Comp Base Std Score	Comp Post Std Score	Comp Delay Std Score
Mean	Treatment	90.4	96.3	99.2	92.7	102	103	93.2	97.8	100.0	6.39	6.85	7.61	7.54	9.46	9.76	8.20	9.78	9.83
	Control	100	–	97.6	98.5	–	99.2	91.9	–	93.6	7.00	–	7.73	9.36	–	10.3	8.73	–	9.18
Median	Treatment	89.0	94.0	97.0	93.0	101	101	93.0	98.0	100	7.00	7.00	7.00	8.00	9.00	10.0	8.00	10.0	10.0
	Control	97.0	–	99.0	103	–	99.0	92.0	–	94.0	7.00	–	7.00	9.00	–	10.0	9.00	–	9.00
Standard deviation	Treatment	6.34	6.77	10.0	5.98	6.32	8.70	7.43	7.07	7.08	2.01	2.40	1.58	1.92	1.50	1.30	1.89	1.72	1.56
	Control	6.12	–	4.78	6.96	–	9.14	7.25	–	6.12	1.48	–	1.90	2.42	–	1.35	1.68	–	1.60
Range	Treatment	24.0	30.0	46.0	25.0	25.0	47.0	29.0	34.0	29.0	8.00	11.0	8.00	9.00	6.00	5.00	9.00	7.00	7.00
	Control	17.0	–	14.0	20.0	–	30.0	24.0	–	20.0	4.00	–	5.00	8.00	–	5.00	5.00	–	5.00
Minimum	Treatment	81.0	85.0	85.0	81.0	91.0	88.0	78.0	77.0	86.0	3.00	2.00	4.00	4.00	7.00	7.00	3.00	6.00	6.00
	Control	93.0	–	89.0	86.0	–	87.0	83.0	–	83.0	5.00	–	5.00	5.00	–	7.00	6.00	–	7.00
Maximum	Treatment	105	115	131	106	116	135	107	111	115	11.0	13.0	12.0	13.0	13.0	12.0	12.0	13.0	13.0
	Control	110	–	103	106	–	117	107	–	103	9.00	–	10.0	13.0	–	12.0	11.0	–	12.0
Shapiro-Wilk W	Treatment	0.964	0.936	0.916	0.981	0.962	0.917	0.971	0.971	0.983	0.935	0.971	0.936	0.931	0.923	0.938	0.932	0.954	0.959
	Control	0.855	.	0.904	0.836	.	0.955	0.937	.	0.974	0.875	.	0.824	0.954	.	0.808	0.945	.	0.910
Shapiro-Wilk p	Treatment	0.217	0.024	0.005	0.719	0.182	0.006	0.376	0.361	0.776	0.022	0.378	0.023	0.015	0.008	0.027	0.017	0.100	0.145
	Control	0.049	–	0.209	0.028	–	0.709	0.490	–	0.925	0.090	–	0.019	0.689	–	0.012	0.580	–	0.241

Treatment group $n = 41$, Control group $n = 11$.
Base = baseline test; Post = Post-test; Delay = Delayed post-test.
Exp = Treatment group; Control = Control group.
WI = Word Identification, WA = Word Attack, PC = Passage Comprehension, Acc = Accuracy, Comp = Comprehension.

Table 3. Chi square and pairwise comparison statistics for Word Identification (WI), Word Attack (WA), Passage Comprehension (PC), Rate, Accuracy (Acc) and Comprehension (COMP).

			Baseline – Post- test		Baseline – Delayed post- test		Post-test – Delayed post-test	
n = 41	χ^2 (2)	p	Statistic	p	Statistic	p	Statistic	p
WI	39.1	<.001	7.1	<.001	7.65	<.001	0.55	0.59
WA	56.9	<.001	11.24	<.001	12.03	<.001	0.79	0.43
PC	35	<.001	6.37	<.001	6.97	<.001	0.59	0.55
Rate	20.6	<.001	3.04	.003	5.15	<.001	2.11	0.04
Acc	56.3	<.001	11.5	<.001	11.5	<.001	0	1
Comp	32.4	<.001	6.51	<.001	5.96	<.001	0.5	0.58

WI = Word Identification, WA = Word Attack, PC = Passage Comprehension, Acc = Accuracy, Comp = Comprehension.

Table 4. Effect sizes of observed improvements in WI, WA, PC, Rate, ACC and Comp.

	Baseline – Post-test			Baseline – Delayed Post-test		
n = 41	Mean difference (SS)	Kendall's W	Effect size	Mean difference (SS)	Kendall's W	Effect size
WI	5.58	.79	Large	8.76	.48	Moderate
WA	8.95	1	Large	10.5	.86	Large
PC	4.56	.6	Large	6.71	.53	Large
Rate	.46	.22	Small	1.22	.42	Moderate
Acc	1.92	.98	Large	2.22	.78	Large
Comp	1.58	.69	Large	1.63	.39	Moderate

WI = Word Identification, WA = Word Attack, PC = Passage Comprehension, Acc = Accuracy, Comp = Comprehension.

As shown in Table 4, all the effect sizes from the baseline to the post-test were large, except for Rate, where a small effect was observed. Regarding the improvements from the baseline to the delayed post-test points, effect sizes were moderate (for Word Identification, Rate and Comprehension) and large (for Word Attack, Passage Comprehension and Accuracy).

Cellfield is typically interpreted in terms of age improvement. Between the post-test and the delayed post-test, reading skill improved as follows: Word Identification: 39 months, Word Attack: 32 months, Passage Comprehension: 44 months, Rate: 24 months, Accuracy: 27 months and Comprehension: 26 months. Following the steep improvement immediately after the intervention, reading skill continued to improve at a rate above the time that passed for all variables, except for the variable Rate. For example, for Word Identification, there was a 39-month improvement over the 26 months that passed between the post-test and the delayed post-test – this equates to a monthly improvement in skill of 1.42 months for each passing month.

Change in skill between treatment and control groups

Visual inspection of the data (Figures 1–6) suggested that the treatment group performed poorer than the control group at the baseline assessment point on all variables, except for Passage Comprehension. Over the 26-month period that passed between the baseline assessment and the delayed post-test, all variables increased for the treatment group. For the control group, most variables also increased over time, except for Word Identification, which decreased. Notably, the improvement over time was steeper for the treatment group, compared to the control group. For Rate and Accuracy, even though the treatment

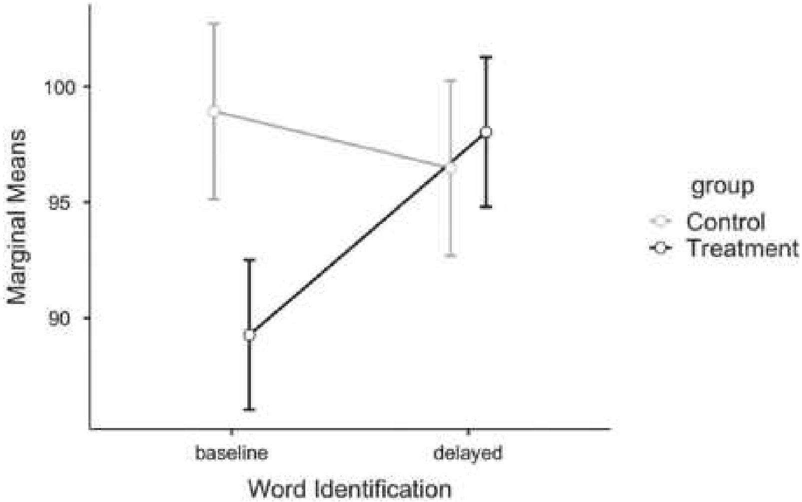

Figure 1. Word identification group comparison.

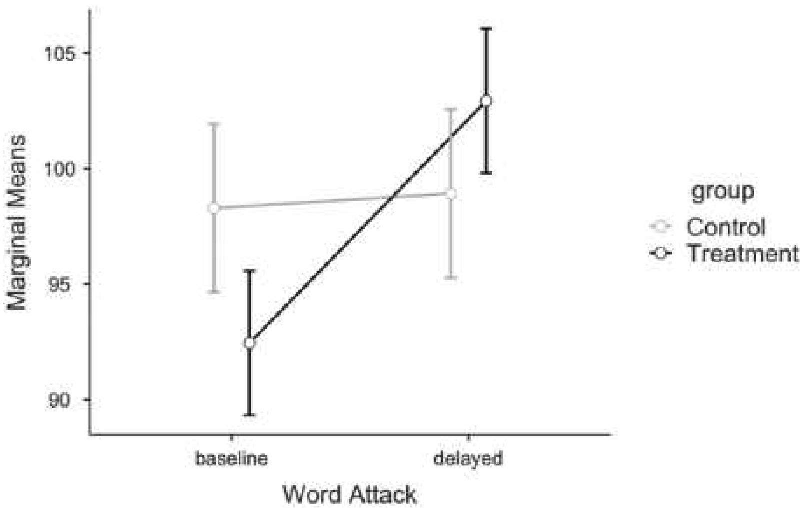

Figure 2. Word attack group comparison.

group had a lower mean at the delayed point than the control group, the rate of improvement suggests that, over time, the skill will continue to improve.

Figures 1–6 below show a graphical representation of marginal means of each variable at the baseline and delayed post-test point for each group.

The Kruskal–Wallis test was used to determine differences between the treatment and control groups. The results showed that, at the baseline test, there was a significant difference in Word Identification between the treatment group ($M = 90.4$) and the control group ($M = 100$) (χ^2 (1) = 12.8 $p < .001$). Similarly, significant differences in Word Attack (treatment group $M = 92.7$, control group $M = 98.5$, χ^2 (1) = 5.88, $p = 0.015$) and Accuracy (treatment group $M = 7.54$, control group $M = 9.36$, χ^2 (1) = 5.96, $p = 0.015$) were observed.

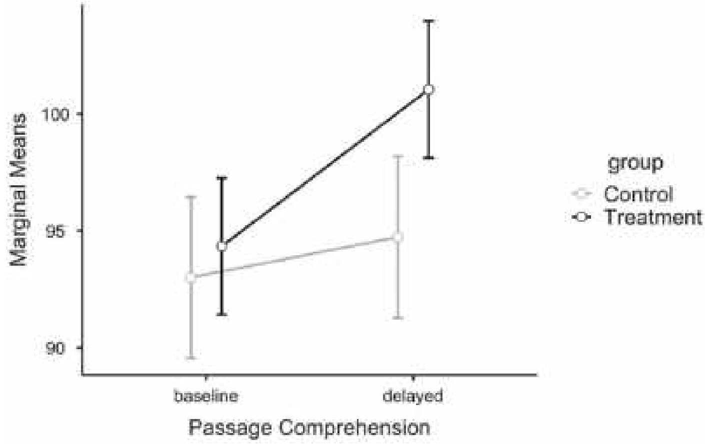

Figure 3. Passage comprehension group comparison.

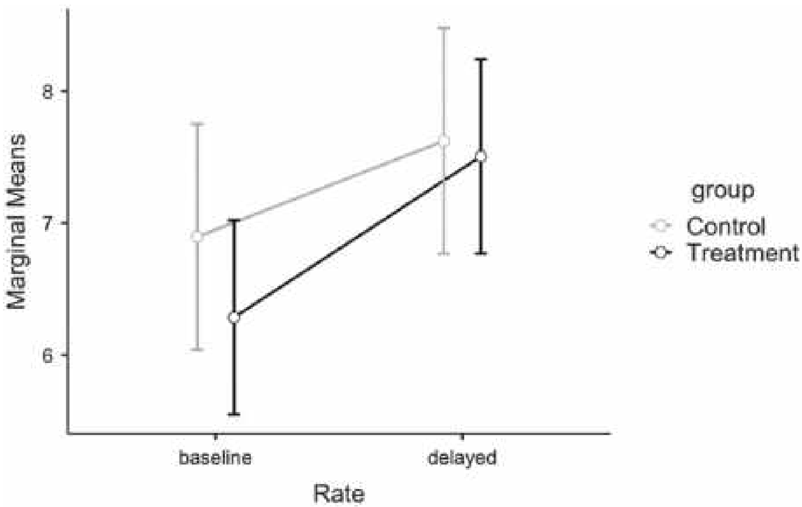

Figure 4. Rate group comparison.

There were no significant differences between the other measures. Based on these statistics, one can conclude that the control group was somewhat stronger in reading skill at the baseline assessment.

At the delayed post-test, only Passage Comprehension was significantly different between the groups (treatment group $M = 100$, control group $M = 93.6$, χ^2 $(1) = 5.7$, p = 0.017). For Passage Comprehension, the treatment group improved their mean standard score from 93.6 to 100, while the mean standard score of the control group changed from 91.3 to 93.6 (Figure 3). Thus, the treatment group outperformed the control group on Passage Comprehension at the delayed post-test point. The rate of reading skill improvement is expected to be 12 months for every passing year; i.e. Reading Age (RA) should be in line with Chronological Age (CA). The mean age difference in the treatment group between the baseline and the delayed test was

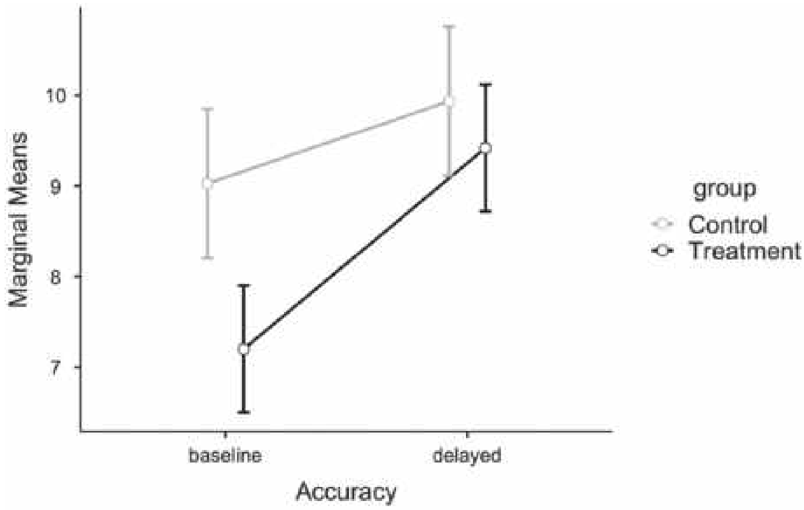

Figure 5. Accuracy group comparison.

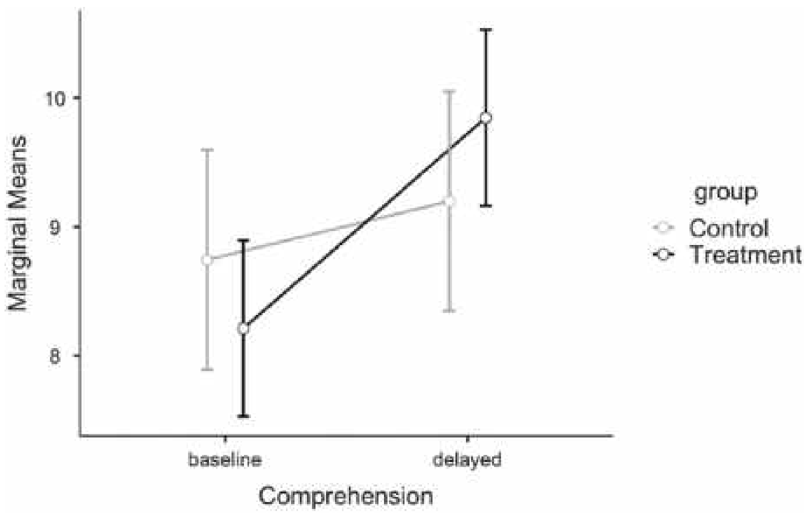

Figure 6. Comprehension group comparison.

27.8 months, while the mean age difference in the control group between the baseline and the delayed test and 30.9 months. In the treatment group, it was observed that reading age improved above the expected rate of 12 months for each passing year. For example, Word Attack skill improved, on average, by 60.5 months. This equates to an improvement of 2.18 months in RA, per month that passed. The control group had a mean improvement of 28.6 months in Word Attack skill from the baseline to the delayed post-test, suggesting that Word Attack in the control group improved by 0.92 months in RA for each passing month.

For the treatment group, it was observed that all variables improved by more than one month for each passing month. For the control group, Wilcoxon tests indicated that only the mean for Accuracy was significantly higher at the delayed assessment point than at the baseline point ($Z = 8.0$, $p = 0.045$).

Discussion and conclusion

The Cellfield intervention is an Australian-developed, computer-based reading intervention consisting of ten 1-h sessions administered as close together as possible, ideally within a two to three-week period. It is based on the multi-deficit hypothesis for reading difficulties which acknowledges that poor readers can have a deficit in various areas, including impaired visual or auditory processing, phonological processing deficits and poor motor skills. Cellfield is designed to target all these potential impairments simultaneously. The main aim of the present study was to investigate the long-term efficacy of the Cellfield reading intervention, as this has, to our knowledge, not been established before. We further compared the performance of a group of struggling readers who received the Cellfield intervention to a group of struggling readers who did not receive the intervention. To determine the long-term outcome of Cellfield (research question 1), we established statistically significant improvements using non-parametric testing.

In the treatment group, directly following the intervention, we found an improvement (in RA) of 14 months in Word Identification, 9.9 months in Passage Comprehension, 16.5 months in Accuracy and 17.2 months in Comprehension. Although the Reading Rate improvement of 3.8 months was the smallest improvement of the reading variables, it was still statistically significant and exceeded the chronological time of 1.5 months that passed between the baseline and post-test. Overall, an accelerated improvement in reading skill was experienced by the participants that underwent the Cellfield intervention. The Friedman test confirmed that improvements in skills from the baseline test to the delayed post-test were also significant. The mean difference in time between these two assessment points was 27.8 months and the improvement in all six variables that was observed directly after the Cellfield intervention was maintained, when measured at the delayed post-test point. Following the Cellfield intervention, reading skill continued to improve at a rate exceeding the time that passed, significantly reducing the delay in skill for struggling readers. The largest improvement, both short term and long term, was observed for Word Attack, which improved by 28 months between the baseline and post-test. This is important, since it is widely accepted that improved work attack (decoding) skills impact positively on comprehension (Garcia & Cain, 2014; Wolf, 2018). For successful comprehension and the associated higher order skills such as inference and analysis of text to take place, automaticity in decoding skill needs to be reached. Wang, Sabatini, O'Reilly, and Weeks (2019) refer to a "decoding threshold", and state that struggling readers below this threshold, who do not receive intervention to improve decoding, will likely remain poor comprehenders. The Word Attack improvement in this study is not only reflective of an improvement in decoding ability – there was also an interconnectivity between reading skills, which was evident as the additional variables tested showed low scores before the intervention, and corresponding improvement with the improved decoding skills.

To compare the change in reading skills between children who underwent the Cellfield intervention, and children who did not (research question 2), we conducted a Kruskal–Wallis test. The control group were participants who were behind their chronological age in reading skill, but on average, they were not as far behind as the treatment group on the reading measures at the baseline point (except for Passage Comprehension). Since we have no additional information on the cognitive abilities of the control group, we cannot explain with certainty why the control group fared better in reading at the baseline assessment. However, we suspect that these children's reading delay was less pronounced – it is a well-known fact that language and reading disabilities exist on a continuum, both in terms of type and severity (Spanoudis, Papadopoulos, & Spyrou, 2019). This explanation is supported by the control group's performance on the standardised measures that were conducted as baseline assessment (i.e. their performance was more in line with what would be expected, given their age). The improvement in skill over time was slower for the control group than for the treatment group. The statistical analysis suggested that the groups were fairly comparable at the delayed post-test assessment point, even though the treatment group was significantly behind the control group in Word Identification, Word Attack and Accuracy at the baseline point. Only one significant difference was observed at the delayed post-test, namely for Passage Comprehension, where the treatment group outperformed the control group. This finding is particularly noteworthy, as it further supports the prediction of the Decoding Threshold Hypothesis that comprehension will remain poor in struggling readers, unless weak decoding skills are remediated. Even though the control group performed significantly better in decoding at the baseline, their decoding skills, as measured on the Word Attack subtest, improved only marginally over the 30 months. Similarly, improvement in Passage Comprehension was less amplified in the control group.

Comparison with previous Cellfield studies

Limited research on the Cellfield reading intervention has been conducted to date. The most comprehensive study by Prideaux, Marsh, and Caplygin (2005) explored the improvements of 262 Australian school children that underwent the Cellfield intervention. Reading skill was measured before and directly after the treatment and children showed significant improvements in decoding and comprehension skills. The effect size for Passage Comprehension was 0.68 (0.92 in the current study) and 1.01 for Word Attack (1.77 in the current study). Sander (2008) studied the Behavioural and Electrophysiological outcomes in a small group of children undergoing the Cellfield treatment ($n = 7$) compared to a placebo group ($n = 5$). The treatment group showed improvement in phonological decoding skills which were maintained after a three-week follow-on programme.

The current research assessed the long-term efficacy of the Cellfield intervention beyond one month. Our delayed post-testing was conducted an average of 27.8 months following the Cellfield intervention. In terms of improvement directly following the intervention, our results were comparable to those of Prideaux, Marsh, and Caplygin (2005) who, for the most part, used the same reading measures (i.e. the Woodcock Reading Mastery test and Oral Gray Reading test). Word identification skill showed an age-related improvement of 14 months, Word Attack improved 28 months (Prideaux et al. reported a 23-month improvement) and Passage Comprehension improved with 10 months (Prideaux et al. reported a 12-month improvement). Prideaux, Marsh, and Caplygin (2005) study measured Oral Reading Proficiency with the Neale Analysis of Reading Ability. Similar to the Gray Oral Reading test, passages are presented in increasing levels of difficulty. Candidates are required to read aloud with time and errors recorded for Rate and Accuracy, as well as a Comprehension component. Prideaux, Marsh, and Caplygin (2005) reported a significant improvement in Accuracy and Comprehension scores following the Cellfied intervention and attributed the decrease in Reading Rate from the baseline to the post-Cellfield assessment to a trade-off between speed and accuracy. In other words, the participants were taking longer to accurately decode words after the intervention, where they had guessed or skipped words before the Cellfield intervention.

In contrast to Prideaux, Marsh, and Caplygin (2005) study, the current study showed improvement on Reading Rate post-Cellfield as measured on the Gray Oral Reading test. Reading Rate was also the only variable that showed significant improvement from the post-test to the delayed post-test in the current study. The two studies were similar in that the samples had similar mean ages (11:5 in Prideaux et al. and 10:8 in the current study). The ratio of male to female participants was also similar. The difference in Reading Rate outcomes may be attributable to the different assessment tools or that there was a difference in the number of children formally diagnosed with dyslexia between the two studies. In Prideaux, Marsh, and Caplygin (2005), 51% of the participants had a formal dyslexic diagnosis, compared to 26.8% in the current study. It is possible that children with less severe impairment benefit more from the Cellfield intervention than children with a more severe impairment. However, Prideaux, Marsh, and Caplygin (2005) report that the improvements made in skills were similar for all participants in their study, regardless of whether they were identified as being at risk for dyslexia or not.

In comparison to Sander (2008), the baseline scores in the present study were higher, suggesting that the samples might not be very comparable (the participants reported on here may have a less severe impairment). However, it is still interesting to mention that Sander (2008) reported larger improvements. Word Identification, for example, improved by 7.85 months (compared to 5.9 months in the current study) between the baseline and post-test scores, while Word Attack improved by 17.43 months, compared to 9.3 months in the current study. Sander's findings could be attributed to the sample size – the treatment group was much smaller ($n = 7$) with a smaller age range (between 12 and 14 years), compared to the current study ($n = 41$, age range 7 to 18 years).

In the present study, reading skill continued to improve beyond the intervention, albeit at a less accelerated rate than between the baseline and post-test assessments. Effects sizes from the baseline to the delayed post-test in the treatment group were moderate to large, with the largest improvement observed for Word Attack. The current study also supports Sander's findings that children with reading difficulties benefit from receiving the Cellfield intervention compared to a group who do not receive the intervention.

Interconnectivity of reading skills and the Cellfield intervention

It is possible for a child to have adequate decoding, but to still struggle with comprehension. Scarborough's (2001) reading rope (an elaboration of Gough and Tunmer's (1986) Simple View of Reading) presents a framework to understand this phenomenon. The reading rope postulates two elements, namely "word recognition" and "language comprehension", which intertwine to develop skilled reading with good comprehension. The complexity of reading is evident as each rope is comprised of additional skills. A weakness in any of these areas can potentially "weaken the rope". Early reading is heavily reliant on the word recognition rope which consists of phonological awareness, decoding and sight recognition of words. At its very foundation, acquiring the alphabetic principle requires an understanding that graphemes represent phonemes, i.e. acquiring the "code" for language to be able to "decode" graphemes back to phonemes by reading. As decoding becomes more automatic and a child's lexicon grows, regular and irregular words are recognised by sight. 65–75% of children diagnosed with reading difficulties in the foundation phase continue to have weak reading throughout their school careers and beyond (Scarborough, 2001). These staggering numbers highlight the importance of acquiring foundation skills in the early grades, and the importance of early intervention.

Successful reading requires that the processes involved in the word recognition strand happen automatically and fluently, so that cognitive resources can be freed up for the process of comprehension. Fluency is commonly accepted as being a combination of speed and accuracy. Wolf (2008) extends the definition of fluency to include a child's ability to utilise all the knowledge about a word – letters and their patterns, grammatical functions, roots and endings and meaning, quickly enough to have time to think and comprehend. She concurs that fluency ensures that the executive system has sufficient resources to attend to higher level skills, such as inferencing, understanding and predicting (Wolf, 2008).

All reading researchers agree that without word recognition skills, a child would not be able to read. However, what remains complex is understanding the contribution of different foundation skills associated with decoding to the process of word recognition, as well as the extent to which these skills are (or need to be) interconnected. Proficiency in phonological processing, rapid naming, visual and auditory processing, and motor skills are all essential for the word recognition strand to develop and should be treated as equally imported constructs within the strand. In reality, and as anticipated by the multi-deficit model of reading difficulties, many weak readers present with mixed profiles, and exhibit different combinations of impaired skills. This complicates both diagnosis and remediation. A child with a reading difficulty thus needs to be assessed for phonological, visual, auditory, RAN and motor difficulties. Depending on the outcomes of the assessment, remediation in one or more of these areas would need to be administered. Interventions based on the multi-deficit theory, such as the Cellfield programme are likely to be impactful, because they remediate multiple possible causes. Cellfield, by its design, addresses phonological, motor, auditory, visual, and visual-to-phonological processing skills, and thus promotes the development of these skills at the construct level, while simultaneously ensuring that these skills to operate in an interconnected manner, which is needed for successful decoding. As demonstrated in this study, improving multiple skills associated with the word recognition strand also led to improvements in reading rate and accuracy (fluency), and reading comprehension.

Limitations and future studies

Several limitations should be considered regarding the results of the present study. The participants were a convenient and small sample consisting of children whose parents had sought assistance for their children's reading. As a commercial treatment, Cellfield is available in certain reading centres and requires a monetary investment by parents. The sample may therefore not be representative of the diverse South African population in terms of standard as well as language of instruction, economic status and home environment. Future studies could therefore explore the impact of Cellfield on a more representative South African sample.

Although all the participants had English as medium of instruction, and most were schooled at private schools where the standard is aligned with international curricula, it is important to note that the psycho-educational assessments that were used, namely the Gray Oral Reading Test and Woodcock Reading Mastery Tests, are internationally normed and their reliable use in a wider South African context has not been determined.

For the treatment group, extraneous variables such as academic input and additional reading at home between the post-test and the delayed post-test could have impacted on the outcomes at the delayed post-test point. Controlling these factors should be considered for future research for example, by conducting interviews and/or questionnaires to determine any additional literacy input in the schooling and home learning environment. The two groups were also not matched well in terms of size in the present study. This shortcoming not only impacted statistical power negatively, but also led to a non-normal distribution in the data. Given these limitations, we opted to conduct nonparametric statistical tests, which means that we have not reported on the interaction between time and group in our group comparison. We can therefore not statistically confirm that the observed differences between the treatment and control group at the endline were in fact due to the Cellfield intervention. Furthermore, the groups were not divided into subgroups according to causes of reading difficulty, and thus the outcomes were an average of change in reading skill regardless of, for instance, visual processing difficulties or SLI as a cause of weak reading. Future studies could focus on the impact of the Cellfield intervention on children with difficulties stemming from specific causes.

Recommendations

In the South African context where most Grade 3 learners cannot read for meaning, the Cellfield intervention can have a significant impact on literacy levels. The challenge, of course, lies in the logistical complications behind scaling a treatment of this nature to learners in the public-school system. Nonetheless, the impact of Cellfield as a multidimensional intervention on children who are behind their age-appropriate level in reading skill has been well established, and we propose that there is clearly value in expanding the reach of the Cellfield intervention to different first languages, as it is widely accepted that strengthening literacy skills in the first language supports literacy in the second language, even when the languages are linguistically and orthographically diverse.

Conclusion

This study primarily set out to determine the long-term efficacy of the Cellfield intervention. Previous research has determined the immediate impact post-treatment, but the current study is the first to explore the retention of improvement beyond a month.

Despite the limitations listed, the present study makes a valuable contribution as it supports the theoretical position that reading difficulties are caused by a multidimensional deficit and that reading intervention should adopt a multidimensional approach. The integrative nature of the Cellfield programme and the significant improvement on all the assessed reading measures in the present study suggest that Cellfield is an impactful and valuable intervention for struggling readers, the outcomes of which are maintained in the long term. The improvement in decoding skills following Cellfield is particularly important, as this skill is critical – decoding must become automatised for other associated reading skills to improve. This study also highlights the importance of integrating the theories of reading difficulties to practical interventions. Children with difficulties should gain the benefit of research for the purpose of improving their reading and use and enjoy reading effectively as a tool for learning to experience academic success.

Disclosure statement

The data was gathered as part of the first author masters project and was previously included in her MA dissertation. The first author is the owner of a reading centre in South Africa, that uses the Cellfield intervention as a reading intervention. The authors confirm that there are no financial or non-financial interests that have arisen from the direct applications of this research.

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Data availability statement

The data that support the findings of this study are openly available in figshare at DOI:10.6084/m9.figshare.23544744.

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