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

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DECLARATION

I declare that A LONGITUDINAL STUDY OF THE EFFICACY OF THE CELLFIELD READING INTERVENTION IN A SOUTH AFRICAN CONTEXT is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of complete references.

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ABSTRACT

Internationally, including in South Africa, many children do not acquire age-appropriate reading skills in the suggested timeframe. As a result, many children are at-risk of not achieving academic success, since reading does not develop into an efficient tool that allows children to read for meaning.

Various theories have been developed to explain why some children struggle to develop reading skills. These theories form the foundation of interventions to assist struggling readers. The Cellfield intervention is based on the multi-deficit theory of reading difficulties, and as such, addresses several foundation reading skills simultaneously. Existing research has confirmed that the Cellfield intervention leads to improvement in reading skill directly following the intervention, but no research exists to determine the long-term efficacy of the Cellfield intervention.

The broad aim of this study was to determine the long-term efficacy of the Cellfield intervention in a group of South African learners (n = 41) whose reading was below age-appropriate level. Using a quasi-experimental design, participants were assessed before and after the Cellfield intervention which was typically conducted over a two to three-week period, and then again, a minimum of one year following the intervention. Using standardised reading tests (the Woodcock Reading Mastery Test and by the Gray Oral Reading Test), six reading variables were measured, including Word Identification, Word Attack, Comprehension, Reading Rate, Reading Fluency and Passage Comprehension. Additionally, the results obtained from the treatment group were compared to a control group (n = 11) who had also been found to be behind in reading, but who did not undergo the Cellfield intervention. Statistical analyses of the findings revealed that the Cellfield intervention had a statistically significant effect on reading skills and that these improvements were maintained in the long-term. Furthermore, the results suggested that the change in reading skill in the treatment group were steeper, compared to the control group.

KEY TERMS

- Cellfield intervention
- Dyslexia
- Long-term reading improvement
- Multi-deficit theory of reading difficulty
- Phonological processing
- Reading difficulty
- Reading intervention

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CHAPTER 1: INTRODUCTION

1.1 Introduction

Reading is not a natural skill to acquire; it needs to be explicitly taught. It is generally expected that reading speed and accuracy need to be in place by the end of the Grade 3 year in order for reading to be used as a tool for learning. If this is not the case, a child is at risk of academic failure.

Worldwide, literacy attainment is a challenge for some children. Many children struggle to acquire age-appropriate reading in the expected time frame. This is also true in the South African context, where large scale assessments of learning suggest that the majority of learners don't reach their literacy milestones. Research suggests that reasons for this include poverty, overcrowded classrooms, underdeveloped pre-literacy skills, language barriers, poor instruction, mismanaged schools, underqualified teachers and learning difficulties (Howie et al. 2017; Spaull and Pretorius 2019). For a subset of these learners, weak reading skills may be caused by developmental disorders, which is the area of focus of this study. More specifically, the present study focuses on the long-term efficacy of a reading intervention programme, known as the Cellfield intervention programme, to alleviate reading delays in struggling readers in a South African context.

The 2016 Progress in International Reading Literacy Study (PIRLS), reported by Howie et al. (2017) reveals that 78% of South African Grade 4 learners cannot read for meaning. The PIRLS assesses reading comprehension internationally, every five years, to monitor trends in literacy. In the 2016 study, South Africa was placed last of the 50 countries tested. The assessment is representative, in that students are assessed in all of the 11 official languages that are used for literacy instruction in the foundation phase (Grade 1 – Grade 3) and across all nine provinces. These alarming outcomes have not changed significantly from the 2011 PIRLS assessment, meaning that South African learners have made little progress in reading levels since 2011.

Possible reasons for these poor reading scores have been suggested by several scholars. Recently, Spaull and Pretorius (2019, 5) provided a succinct summary of the barriers to literacy attainment in South Africa. They report that “How well they learn to read depends on how well they are taught and how many opportunities are given to read”. Furthermore, the PIRLS study reflects weaker literacy skills for children who come from homes where there are few books, where parents do not read stories, engage in developing vocabulary skills or support children academically. This home disadvantage is exacerbated by a “school literacy disadvantage” (Spaull and Pretorius 2019, 6). Classrooms are overcrowded, and 62% of schools do not have functioning libraries (Howie et al. 2017).

Good literacy skills can be achieved, even in low poverty contexts, with the correct resources such as graded readers, libraries and access to books at home. In addition, because reading is a skill that needs to be taught, adequate acquisition of reading for students relies on efficient instructional practices. Teachers need to be adequately equipped to understand the process of reading and the foundation components of reading (i.e. decoding and oral language comprehension) that lead to comprehension. Very few South African teachers receive the necessary training in reading instruction, as the teacher education curricula offered by higher education institutions do not provide adequate training in this regard (Spaull and Pretorius 2019; Taylor 2014; Draper and Spaull 2015; Spaull 2016). Additionally, much teaching, especially in rural areas, relies on an inefficient oratorical approach (Rule and Land 2017; Cilliers and Bloch 2018).

The PIRLS study assesses reading comprehension only. Understanding of a text relies on efficient decoding of material, as well as oral language proficiency, specifically vocabulary knowledge (Spaull and Pretorius 2019). Decoding is a foundation skill for reading and should be automatic by the end of the Grade 3 year. Decoding relies on phonological awareness, letter-sound association and word recognition, skills that should be developed in the foundation phase (Grades 1 – 3). Oral reading fluency (the ability to read a text quickly, accurately and with meaningful expression) relies on automatic decoding, and is critical for comprehension (Draper and Spaull 2015).

A learner's reading ability at the early educational stage predicts how children perform later in their schooling careers (van der Berg 2015; Spaull et al. 2016). If foundation skills are not in place, children fall further and further behind their expected levels of performance as they progress through their schooling. It would be expected that the average rate of improvement for children acquiring the skill of reading is in line with chronological age, i.e. 12 months for every year that passes. For children who do not have the same *rate* of reading improvement or who are behind their peers, the gap widens between where they are, and where they need to be. This in turn impacts learners' ability to achieve a Grade 12 Bachelor pass and to proceed to tertiary or higher education and social advancement.

The challenge in remediating a significant delay, is that proficient readers continue to improve, with the goalposts constantly moving forward. An intervention that can close this widening skills gap in a short period of time could address this remediation challenge.

Where a delay in reading skill is not attributable to environmental, instructional or cognitive impairment, a child may suffer from a learning difficulty specifically related to reading. Such children display delays in the development of one or more areas of phonological, visual, auditory, motor skills and working memory, impacting on the ability to read fluently and with good comprehension. Within the group of children with learning difficulty in reading, understanding and spelling, some children (around 10% of the population) will be diagnosed with dyslexia (also referred to as Specific Learning Difficulty in Reading). For these children, difficulty in reading can vary in severity, is persistent, and contrasts with other areas of academic achievement in that they have average, to above average IQ.

There is some debate around the definition of dyslexia and distinguishing between children who have a clinical diagnosis of dyslexia and weak readers who have no dyslexia diagnosis. The unexpected difference in reading ability compared to cognitive ability is said to be characteristic of dyslexia. However, Elliot and Grigorenko (2014a) highlight that difficulties in decoding is evident across the full range of intellectual ability, and the relationship with measured IQ is only evident with comprehension difficulties and not decoding.

Peterson and Pennington (2012, 1997) state that on a psychometric assessment, those with dyslexia “represent the lower end of a normal distribution of word reading ability”. This does not clearly separate a dyslexic reader from a weak reader. Ramus (2014) challenges this description of dyslexia, and argues that the brain differences observed in dyslexia are not any different from those with weak reading associated with low IQ or other forms of poor reading. Elliott and Grigorenko (2014b) argue that the label ‘dyslexia’ is scientifically questionable and call for additional focus on identifying an individual’s particular difficulty in order to remediate appropriately.

While the debate of whether to diagnose and label dyslexia continues, what *has* been established, is that reading difficulties present in various ways, and there can be mixed profiles of the areas of difficulties in all weak readers. Teaching methods and interventions designed for dyslexic students have been found to be effective for most weak readers, regardless of their diagnosis. According to Ramus (2014, 3373). “In the current state of the evidence, the best interventions for reading disabilities are phonics-based teaching programmes that are particularly intensive, systematic and explicit. And they have apparently been applied with equal (but moderate) success to all kinds of poor readers”.

The current study will investigate the efficacy of one specific dyslexia intervention programme, namely the Cellfield intervention programme, in a group of below-average readers where the underlying reason for the learning difficulty has not been clearly established for every participant. In the sample, approximately one third of participants have been diagnosed with dyslexia.

In the South African context, where the majority of children are below their age appropriate level in reading, an efficient and effective intervention with long lasting results could be impactful for all children. The following section will briefly introduce the Cellfield intervention programme.

1.2 The Cellfield intervention

Research shows that some children who struggle with reading can present with difficulties in one or more of the following areas: phonological skills, visual processing, auditory processing, motor skills and/or working memory. These difficulties are thought to result in an inability to acquire proficient reading.

A better understanding of the nature of reading difficulties over the past three decades has led to the development of a large number of reading intervention programmes. Most interventions target *specific* causes of reading difficulties i.e. either auditory/phonological, visual or motor impairments. A notable exception is the Cellfield intervention, which was developed to target multiple skills that have been found to be impaired in reading disabled children. Addressing several skills simultaneously has been found to be an effective way to improve reading (Fälth et al. 2013; Morris et al. 2012; Wolf 2011).

The Cellfield Reading Intervention, developed in Australia in the early 2000's, is a computer-based treatment for children with dyslexia/specific reading difficulty. Based on the multi-deficit hypothesis of dyslexia (which will be presented in section 2.4.5), it aims to alleviate the symptoms of this developmental disorder by simultaneously targeting multiple skills that could potentially co-occur in the struggling reader, such as phonological, visual, and visual-to-phonological processing skills. Details of each of the components of the Cellfield intervention will be described in section 2.6.1.

Functional brain imaging studies show that individuals with dyslexia do not activate the same neural pathways as 'normal' readers. The tasks presented during the Cellfield treatment stimulate visual and auditory processing together, the way the 'typical' brain works during proficient reading. This stimulation of neural pathways is thought to activate the most efficient route for processing information, resulting in more automatic decoding, and therefore enhanced comprehension.

Although the Cellfield was originally developed to alleviate symptoms of dyslexia, it has been found to also be an effective intervention for children who do not have a clinical diagnosis of dyslexia, but who are behind their age-appropriate level in reading. The largest study to date, in which 262 Australian school children underwent the Cellfield intervention, was conducted by Prideaux, Marsh and Caplygin (2005). The outcomes showed support for the efficacy of Cellfield, with improvements of 23 months in Word Attack and 12 months in Comprehension skills, as measured on the Woodcock Reading Mastery Test. With a mean of 26 days between pre-and post-testing, these results reflected improvements immediately following the intervention. Approximately half of the participants were identified as being at risk for dyslexia. Gains in reading skill were similar for all participants, regardless of their level of difficulties or diagnosis of dyslexia. Additional evidence for the efficacy of the Cellfield was presented by Coltheart (2008) and Sander (2008) and will be discussed in section 2.6.2.

1.3 Gap in the research

Improvements directly before and after the Cellfield intervention have been researched (Prideaux, Marsh and Caplygin 2005; Coltheart 2008). Additionally, a thesis study by Sander (2008) investigated the outcomes of the Cellfield intervention with a group of 12 students (seven of which completed the Cellfield treatment and five underwent a placebo programme). The test group showed improvement in skills which were maintained after a three-week period. These previous studies by Prideaux, Marsh and Caplygin (2005) and Coltheart (2008) show improvements directly following, and a month after intervention respectively. However, the long-term efficacy beyond a month has not been researched. The aim of the present study is to determine the long-term efficacy of the Cellfield intervention in a South African context, in alleviating the symptoms of struggling readers who do not necessarily have a dyslexia diagnosis, but that exhibit reading levels that are significantly below the norm.

1.4 Aims of the present study

The aims of this study are:

-to explore the immediate impact of the Cellfield intervention on a sample group of children experiencing reading difficulties.
-to investigate the long-term efficacy of the Cellfield reading intervention on the same group of children that underwent the treatment.
-to compare reading skills over time between two groups of children with reading challenges, namely a treatment group (that received the Cellfield intervention), and a control group (that did not undergo the Cellfield intervention).
-to explore whether the relationships between the outcome variables (i.e. the six reading skills – see section 1.7) changes after the Cellfield intervention and in the long term.

1.5 Research questions

The research questions for this study are:

i. Do reading scores in individuals with reading difficulties improve significantly after undergoing the Cellfield intervention in a South African context?
ii. What are the long-term effects of the Cellfield intervention in a South African context?
iii. 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?
iv. What is the nature of the relationships between the reading skills addressed by the Cellfield intervention, pre- and post-intervention, as well as in the long term*?*

1.6 Hypotheses

It is expected that this study will support the notion that remediating a reading difficulty needs to be approached from a multi-causal perspective.

i. It is hypothesised that the Cellfield intervention will have a positive effect on reading scores of individuals with reading difficulties.
ii. Regarding the second research question, it is hypothesised that the effect of the Cellfield intervention will be retained over time, given the particular multi-faceted nature of the intervention. However, this hypothesis is tentative, as little information about long-term effects of the intervention is available. If it is shown that the gains are maintained over time, it would lend to Cellfield being a noteworthy and efficient intervention for struggling readers, as shown by Prideaux, Marsh and Caplygin (2005), Coltheart (2008) and Sander (2008).
iii. It is further hypothesised that the treatment group in the present study will show larger gains in a range of reading skills, compared to the control group (that will not undergo the Cellfield intervention).
iv. With regards to the final question, it is expected that some correlation exists between the variables tested before and after Cellfield as well as in the long term, and that the strength of these correlations may change over time. Gains in reading skill maintained over time would further validate Cellfield as an effective intervention, in line with current research which suggests that neural pathways of the brain of a struggling reader can be changed for more efficient reading (Gabrieli 2009; Shaywitz 2005).

1.7 Methodology

A quasi-experimental, quantitative, longitudinal study will be conducted. The present study will examine secondary data that was collected before and after treatment for the treatment group, to determine the significance of the changes immediately following the Cellfield intervention. Parallel tests will then be administered at least one year after the Cellfield treatment and the results will be statistically analysed to determine the change in reading skill since the intervention. This will enable the researcher to establish whether any improvements experienced directly after the intervention are maintained over time.

The treatment group consists of 41 children who are behind in their reading age and who chose to undergo the Cellfield reading intervention after a consultation with the researcher. The control group is made up of 11 participants, who are also behind in their reading age but who chose not to undergo the Cellfield intervention. The initial reading assessments completed by participants in the control group are also secondary data. The control group participants were contacted a minimum of a year since the initial assessment. The change in reading skill over time between the two groups is compared to determine whether it is beneficial for children behind reading skill to undergo the Cellfield intervention.

The variables in this study are operationalised by two standardised reading assessments, namely the Woodcock Reading Mastery Test and by the Gray Oral Reading Test. Each test contains three sub-tests. Word Identification, Word Attack and Passage Comprehension are measures with the Woodcock Reading Mastery Test, while Rate, Accuracy and Comprehension are measured by the Gray Oral Reading Test. These tests will be described in more detail in section 3.3.1. The correlation between the variables will also be statistically analysed to determine correlations at each of the three points of testing.

1.8 Contribution of the study

This study will contribute to studies done on the efficacy of the Cellfield as an intervention that targets multiple aspects of reading simultaneously, as well as determining its lasting effects. In addition, the study will determine whether the outcomes experienced in a South African context are comparable to those reported in international studies providing a potential for future studies of low literacy readers and English second language (ESL) learners. In addition, it is expected that the study will support that intervention targeting multiple skills is effective for weak readers.

1.9 Limitations of the study

It is acknowledged that this research is limited because of the sample tested. The learners in the study are not representative of the diverse status of South African scholars in terms of economic status, home environment and language of instruction. All of the families in the study contacted the researcher at some point for assistance with their child's reading. It is also difficult to control or determine any additional factors that may have impacted on a child's reading between assessments. Extraneous variables such as scholastic input or additional reading at home could impact on a change in reading ability. All the children in the sample were assessed using assessments normed internationally due to the lack of South African-normed reading assessment instruments.

1.10 Outline of the dissertation

This dissertation is organised as follows:

Chapter One contains the introduction and presents the Cellfield intervention. The gap in existing research, aims, research questions and hypotheses are introduced. An outline of the methodology, contributions and limitations of the study are given.

Chapter Two is the Literature review which focuses on providing a theoretical background to the current study. The process of learning to read is explored and the main theories of reading difficulties is presented. A general discussion of reading interventions is followed by a detailed discussion of the Cellfield intervention. Existing research on the Cellfield intervention are discussed.

The Methodology is presented in Chapter Three, and outlines the research design choices in relation to the aims and questions. Details of the participants

and instruments are given. Furthermore, the research procedures and data analysis are explained.
Chapter Four presents the findings of the study. Descriptive and inferential statistics pertaining to each of the research questions provide an overview of the data and determine significant effects.

Chapter Five is a discussion and conclusion. This chapter summarises the findings in relation to previous studies on the Cellfield intervention as well as the multi-deficit theory of reading difficulties. Limitations of the current study and suggestions for future research are given.

1.11 Conclusion

Because the Cellfield addresses visual and auditory processing simultaneously, the researcher expects that this intervention will result in improved reading with long lasting effects for children with reading difficulties. A study by Lovett et al. (2008) showed that an intervention presented in English was successful for children with English as a First Language as well as for children with English as a Language of Learning and Teaching (LoLT), where English was not their home language (also referred to as 'mother tongue' or first language'). Most South African learners are taught in English; which is not their first language. Since reading interventions have been found to be effective for ESL learners in other parts of the world, and Cellfield has been shown to be an effective intervention, it is worthwhile to investigate the programme's efficacy for ESL children in the South African context. The next chapter will present the literature review and theoretical framework that informed the present study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Successful reading requires the acquisition of a range of interconnected skills. There are different theories that explain why some learners do not read successfully, and linked to these theories are suggestions of how reading difficulties should be remediated.

In this chapter, the process of learning to read will be explored, the skills required for reading acquisition will be explained, and the most prominent theories that explain reading difficulties will be presented. The Cellfield intervention will then be presented and examined as an intervention that simultaneously addresses deficiencies in potential areas of weakness.

2.2 The process of learning to read

Children first 'read' familiar signs and words by shape, pattern and colour. This stage typically occurs before the onset of formal literacy instruction, and is described as the "logographic" stage (Shaywitz 2005, 102). An example of this is the recognition of a logo – a young child cannot, for instance, allocate the sounds to the letters in the McDonalds sign, yet recognises it as a complete 'picture'.

With the onset of formal schooling, letter-sound associations are taught, which help children to connect visual elements (graphemes) to phonemes, also referred to as the alphabetic principle. While the precise brain pathways for letter-sound association are not yet fully understood, it is known that the left temporal region of the brain receives information directly from the visual areas. As letters are blended into words, more complex processing is required. Dehaene (2009, 109) explains that the inferior parietal region, together with Broca's area create an "articulatory or phonological loop". The phonological loop enables the developing reader to decode, store and retrieve sounds and sound patterns automatically.

As reading becomes more fluent, reliance on overt decoding declines and the recognition of familiar and regular words becomes increasingly automatised and efficient (Snowling, Hulme and Nation 2020). Visual, auditory and semantic information is processed in the occipito-temporal region. This is referred to as the lexical (Cestnick and Coltheart 1999), or orthographic route (Shaywitz 2005) and allows instant recognition of irregular words which are processed as a 'whole'. In contrast to the orthographic route of processing, the phonological route (Shaywitz 2005) or non-lexical route (Cestnick and Coltheart 1999) is used when direct grapheme-phoneme decoding is required. This route is used for processing pseudo- or unfamiliar words. Both the orthographic and phonological routes are available to proficient readers, and many scholars agree that a dual-route model of reading acquisition best describes the reading process that takes place in proficient readers (Papadopoulos and Kendeou 2010; Pritchard et al. 2012).

Fluent reading relies on a bi-directional interconnectivity between the relevant visual and language areas of the brain, which allows readers to recognise words instantly. As a child learns to master reading, the brain changes. These changes are maintained, so that the skill does not need to be re-learned each time a proficient reader reads (Elliot and Grigorenko 2014a; Dehaene-Lambertz, Monzalvo and Dehaene 2018).

Automatic decoding skills are needed for fluent reading, which, in turn, impacts comprehension (Wolf 2018; Wang et al. 2018). If a reader does not develop automaticity, laboured decoding impacts working memory. As a result, insufficient attention and processing capacity are available for drawing meaning from text, as well as applying higher-order thinking skills such the ability to analyse and infer information from a text (Pikulski and Chard 2005; Cotter 2012). In a meta-analysis of 110 studies, Garcia and Cain (2014) established a strong correlation (r = .74) between decoding and comprehension. This highlights the importance of developing automaticity in decoding, in order to support reading comprehension.

Efficient reading involves many processes: solid letter-sound association, understanding the nature of words and the ability to manipulate their parts (phonological awareness), visual processing, auditory processing, semantic competence, working memory and motor skills. In addition, children need to have adequate language skills such as vocabulary, grammatical, semantic and syntactic competence, receptive and expressive skills.

A child that learns to decode with automaticity, acquires a good ‘vocabulary’ of words that are recognised easily in text. Additionally, passage reading at a good rate with accuracy lead to solid understanding of the material that is read, both in silent and out loud reading. These six skills (decoding, word identification, rate, accuracy, comprehension in silent reading and comprehension in out loud reading) are assessed in the research instruments used and addressed in section 3.3.3.

By the Grade 3 school year, solid reading skills should be in place, as fluent reading is one of the most important skills that enables a child to cope with an increasing academic workload. Poor reading skills impact on learning, as the majority of the curriculum is presented to learners in written format. For this reason, teaching strategies, as well as remediation, need to reflect what is increasingly understood about reading and the brain, so as to allow young readers to reach their full potential.

The following section describes the skills that are implicated in reading acquisition in more detail. Auditory processing, phonological processing and visual processing skills will be discussed. The reason for highlighting these cognitive skills is that the Cellfield intervention programme aims to improve all these skills in struggling readers.

2.3 Auditory processing, phonological processing and visual processing in reading

2.3.1 Auditory processing

Children are exposed to language from birth. Spoken language is acquired by being immersed in a language, in other words, it does not need to be explicitly taught (Coltheart 2019). By being spoken to, and learning to speak, children develop linguistic awareness and acquire the phonological, semantic, syntactic and morphological structures of language. Children understand and appropriately apply the grammatical relationships within, and between, words (Wolf 2008; Beringer and Richards 2002). By the time formal schooling starts, children (on average) have an extensive auditory vocabulary of over 10 000 words (Coltheart 2019). One of the key skills that supports the language acquisition process is called auditory processing.

Auditory processing refers to the process through which the brain receives information from the ears. The magno-cells of the brain specialise in the detection of subtle changes in acoustic information, such as transitions between similar-sounding sounds (e.g. /buh/ and /duh/). Auditory processing is what enables an individual to form stable phonological representations of individual sounds (such as /b/ and /d/) – in other words, stable phonological representations cannot form if an individual has an auditory processing deficit. Unstable phonological representations can lead to poor phonological processing skills, which are thought to result in a difficulty in learning to learn to read (Ramus et al. 2003).

2.3.2 Phonological processing

Phonological processing is defined as using the sounds of one's language (phonemes) to process spoken and written language (Wagner and Torgesen, 1987). It comprises three components, namely phonological awareness, phonological working memory and phonological retrieval or rapid automatised naming (RAN). These components of phonological processing are important for the development of both spoken and written language skills.

2.3.2.1 Phonological awareness

Phonological awareness is the ability to discriminate and manipulate sounds, and to understand different parts of sound units: phonemes, syllables, as well as onset and rhyme (Anthony and Lonigan 2004; Shaywitz 2005). The relationship between phonological skills and reading development has been well-established (Castles and Coltheart 2004) and children’s performance on phonological skills at kindergarten level can be used as a predictor of potential reading difficulties (Schatschneider et al. 2004; Puolakanaho et al. 2008; Shaywitz 2005).

Following longitudinal testing of phonological awareness skills in pre-school and early grade children, Anthony and Lonigan (2004, 53) concluded that “pre-school phonological sensitivity is an early manifestation of the same ability that plays a causal role in learning to read”.

An additional longitudinal study by Muter et al. (2004) assessed various phonological skills of pre-school children and concluded that letter knowledge and phoneme sensitivity was linked to the acquisition of word recognition skills, and that early word recognition, vocabulary and grammatical skills in turn predicted comprehension skills. Research also suggests that early training in phonological processing skills, leads to enhanced literacy skills in later grades. For instance, Kjeldsen et al. (2019) followed a group of children from Grade 1-9 in Finland. The intervention group received eight months of phonological awareness training in kindergarten and outperformed the control group in both word-reading and comprehension ability in the long term.

It follows then, that early screening and identification of children with weak phonological awareness skills provides an opportunity to introduce remediation before reading failure is potentially experienced. Early remediation of reading problems would diminish the associated academic, behavioural, social and psychological difficulties that frequently accompany reading challenges (Muter et al. 2004).

2.3.2.2 Phonological working memory

Phonological working memory facilitates an active process that involves storing phoneme information in a temporary, short-term memory store (Wagner and Torgesen 1987) allowing it to be available for manipulation during phonological awareness tasks, as well as deriving content and meaning from text (Brandenburg et al. 2017; Kibby, Lee and Dyer 2014; Peng et al. 2018).

Baddeley's (1982) model of phonological working memory is composed of a central executive, and 'slave systems', namely the phonological loop, the visuo-spatial sketchpad and the episodic buffer. The central executive is responsible for supervising and controlling the flow of information. The phonological loop holds verbal and auditory content in a phonological store and rehearses it in a short-term storage centre (the articulatory loop) in order to maintain the "memory trace" (Baddeley 1982, 172) until it can be processed accurately. The visuo-spatial sketchpad attends to visual and spatial information, such as colour, shape, and location. The episodic buffer is a temporary store that integrates and collates information from the other components, so that events occur in the correct sequence.

Because reading is a complex task that involves accessing, processing and storing information simultaneously, phonological working memory plays an important role. Words first need to be processed visually, their components then matched with the phonological, orthographic and semantic representations in long-term memory and then linked to the context to draw meaning from the passage (Peng et al. 2018; Wilsenach 2016).

A meta-analysis by Peng et al. (2018) of 197 studies found a significant moderate correlation between reading and working memory. Their findings conclude that the central executive component also plays a role in reading performance, especially in early reading acquisition. The retrieval of verbal knowledge from long-term memory, and the integration with language-based information requires efficient verbal working memory and is more strongly implicated in later reading performance. Their findings also confirm the bi-directional relationship between reading and verbal memory.

2.3.2.3 Rapid Automatised Naming (RAN)

Rapid Automatised Naming (RAN) is defined as the ability to name visually presented stimuli as fast as possible. These stimuli can be colours, digits, letters and objects. Several studies have established that rapid automatized naming (RAN) is a strong predictor of reading across languages (Wolf et al. 2009;

Powell and Atkinson 2021). Automatised naming is multi-componential in nature and requires the co-ordination of several processes such as attention, phonological, orthographic, motor, memory and articulatory skills. It is not clear why RAN predicts reading as any of these processes could impact on the relationship between RAN and reading (Papadopoulos, Spanoudis and Georgiou 2016).

Many researchers have explored the contribution of these individual components of phonological processing to reading performance. Kibby, Lee and Dyer (2014), for example, explored how the individual components of phonological processing predict reading performance in the following areas: word recognition, pseudoword decoding, fluency and comprehension. Phonological awareness and RAN predicted all aspects of reading assessed, and phonological memory predicted word identification and decoding.

The impact of phonological processing skills across languages is also an important factor, particularly where children have differing home languages to their language of learning, as is the case for the majority of South African learners. Pugh and Verhoeven (2018) and call for more research to be done in the extent to which phonological processes affect reading difficulties across languages.

A recent meta-analysis by Landerl, Castles and Parrila (2021) showed that naming speed is associated with fluency across languages (and orthographies) and they highlight that RAN “indicates the efficiency with which visual-verbal associations can be built and retrieved” (p9).

Engel de Abreu and Gathercole (2012) studied the links between phonological processing skills of a group of multilingual Luxembourgish 8-9-year olds. Although Luxembourgish is the national language, the education system in Luxembourg is trilingual with Luxembourgish as the language of instruction in pre-school. At the onset of schooling, (age 6-7) German is used as the language of instruction. French is introduced in Year 2 (age 7-8) and French literacy starts in Year 3. Luxembourgish and German are structurally similar in word order and phonology rules, but French has a less transparent orthography. The outcomes showed that phonological awareness skills contributed to word decoding and spelling between languages, and working memory skills related to grammar, reading comprehension and spelling across the languages.

The Engel de Abreu and Gathercole (2012) study is similar to the South African context for some children who have a first language that is orthographically transparent (such as Northern Sotho or isiZulu) but are required to learn English, which has a less transparent orthography. Engel de Abreu and Gathercole (2012) note that phonological processing abilities in a first language assist in the learning of a second language with an unfamiliar phonology, and the executive process of working memory contribute in a more general way to language learning in terms of maintaining attention and controlling processes during complex learning activities.

Despite the existence of interrelationships between the three components of phonological processing, some researchers (e.g. Nelson et al. 2012; Jacobs 2007) have suggested that the three components of phonological processing are best conceived as separate, but correlated abilities. Particularly, there is an ongoing debate about whether RAN is a component of phonological processing, or whether it is an independent ability that uniquely predicts reading fluency.

2.3.3 Visual processing

The magno- and parvocellular cells work together to process the information coming into a visual field. According to Stein and Walcott (1999, 65), the magno-cells process the 'where' of visual information and "provides the main visual input to the brain stem structures controlling reflex eye and other movements". The parvocellular cells process colour, contrast, texture and depth. During reading, the eyes move in a series of jumps, or saccades, across text, centering on a letter and seeing five letters ahead and three letters behind. As the eyes fixate at these stops, individual words are identified. The magnocellular system allows stable fixation and guides the eyes to their next saccade (Stein and Walcott 1999).

Wilmer et al. (2004) explain that two subtypes of visual processing are important for reading. A reader needs to be able to detect the integration of motion signals (‘coherent motion’) in order to read accurately, and has to be able to recognise the difference between the speed of motion signals (‘velocity’), in order to read quickly and fluently.

There is some disagreement about the role of visual processing in reading disorders. Vellutino et al. (2004) proposed that visual processing difficulties are a symptom and not a cause of reading difficulties. They claim that the magnocellular system has not been shown to be related to reading difficulties but acknowledge that a correlate between weak reading and the magnocellular system exists, and may possibly be used as a biological marker.

In 2014, a reaffirmed policy statement, ‘Learning Disabilities, Dyslexia, and Vision’, was issued jointly by the American Academy of Pediatrics, the American Academy of Ophthalmology, the American Association for Pediatric Ophthalmology and Strabismus, and the American Association of Certified Orthoptists. The report stated that vision problems can interfere with the process of learning but are not the cause of dyslexia or learning disabilities. The report acknowledges that reading requires adequate vision and that the brain needs to interpret the visual images seen by the eyes, in other words, proficient readers need good visual acuity and good visual processing. The policy document highlights that studies show that deficits in visual processes such as visualisation, visual sequencing, visual memory, visual perception and perceptual-motor abilities are not causes of reading difficulties. The document claims that maintaining directionality is a symptom of a reading disorder and that word reversals, skipping words, and difficulty with saccades are a result of linguistic deficiency and not a visual or perceptual disorder. The following section will focus on how an impaired skill, or a combination of compared skills, may lead to reading difficulties.

2.4 Reading difficulties

Drawing meaning from text (comprehension) is the primary reason for reading, eloquently described by Nation (2019, 47) as a task “for the reader to create the mental world of the writer”.

Children may not read adequately because of environmental factors such as poor teaching, poverty, or language barriers. Some children, despite adequate cognitive ability, adequate instruction and other environmental factors, still struggle to learn to read. The sample in this study is representative of such children. Research suggests that these struggling readers can be divided into distinguishable groups based on their comprehension outputs (Gough and Tunmer 1986).

Some struggling readers have weak comprehension but good word recognition, decoding and spelling. These children are said to have Developmental Language disorders (DLD), also referred to as Specific Language Impairment (SLI) or they are referred to as ‘weak comprehenders’. The term Specific Language Impairment (SLI) has typically been used for children with poor language learning in the absence of factors which may explain this difficulty. These include neurobiological and environmental factors (e.g. learning difficulties, autism, bilingualism, socioeconomic considerations), neurodevelopmental factors (e.g. ADD and ADHD), and those that have discrepancy between verbal and nonverbal scores in psychoeducational assessments. Because of the defining factors of SLI, access to specialist resources and interventions has excluded many of these children. As a result of this exclusion, and disagreement about the diagnostic criteria of SLI, it has been suggested the term Developmental Language Disorder (DLD) be used which include children with any of the factors listed above (Bishop et al. 2017; AFASIC 2016). This allows more children to receive the assistance that they need.

Other readers have good comprehension skills but poor phonological skills. These children *can* struggle with comprehension when reading because of laboured decoding which requires a high cognitive workload, in turn impacting on the ability to draw meaning from text (Catts, Adolf and Ellis Weismer 2006; Snowling and Hulme 2012). This difference in their understanding is evident when reading, or being read to. Comprehension will be good when they are being read to, but poor when they read the material themselves. A difficulty with the phonological aspects of reading is referred to as ‘developmental dyslexia’ (or simply dyslexia), ‘Specific Learning Difficulty in Reading’ or these readers are referred to as ‘weak decoders’. Because of the range of symptoms associated with dyslexia (in the linguistic, auditory processing and visual processing domain), and the heterogeneous manifestation of the disorder, scholars working in the field have had difficulties defining it. The International Dyslexia Association’s webpage defines dyslexia as:

> a specific learning disability that is neurobiological in origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological component of language that is often unexpected in relation to other cognitive abilities and the provision of effective classroom instruction. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge.
>
> International Dyslexia Association (2019)

The British Dyslexia Association (BDA) website acknowledges Rose’s (2009) definition of dyslexia as visual and auditory processing difficulties that are experienced by some individuals. The term Specific Learning Difficulties (SpLD) is frequently used in the education community, and covers a range of learning-related disabilities including dyslexia, speech and language delay and dyspraxia. A child delayed in reading skill is described as having a Specific Learning Difficulty in Reading. Wolf (2008,167) also recognises the variations in defining dyslexia and says that some researchers use more general descriptions such as ‘reading disabilities’ or ‘learning disabilities’ rather than using the term ‘dyslexia’.

Using the term ‘Specific Learning Disorder in Reading’ rather than ‘Dyslexia’ is also recommended in the revisions to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V).

According to DSM-5, the diagnosis of a specific learning disorder includes the following symptoms:

> 1. Persistent difficulties in reading, writing, arithmetic, or mathematical reasoning skills during formal years of schooling. Symptoms may include inaccurate or slow and effortful reading, poor written expression that lacks clarity, difficulties remembering number facts, or inaccurate mathematical reasoning.
>
> 2. Current academic skills must be well below the average range of scores in culturally and linguistically appropriate tests of reading, writing, or mathematics. Accordingly, a person who is dyslexic must read with great effort and not in the same manner as those who are typical readers.
>
> 3. Learning difficulties begin during the school-age years.
>
> 4. The individual's difficulties must not be better explained by developmental, neurological, sensory (vision or hearing), or motor disorders and must significantly interfere with academic achievement, occupational performance, or activities of daily living.
>
> American Psychiatric Association (2013)

Several researchers have explored whether SLI and dyslexia are distinct disorders. Catts et al. (2005), for instance, identified 527 children with SLI in kindergarten and then tested these children for dyslexia in the second, fourth and eighth grades. The outcomes showed limited but statistically significant overlap between SLI and dyslexia. In a second related study, Catts, Adolf and Ellis Weismer (2006) examined phonological processing in a subsample of participants: a group of dyslexic-only children, a group of SLI-only children, a third group with both SLI and dyslexia and a control group of proficient readers. The children with dyslexia and the combination group performed worse on measures of phonological processing than the SLI and typical-reader groups.

In a more recent study, Spanoudis, Papadopoulos and Spyrou (2019) questioned whether SLI and reading disability (dyslexia) have a categorical distinction or exist on a continuum. They examined four groups of children in Greek, an orthographically consistent language. Outcomes showed that all three clinical groups (dyslexia, SLI and co-morbid groups) performed similarly in phonological awareness and on naming speed tasks. Group differences were observed in orthographic processing, reading, semantics and phonological memory. They conclude that SLI and dyslexia are distinct disorders manifesting with different symptoms but sharing common characteristics.

Gough and Tunmer (1986) presented the Simple View of Reading (SVR) model where Reading (R) = Decoding (D) x Oral Language Comprehension (C). A reading disability can result from poor decoding, poor oral language comprehension or both. This SVR model can be represented graphically as seen in Fig 2.1.

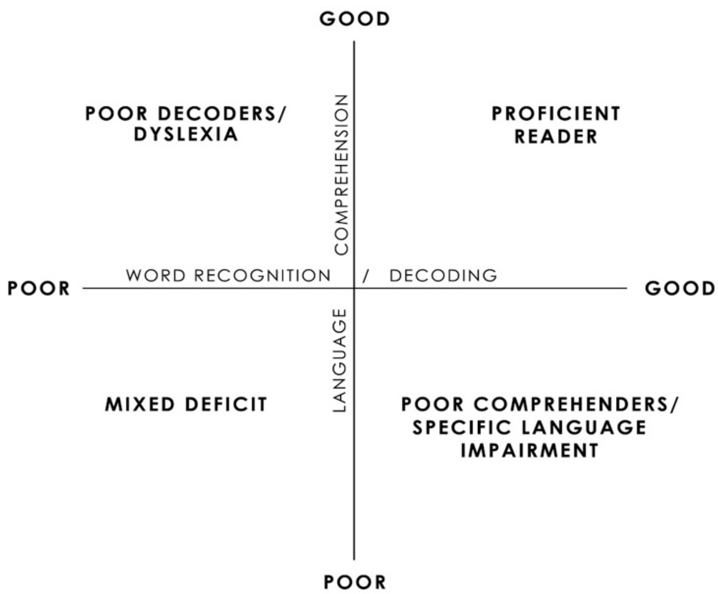


Fig. 2.1 The Simple View of Reading

A child with both good word recognition/decoding and good language comprehension skills would be a proficient reader. Someone with poor word recognition/decoding ability but good language comprehension skills would fall into the quadrant of dyslexia. A child with good word recognition/decoding ability and weak language comprehension would have specific language impairment (SLI) and some children would fall into the fourth quadrant with a deficit in both word recognition/dyslexia and language comprehension skills. However, since dyslexia and SLI seem to exist on a continuum, defining and diagnosing these disorders can be difficult. In addition, there is considerable overlap between the two conditions.

Good Oral Language development precedes both adequate decoding ability and language comprehension (van Viersen et al. 2018; Hulme and Snowling 2016). For dyslexics, problems with oral language development that persist in speech sounds manifest in problems with decoding at the onset of formal reading. Difficulties in comprehension skills result from oral language skills that persist in grammatical structures and understanding word meanings. SLI can be diagnosed in preschool but dyslexia is usually only diagnosed later when children fail to learn to read. Studies of children at the early stages of learning to read, suggest that children who go on to be diagnosed with SLI show weaknesses in vocabulary knowledge, grammar and syntax from an early age (Catts, Adolf and Ellis Weismer 2006). In addition, SLI children have weak auditory perception, weak verbal working memory, processing speed difficulties, weak non-word repetition and poor sentence recall (Leonard 2014; Spanoudis, Papadopoulos and Spyrou 2019).

As they progress through their schooling, children can also experience higher-order language difficulties – problems with inferring and analysing text, figurative language, comprehension and knowledge of story structure. It is unclear whether some of these areas are a cause or consequence of reading comprehension impairments, and there can be considerable heterogeneity within the group (Snowling and Hulme 2012).

Researchers use various measures to distinguish between weak readers with and without dyslexia. One aspect of defining dyslexia is based on discrepancy criteria i.e. children are considered dyslexic if there is a discrepancy between intelligence quotient (IQ) and reading age as measured by standardised tests (Kuerten, Mota and Segaert 2019). Dyslexic children are said to show average to above average IQ but this does not reflect in reading age. In other words, in dyslexia, weak reading is unexpected given the child's high non-verbal skills and this discrepancy means a dyslexic child is often not achieving to his potential. A child with broad language deficits will typically score lower on non-verbal IQ and reading level is weak, so there is no discrepancy between potential and performance. These children are often thought to not benefit much from remediation (Adlof and Hogan 2018).

IQ discrepancy as a determining factor has been problematic and criticised, as it excludes children with weak reading (but without a formal diagnosis of dyslexia) from being eligible for remedial services based on their reading performance. In addition, the presence or absence of IQ-achievement discrepancies do not reliably differentiate children in terms of long-term prognosis, response to intervention, or in terms of the cognitive skills (e.g. phonemic awareness, phonological recoding) that underlie the development of word recognition (Snowling and Hulme 2012; Vellutino et al. 2008). Vellutino et al. (2008) found in a multi-tiered, longitudinal intervention study, that intelligence tests did not reliably distinguish between at-risk children who became independent readers with small-group intervention, and those who did not; nor between children who attained grade-level expectations after receiving more intensive, individualised remedial assistance following the small-group intervention and those who did not attain grade-level expectations.

Because reading skill exists on a continuum, there is no distinct point at which weak reading ends and dyslexia begins. Researchers do not use a standard measure to determine the point of being dyslexic. A common criterion for measurement is 1.5 SD below the mean in reading accuracy (Hulme and Snowling 2016). Catts et al. (2005) use 1 SD below the mean on a word recognition test as a potential indicator of dyslexia. Pennington et al. (2012)

suggested that dyslexia is present when readers perform at ≤ the 10th percentile in reading fluency, suggesting that dyslexics are at the lowest end of a normal distribution of readers.

Shaywitz suggests that a wide range of factors should be taken into account when diagnosing dyslexia and says that there is “no single test score that ensures diagnosis of dyslexia. It is the overall picture that matters” (Shaywitz 2005,139). The reading deficits in the sample under investigation are most likely heterogeneous, falling into 3 quadrants of the SVR: weak decoding, weak comprehending and co-morbid. The broader term ‘reading difficulties’ is therefore deemed more appropriate to use with the current sample. The next section will introduce the most prominent theories that have been developed by scholars in an attempt to explain specific reading difficulties.

2.5 Theories of reading difficulties

Why some children struggle to acquire reading has been questioned, researched and explained from various perspectives. Frith (1999) distinguishes three levels of theories: biological, cognitive and behavioural. Symptoms of dyslexia such as poor reading and rhyming are explained at the behavioural level. Theories relating to phonological awareness, slow processing and automaticity are explained at the cognitive level and theories relating to the magnocellular pathways and cerebellum are explained at the biological level. Many researchers have referred to Frith’s three-level model including Fawcett (2001), Bosse, Tainturier and Valdois (2007), Elliot and Grigorenko (2014a) and Kuerten, Mota and Segaert (2019).

The various theories are explored here, with reference to studies that have related constructs underlying these theories.

2.5.1 Phonological theory of reading difficulties

The intention of reading is to draw meaning from text. Understanding, inferring and analysing information are referred to as metacognitive skills (also referred to as higher order thinking). Whilst children with difficulties do not comprehend well, it can be the case that the difficulty does not stem from this higher level, but exists at the single word level, and at the letter-sound level. Referring back to the acquisition of reading skill, when the foundation skills of letter-sound association and automatic decoding are not in place, efficient reading, and as a result, comprehension can be affected.

The phonological deficit theory explains reading difficulties as a cognitive impairment in grapheme-phoneme conversion, and single word decoding (Dehaene 2009). When children have difficulty representing, storing, manipulating and retrieving speech sounds, the fundamentals of reading are impacted. It is widely accepted that phonological processing problems play a central and causal role in dyslexia (Ramus et al. 2003; Shaywitz 2005*)* and that weak decoding is a consequence of inadequate phonological processing skills (van Rijthoven, Kleemans and Segers. 2018). Functional brain imaging (fMRI) studies seem to indicate a dysfunction in the left hemisphere of the brain as a basis for the phonological deficit (Shaywitz 2005). This is thought to be genetic, explaining the hereditary nature of dyslexia. Shaywitz discovered under-activation of the left-temporal region compared to proficient readers. More recent research by Christodoulou et al. (2014) and Waldie et al. (2017) show asymmetry in brain activation between proficient readers and those who are not. Struggling readers have reduced activation of temporo-parietal areas during phonological tasks as well as activation in the right brain hemisphere; which is not evident in good readers and thought to be a compensatory strategy.

As explained in section 2.3.1, phonological awareness (one component of phonological processing) is particularly important for decoding. As such, phonological awareness specifically is implicated in the phonological deficit theory, and the assumption is that poor phonological awareness skills cause decoding problems. Typically, assessments that are used to measure phonological awareness include measuring the ability to recognise and produce rhyming words, the ability to segment words into syllables/phonemes, and the ability to read ‘nonsense words’. This pseudo-word reading measures whether a child has the ability to read a word never seen before, thereby relying on letter-sound association and decoding, and not relying on recalling the whole word from memory.

Gellert and Elbro (2018) predicted reading difficulties using a dynamic assessment of decoding. 158 kindergarten children were taught three novel letters and how to blend them into new words. At the end of Grade 2, they were assessed on the outcomes of reading. The initial decoding assessment predicted difficulties in reading fluency, and more so, predicted difficulties with reading accuracy. Outcomes from the initial decoding assessment substantially improved the prediction of reading difficulties over and above the traditional testing methods of letter identification, phonological awareness and rapid naming.

Criticism of the phonological deficit theory is that not all dyslexics demonstrate difficulties in phonological processing (Kuerten, Mota and Segaert 2019). Additionally, phonological deficits are not exclusive to dyslexics, as it has been found that there is no difference in the phonological abilities of dyslexic children compared to readers that are weak for other reasons such as environmental factors or weak ability (Stanovich 1994; Stein 2018).

The following sub-section addresses two distinct cognitive deficits namely phonological deficit, and rapid-naming deficit, which together comprise the double deficit theory, which is claimed to be responsible for weak phonological processing.

2.5.2 Double-deficit theory of reading difficulties

Successful reading relies on links between cognitive and linguistic processes. Wolf and Bowers (2000) explored the presence of a speed deficit in struggling readers. The “integrity, speed and automatic connections” (Wolf et al. 2009, 86) between these processes can affect fluency and comprehension. Based on their research, which focused on dyslexics’ ability to rapidly name a series of known symbols (numbers and letters) and concepts (objects and colours), Wolf and Bowers (2000) proposed three subtypes of impaired readers: phonological-deficit readers who display phonological deficits without naming-speed difficulties, naming speed deficit readers displaying no deficits in decoding or phonological awareness and double-deficit readers who display a naming speed difficulty in conjunction with a phonological difficulty.

There is not full agreement about the double-deficit theory regarding reading difficulties and RAN has been shown to be a separate entity from phonological awareness (Jacobs 2007). It appears that a phonological deficit has a strong relationship with decoding accuracy, while naming speed impacts more on reading fluency (Kuerten, Mota and Segaert 2019).

Whilst rapid naming and phonological difficulties often co-exist, additional questions have been raised of whether these subtypes account for possible additional co-occurring difficulties such as attention issues or motor difficulties, or whether a rapid naming difficulty is possibly a reflection of a general processing speed deficit (Savage 2004; Pennington 2006; Brandenburg et al. 2017). Nevertheless, Wolf et al. (2009) highlight that interventions should address the individual components of reading (orthographic, phonological, semantic, syntactic and morphological) as well as the connections between them. By doing so, through extensive learning and practice, *automatic decoding* will result in fluency with good comprehension.

2.5.3 Cerebellar theory of reading difficulties

The Cerebellar Deficit Theory of reading difficulties has its roots in neurobiology and claims that the cerebellum of the reading-disabled individual is mildly dysfunctional. This is said to result in difficulties with motor co-ordination, balance, speech articulation and automatisation (Ramus et al. 2003; Fawcett 2001). The slight deviation in the cerebellum is theorised to interfere with the automatisation of skills associated with, and required for, reading. Much research to support this was done by Nicolson and Fawcett, including an early study (Nicolson and Fawcett 1990,159) in which they postulated that a reading difficulty may be a "symptom of a more general learning deficit – the failure to fully automatise skills". When skills are automatic, there is little cognitive effort required and processing speed is high.

In the Nicolson and Fawcett (1990) study, 23 dyslexic children were required to do a primary task of balancing. A secondary task (backward counting) was introduced which was done concurrently with the primary task. For the primary task alone, the dyslexic group performed as well as a control group. As Nicolson and Fawcett hypothesised, on the dual task, the dyslexic group performed significantly worse than the control group. Because counting has a phonological element, which is known to be a challenge in dyslexia, an additional experiment was conducted in which the secondary task was a reaction to tones. Participants were required to press a button held in the left hand in response to a high tone, and the right hand in response to a low tone. Again, the control group performed better than the reading-impaired group.

It should be noted, however, the weak performance of the reading impaired group on the tone task could be attributed to poor auditory processing, poor processing speed in translating the interpretation of the high/low sound into pressing the appropriate button, or weak directionality/visual spatial difficulties. All of the above are skills can be challenging for weak readers. Nicolson and Fawcett's work highlighted that research into dyslexia needed to be broadened to include *general* skills that could possibly lead to a better understanding of difficulties, with the goal of developing effective remediation strategies.

Questions have been raised as to whether deviant cerebellar functioning is indeed a cause of reading impairment. Ramus et al.'s (2003) main critique of the cerebellar theory is that the causative connection assumed between articulation and phonology in the theory was based on a, now discarded, view of the motor theory of speech (which hypothesised that developing stable phonological representations depends on speech articulation). Motor problems are found within a sub-group of dyslexics, suggesting that the cerebellum could perhaps be used as a compensatory measure for weak reading.

More recently, scholars have also used neuroimaging to try and determine the role of the cerebellum in reading impairment. Baillieux et al. (2009), for instance, conducted Functional Magnetic Resonance Imaging (fMRI) scans on a group of reading-impaired children presented with a noun-verb task. They were given a noun and required to produce an associated verb e.g. BOAT – SAILING. The fMRI showed scattered activation in the left-brain hemisphere compared to the control group, including cerebellar activation. Questions raised were if the cerebellum is indeed a cause of reading impairment; if the task presented was a phonological or semantic one; and whether the cerebellum is perhaps used as a compensatory measure or tool.

2.5.4 Magnocellular theory of reading difficulties

Acuity in terms of vision and hearing refers to the sharpness of sight and sound, in other words, how well you can see, or how well you can hear, and is an obvious necessity for reading. Visual and auditory *processing* is different from acuity in that it refers to the *processing* of information that the brain receives from the eyes and ears, in other words, how the brain interprets the information it receives via the eyes and ears. The magno-cells of the brain specialise in the detection of rapidly changing stimuli with regards to location and shape (i.e. visual processing) and in detecting changes in acoustic information (i.e. auditory processing).

The magnocellular theory of reading difficulties, a biological theory, was proposed by Stein (2001) and he continues to voice support for his theory. The magnocellular theory postulates that a dysfunction in either the visual or auditory magnocellular system results in difficulties with reading. The visual processing and auditory processing aspects of the magnocellular difficulty will be discussed in turn, in the sections following.

2.5.4.1 Visual processing deficit

Suggestions have been made that subtypes of visual processing difficulties can result in different behavioural manifestations of reading difficulties. For example, a study by Wilmer et al. (2004) showed that poor readers who have weak detection of ‘coherent motion’ (i.e. the ability to detect integration of motion signals) have *inaccurate* reading, while poor readers who have weak detection of ‘velocity’ (i.e. the ability to recognise the difference between the speed of motion signals) have *slower* reading. Visual attention span (VAS) disorder is a limit in the number of visual items that can be processed simultaneously (Peyrin et al. 2012). Studies show that difficulties in VAS can contribute to reading impairments and occur separately from phonological difficulties (Bosse, Tainturier, and Valdois 2007; Peyrin et al. 2012; Chen et al. 2016). Van den Boer and Jong (2018) claim that visual attention span predicts reading performance over time, more accurately than phonemic awareness.

As explained in section 2.3.3, there is some disagreement as to whether a visual processing deficit can cause reading disorders such as dyslexia. Even so, the 2014 policy statement of the American Academy of Pediatrics, the American Academy of Ophthalmology, the American Association for Pediatric Ophthalmology and Strabismus, and the American Association of Certified Orthoptists acknowledges that secondary forms of reading difficulties can be caused by visual or hearing difficulties. However, the policy statement suggests that these reading difficulties should be separated from dyslexia. This appears to contradict the idea presented that children may have a “treatable visual problem that accompanies or contributes to their primary reading or learning dysfunction” (p7). The report states that, for instance, addressing a convergence insufficiency will make reading more comfortable but will not improve decoding or improve comprehension. As there are studies that both support and refute the magnocellular theory, the policy document states that there is “insufficient evidence to base any treatment on this possible deficit” (p3). They conclude by stating that dyslexia and learning difficulties are complex problems with no simple solution and align with the view that dyslexia is a language-based disorder.

Researchers like Olulade, Napoliello and Eden (2013) also argued that deviant visual motion processing is not a cause of dyslexia. In a study comparing a dyslexic group against younger reading-matched children, the same deficits in magnocellular pathways were found in both groups. Olulade, Napoliello and Eden (2013) suggest that because dyslexics have restrictions in the amount and quality of material they read, this results in inadequate development of the magnocellular pathways, in other words, the deviant visual processing in dyslexics is a developmental problem because they don’t read enough.

Despite this scepticism, Stein (2019) continues to claim that an intervention that improves magnocellular cell function and also improves reading will demonstrate that magnocellular cell function has a causal influence on the ability to learn to read. A study in training magnocellular pathways was done by Lawton (2016) who found greater improvements in reading accuracy and fluency by training magnocellular pathways exclusively (with no explicit reading component) than word building or auditory timing interventions. Improvements were also noted in attention and working memory.

There has been a resurgence of interest in the role of visual processing in reading difficulties and inconsistent findings are further complicated by differences in terminology used in studies, differences in testing formats and scoring methods (Elliot and Grigorenko 2014b). The cause/consequence argument should not detract from the evidence that poor visual processing is seen in poor readers, and that it is a vital skill for efficient reading. As such, it is sensible for reading intervention materials to address a potential visual processing deficit.

2.5.4.2 Auditory processing disorder

Central Auditory Processing Disorder (CAPD), as defined by the American Speech-Language-Hearing Association

> is the perceptual processing of auditory information in the central auditory nervous system (CANS) and the neurobiological activity that underlies that processing and gives rise to electrophysiologic auditory potentials
> (American Speech-Language-Hearing Association [ASHA], 2005).

If sounds and transitions between sounds aren't correctly represented (e.g. distinguishing between /buh/-/duh/), the hypothesis is that an auditory deficit, as described above, could be a direct cause of a phonological deficit. The rationale here is that stable phonological representations of individual sounds (such as /b/ and /d/) cannot form if an individual has an auditory deficit. Unstable phonological representations are thought to result in a difficulty in learning to learn to read (Ramus et al. 2003).

Iliadou et al. (2009) have reported that around 25% of reading disabled individuals have a co-morbidity of reading and auditory processing difficulties. They call for more auditory screening in children struggling with reading, saying that auditory training may provide better phonological awareness, speech discrimination and reading skills. Stein (2018) claims that, like a visual magnocellular impairment, an auditory impairment causes phonological failure. Magnocellular dysfunctions can be diagnosed early (i.e. before the onset of reading failure) and Stein thus echoes Iliadou's calls for early testing.

Magnocellular difficulties are well documented in the literature as an explanation of dyslexia. However, most definitions of dyslexia state that the difficulty excludes any other factors including visual or auditory problems (de Jong and van Bergen 2017). Additionally, dyslexia is defined as a difficulty that is persistent in spite of intervention, yet auditory and visual magnocellular impairment can be remediated with some success and have been linked to improved phonological skills that positively impact on reading difficulties. Goswami (2015) proposes that weak sensory skills result from less reading in children with dyslexia and suggests that if the sensory issues are indeed a causal factor, longitudinal studies need to be done, beginning in infancy, in order to successfully identify the neural basis of dyslexia. In addition, she states that these studies could have a strong impact on remediation.

As with most other deficits associated with reading difficulty, scholars agree that not all individuals diagnosed with reading difficulty have an auditory processing deficit. Lallier, Thierry and Tainturier (2013) explored the relationship between two groups of reading impaired candidates, those with, and those without phonological difficulties. Only those with phonological difficulties displayed auditory processing deficits. This would suggest that the magnocellular deficit theory cannot account for all cases of reading impairment, highlighting once again that struggling readers have heterogeneous profiles.

The inconsistencies in defining exactly what dyslexia is, the diversity in characteristics displayed by those with reading difficulties, and the existence of multiple theories that hypothesise one or two underlying causes, but that cannot account for all cases of reading difficulty, has resulted in the multi-deficit theory.

2.5.5 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 and Black 2018). Potential difficulties can surface as a result of a deficit in any of the skill areas that were discussed in the previous sections. These deficits 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 SLI or ADHD (Pennington 2006; van Bergen, van der Leij and de Jong 2014).

The multiple-deficit theory can explain the heterogenous nature of reading difficulties. It also explains characteristics such as the continuous nature of difficulties, that different deficits can be found in different individuals and that co-morbidity amongst disorders is common (van Bergen, van der Leij and de Jong 2014; de Jong and van Bergen 2017; Snowling, Hulme and Nation 2020; Tschentscher et al. 2019).

The correlation between various theories of dyslexia was explored in a study by Ramus et al. (2003). 16 dyslexic university students were administered a full battery of assessments including psychometric, phonological, auditory, visual and cerebellar tests. All participants showed phonological impairment, with various overlaps between additional categories of auditory, visual and cerebellar disorders as demonstrated in the following figure (where the capital letters represent each individual that was tested):

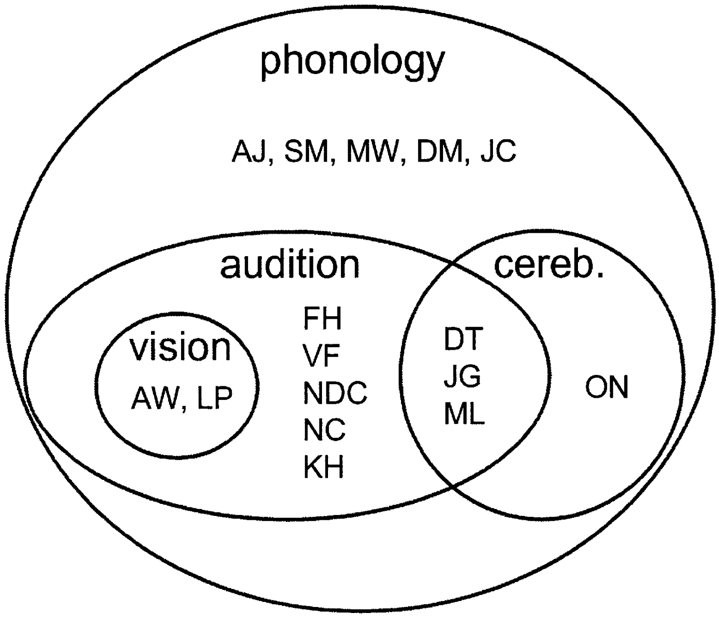


Fig.2.2 Graphical representation of how impairments overlap in individuals with dyslexia (Ramus et al. 2003,859)

The multi-deficit model acknowledges mixed profiles in poor readers and highlights that assessments should be widened with the purpose of providing the best clinical profile, which would ensure the most effective intervention (Zoubrinetzky, Bielle and Valdois 2014).The value of broadening assessments was explored in a study by Giofré et al. (2019) who assessed for both visual and phonological skill in a group of 316 Italian children, clustering them into two distinct groups; both groups were impaired in visual processing, but one group was more severely impaired in phonological skills. They state that dyslexia should be an 'umbrella term' encompassing different sub-groups.

Recent research by Ring and Black (2018) supports the multi-deficit model of reading and proposes that poor reading "can result from the presence of additional risk factors beyond compromised phonological awareness" (Ring and Black 2018, 106).

Additionally, the profiles of struggling readers may also vary depending on the orthographical structure of the language Georgiou et al. (2012) examined whether children diagnosed with dyslexia have auditory and visual processing deficits, and if these are associated with phonological awareness, rapid naming speed and orthographic processing. Twenty-one Greek-speaking, Grade 6, Cypriot children were allocated to a dyslexia group if they scored 1 SD below the age norm on two of three reading fluency tasks (that included word reading fluency, pseudoword reading fluency and text reading fluency) and additionally, if they were within the average range on both verbal and non-verbal ability tasks. Only three children had a formal diagnosis of dyslexia. Groups of Reading-age (RA) matched and Chronologically age (CA) matched groups were used as controls. The results indicated that the children from the dyslexia group did not show any auditory processing deficits. The authors attribute this to the characteristics of Greek which has a consistent orthography. Half the test group had visual processing deficits. Both RAN and orthographic processing were associated with the dyslexic group. Only seven of the 21 participants had phonological deficits and this was not significantly different from the RA or CA control groups.

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. Concisely summarised by Protopapas (2019, 7) "if the trend is away from single causes and toward the recognition that reading skill, and reading failure, is multi-factorial, multi-level, and polygenic, then you are more likely to recognize that assessment and remedial efforts are best focused directly on reading skill and the well-known pre-requisites for its development".

2.6 Intervention

Just as there is no agreement in terms of defining and identifying causes of reading difficulties, there are equally diverse suggestions on how best to remediate reading disorders. Whilst comprehensive, explicit phonics-based methods of reading *instruction* are beneficial to all learners, remediation or intervention for a child who is behind in reading needs to be effective and efficient, working quickly to close the gap from where the child is, to where he needs to be. A child falling behind in reading will struggle to close the gap as his peers continue to improve in skill as time passes. The importance of early intervention was highlighted in a study by Solis et al. (2014), in which adolescents received intervention over three years. Whilst they improved at a better rate than children not receiving intervention, they still remained behind their age appropriate level.

Early screening is therefore vital and there has been a focus in doing more assessment and remediating weak phonological awareness skills and/or oral language skills at a pre-school level. Remediating weak skills without waiting for the onset of formal reading tuition may prevent a potential reading difficulty. This, of course, may assist some children who have weak foundation skills but may not impact on those with neurobiological difficulties that could manifest in more severe reading difficulties such as dyslexia. Because of the multi-faceted nature of reading, and the many variables that could impact on a reading difficulty, the question becomes what to test for in early screening. Given the mixed profiles of poor readers, using only an assessment such as pseudoword reading (which in the past has often been used as sole screening measure for dyslexia) is probably not sufficient. Measures such as visual attention span and RAN contribute to reading performance in proficient and dyslexic readers independent of their phonological skills (Zoubrinetzky, Bielle and Valdois 2014). Children should thus also be screened for visual attention span and rapid processing ability in order to find the most appropriate intervention.

Neuro-imagery has been used to indicate how the functioning of a typical reader's brain differs from that of a struggling reader and can predict whether a child will develop reading difficulties. A study on 19 non-reading kindergarten children was conducted by Bach et al. (2013). Behavioural pre-cursors of reading were assessed before an 8-week letter-speech sound association computerised training game. Following the training, event-related potentials (ERP) and functional magnetic resonance imaging (fMRI) data were recorded during a word/symbol processing task. Reading skills were then assessed in Grade 2 in order to see if neuroimaging predicted reading skill over behavioural data alone. Results indicated that combining neuroimaging and behavioural data led to more accurate prediction of difficulties and Bach et al. suggested that these assessments should be included in early screening. They do acknowledge that this may not be a practical approach due to expense and time factors, but for children with familial risk of poor reading, early intervention could be administered before reading failure and negative school experiences emerge.

It has also been shown that interventions can impact brain functioning, changing the pathways that are used and resulting in improved reading (Keller and Just 2009; Shaywitz 2005; Dehaene 2009; Doidge 2007; Zygouris et al. 2018; Hasko et al. 2014). It is important therefore, to explore the impact of intervention at a neural level in order to guide the development of effective interventions.

2.6.1 Characteristics of interventions

Intervention is a complex process that goes beyond diagnosing that a reading difficulty exists (Protopapas 2019). Most schools group weak readers together for a standard intervention. Such an intervention approach seems in line with recommendations of institutions such as the Scottish Rite Hospital (n.d), which states that dyslexia should not be subtyped, and could be linked to clinical criteria which does not include criteria for subtypes of dyslexia, as is the case in the Diagnostic and Statistical Manual of Mental Disorders (5^{th} Edition). It suggests that clinicians "should be prepared to flexibly evaluate and remediate all factors contributing to the reading problems of children with dyslexia based on student needs" (p2).

In contrast to a standard intervention approach, Jones, Conradi and Amendum (2016) propose an approach that is targeted toward the *specific weakness* of the reader. The study identified three particular areas of weakness in 6 000 third grade readers who failed a state reading comprehension test. The smallest group had weak decoding of grade-level text with appropriate accuracy, the second group decoded with fair accuracy but lacked automaticity, and the largest group read accurately but had weak comprehension. Jones, Conradi and Amendum (2016) suggest that teachers and specialists be trained in classroom and intervention techniques in order to address the particular difficulty of the weak reader.

Targeted intervention can also be successful where children display visual processing difficulties. Visual disorders related to deficiencies in the magnocellular system manifest as increased thresholds for the detection of low contrast, poor sensitivity to visual motion and weak capacity for directing attention, eye movement and conducting visual search – all required for reading (Elliot and Grigorenko 2014b). A study conducted by Chouake et al. (2012) explored the relationship between magnocellular training and reading abilities. Magnocellular training was conducted on a group of readers which improved the speed of lexical decision. In addition, there is some indication that magnocellular training may also relate to reading accuracy such as the study by Lawton (2016) discussed in section 2.5.4.1.

Children with Specific Language impairment have been shown to display weak auditory perception, poor working memory and sentence recall, impaired pseudoword repetition and/or processing speed deficits (Leonard 2014; Spanoudis, Papadopoulos and Spyrou 2019). These impairments overlap with weak skills shown by dyslexic children and we can expect to see interventions that work for dyslexic children assist all weak readers.

Additionally, the concept of broad benefit for children receiving intervention can be extended to English second language learners, and those with lower IQ scores. Lovett et al. (2008) evaluated the outcomes, over four years, of reading intervention on weak readers from different language backgrounds and how they differed in response to phonologically-based intervention. 166 weak readers were assessed before, during and after an intervention of 105 hours. Students were allocated to the English-Language Learner (ELL) group if their primary language at home was not English but they were schooled in mainstream English schools. This group consisted of 76 students ranging from 6 – 13 years. Nine languages were spoken by the sample group, with Portuguese and Spanish being prevalent. 90 students were allocated to the English First Language L1 group. Lower and higher IQ children responded equally to the interventions, as did the ELL and the English L1 children. However, oral language skill at the initial testing point, did predict final outcomes and reading growth during intervention with greater growth in children with greater language impairment.

Motivation and engagement are important aspects to be integrated into intervention. Frijters et al. (2017) discuss how learning experiences can motivate candidates to engage in future learning. Increased success is associated with increased motivation and a sense of competence. Feuerstein, Falik and Feuerstein (2013) extend the impact of motivation and engagement to neuroplasticity. Specific brain functions must be activated and stimulated to develop behaviour. Additionally, intense intervention, repetition, novelty, challenge and multi-modality stimulation can result in changes to the brain.

Interventions that are computer-based have also been shown to be beneficial (van Gorp, Segers and Verhoeven 2016; Fälth et al. 2013). Enhanced motivation and engagement of a computer 'game' that address word repetition, corrective feedback, semantic retrieval with gamification elements related to decoding speed play an important role in the improvement of reading skill. In the Fälth et al. (2013) study, four groups of Swedish children with reading difficulties were observed. Two groups received different computer interventions and the third received a combination of both interventions. The fourth group received ordinary special instruction. In addition to highlighting the benefit of intervention presented in a computer game format, the study highlighted the benefit of addressing multiple skills during intervention as the group that received the combined intervention (decoding, phonological skills as well as word and sentence levels) showed the greatest improvement over a year.

The concept of addressing multiple skills in intervention was further explored in a study by Pape-Neumann et al. (2015) who investigated whether phonological awareness training is an effective intervention to improve reading in German dyslexic third and fourth graders with a phonological awareness deficit, and whether they would equally benefit from phonology or visually-based training. Children were diagnosed dyslexic based on scoring below average on a standardised reading screening, were required to be monolingual German, have at least average non-verbal intelligence, display phonological awareness deficits and have no severe sensory visual or auditory deficits. 40 children with predominantly phonological deficits were randomly assigned to either a phonological awareness training, a phonology-based reading programme or a visual-based reading programme. The long-term improvement in decoding and comprehension was similar across all training groups regardless of differences directly following the interventions. They conclude that phonological awareness training is an effective intervention to improve reading comprehension, but that children can equally benefit from visually-based training and that phonology-based training can impact on decoding skills. They propose a comprehensive approach where combining skills addressed can have a more significant impact on improving reading.

Interventions that include multiple components were also measured by Morris et al. (2012) who concluded that superior effects across a range of reading skills, including fluency and comprehension, were produced by interventions that incorporated multiple components of language and target a range of core deficits. In addition, these improvements are seen across a range of weak readers regardless of IQ, ethnic backgrounds or environmental circumstances.

Papadopoulos and Kendeou (2010, 1301) highlight that “remediation is not instruction” and that remediation is required when instruction has failed. They also note, as has been shown in the studies discussed, that remediation that focuses on just one component of the reading process is less effective.

The Cellfield intervention, which is the focus of this study is an intervention that addresses multiple skills. The breakdown of tasks in the programme will be discussed in the section following.

2.7 The Cellfield intervention

Most interventions target *specific* causes of reading difficulties i.e. either auditory, visual or motor deficits. The Cellfield Reading Intervention aims to create a bigger impact on improvement, by simultaneously addressing a broad range of deficits during intervention.

The Cellfield intervention, developed by Dimitri Caplygin, in Australia in the early 2000's, is based on the multi-deficit hypothesis for reading difficulties (which was explored in section 2.5.5). The computer-based intervention targets phonological, auditory, visual, and visual-to-phonological processing, simultaneously.

The average expected rate of progress for children acquiring reading skills is 12 months for every year that passes. For children who don't have the same *rate* of reading improvement or who are behind their peers, the gap widens between where they are, and where they need to be. The challenge in remediating a significant delay is that proficient readers continue to improve, with the goalposts constantly moving forward. An intervention that can close this gap in a short period of time could eliminate this remediation challenge.

The Cellfield intervention addresses the impaired skills that could potentially co-occur in a struggling reader. Visual, auditory, phonological and motor skills as well as working memory are all activated simultaneously in the brain of the proficient reader during intervention. According to Wolf (2008, 148) "the expert reading brain is a veritable collage of these networks for every type of mental representation across the entire brain from visual and orthographic pattern representations to phonological ones". It has been shown that this is not the case in the brain of the impaired reader (Shaywitz 2005; Christodoulou et al. 2014; Walid et al. 2017). This underlies the rationale for the Cellfield intervention - simultaneously remediating multiple skills that could be impaired.

Groups of cells learning to operate as working units and a network are triggered specific to a task. The phrase commonly used in neuroscience, 'cells that fire together, wire together' suggests that by stimulating the pathways and activating the cells through activities, new neural pathways can be formed. In the context of reading, if the areas of the brain that should be used for reading are activated simultaneously, and more efficient neural pathways are formed, this should result in improved reading skills.

2.7.1 Structure of the Cellfield intervention

The Cellfield consists of ten, one-hour, computerised sessions conducted by a licensed practitioner in a reading centre. Each session increases in difficulty. The ten sessions are scheduled over a two to three-week period. Intense interventions have been shown to be more effective than those that are drawn out (Wolff 2011; Solis et al. 2014). Each of the ten sessions includes exercises which target, amongst other skills, phonological awareness, visual and auditory processing, ocular/motor tasks, orthographic to phonological skills (connecting letters to sounds), working memory, coding and decoding skills. For the majority of the session, letters, words or sentences presented have corresponding aural input. This activates the necessary visual-auditory neural pathways that should be activated in proficient reading.

There are five levels of difficulty in the Cellfield intervention. The pre-assessment determines which level will be used so that the candidate is working in a band that is challenging but achievable – also referred to as Vygotsky's 'zone of proximal development' where new concepts are "maximally learnable" (Dehaene 2009, 259) because they are challenging enough to keep the child engaged, but not so difficult that the child is overwhelmed.

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 candidate 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 e.g. /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. For example, the target word /vat/ is presented aurally, sounded out into its phonemes and then given as a whole word. Four rhyming words /fat/, /vat/, /that/ and /hat/ are then presented, and the candidate is required to select the target word.

The homophone section of the intervention presents a homophone set and a sentence for selection of the appropriate homophone option. For example, the homophone pair /blue/ and /blew/ are presented with a corresponding sentence given aurally: ‘We painted our boat blue.’ The candidate is required to select the appropriate option. Homophones have the same auditory representation but differ orthographically and semantically. With the semantic aspect added to this task, neural areas that process visual, auditory, orthographic and semantic information are activated simultaneously.

Embedded text exercises strengthen phonological awareness in addition to demanding high levels of attention and working memory. A target phrase is presented visually and aurally, then removed. The candidate 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 place 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. For example, in the word /flat/, the candidate has to ‘code’ the word by taking the first letter to the end and adding an /a/ to create /latfa/. This is all done in working memory. He then has to scan rows of moving words to find the target pseudoword. Following a set of ‘word to pseudoword’ conversions, pseudowords are presented that need to be ‘decoded’ back to words. For example, /oftsa/ is presented. In working memory, the candidate is required to drop the final /a/ and move the last letter (s) back to the front of the word to create /soft/ and then scan moving text for the target word. In the later sessions, longer phrases or sentences are presented for decoding only, for example ‘Water the garden to make it grow’ is presented as ‘aterwa heta ardenga ota akema tia rowga’ which needs to be decoded and the words searched for in amongst other moving words.

This decoding exercise is a phoneme manipulation task that is similar in concept to 'Pig Latin', where the onset of the word is separated from the rime, and moved to the end of the word, and the suffix /-ay/ is then added. For example, in Pig Latin, /cat/ becomes /at-cay/. This task is associated with strong phonological awareness. 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 (Strattman and Hodson 2005; Hester and Hodson 2004).

Additionally, pseudoword reading requires good phoneme-grapheme knowledge and high levels of phonological processing. The reader cannot rely on contextual cues or sight word familiarity. It also reflects the reader's strategy for approaching unfamiliar words. The pseudoword paradigm is used extensively in testing and remediation of reading difficulties and is described as "a particularly powerful and illuminating technique" (Probert and de Vos 2016, 3).

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, and Valdois 2007; Zoubrinetzky, Bielle and Valdois 2014; van den Boer and Jong 2018).

Between each of the exercise groupings, a mosaic exercise provides a break from the 'reading' exercises while enhancing 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 in "eye movement control, working memory, sequencing, peripheral vision and visual persistence" (Prideaux, Marsh and Caplygin 2005, 52). These motion graphics are translucent in the early sessions, gradually becoming more opaque until they are solid. Cellfield's moving graphics enhancing motion detection and stimulating the magnocellular pathways is believed to have a positive effect on increasing reading skill (as highlighted by Chouake et al. 2012 and Elliot and Grigorenko 2014b, discussed in section 2.6.1). 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.

Many children coming into a remediation process have already experienced failure and display poor self-esteem and confidence which can lead to avoidance of tasks. Cellfield allocates scores for each exercise and participants earn ‘smiley faces’, which provides immediate positive feedback. Children are motivated to improve their own scores from the previous session. As they do, they are further motivated. The benefits of motivation in intervention were explored in section 2.6.1 (Frijters et al. 2017; Feuerstein, Falik and Feuerstein 2013). Additionally, the Cellfield computer programme is presented in a game style with scoring, time limitations, novelty and challenge, keeping the participants engaged and motivated.

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 and Caplygin 2005) due to the nature of its design addressing multiple skills. The research that has been done in response to intervention in children with varying cognitive measures, varying home language, and various impairments further extends the possible reach of an intervention such as Cellfield. The existing research that has been done in support of the Cellfield intervention will be discussed in the next section.

2.7.2 Existing support of the Cellfield intervention

The largest study conducted to date that assessed the efficiency of the Cellfield was conducted by Prideaux, Marsh and Caplygin (2005). In this study, 262 Australian school children (mean age 11;5) whose reading skill was below age level, underwent the Cellfield intervention. The outcome showed support for the efficacy of Cellfield with improvements of 23 months in Word Attack and 12 months in Comprehension skills, as measured on the Woodcock Reading

Mastery Test. With a mean of 26 days between pre-and post-testing, these results reflect improvements immediately before and after the intervention. Approximately half of the participants were identified as being at risk for dyslexia. Gains in reading skill were similar for all participants regardless of their level of difficulties.

In 2008, data was collected from 27 participants from four Cellfield centres worldwide (including seven participants from the researcher's centre) and analysed by Coltheart. Two pre-treatment assessments were conducted as well as two post-assessments following the Cellfield intervention. An average of a month separated the two pre-treatment assessments, as well as the two post-treatment assessments. The Cellfield intervention was started almost immediately following the second pre-assessment and the first post-assessment was conducted immediately following the treatment. This design was intended to control for maturation, practice and re-testing effects as well as to determine whether the improvements persist beyond the 10 Cellfield sessions with no additional treatment being received by the participants in the month following the intervention. Outcomes reflect clear statistical evidence that Cellfield improved the participants' reading ability and that the gains were maintained a month beyond the intervention (Coltheart 2008).

Sander (2008) compared the effects of the Cellfield to a placebo programme in a dissertation study. Twelve students identified with reading and spelling difficulties participated in the study with seven completing the Cellfield intervention and five the placebo programme. The efficacy was measured using behavioural measures such as reading, phonological awareness, spelling measures, reaction time and accuracy as well as electrophysiological (ERP) indicators before and after the intervention. The Cellfield group showed significant decrease in overall risk for dyslexia and improvement in decoding skills from the pre-test to the post-test immediately following the intervention. Three weeks of follow-on practice training in fluency, comprehension and spelling followed the treatment with a subsequent assessment. The gains experienced by the Cellfield group were maintained in the third assessment. ERP indicators changed over the Cellfield intervention indicating plasticity of neural functions in the Cellfield group.

The present dissertation addresses the gap in research, namely that there have been no systematic studies that have addressed the long-term efficacy of the Cellfield intervention.

2.8 Conclusion

This chapter explored the nature of reading, and the reading acquisition process. The theories of why some children struggle to acquire age-appropriate reading skills were investigated.

The components of the Cellfield intervention were shown to be aligned with the multi-deficit theory of reading difficulties, addressing a broad range of reading skills such as phonological skills, auditory processing and visual processing. Additional aspects of successful intervention, such as novelty and challenge, immediate feedback and repetition, are also integrated into the treatment.

The existing research on the Cellfield intervention was presented which lends support to an intervention of this nature, addressing multiple skills simultaneously, as a relevant and impactful intervention. The purpose of this study is to explore whether gains acquired are maintained over time. The next chapter will present the research methodology of the present study.

CHAPTER 3: METHODOLOGY

3.1 Introduction

The previous chapter outlined the process of learning to read and explored the various theories that attempt to explain reading difficulties. These theories were then linked to the various aspects of the Cellfield intervention, which was also discussed as part of the literature review. This chapter will restate the research aims and questions and will discuss the methodology (the research approach and design), the research procedures and the data analysis techniques used in the research. Ethical considerations will also be discussed.

3.2 Research aims and questions

The main aim of this study is to determine the long-term efficacy of the Cellfield intervention in a South African context. Improvements directly before and after the Cellfield intervention have previously been researched (Prideaux, Marsh and Caplygin 2005; Coltheart 2008; Sander 2008). The Sanders (2008) study reported outcomes three weeks following the intervention and the Coltheart (2008) study reported outcomes a month following the Cellfield intervention. However, the efficacy of the Cellfield intervention beyond one month has not been investigated.

Additional aims of this study are to confirm that reading skill improves over the Cellfield intervention, to compare reading skills between a treatment group (that completed the Cellfield programme) and a control group (who did not complete the Cellfield), and to explore the nature of the relationship between reading measures before and after the Cellfield intervention.

3.2.1 Research questions

The Cellfield programme is a computer-based reading intervention based on the multi-deficit theory of reading difficulties.

The research questions that will be addressed in this study were posed in section 1.4, and are repeated here for ease of reference:

i. Do reading scores in individuals with reading difficulties improve significantly after undergoing the Cellfield intervention in a South African context?
ii. What are the long-term effects of the Cellfield intervention in a South African context?
iii. 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?
iv. What is the nature of the relationships between the reading skills addressed by the Cellfield intervention, pre- and post-intervention, as well as in the long term?

3.3 Methodology

Research approaches and data that are collected can be placed into two main categories: qualitative or quantitative. Each approach has its own purpose, strengths and limitations.

Qualitative research aims to gain an understanding of reasons, opinions and motivations. Data are usually collected through observation, interviews and open-ended questionnaires. The outcomes are examined and analysed for patterns and categorised, in order to identify themes (Elliott 2020). The benefit of this approach is that, because of the close involvement of the researcher, a more personal view of the inquiry can highlight subtle complexities and allow for ambiguities and contradictions, which are often a reflection of social reality (McLeod 2019a). Because of the greater time involved in qualitative data collection, analysis and interpretation, smaller data sets are generally used which can be a limitation. Additionally, the validity and/or reliability of research instruments and data analysis can be disputed because of the subjective nature of data collection and interpretation.

Quantitative Research is used to quantify attitudes, opinions, behaviours, and other defined variables by generating numerical or measurable data and transforming them into usable statistics. By supporting or refuting a hypothesis, the results can be used to uncover patterns, draw general conclusions and make predictions in a wider population. The data collection methods are more structured than qualitative data collection and methods, in the human and social sciences, include surveys, standardised (or custom-made) tests and controlled experiments.

Statistical analysis software is typically used to analyse quantitative data. Statistics can be 'descriptive', where the data is merely summarised, or 'inferential', where differences or relationships between groups and variables are identified. The quantitative approach is viewed as scientifically objective because data are analysed using statistical methods. The sample size in quantitative research is usually larger and intended to be representative of the population (Queiros, Faria and Almeida 2017). Limitations of quantitative research are that researchers take 'snapshots' of experiences or behaviour and do not report the participants' experiences (Rahman 2017).

The strengths of both qualitative and quantitative research can be combined by using a mixed-methods approach, which produces a more complete, in-depth outcome for a research question. In addition, using a mixed-methods offsets the weakness in using each approach independently.

The choice of methodology is driven by the research questions. The aim of the current study involved determining the long-term efficacy of the Cellfield intervention by exploring questions that can be answered by administering reading assessment instruments. Furthermore, the researcher was interested in the correlations that existed between the dependent variables (see section 4.6 below) prior to, and following the intervention. The research instruments selected for this study (described in section 3.3.3) generated quantitative (i.e. numerical) data that measured reading skill in the participants. Statistical analysis of the data is required in this study to determine whether the Cellfield intervention had a significant impact on reading ability of the group that underwent the intervention, to compare reading skills between the treatment and control groups and to determine the nature of the associations between the dependent variables. For this reason, a quantitative approach was deemed most appropriate and selected for the study.

3.3.1 Research design

Experimental designs aim to establish a causal relationship between an independent and dependent variable, and is typically projectable to a larger population. In the current study, the independent variable is the Cellfield intervention and the dependent variables are the reading outcomes, namely Word Identification, Word Attack, Passage Comprehension, Reading Rate, Accuracy and Comprehension. In a true experimental design, participants from the larger population are randomly assigned to groups. However, in many situations, random allocation cannot be used for ethical or practical reasons. Where participants are allocated to groups, and the allocation is not random, the design is known as quasi-experimental. In the current study, participants were not randomly sampled – they were allocated to groups depending on whether they had previously undergone the Cellfield intervention or not. This was also a convenient sampling method as the participants came from families that had previously contacted the reading centre with concerns in relation to their children’s reading. Given this, the present study was not a true experiment, but a quasi-experiment.

Additionally, research studies can be cross sectional or longitudinal. A cross sectional study gathers information from a ‘cross section’ of the population at a single point in time. A longitudinal research design involves collecting repeated observations from the same group multiple times and follows changes in outcomes over time.

Considering the research question of whether gains following the Cellfield intervention were maintained in the long term, assessment outcomes at various points in time were required. Therefore, the research design of the present study could be described as quantitative, quasi-experimental and longitudinal.

This study incorporated baseline assessments from 52 children who were assessed at the reading centre after being identified as having a delay in reading skill. The treatment group (n = 41), i.e. the group that underwent the intervention, was re-assessed following the Cellfield intervention (post-test assessment). Both of these sets of data were secondary data as they were collected prior to the onset of the research study. At the onset of the current study, parallel assessments were then conducted (delayed post-test), provided at least one year had passed since the Cellfield treatment was completed, and the results were statistically analysed. This enabled the researcher to establish whether the intervention was effective directly following the intervention and in the long run.

The control group (n = 11) were children that approached the reading centre, prior to the onset of this research project, with concerns over their reading skills. They were assessed and chose not to undergo the Cellfield intervention for various reasons including that they felt their reading difficulty was not severe enough to warrant the intervention, or for time or financial reasons. The initial baseline assessment of the control group was therefore also secondary data. At the onset of the research, families of the control group were contacted if the baseline assessment had taken place at least one year prior, and reassessed (delayed post-test) to compare skill change over time compared to the treatment group.

Part of the procedure of administering the Cellfield intervention is a post-test immediately following treatment to measure the change in skill directly after the intervention. This is the second testing point for the treatment group. Because the control group did not undergo the Cellfield intervention, there is no data for them at the post-test point.

The present quasi-experimental design thus included three assessments for the treatment group – a baseline assessment and two follow-up assessments (post-test and delayed post-test). However, the design differs from a typical quasi-experimental design in that the control group was only assessed twice – a baseline assessment and at the delayed assessment point (as explained above).

3.3.2 Participants

The entire sample of participants consisted of 52 children whose parents previously approached the reading centre owned by the researcher, given their concern over their children's reading skills, and of children who were previously referred to the reading centre via their schools, educational psychologist or other professionals. The participants had an age range of 7;3 to 16;3 and included 33 males and 19 females.

All children had English as a Language of Learning and Teaching (LoLT) with the following home languages: English: 39; isiZulu: 4; Northern Sotho: 4; Afrikaans: 3; Persian: 1; Marathi: 1. Of the entire sample, 48 children attended private schools and 4 children attended public schools. 11 children were formally diagnosed with dyslexia, and 16 had a family history of dyslexia. 7 children received additional academic support and 9 received concessions of either additional time, reader or scribes in exams and tests. Medication for ADD/ADHD was prescribed to 14 children and 3 children were taking medication for either allergies or anxiety.

The 52 participants all exhibited significant impairment in reading as reflected on the baseline assessments, which were done between September 2016 and July 2019. As discussed in chapter 2.4 in the discussion on reading difficulties, there is no clear consensus as to what measures define a reading difficulty, and researchers tend to use different cut-off points. For the purpose of 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 (see next section for a description of these tests):

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)

All participants (via their parents) were contacted at least a year following the intervention (treatment group) or the baseline assessment (control group) and invited to participate in the research. In the entire sample, 41 children completed the Cellfield intervention following the baseline assessment, while 11 children did not proceed with the intervention, due to financial constraints or time commitments. In some of these cases, the children received standard once a week 45-minute remedial sessions. In the present study, those who completed the reading intervention were included in the treatment group, while those who did not complete the intervention were included in the control group. The two groups of participants will be discussed in more detail in the subsequent sub-sections.

3.3.2.1 Treatment group

The treatment group participants (n = 41) measured significantly behind in reading skill and underwent the Cellfield intervention not less than 12 months prior to this study. The age range in this group was from 7 – 18 years with an average chronological age of 10;8 at the baseline assessment, 10;9 at the post Cellfield assessment and 13;0. at the delayed post-test. Within this group 23 participants were male and 18 were female.

All of the participants in the treatment group were schooled in English with 31 participants having English as a home language. The other ten participants' home languages were isiZulu: 2, Northern Sotho: 4, Afrikaans: 3, and one participant with Persian home language. In this group, 37 participants attended private schools and four attended public schools. 11 of the participants in the treatment group were formally diagnosed with dyslexia and 14 participants had a family history of dyslexia or learning difficulties.

3.3.2.2 Control group

The control group participants (n = 11) were assessed (at least 12 months prior to the study) and found to be significantly behind in reading skill. However, this group did not undergo the Cellfield intervention. Many families who contacted the centre for an assessment and then did not proceed with the Cellfield, did not maintain contact with the centre. As there was over a year that had passed since the assessment, families were more reluctant to participate. This was exacerbated by onset of the first COVID lockdown and the adjustment that families had to make to schooling and working from home. This accounts for the smaller number of participants in the control group than the treatment group who had maintained more contact with the reading centre and were more inclined to participate in the study. Additionally, the treatment group were interested in the long-term efficacy of the intervention that their children had undergone.

The age range in this group was also 7 years – 17 years with an average chronological age of 11;4 at the baseline assessment and 13;10 at the delayed post-test. As with the treatment group, all participants were schooled in English with eight participants having English as home language, two participants with isiZulu as home language and one participant with Marathi as home language. The control group consisted of ten males and one female. All the participants in this group attended private schools. None of these children had received a formal diagnosis of dyslexia, and two had a family history of dyslexia or learning difficulties.

3.3.3 Research instruments

The data were collected using standardised reading assessment instruments. The same instruments are prescribed to be used by all Cellfield providers worldwide. This facilitates like for like comparisons of outcomes before and after intervention for children undergoing the Cellfield intervention worldwide. An example of a Cellfield study that used the same reading measurements is that of Coltheart's (2008) study discussed in 2.6.2. These instruments were readily available and familiar to the researcher. In addition, a questionnaire, custom-designed by the researcher, was used to gather biographical information from the participants.

3.3.3.1 Psychometric assessments

The Woodcock Reading Mastery Test and the Gray Oral Reading Test were used to assess reading development across six areas of reading. These tests are widely used, standardised reading assessments. Validity data is reported in the manuals. Although the assessments were normed on samples in the United States of America, it is considered that they are reliable for the current sample, considering the majority of the participants are English home language speakers, and schooled at private schools where the curriculum is often aligned to international curricula.

These instruments are copyright protected and are therefore not included as appendices. Additional information on these instruments can be accessed on the publishers' websites (Woodcock Reading Mastery Tests: www.pearsonassessments.com; Gray Oral Reading Test: www.predinc.com).

3.3.3.1.1 Woodcock Reading Mastery Test – Revised (WRMT-R)

The WRMT-R (Woodcock 1998) is a psycho-educational instrument that measures an individual's literacy skills. The purpose of the test is to measure encoding and decoding skills which are needed to acquire basic reading skills. For all subtests, a ceiling is reached, and the assessment ended, when the individual offers six consecutive items incorrectly and all items on a test page are administered. One point is allocated for a correct response and zero for an incorrect response (or failure to respond). The total raw score for each subtest equals the number of correct responses.

The WRMT-R has parallel tests (Form G and Form H) to facilitate re-testing before and after intervention. The following subtests of the WRMT-R were administered:

Word Identification

The Word Identification sub-test 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' with one point allocated for each correct word, to a maximum of 106 points.

Word Attack

The Word Attack sub-test requires the child to read aloud nonsense words of increasing difficulty. For example, the individual is asked to read words such as *pog* and *straced*. The test measures the child's ability to decode written text and 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. One point allocated for each correct word and a maximum of 45 points can be scored.

Passage Comprehension

The Passage Comprehension test measures an individual's ability to study a short passage, usually 2-3 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 also serves as a cue for the answer. The remainder of the items are text only. One point allocated for each correct word and a maximum of 68 points can be scored.

3.3.3.1.2 Gray Oral Reading Test 4 (GORT-4)

The GORT-4 (Wiederholt and Bryant 2011) is a measure of oral reading ability, assessing both reading fluency (speed and accuracy) and reading comprehension. There are 14 separate stories of increasing difficulty and length starting with a five-sentence story of simple sentences. Each story/passage has five questions related to the text. In general, a starting point is selected corresponding with a student's grade level or slightly below as it is expected that the children assessed will be below age appropriate level in reading skill (i.e. a child in Grade 5 will start at story 3 or 4). 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 5.

The GORT-4 has parallel tests (Form A and Form B) to facilitate re-testing before and after intervention.

Reading Rate

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 using the conversion table provided where five is the best and zero is the worst score. A ceiling (cut-off/discontinuation) is a score of one point.

Reading Accuracy

As the child reads each of the passages, the number of errors is recorded. The total number of errors is converted to a point score using the provided conversion table, again, with a score between zero and five points with five as the best score. As with the rate score, a ceiling for accuracy is a score of one point.

Comprehension

Following the reading of each passage, five multiple-choice questions are read to the child, who is required to answer without referring back to the text. The score is the total number of correct answers out of five. The ceiling is reached (and the test discontinued) when the child achieves two or below answers correctly for the five questions.

3.3.3.1.3 Gray Oral Reading Test 5 (GORT-5)

GORT-5 (Wiederholt and Bryant 2012) is an updated assessment tool, following on the GORT-4. There are 16 separate stories which increase in difficulty and length.

The procedure for testing is the same as for GORT-4 with the child reading passages of increasing difficulty aloud, while being timed and with errors being recorded.

The questions on the updated version are open ended as opposed to multiple choice as in GORT-4. As with the GORT-4, the comprehension questions are presented without the child being able to refer back to the passage. Additional feature changes of the GORT-5 are new normative data, an extended age range and additional reliability and validity studies added.

The GORT-5 is thus an updated version of the GORT-4 which was acquired in the reading centre and subsequently used for assessments for all new children. Children that were originally assessed on the GORT-4 instrument at the baseline test were assessed on the same version on all subsequent tests. Similarly, children assessed on GORT-5 at the baseline test were tested on the same version on all assessments. The stories presented are the same for both versions with 2 additional stories at the end of GORT-5.

3.3.3.2 Assessment rationale

The combination of assessments that were used measure a variety of reading skills and when viewed collectively, give a full picture of the participant's reading skill proficiency. This would not be the case if these were viewed in isolation. For example, the WRMT Word Identification subtest measures the ability to read words to age appropriate level. It would be expected, that if a child displays competence in reading words in isolation that he would be able to accurately read words when they are combined into a passage, i.e. they should measure age appropriately in Accuracy on the GORT. It is not always the case that skill in single word reading transfers across to passage reading. The inverse may also be seen where (difficult) words read in isolation are weak, but accuracy in passage reading may be stronger if the child is able to draw on cues from the context of the text to assist in recognising words.

Similarly, decoding (as measured on the WRMT Word Attack subtest) may be accurate, however, this test alone will not give an indication of automaticity which can impact on comprehension. Accurate (but laboured) pseudoword reading can be foiled against the GORT reading rate score to show potential difficulties with automaticity. Decoding is important to measure, but proficient reading also requires efficient processing of word sequences (as measured in passage reading) because it facilitates comprehension (Protopapas 2019).

Draper and Spaull (2015) state that Oral Reading Fluency measured by reading aloud, is a better correlate of comprehension than silent reading fluency. The assessments used in this study include both silent and out loud reading.

Additional factors such as sub-vocalisation during silent reading, visual tracking and anxiety around reading in both silent and out loud reading can be observed and give a full picture of the participant's reading competence.

Landsburg, Kruger and Swart (2016) also caution against perceiving only fluent decoding and word recognition as criterion for reading age. They stress the importance of including the measure of comprehension. Given this, the researcher's decision to measure reading across six areas, should be seen as an attempt to achieve an overall picture of reading skill and to gain insight into the interconnectivity between these skills.

3.3.3.3 Questionnaire

A questionnaire was administered to collect biographical information from the parents, including contact information, family history of learning difficulties, parent perception of skills and behavior, and additional information which may impact on difficulties. The questionnaire has been added as Annexure A in this dissertation.

3.4 Procedures

Parents of children were contacted to participate in the study, and ethical procedures were adhered to first (see section 3.6 for more detail). Due to COVID lockdown restrictions which were in place during 2020, when the present study was conducted, assessments were mostly conducted via Zoom sessions. A suitable time was arranged, and parents assisted with remote computer access if required for younger children. A quiet, uninterrupted environment was requested with the child seated at a table or desk. The tests were then conducted in the same manner as they would have been in person, with the researcher explaining the procedure and presenting the instructions. Using a screen share format, the test material was presented in real time to the participants, and scoring was done in real time by the researcher. Because there was camera access, it was possible to monitor the child at all times. This was a suitable way to conduct the assessments under the COVID restrictions as it closely resembled an ‘in person’ assessment. Children were also accustomed to working remotely as school lessons were conducted online at this time.

The questionnaire and consent forms were completed and signed by the parents and children. Where sessions took place via Zoom, the forms were submitted electronically.

When restrictions were lifted, participants were able to visit the reading centre to be assessed. Assessments were done in person with strict regulations in place of mask wearing, sanitising the centre and all surfaces between appointments, hand sanitation and temperature taking of all persons upon entry to the centre.

Following the assessment, a short feedback report was sent to the parents, outlining the results of each point of assessment for participants in both the treatment and control groups.

3.4.1 Overview of assessment of the treatment group

Secondary data from the baseline and post Cellfield assessments were available from participants’ files, which were available to the researcher as she had assessed the children when their parents had previously contacted the reading centre prior to the onset of the current research project. For the delayed post-test, the assessment form used in the pre-Cellfield assessment (i.e. the baseline assessment) was administered.

The testing procedure for the treatment group is set out in Table 3.1:

Table 3.1 Testing procedure for the treatment group

	WRMT-R	GORT 4/5
Baseline (before Cellfield intervention): conducted between 11.2014 – 07.2019, secondary data	Form G	Form A
Post-test (directly after Cellfield intervention): conducted between 02.2015 – 08.2019, secondary data	Form H	Form B
Delayed post-test (minimum of 12 months after Cellfield intervention): conducted between 03.2020 – 09.2020	Form G	Form A

3.4.2 Overview of assessment of the control group

The same procedures were followed as described for the treatment group. As there was no intervention, there was no midline assessment. The parallel assessment form of what had been done in the baseline assessment was administered at the delayed post-test point. The testing procedure for the control group is set out in Table 3.2:

Table 3.2 Testing procedure for control group

	WRMT-R	GORT 4/5
Baseline: conducted between 09.2016 – 07.2019, secondary data	Form G	Form A
Delayed post-test: conducted between 03.2020 – 09.2020	Form H	Form B

3.5 Data analysis

During the initial data processing, raw scores from the assessments were converted to standard scores and age equivalent measures, using the tables and calculation methods provided in the reading assessment manuals. These were recorded in spreadsheets, allowing the researcher to calculate means for each group and each subtest.

For the treatment group, the following were considered:

a. The average improvements in reading directly following the Cellfield intervention. This data has been analysed for each child at the time of the intervention as reports were submitted to parents outlining baseline and post Cellfield scores to show improvement over the Cellfield intervention.
b. Change in reading skill from the baseline to the post Cellfield assessment to the delayed post-test to determine whether changes in reading skill following the Cellfield intervention has been maintained in the time that has passed since the intervention.
c. A comparison between the long-term results of the groups, to measure the difference in reading skill development over time between the treatment group and the control group.

For the control group, the following was considered:

a. The improvement in reading skill between the baseline and delayed post-test.
b. A comparison between the long-term results of the groups, to measure the difference in reading skill development over time between the treatment group and the control group.

3.5.1 Statistical analysis

The statistical software package Jamovi V1.2.27 was used for data analysis. The software provides for analyses of data including t-tests, ANOVAs, correlation and regression, non-parametric tests, contingency tables, reliability and factor analysis (https://www.jamovi.org). Jamovi was used as it is freeware, is well-supported by the developers, and was available to the researcher.

Once data collection was completed, the distribution of the raw test scores were determined using the Shapiro-Wilk test. Descriptive statistics also presented summarised information about central tendency and dispersion. As some of the measures did not have a normal distribution and due to the small sample size of the control group, the non-parametric Kruskal-Wallis and the Wilcoxon tests were deemed more appropriate (than their parametric counterparts) to use to determine statistical significance in the present study.

For question one, the Wilcoxon T-tests determined changes from the baseline to the post-test in the treatment group. The Friedman test of differences was used to assess longitudinal changes from the baseline to the post-test to the delayed post-test in the treatment group, to determine the long-term efficacy of the Cellfield intervention for the second research question.

The between group differences in reading ability changes were tested using the one-way ANOVA where group was entered as the independent variable, and the reading assessment subtests, Word Identification, Word Attack, Passage Comprehension, Rate, Accuracy and Comprehension were entered as dependent, continuous variables. The non-parametric Kruskal Wallis test was used to determine statistical significance.

The correlation between the six variables were explored in the fourth question for the treatment group and the Pearson correlation coefficients presented. This was done at each of the three testing points to examine the changes between the variables following the Cellfield intervention and then again at the delayed post-test point.

The statistical tests employed in the analyses are discussed in more detail in Chapter 4.

3.6 Ethical considerations

Ethical approval for this study was granted by the College of Human Sciences Research Ethics Committee at the University of South Africa. A copy of the ethical clearance certificate is included in Annexure B.

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 (previously collected) in this research study (see Annexure C and D).

In the case where the assessment took place via Zoom, the questionnaire and consent forms were emailed to the parents who filled them in, facilitated the signing by their children and returned the forms via email before the assessment.

At the time of the assessment, the procedure was explained to the participants and the assessment commenced once they verbally confirmed that they understood the research and were willing and comfortable to participate. The researcher ensured that participants knew what to expect during the assessment process. The familiar one-on-one environment supported the participants' comfort level through tasks that may have been challenging for them. Participants were given the option to withdraw from the study at any time. These measures ensured that no physical or emotional harm came to any participant.

Confidentiality was ensured. All assessment documents containing personal information were kept securely in files at the reading centre with restricted access. All requirements of the Protection of Personal Information Act, particularly Section 35 referring to authorisation concerning personal information of children were adhered to (POPI 2019). Numerical identifiers replaced individual's names. No names were used in data analysis or reporting.

3.7 Conclusion

This chapter provided a description of the research methodology, which was informed by the aim and questions of the study. An in-depth discussion on how the research was conducted was given, and ethical considerations were discussed. The results of the research will be discussed in Chapter 4.

CHAPTER 4: RESULTS

4.1 Introduction

The previous chapter dealt with the methodology and procedures used for the research and discussed the research instruments that were used in the study. The research aim and questions were also restated.

This chapter will present the results of the assessments conducted in terms of standard scores and changes in reading age on the six reading measures described in Chapter 3. The standard scores and reading age from all assessments were originally recorded in MS Excel for each variable, for both the experimental and control groups. Additional information pertaining to chronological age at each testing point, home language, Language of Learning and Teaching (LoLT), type of school (private or public) and dyslexia diagnosis was also recorded. This information was then used as a basis for creating the data files in Jamovi V1.2.27, which was used for the statistical analysis. The descriptive statistics presented in this chapter provide an overview of the quantitative data, while inferential statistical techniques were used to determine significant effects. A preliminary analysis was conducted on all six dependent variables, to assess whether parametric or non-parametric tests would be more suitable to employ in the statistical analysis. This analysis (see section 4.2) suggested that non-parametric tests would be more suitable for the analysis, given the nature of the data.

For all inferential analyses, the independent variable was the Cellfield intervention, which divided the sample into two groups, namely the treatment group that received the Cellfield treatment, and control group that did not undergo the Cellfield treatment. The dependent variables were the reading measures, namely Word Identification, Word Attack, and Passage Comprehension on the Woodcock Reading Mastery Test (WRMT), as well as Rate, Accuracy and Comprehension on the Gray Oral Reading Test (GORT).

This chapter first presents the descriptive statistics. This is followed by the outcomes of the inferential statistics, which will be presented in relation to each of the research questions.

4.2. Descriptive statistics

The descriptive statistics for the two groups (treatment and control) are provided in Table 4.1. The standard scores for both groups for all subtests are presented. 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. There is no post-test Cellfield data for the control group as they did not undergo the Cellfield intervention (see Section 3.3.1).

As observed in Table 4.1, there was a general pattern in which the mean standard score was higher in the control group than the treatment group at the baseline testing for all variables, except Passage Comprehension on the WRMT, where the treatment group had a slightly higher average score. It follows then that if the scores of the control group were higher, this could have been a contributing factor for them selecting to not undergo the intervention. In other words, the treatment group required intervention more, as their reading was weaker.

In the delayed post-test, the treatment group scored higher than the control group on all variables except in Rate and Accuracy on the GORT, suggesting that the intervention had a positive long-term impact on the reading skills of the treatment group. The statistical significance of the group differences observed in the delayed post-test is explored in Section 4.5.

An additional noteworthy observation in the treatment group was the within group changes over time; where the standard scores improved at each testing point (from the baseline to the post-test, and from the post-test to the delayed post-test) for all variables. For the control group, there was an increase in standard scores from the baseline to the delayed post-test on all variables except Word Identification on the WRMT.

Table 4.1 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	Exp	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	Exp	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	Exp	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	Exp	24.0	30.0	46.0	25.0	25.0	47.0	29.0	34.0	29.0	8.0	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	Exp	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	Exp	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	Exp	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	Exp	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

In addition to the mean standard scores, Table 4.1 provides an overview of the standard deviation, range, median, minimum and maximum scores. The standard deviation was higher for the outcomes on the WRMT than the GORT for both the treatment and control groups at all measuring points. For the treatment group, the standard deviation increased for Word Identification and Word Attack at each assessment point indicating that some individuals gained substantial benefit from the Cellfield when it comes to these measures. For Rate, the standard deviation increased from the baseline to the post-test. For all other variables, the standard deviation decreased at each testing point in the treatment group. For the control group, the standard deviation increased between the two testing points for Word Attack and Rate, and decreased for all other variables.

Table 4.1 also presents the results of the normality tests that were conducted to establish whether the data on each variable were normally distributed or not. The Shapiro-Wilk test was used to assess normality. The data violated the assumption of normality for the treatment group on following variables: Word Identification at the baseline test, Word Attack at the baseline and post-test, Passage Comprehension at the baseline, post-test and delayed post-test, Rate at the post-test and Comprehension at the post-test and delayed post-test. For the control group, the data violated the assumption of normality for Word Identification at the delayed post-test, Word Attack at the delayed post-test, Passage Comprehension at the baseline and delayed post-test, Rate at the baseline test, Accuracy at the baseline test and Comprehension at the baseline and delayed post-test. Given the non-normal distribution of the data, and the small sample size of the control group, non-parametric tests (Kruskal-Wallis and the Wilcoxon tests) were deemed more appropriate to determine statistical significance. The outcomes of these tests are explored in detail in the relevant sections to follow.

4.3 The short-term effect of the Cellfield intervention on reading

The first research question asked whether there was a significant improvement in the reading scores of individuals who underwent the Cellfield intervention (i.e. the treatment group) immediately following the treatment. In order to answer this question, the medians (presented in Table 4.1 above) at the baseline and post-test were compared, using the Wilcoxon signed-rank test (also referred to as the Wilcoxon T-test). Secondary data were used in the analysis for both the baseline and the post-test, as explained in Section 3.4.1. The baseline assessment was conducted prior to intervention and the post assessment was done immediately following the Cellfield treatment (an average of 6 weeks between baseline and post-test assessments). The statistical results are presented in Table 4.2 below.

Table 4.2 Wilcoxon results per variable: baseline to post-test for treatment group

			Statistic	p
WI Std baseline	WI Std post-test	Wilcoxon W	8.00	< .001
WA Std baseline	WA Std post-test	Wilcoxon W	0.00	< .001
PC Std baseline	PC Std post-test	Wilcoxon W	58.50	< .001
Rate Std baseline	Rate Std post-test	Wilcoxon W	31.00	0.004
Acc Std baseline	Acc Std post-test	Wilcoxon W	0.00	< .001
Comp Std baseline	Comp Std post-test	Wilcoxon W	6.00	< .001

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

The results of the Wilcoxon test suggest that there was a statistically significant improvement from the baseline to the post-test in the treatment group in all variables, as follows: Word Identification: W(40) = 8.0, *p* = .001; Word Attack: W(40) = 0, *p* = .001; Passage Comprehension: W(40) = 58.50, *p* = .001; Rate: W(40) = 31.00, *p* = .004; Accuracy: W(40) = 0, *p* = .001 and Comprehension: W(40) = 6.00, *p* = .001.

The statistical significance, reported above, conveys whether the change in a variable is due to chance – in this case the p values, which were all smaller than 0.05, suggest that the observed changes in scores were not due to chance. Effect size conveys the size of the effect or the strength of the relationship between variables. Table 4.3 presents the effect sizes for the treatment group from the baseline to the post-test. The outcomes for both Cohen’s d and the rank biserial correlation are presented. The rank biserial correlation is used for the non-parametric Wilcoxon test. The benchmarks for interpreting the size of the effects have been widely adopted across tests with *d* = 0.2 considered a 'small' effect size, 0.5 represents a 'medium' effect size and 0.8 a 'large' effect size (McLeod 2019b; McGrath and Meyer 2006). There is a large effect size for all variables on both the Cohen's d and rank biserial correlation except for Rate. Rate was also the only variable where the rank biserial correlation measured larger than Cohen's d.

Table 4.3 Effect sizes between post-test and baseline for treatment group

			Statistic	df	p		Effect size
WI post	WI base	Student's t	9.15	40.0	< .001	Cohen's d	1.429
		Wilcoxon W	8.00		< .001	Rank biserial correlation	0.980
WA post	WA base	Student's t	11.36	40.0	< .001	Cohen's d	1.774
		Wilcoxon W	0.00		< .001	Rank biserial correlation	1.000
PC post	PC base	Student's t	5.86	40.0	< .001	Cohen's d	0.916
		Wilcoxon W	58.50		< .001	Rank biserial correlation	0.850
Rate post	Rate base	Student's t	2.89	40.0	0.006	Cohen's d	0.451
		Wilcoxon W	31.00		0.007	Rank biserial correlation	0.674
Acc post	Acc base	Student's t	9.85	40.0	< .001	Cohen's d	1.538
		Wilcoxon W	0.00		< .001	Rank biserial correlation	1.000
Comp post	Comp base	Student's t	7.47	40.0	< .001	Cohen's d	1.166
		Wilcoxon W	6.00		< .001	Rank biserial correlation	0.977

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

Table 4.4 presents the gains in terms of age (in months) at the baseline and post-test point. The mean chronological age of the treatment group was 128.5 months at the time of the baseline assessments. For all of the variables, the participants achieved lower than anticipated scores, considering their age, in other words, their reading age was below their chronological age prior to the intervention. In terms of Word Identification, the mean suggested that the group performed at the level of children who are 110 months old, indicating an age delay of 18.5 months on this skill. Similarly, in Word Attack, the group performed at the level of children who are 104 months old, a delay of 24.5 months. Passage Comprehension was 15.5 months behind age level, Rate was 29.5 months behind, Accuracy 22.5 months and Comprehension was 19.5 months behind age level.

Table 4.4 Descriptives: Reading age **in months** baseline to post-test (post- Cellfield)

			Woodcock Reading Mastery Test (WRMT)						Gray Oral Reading Test (GORT)					
	Base Chr Age	Post Chr age	WI base	WI post	WA base	WA post	PC base	PC post	Rate base	Rate post	Acc base	Acc post	Comp base	Comp post
Mean	128.5	130	110	124	104	132	113	123	99.0	103	106	123	109	127
Std deviation	28.8	28.6	22.9	47.6	15.9	35.7	22.1	26.4	22.1	23.6	26.2	29.1	23.4	26.0
Range	108	108	127	309	70	128	106	111	75	93	144	144	120	126
Minimum	88	89	85	87	87	94	79	88	72	72	72	72	72	72
Maximum	196	197	212	396	157	222	185	199	147	165	216	216	192	198
Shapiro Wilk W	0.941	0.942	0.776	0.510	0.827	0.858	0.930	0.913	0.918	0.926	0.859	0.963	0.938	0.964
Shapiro Wilk p	0.033	0.037	< .001	< .001	< .001	< .001	0.014	0.004	0.006	0.011	< .001	0.200	0.027	0.220

Base Chr Age = Baseline Chronological age, Post Chr age = Post-test Chronological age

Base = baseline test, Post = post-test

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

In the post-Cellfield assessments, the average age of the treatment group was 130 months. On average, the group’s skill on Word Identification improved by 14 months, 28 months in Word Attack, 9.9 months in Passage Comprehension, 3.8 months in Reading Rate, 16.5 months in Accuracy and 17.2 months in Comprehension over the 1.5 months that passed between the baseline and the post-test.

Figures 4.1 to 4.6 show the gains in each variable from the baseline assessment to the post-test in graph form. These gains are shown in terms of age gains (represented as months) for each variable.

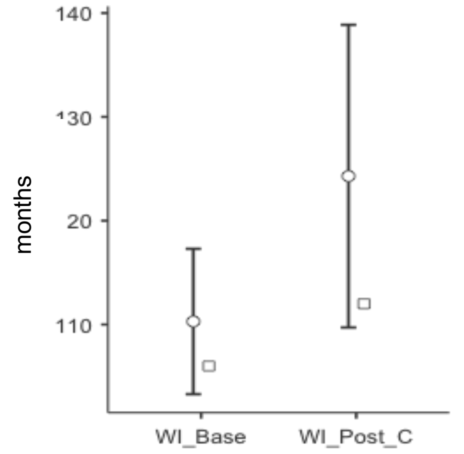


Fig. 4.1 Word Identification at baseline and post-test

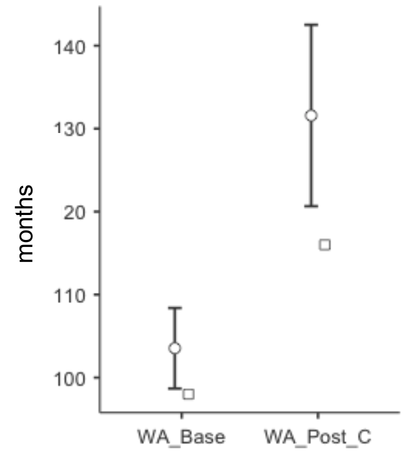


Fig. 4.2 Word Attack at baseline and post-test

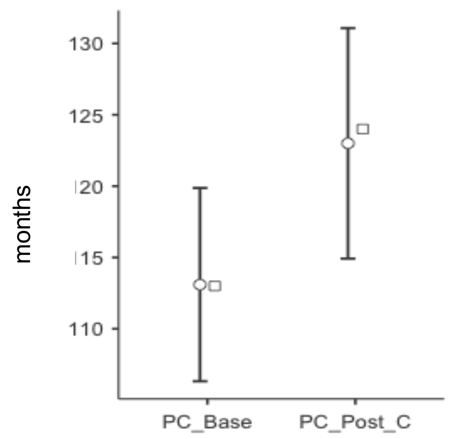


Fig. 4.3 PC at baseline and post-test

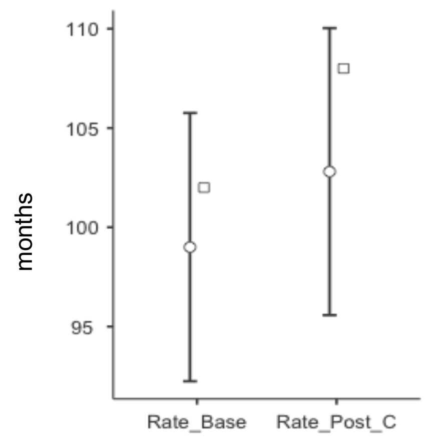


Fig. 4.4 Rate at baseline and post-test

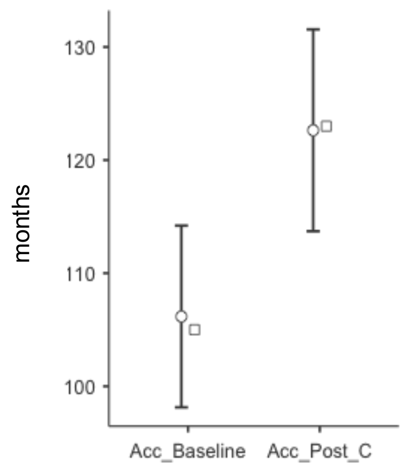


Fig. 4.5 Accuracy at baseline and post-test

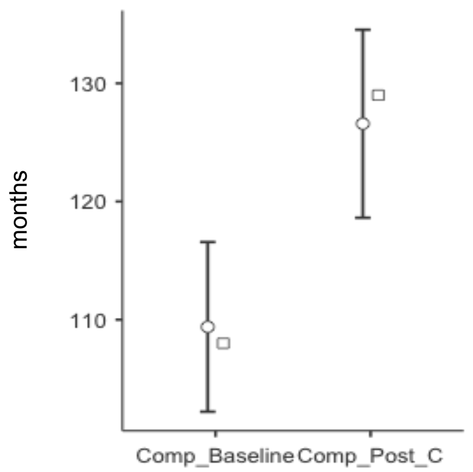


Fig. 4.6 Comprehension at baseline and post-test

PC = Passage Comprehension

○ Mean (95% CI)
□ Median

4.4 The long-term effects of the Cellfield intervention in a South African context

To answer the question of whether the immediate gains in reading skill following the Cellfield intervention is sustained over time in the treatment group, all six dependent variables were considered at the three testing points (baseline, post-test and delayed post-test). As some of the data violated the assumption of normality (refer to Table 4.1), a non-parametric Friedman test of differences was conducted to measure the significance of the within-subject changes for the treatment group at the three measuring points.

The Chi-square results obtained as part of this analysis was as follows:
Word Identification: $\chi^2(2) = 39.1$, $p < .001$; Word Attack: $\chi^2(2) = 56{,}9$, $p < .001$; Passage Comprehension: $\chi^2(2) = 35{,}0$, $p < .001$; Rate: $\chi^2(2) = 20{,}6$, $p < .001$; Accuracy: $\chi^2(2) = 56{,}3$, $p < .001$ and Comprehension: $\chi^2(2) = 32.4$, $p < .001$. Pairwise comparisons (Durbin-Conover) are shown for each variable in Tables 4.5 to 4.10 below:

Table 4.5 Pairwise Comparison: Word Identification

	Statistic	p
WI baseline - post-test	7.102	< .001
WI baseline - delayed post-test	7.648	< .001
WI post-test - delayed post-test	0.546	0.586

Table 4.6 Pairwise Comparison: Word Attack

	Statistic	p
WA baseline - post-test	11.238	< .001
WA baseline - delayed post-test	12.034	< .001
WA post-test - delayed post-test	0.796	0.429

Table 4.7 Pairwise Comparison: PC

	Statistic	p
PC baseline - post-test	6.376	< .001
PC baseline - delayed post-test	6.969	< .001
PC post-test - delayed post-test	0.593	0.555

Table 4.8 Pairwise Comparison: Rate

	Statistic	p
Rate post-test - delayed post-test	3.04	0.003
Rate baseline - delayed post-test	5.15	< .001
Rate post-test - delayed post-test	2.11	0.038

Table 4.9 Pairwise Comparison: Accuracy

	Statistic	p
Acc baseline - post-test	11.5	< .001
Acc baseline - delayed post-test	11.5	< .001
Acc post-test - delayed post-test	0.0	1.000

Table 4.10 Pairwise Comparison: Comprehension

	Statistic	p
Comp baseline - post-test	6.509	< .001
Comp baseline - delayed post-test	5.960	< .001
Comp post-test - delayed post-test	0.549	0.585

PC = Passage Comprehension

The Friedman test confirmed that, for each variable, there was a significant improvement from the baseline test to the post-test, (which has already been established in Section 4.3). 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 from the post-test to the delayed post-test. Interestingly, a paired samples t-tests comparing the scores from the post-test to the delayed post-test does show significant improvement for Word Identification, Passage Comprehension and Rate as shown in Table 4.11 below.

Table 4.11 Paired Samples T-Test for all variables: post-test to delayed post-test for treatment group

			Statistic	p
WI post-test	WI delayed	Wilcoxon W	191	0.013
WA post-test	WA delayed	Wilcoxon W	317	0.106
PC post-test	PC delayed	Wilcoxon W	228	0.031
Rate post-test	Rate delayed	Wilcoxon W	103	0.017
Acc post-test	Acc delayed	Wilcoxon W	150	0.065
Comp post-test	Comp delayed	Wilcoxon W	208	0.551

Delayed = delayed post-test,
WI = Word Identification, WA = Word Attack, PC = Passage Comprehension, Acc = Accuracy, Comp = Comprehension

The divergent findings obtained from the Friedman test and a Paired samples T-test could be explained as a result of the non-parametric Friedman test not considering all the characteristics of the data. As a result, this test tends to be more conservative than parametric alternatives. In other words, if a null hypothesis for a study is false, a non-parametric test is less likely to reject it than a parametric test. Since several reading variables were not normally distributed, the researcher opted to conduct non-parametric tests where possible. It can be noted here though, that T-tests are relatively robust (Fagerland 2012) and that the significant differences observed between the post-test and delayed post-test when conducting this parametric test should at least be considered as meaningful.

Additionally, Table 4.12 shows a large effect size between the baseline and delayed post-test point for all variables (except for a moderate effect in terms of the improvement on Rate on the Cohen's d measure). Large effect sizes were evident regardless of whether the T-test or non-parametric Wilcoxon is used.

Table 4.12 Effect sizes between delayed post-test and baseline for treatment group

			Statistic	df	p		Effect size
WI delay	WI base	Student's t	6.65	40.0	< .001	Cohen's d	1.039
		Wilcoxon W	18.50		< .001	Rank biserial correlation	0.947
WA delay	WA base	Student's t	8.95	40.0	< .001	Cohen's d	1.397
		Wilcoxon W	2.50		< .001	Rank biserial correlation	0.994
PC delay	PC base	Student's t	5.72	40.0	< .001	Cohen's d	0.893
		Wilcoxon W	59.50		< .001	Rank biserial correlation	0.847
Rate delay	Rate base	Student's t	4.38	40.0	< .001	Cohen's d	0.684
		Wilcoxon W	36.50		< .001	Rank biserial correlation	0.820
Acc delay	Acc base	Student's t	7.98	40.0	< .001	Cohen's d	1.246
		Wilcoxon W	6.50		< .001	Rank biserial correlation	0.980
Comp delay	Comp base	Student's t	4.97	40.0	< .001	Cohen's d	0.776
		Wilcoxon W	55.00		< .001	Rank biserial correlation	0.804

WI = Word Identification, WA = Word Attack, PC = Passage Comprehension, Acc = Accuracy, Comp = Comprehension
Delay = delayed post-test; Base = baseline test

Figures 4.7 to 4.12 below show descriptive plots of standard scores at the three testing points for each variable. It is evident that there was a sharp improvement from the baseline to the post-test and that skills continued to improve following the Cellfield intervention, but at a less accelerated rate. It is important to note, when interpreting the figures, that the time difference between these points was not even. There was a 1,5-month difference between the baseline to the post-test, and 26 months that passed between the post-test and the delayed post-test which, if reflected on the figure, would further emphasise the less accelerated improvement between the post-test and the delayed post-test.

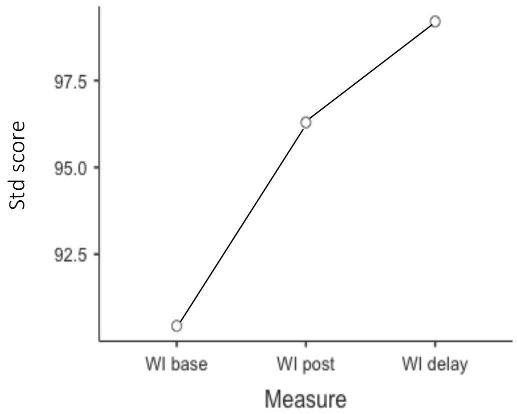


Fig. 4.7 Descriptive plot of WI at all testing points

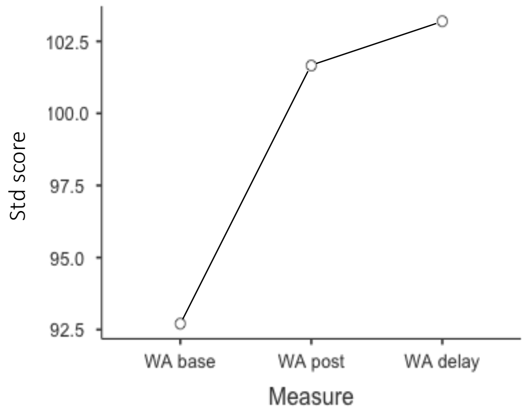


Fig. 4.8 Descriptive plot of WA at all testing points

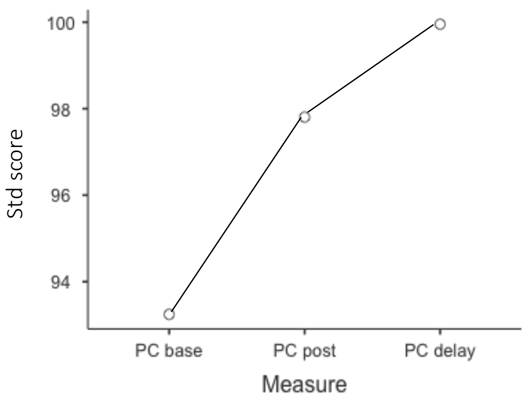


Fig. 4.9 Descriptive plot of PC at all testing points

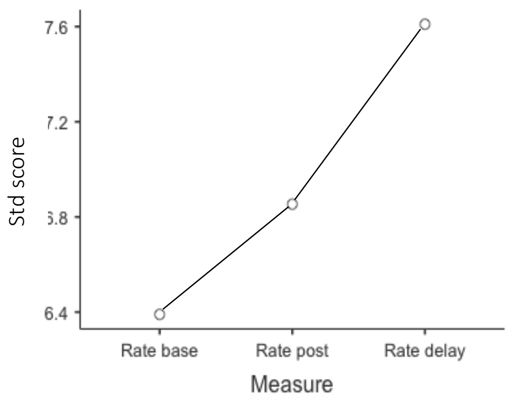


Fig. 4.10 Descriptive plot of Rate at all testing points

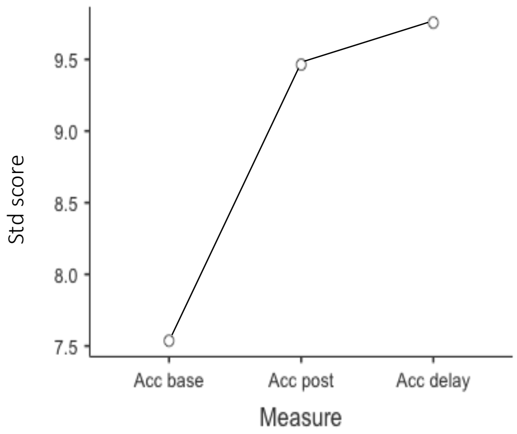


Fig. 4.11 Descriptive plot of Acc at all testing points

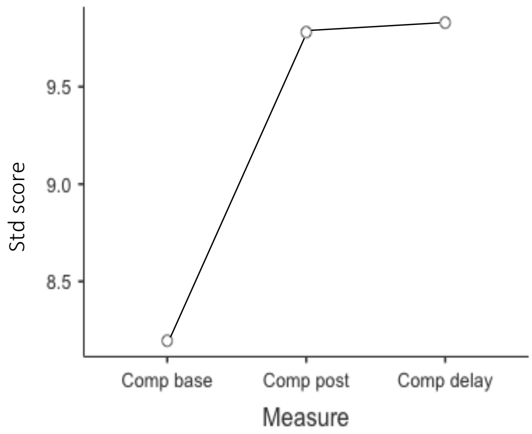


Fig. 4.12 Descriptive plot of Comp at all testing points

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

In the treatment group, there was an average time difference of 26 months from the post-test to the delayed test. The mean Reading Ages for each variable are presented in Table 4.13. Between the post-test and the delayed post-test, reading skill improved as follows for each variable: Word Identification: 39 months, Word Attack: 32 months, Passage Comprehension: 44 months, Rate: 24 months, Accuracy: 27 months and Comprehension: 26 months.

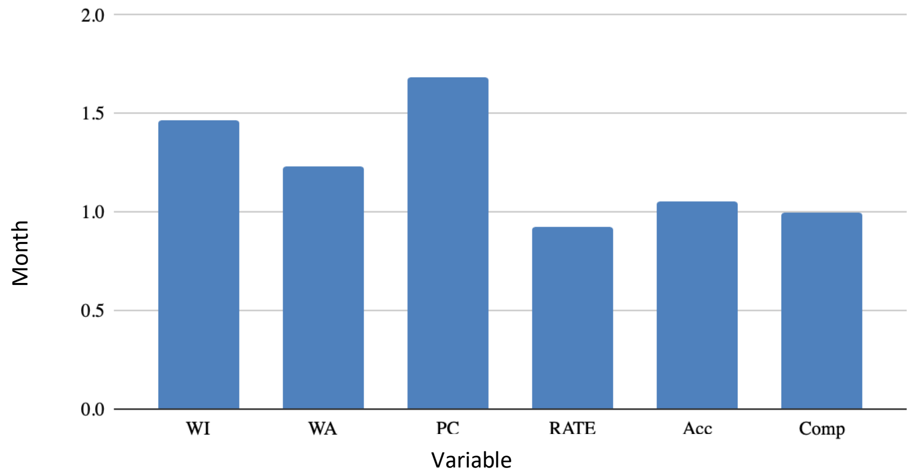
Table 4.13 Descriptives of mean reading age per variable at the post-test and delayed post-test

	Age post-test	Age delayed post-test	WI post-test	WI delayed post-test	WA post-test	WA delayed-post-test	PC post-test	PC delayed post-test	Rate post-test	Rate delayed post-test	Acc post-test	Acc delayed post-test	Comp post-test	Comp delayed post-test
Mean	130	156	124	163	132	164	123	167	103	127	123	150	127	153
Std deviation	28.6	28.8	47.6	70.5	35.7	40.9	26.4	75.9	23.6	25.5	29.1	34.5	26.0	29.4
Range	108	122	309	299	128	122	111	331	93	117	144	129	126	120
Shapiro Wilk W	0.941	0.967	0.510	0.694	0.858	0.914	0.913	0.597	0.926	0.950	0.963	0.928	0.964	0.980
Shapiro Wilk p	0.035	0.274	< .001	< .001	< .001	0.004	0.004	<. 001	0.011	0.069	0.200	0.013	0.220	0.668

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

Following the steep improvement immediately after the Cellfield intervention, reading skill continued to improve at a rate above the time that passed for all variables, except for the variable Rate. For example, there was a 39-month improvement in the Word

Identification score 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. Figure 4.13 below provides a visual representation of the change in variables calculated per month that passed between the post-test and delayed post-test points.



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

Fig. 4.13 Improvement, per month, per variable, from post-test to delayed post test

4.5 Change in skill between treatment and control groups

The third research question asked how the reading skill of the children who underwent the Cellfield intervention differed over time from those of children with reading difficulties who did not undergo the intervention. One-way ANOVAs were conducted to determine significant differences in standard scores between the treatment group and control group in the baseline assessments and the delayed post-test assessments. The non-parametric Kruskal-Wallis test was used because the samples were uneven in number (n = 41 in the treatment group and n = 11 in the control group). Additionally, not all the variables were normally distributed, as explained in section 4.2.

The means and standard deviations obtained for each variable at the baseline and post-test assessment points were presented in Table 4.1, but these descriptive statistics are repeated here in Table 4.14 for ease of reference.

Table 4.14 Means and Standard Deviation for all variables at baseline and delayed post-test

	Group	WI base Std Score	WI delay Std Score	WA base Std Score	WA delay Std Score	PC base Std Score	PC delay Std Score	Rate base Std Score	Rate delay Std Score	Acc base Std Score	Acc delaye Std Score	Comp base Std Score	Comp delay Std Score
Mean	Exp	90.4	99.2	92.7	103	93.2	100.0	6.39	7.61	7.54	9.76	8.20	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
Std deviation	Exp	6.34	10.0	5.98	8.70	7.43	7.08	2.01	1.58	1.92	1.30	1.89	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

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

Tables 4.15 and 4.16 present the results of the statistical analyses that compared the two groups at the baseline and delayed assessment points.

Table 4.15 One-way ANOVA baseline test for all variables

	x^2	df	p
WI baseline Std Score	12.806	1	< .001
WA baseline Std Score	5.883	1	0.015
PC baseline Std Score	0.354	1	0.552
Rate baseline Std Score	0.779	1	0.377
Acc baseline Std Score	5.964	1	0.015
Comp baseline Std Score	0.607	1	0.436

Table 4.16 One-way ANOVA delayed post-test for all variables

	x^2	df	p
WI delayed Std Score	0.00617	1	0.937
WA delayed Std Score	1.46963	1	0.225
PC delayed Std Score	5.70803	1	0.017
Rate delayed Std Score	0.00213	1	0.963
Acc delayed Std Score	1.84647	1	0.174
Comp delayed Std Score	1.60638	1	0.205

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

Table 4.15 shows that Word Identification, Word Attack and Accuracy were significantly weaker in the treatment group than the control group at the baseline point (also represented in Figures 4.14 to 4.19 below).

Table 4.16 shows significant mean differences between the groups at the delayed post-test testing point in Passage Comprehension only. Exploring the Passage Comprehension changes in graphical form in Figure 4.16 below, the treatment group improved their mean standard score from 93.6 to 100 and the mean standard score of the control group changed from 91.3 to 93.6. The results of the ANOVA confirmed that the higher mean obtained by the treatment group on this variable was significant, suggesting that the treatment group significantly outperformed the control group on Passage Comprehension at the delayed assessment point.

Figures 14.14 to 4.19 below, show that the treatment group performed below the control group at the baseline assessment point on all the dependent 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, the standard scores for most variables also increased over time, except Word Identification, which decreased. As can be seen from the trajectory of the graphs, the improvement over time is steeper for the treatment group and less steep for the control group. For Rate and Accuracy, even though the treatment 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 4.14 – 4.19 below show a graphical representation of marginal means of each variable at the baseline and delayed post-test point for each group

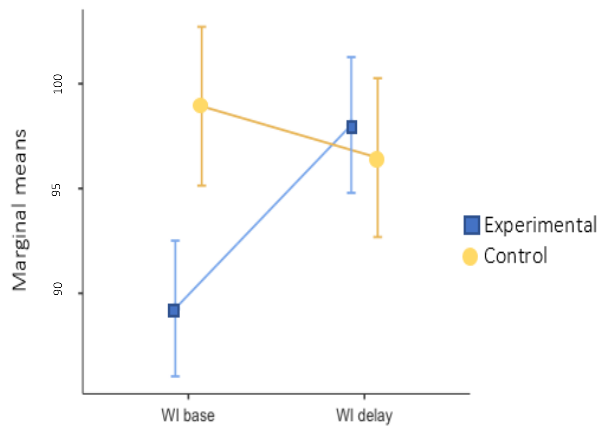


Fig. 4.14 WI: baseline to delayed post-test

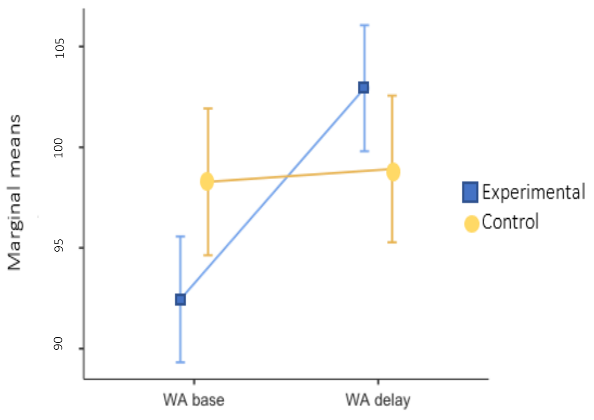


Fig. 4.15 WA: baseline to delayed post-test

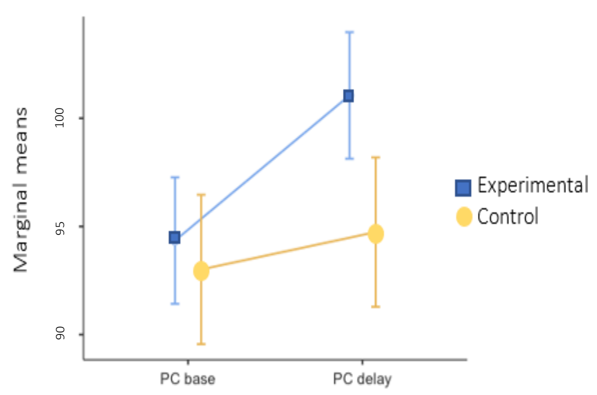


Fig. 4.16 PC: baseline to delayed post-test

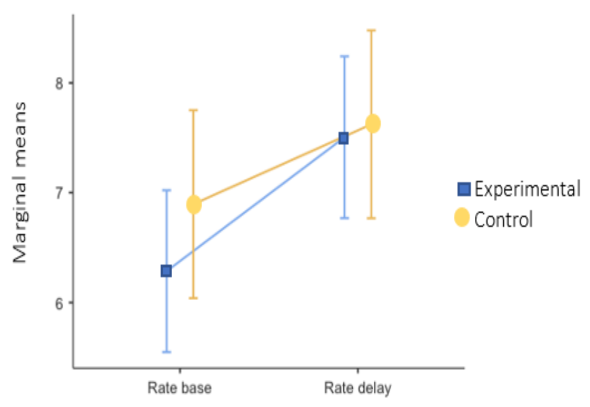


Fig. 4.17 Rate: baseline to delayed post-test

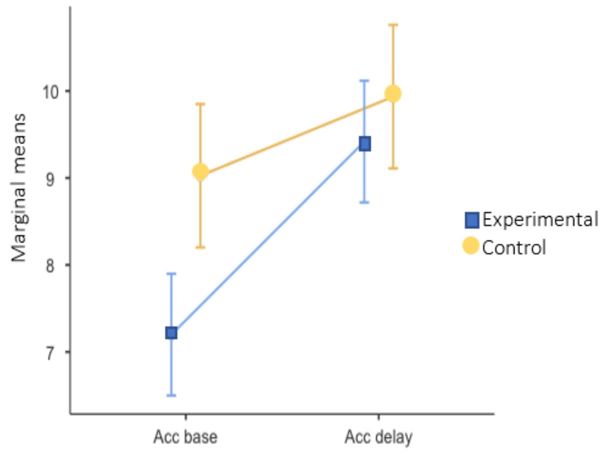


Fig. 4.18 Acc: baseline to delayed post-test

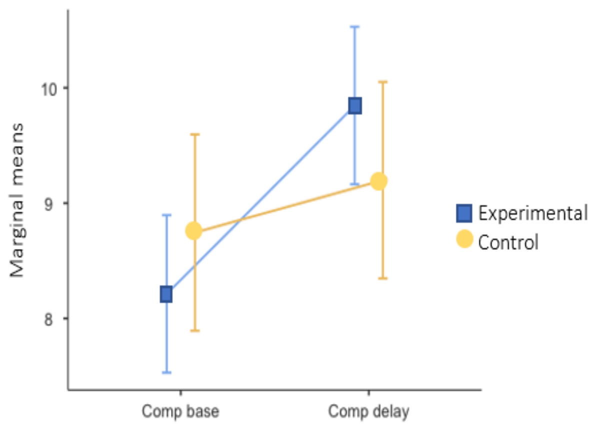


Fig. 4.19 Comp: baseline to delayed post-test

Table 4.17 below shows the change in months between the baseline and delayed post-test for the variables per group in Reading Age. There was a significant outcome for all variables except Accuracy and Comprehension in the treatment group and only significant outcome for the control group in Passage Comprehension.

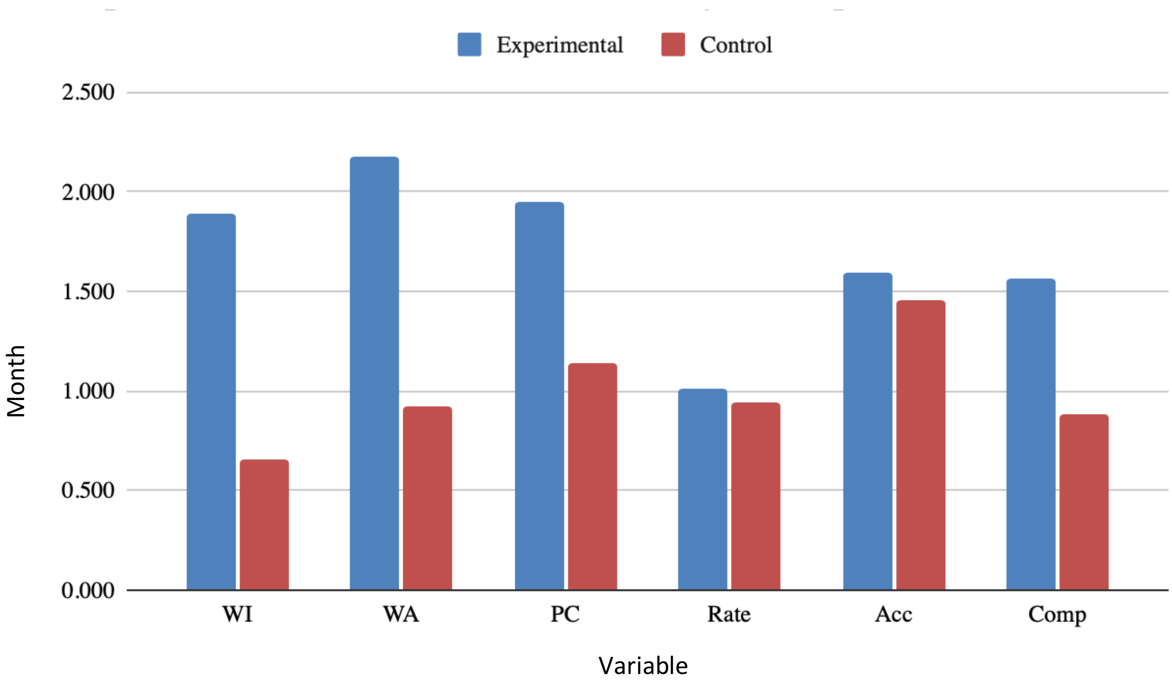
Table 4.17 Reading age change from baseline to delayed post-test, per group, in months

	Group	Age diff	WI diff	WA diff	PC diff	Rate diff	Acc diff	Comp diff
Mean	Exp	27.8	52.6	60.5	54.3	28.2	44.2	43.5
	Control	30.9	20.4	28.6	35.3	29.2	45.0	27.3
Std deviation	Exp	13.1	56.7	31.7	67.4	17.1	24.2	21.7
	Control	10.8	19.0	24.9	45.2	16.3	21.2	14.4
Shapiro Wilk W	Exp	0.904	0.631	0.942	0.584	0.924	0.952	0.956
	Control	0.908	0.906	0.974	0.590	0.937	0.894	0.941
Shapiro Wilk p	Exp	0.002	< .001	0.037	< .001	0.009	0.081	0.118
	Control	0.230	0.219	0.921	< .001	0.485	0.155	0.527

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

As discussed in Section 1.1 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 27.8 months, while the mean age difference in the control group between the baseline and the delayed test and 30.9 months.

Figure 4.20 below shows a graphical representation of the improvements in each variable over time between the groups. The mean monthly reading age improvement is shown, per month, between the baseline test and delayed post-tests. For example, in the treatment group, over the 27.8 months that passed between the baseline and the delayed post-test, the Word Attack score improved by an average of 60.5 months. This equates to an improvement of 2.18 months in skill, 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. Calculated as a per month improvement over the 30.9 months that passed between these two assessment points, the Word Attack skill of the control group improved by 0.92 months for each passing month.



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

Fig. 4.20 Improvement, per month, per variable, between groups

For the treatment group, it was observed that all variables improved by more than one month for each passing month. In the control group, only the mean obtained of the variable Accuracy was significantly higher at the delayed assessment point. This is reflected in the Wilcoxon test shown below in Table 4.18.

Table 4.18 Wilcoxon test: baseline to delayed post-test for control group

			Statistic	p
WI base	WI delay	Wilcoxon W	53.50	0.970
WA base	WA delay	Wilcoxon W	30.00	0.412
PC base	PC delay	Wilcoxon W	27.50	0.328
Rate base	Rate delay	Wilcoxon W	3.50	0.085
Acc base	Acc delay	Wilcoxon W	8.00	0.045
Comp base	Comp delay	Wilcoxon W	11.00	0.177

base = baseline test, delay = delayed post-test

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

4.6 Correlation between variables at each testing point

The final question asked what the nature of the relationships were between the variables at each testing point for the two groups. Tables 4.19 to 4.21 present the correlations between variables as observed in the treatment group (at the three assessment points). Table 4.19 shows the correlation between the variables at the baseline test. There were strong correlations between Word Identification and Word Attack, and between Rate and Accuracy. There were moderate correlations between Word Identification and Passage Comprehension, Passage Comprehension and Accuracy and Comprehension and Accuracy. Negative correlations existed between Word Attack and Rate, and Word Attack and Comprehension.

The matrix at the post-test point (Table 4.20) showed that skills were more correlated with each other following the Cellfield intervention. Strong correlations existed between Accuracy and Word Identification, Accuracy and Passage Comprehension, Accuracy and Rate, Accuracy and Comprehension, and Comprehension and Rate. Moderate correlations existed between Word Identification and Word Attack, Passage

Comprehension and Comprehension, Passage Comprehension and Word Identification, and Comprehension and Word Identification.

Table 4.19 Correlation matrix at baseline test: treatment group

		WI base	WA base	PC base	Rate base	Acc base	Comp base
WI base	Pearson's r	-					
	p-value	-					
WA base	Pearson's r	0.743 ***	-				
	p-value	< .001	-				
PC base	Pearson's r	0.551 ***	0.412**	-			
	p-value	< .001	0.008	-			
Rate base	Pearson's r	0.163	-0.098	0.472**	-		
	p-value	0.310	0.541	0.002	-		
Acc base	Pearson's r	0.490 **	0.146	0.566***	0.733***	-	
	p-value	0.001	0.361	< .001	< .001	-	
Comp base	Pearson's r	0.220	-0.008	0.366*	0.493 **	0.583 ***	-
	p-value	0.166	0.960	0.019	0.001	< .001	-

Note. * p < .05, ** p < .01, *** p < .001

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

Table 4.20 Correlation matrix at post-test: treatment group

		WI post	WA post	PC post	Rate post	Acc post	Comp post
WI post	Pearson's r	-					
	p-value	-					
WA post	Pearson's r	0.580 ***	-				
	p-value	< .001	-				
PC post	Pearson's r	0.522 ***	0.378 *	-			
	p-value	< .001	0.015	-			
Rate post	Pearson's r	0.416 **	0.178	0.416 **	-		
	p-value	0.007	0.267	0.007	-		
Acc post	Pearson's r	0.732 ***	0.402 **	0.616 ***	0.719 ***	-	
	p-value	< .001	0.009	< .001	< .001	-	
Comp post	Pearson's r	0.511 ***	0.087	0.533 ***	0.631 ***	0.706 ***	-
	p-value	< .001	0.589	< .001	< .001	< .001	-

Note. * p < .05, ** p < .01, *** p < .001

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

Table 4.21 presents the correlations at the delayed post-test. At this point, strong correlations existed between Passage Comprehension and Rate, Accuracy and Comprehension, between Word Identification and Word Attack, Rate and Accuracy, Rate and Comprehension, and Comprehension and Accuracy.

Word Identification correlated significantly only with Word Attack, Passage Comprehension and Accuracy at the baseline, but with all five variables at the post-test point and at the delayed post-test point (although the strength of the relationships did diminish at the delayed assessment, they were still significant). Improved Accuracy and reading Rate would lead to improved Comprehension and the correlations between these variables do move, for the most part, from moderate (at the baseline testing point), to moderately strong (at the post-test point), to strong (at the delayed post-test). This suggests that Cellfield had an effect on the extent to which Rate and Accuracy correlate with Comprehension, and that following the intervention, an increase in Rate/Accuracy lead to an increase in Comprehension. However, the correlation between Accuracy and Rate is steadier (in terms of strength) over time, possibly suggesting that these constructs rely on the same underlying skill (such as general processing) and that the relationship between these constructs were not impacted by the Cellfield intervention (although independently from each other they did improve as a result of the intervention).

Tables 4.22 and 4.23 present the correlations between the variables for the control group at the baseline and delayed post-test points respectively. At the baseline point, there were only strong correlations between Word Attack and Passage Comprehension; Passage Comprehension and Accuracy, and Accuracy and Comprehension. Word Identification had a negative correlation with three other variables, namely Passage Comprehension, Rate and Comprehension.

At the delayed post-test for the control group, there were strong correlations between Word Identification and Word Attack, and Rate and Comprehension. Comprehension had negative correlations with Word Identification, Word Attack and Passage Comprehension. It appears that the relationships between the variables in the control group were less correlated over time.

Table 4.21 Correlation matrix at delayed post-test: treatment group

		WI delay	WA delay	PC delay	Rate delay	Acc delay	Comp delay
WI delay	Pearson's r	-					
	p-value	-					
WA delay	Pearson's r	0.624 ***	-				
	p-value	< .001	-				
PC delay	Pearson's r	0.524 ***	0.413 **	-			
	p-value	< .001	0.007	-			
Rate delay	Pearson's r	0.358 *	0.208	0.658 **	-		
	p-value	0.022	0.193	< .001	-		
Acc delay	Pearson's r	0.590 ***	0.552 ***	0.691 ***	0.683 ***	-	
	p-value	< .001	< .001	< .001	< .001	-	
Comp delay	Pearson's r	0.322 *	0.258	0.681 ***	0.610 ***	0.643 ***	-
	p-value	0.040	0.104	< .001	< .001	< .001	-

Note. * p < .05, ** p < .01, *** p < .001

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

Table 4.22 Correlation matrix at baseline: control group

		WI base	WA base	PC base	Rate base	Acc base	Comp base
WI base	Pearson's r	-					
	p-value	-					
WA base	Pearson's r	0.494	-				
	p-value	0.123	-				
PC base	Pearson's r	-0.052	0.685 *	-			
	p-value	0.880	0.020	-			
Rate base	Pearson's r	-0.033	0.368	0.270	-		
	p-value	0.923	0.266	0.422	-		
Acc base	Pearson's r	0.268	0.593	0.601	0.418	-	
	p-value	0.426	0.055	0.050	0.201	-	
Comp base	Pearson's r	-0.309	0.177	0.409	0.361	0.765 **	-
	p-value	0.356	0.604	0.212	0.275	0.006	-

Note. * p < .05, ** p < .01, *** p < .001

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

Table 4.23 Correlation matrix at delayed post-test: control group

		WI delay	WA delay	PC delay	Rate delay	Acc delay	Comp delay
WI delay	Pearson's r	-					
	p-value	-					
WA delay	Pearson's r	0.718 *	-				
	p-value	0.013	-				
PC delay	Pearson's r	0.368	0.130	-			
	p-value	0.266	0.703	-			
Rate delay	Pearson's r	0.439	0.170	0.266	-		
	p-value	0.177	0.617	0.430	-		
Acc delay	Pearson's r	0.358	0.572	0.219	0.383	-	
	p-value	0.279	0.066	0.517	0.245	-	
Comp delay	Pearson's r	-0.082	-0.098	-0.054	0.675 *	0.299	-
	p-value	0.811	0.774	0.875	0.023	0.372	-

Note. * p < .05, ** p < .01, *** p < .001

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

4.7 Conclusion

This chapter presented the results of the assessments conducted in relation to the research questions. The statistical software programme Jamovi V1.2.27 was used to analyse the data. Due to the small size of the control group and the data not being normally distributed, non-parametric tests were deemed more suitable for the inferential statistical analyses.

For Question 1, it was hypothesised that there would be a significant change in reading skill, for children with reading difficulties, following the Cellfield intervention. It was shown that there was significant changes in all variables over the intervention for the experiment group.

Question 2 explored the long-term efficacy of the intervention for the treatment group. Section 4.4 discussed the outcomes at each of the testing points for the treatment group for each variable, showing significant improvement over time from the baseline to the delayed post-test.

Question 3 compared the change in reading skill over time between the treatment group, that had received the Cellfield intervention, to that of the control group, who had reading difficulties, but did not receive the Cellfield intervention. Mean scores for the treatment group were lower than those for the control group the baseline testing for all variables except Passage Comprehension on the WRMT. In the delayed assessment, the treatment group scored higher on all variables than the control group except in Rate and Accuracy on the GORT.

The final question asked what the nature was of the correlations between the variables. Correlation matrices presented these relations at each testing point. The results showed increases in the strength of some correlations, in other words, stronger relationships between some reading skills were detected following the Cellfield intervention.

The next chapter will discuss the implications of the results in the context of the literature in the field and previous research on the Cellfield intervention. Limitations and suggestions of future research will also be presented.

CHAPTER 5: DISCUSSION AND CONCLUSION

5.1 Introduction

For children with reading difficulties, an effective and long-lasting intervention could be impactful in preventing the potential academic failure and emotional distress that comes with a reading skill delay. The main purpose of conducting this research, was to determine whether the improvement in reading skill experienced after completing the Cellfield intervention is maintained in the long term in South African learners who are schooled in middle-to-high-income contexts.

The Cellfield intervention is an Australian-developed, computer-based reading intervention consisting of ten, one-hour 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 visual or auditory processing, phonological processing difficulties or poor motor skills. Additionally, they can present with a combination of these difficulties. The Cellfield intervention simultaneously targets multiple skills that could potentially co-occur in the struggling reader, such as phonological, visual, and visual-to-phonological processing skills. The aim of this simultaneous remediation is naturally to alleviate the symptoms of reading difficulties as effectively as possible.

In the current study, a treatment group of 41 participants underwent the Cellfield intervention. The results obtained on a battery of parallel reading tests (WRMT-R, GORT-4/5) were explored before (baseline test) and directly after the treatment (post-test) to measure the immediate effect of the intervention on reading skill. The participants were then assessed 26 months after the post-test (delayed post-test), using the parallel version of the same test battery, to measure the long-term effects of the Cellfield and whether the improvements experienced directly following the intervention were maintained over time.

A control group of 11 participants was measured with the same battery of reading tests at the baseline point and found to be behind their expected reading age. These children did not undergo the Cellfield intervention. At the onset of the research project, they were contacted and re-assessed at the delayed assessment point using a parallel test of the WRMT-R and GORT-4/5 . A mean of 30.9 months passed between the baseline and delayed post-test for the control group. The outcomes of the assessments were examined to determine the change in skill over time and compare the change in reading skill to the treatment group in order to ascertain whether it is beneficial for children with reading difficulties to undergo the Cellfield intervention.

The correlations between the reading skills were also examined to determine the changes in relationships between variables at each measuring point. This chapter will discuss the outcomes of the results (presented in Chapter 4) in the context of the existing literature. In addition, the limitations of this study will be discussed and recommendations for further studies will be given.

5.2 Summary and discussion of main findings

The first research question investigated the improvement of a treatment group directly following the Cellfield intervention. Secondary data obtained on six reading variables, namely Word Identification, Word Attack, Passage Comprehension on silent reading on the Woodcock Reading Mastery test, and Reading Rate, Accuracy in passage reading and Comprehension on out-loud passage reading on the Gray Oral Reading Test, were analysed before and after intervention. The Wilcoxon test showed significant improvement in all six variables and the rank biserial correlation effect sizes for these improvements were found to be large for Word Identification, Word Attack, Passage Comprehension, Accuracy and Comprehension. The effect size for Rate was medium. The overall effect size (i.e. the mean of the effect sizes reported for the six reading variables) of the Cellfield was 0.9.

A critical component of the Cellfield intervention is the decoding exercise, as described in Section 2.7.1. In the assessments used in this dissertation, decoding ability was measured on the Word Attack subtest of the Woodcock Reading Mastery Test at each testing point. This was the variable that showed the biggest improvement at the post-test, directly following the Cellfield intervention. In the treatment group, Word Attack skill showed an improvement of 28 months (in terms of age-related performance) in the 1.5 months that passed between the baseline and post-treatment assessments. It is widely accepted that improved decoding impacts positively on comprehension (Garcia and Cain 2014; Wolf 2018). In order 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 et al. (2019) refer to a 'decoding threshold', and state that struggling readers below the 'decoding threshold' who do not receive intervention to improve decoding, will likely remain poor comprehenders. The Decoding Threshold Hypothesis, which holds that the relationship between decoding and reading comprehension becomes unpredictable when decoding falls below a threshold, was supported by Wang et al's data. 38% of the Grade 5 learners and 19% of the Grade 10 learners in Wang et al.'s sample were found to be below the decoding threshold. Compared to their peers who progressed normally in reading comprehension, the below-threshold learners did not progress in terms of their reading comprehension score in the three years following the initial measurement. Studies like these confirm the crucial role of decoding, not only for developing automatic Word Attack, but also for comprehension. Identifying students with poor decoding, who are at-risk of being poor comprehenders, is thus crucial, and improving their decoding to a level above the decoding threshold should be paramount.

With the Cellfield, it is possible to remediate poor decoding skills; and it is the view of the present researcher that an intervention that does not address poor decoding skills is less likely to be successful. The results of the present study support the idea that learners who are below the decoding threshold will also struggle in other skills that are necessary for successful reading. 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 to the decoding skills. There was an improvement 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.

Section 4.4 presented the outcomes of the long-term efficacy of the Cellfield intervention. The Friedman test of differences showed a significant change in skill from the baseline test to the delayed post-test. The mean difference in time between these two assessment points was 27.8 months. The improvement in all of the six variables that was experienced directly after the Cellfield intervention was maintained when measured at the delayed post-test point. An accelerated improvement was experienced immediately following the intervention, with a less steep improvement in the various skills between the post-test and the delayed post-test. 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. Generally speaking, reading intervention studies do not report on the long-term efficacy of a particular treatment. A notable exception is the study by Morris et al. (2012). In this study, the treatment group that received a combination of two multidimensional interventions demonstrated higher outcomes on pseudoword and word identification outcomes, as well as greater growth in passage fluency and comprehension than the group receiving predominantly phonologically based instruction. These improvements were measured directly after 70 hours of intervention, as well as at the one-year follow-up point. The skills addressed in the intervention included phonological skills, orthography, morphology as well as semantics and syntax. The present study supports Morris et al's findings that a reading intervention programme that focuses on multiple cognitive-linguistic skills has a positive effect in the long run – in the present study two years after the intervention, the participants who underwent the treatment clearly maintained their improved skills, and were seemingly on a continuous upward trajectory on all the reading variables that were measured.

The third question compared the change in reading skills between the treatment group of participants who underwent the Cellfield intervention, to the change in reading skill of a control group who did not undergo the Cellfield intervention. The control group (n = 11) 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 (with the exception of Passage Comprehension). The improvement in skill over time was slower for the control group than the treatment group that had received the Cellfield intervention. Put differently, there was a steeper improvement in all the variables for the treatment group than the control group from the baseline test to the delayed post-test. The statistical analysis suggested that the groups were fairly comparable at the delayed post-test assessment point (recall that at the baseline point the treatment group was significantly behind the control group in Word Identification, Word Attack and Accuracy).

Only one statistically significant group difference was observed at the delayed post-test, namely for Passage Comprehension, where the treatment group outperformed the control group. This is a highly significant finding, 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). Despite the fact that the control group had notably *better* decoding skills than the treatment group in the baseline test (this was a significant group difference at the baseline), the control group's decoding skills (as measured on the Word Attack subtest) improved only marginally over the 30 months. The same is true for their Passage Comprehension. The Wilcoxon test showed significant improvement in all six variables and the rank biserial correlation effect sizes from the baseline to the delayed post-test were found to be large for all of the variables (Word Identification, Word Attack, Passage Comprehension, Rate, Accuracy and Comprehension). The overall effect size of the Cellfield at the delayed assessment point was 0.89, which is still indicative of a large effect.

The correlation between the variables at each testing point was examined in the fourth question. The strength in correlations between the six variables in the treatment group increased following the Cellfield intervention and continued to strengthen to the delayed post-test point. This suggests that reading skills are dependent on each other. At the baseline test, there was a negative correlation between Word Attack and Rate as well as Word Attack and Comprehension. Following the Cellfield intervention, there was a stronger correlation between these variables which continued to strengthen to the delayed post-test point. This outcome highlights the interconnectivity between reading skills. Considering the significant improvement in Word Attack score over the Cellfield intervention (28-month improvement over 1.5 months between baseline and post-test), it is evident that improved decoding impacts on additional reading skills, leading to improved comprehension. Strong correlations existed at each testing point between Word Attack and Word Identification scores.

At the baseline point, strong correlations existed between two sets of variables: Word Identification and Word Attack, and Rate and Accuracy. At the post-test point, there were strong correlations between five sets of variables: Word Identification and Accuracy, Accuracy and Passage Comprehension, Accuracy and Rate, Rate and Comprehension as well as Accuracy and Comprehension. At the delayed post-test, strong correlations were evident between seven sets of variables. The relationship between skills and how Cellfield affects reading will be discussed in the context of the multi-deficit theory of reading difficulties in Section 5.4 below.

At the onset of the study, it was hypothesised that the Cellfield intervention would have a positive effect on reading scores of individuals with reading difficulties and that the improvements over the intervention would be retained in the long term. The data analysed supports these hypotheses. Additionally, the data supported the hypothesis that children with reading difficulties undergoing the Cellfield intervention would improve their skill levels more, compared to children who have an age-delay in reading and that did not undergo the Cellfield intervention.

Finally, the expectation that correlations between reading skills would be stronger following the Cellfield intervention was also supported in the present study.

5.3 Current outcomes in relation to previous reading intervention studies

5.3.1 Comparison with previous Cellfield studies

Limited research on the Cellfield reading intervention has been conducted to date (as discussed in section 2.7.2). 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 of a group of children undergoing the Cellfield treatment (n = 7) compared to a placebo group (n = 5). The test group (n = 7) showed improvement in skills which were maintained after a three-week follow-on programme. The Coltheart (2008) study was designed to control for maturation, practice and re-testing effects by testing a month before intervention, directly before the intervention, directly following the intervention and a delayed assessment a month afterwards. The outcomes attributed the improvement in skill to the Cellfield intervention with an accelerated improvement in skill directly following the intervention which were maintained after a month.

The current research is, to the best of the researcher's knowledge, the first study measuring the long-term efficacy of the Cellfield intervention beyond one month. In the current study, the delayed post-test was conducted an average of 26 months following the Cellfield intervention.

The results presented in section 4.3 support previous research that the Cellfield intervention has a significant and positive impact on reading skill, with participants showing a significant improvement in reading skill directly following the intervention. Tables 5.1 and 5.2 present the findings from the current study alongside the same variables from the Prideaux, Marsh and Caplygin (2005), Coltheart (2008) and the Sander (2008) studies respectively. The outcomes presented here were all measured with the same assessment tools (Woodcock Reading Mastery test: Word Identification, Word Attack and silent reading Passage Comprehension).

The 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 Cellfield intervention.

Table 5.1 Improvement in months from baseline to post-test: current study in relation to previous studies

	Prideaux et al. (2005)	Coltheart (2008)	Current study
Word Identification	-	9.67 months	14 months
Word Attack	23 months	29.37 months	28 months
Passage Comprehension	12 months	10.82 months	10 months

The decrease in reading Rate from the baseline to the post-Cellfield assessment in the Prideaux, Marsh and Caplygin (2005) study was attributed to a ‘trade off’ between speed and accuracy. In other words, the participants were taking longer to accurately decode words where they had guessed or skipped words before the Cellfield intervention. Additionally, more self-correcting behaviour was observed where the candidates reverted in their reading to correct an error. While this impacts on reading Rate, it shows an improved understanding of the material read, and awareness of errors made.

In contrast to the 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 test in the current study. The two studies were similar in that the samples had similar mean ages (11;5 in Prideaux, Marsh and Caplygin (2005) and 10;8 in the current study). The ratio of male - 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 the Prideaux, Marsh and Caplygin (2005) study, 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 the Coltheart (2008) study, only the Woodcock Reading Mastery test subtests were reported, namely Word Identification, Word Attack and Passage Comprehension. The outcomes for Word Attack and Passage Comprehension were similar for both studies, but there was a larger improvement in Word Identification (14 months) in the current study between the baseline and post-test compared to 9.67 months in the Coltheart (2008) study. Effect sizes were not reported in the Coltheart (2008) study.

Table 5.2 Mean standard scores of current study, in relation to Sander's study

	Sander (2008)		Current study	
	Baseline	Post-test	Baseline	Post-test
Word Identification	65.29	73.14	90.4	96.3
Word Attack	71.86	89.29	92.7	102

Table 5.2 above shows the mean standard scores of the Woodcock Reading Mastery test variables: Word Identification and Word Attack for the Sander (2008) and the current study. The baseline scores were higher in the current study suggesting that the reading skills were weaker in the Sander (2008) study. However, there was a bigger improvement in mean scores on the variables in the Sander (2008) study. For Word Identification, the mean score improved by 7.85 compared to 5.9 on the current study between the baseline and post-test scores. For Word Attack, the mean standard scores improved by 17.43 in the Sander (2008) study and 9.3 on the current study. The differences in outcomes may be attributed to the sample size – the treatment group being much smaller (n = 7) with a smaller age range (between 12 and 14 years), compared to the current study (n = 41) and age range between 7 and 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. The biggest improvements were in Word Attack scores which improved by 28 months between the baseline and post-test. The average time between these two testing points was 1.5 months.

Additionally, the current study 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. At the baseline test, the control group had higher raw scores on all variables except in the WRMT Passage Comprehension. In the delayed test, the treatment group had surpassed the control group in all variables except reading Rate and Accuracy (as measured by the GORT). Considering the trajectory of improvement as seen in Figures 4.14 to 4.19, it appears that a further assessment at a later stage will show continued improvement of Rate and Accuracy in the treatment group, that will possibly surpass the control group.

5.3.2. Comparison with other reading intervention studies

In order to gain a better understanding of the impact of the Cellfield intervention, compared to other reading intervention programmes, this section discusses previous research that focused on different types of interventions, and places the current study within this dialogue. Broadly speaking, reading intervention studies can be divided into those that aim to improve a single skill (e.g. phonological awareness/decoding), or a combination of two skills (e.g. decoding and letter knowledge) and those that aim to address and improve multiple skills (e.g. phonological awareness/decoding, working memory, automaticity, auditory and visual processing etc.). Interventions can also be classified as being high-intensity (often a short intervention period), or low-intensity, (often a longer intervention period). The Cellfield aims to remediate a multitude of skills, and is delivered in a high-intensity manner over a short time.

Torgesen et al. (2001) studied the outcomes of 60 children with severe reading difficulties that underwent intensive remedial instruction. The group was divided between two interventions that focused on explicit and systematic instruction at the word-reading level. The *Auditory Discrimination in Depth (ADD)* which is now known as the *Lindamood Phoneme Sequencing Program for Reading, Spelling and Speech* (Lindamood and Lindamood 1998) stimulates phonemic awareness and much of the instructional time is spent building phonemic and articulatory awareness and word-reading skills. The *Embedded Phonics (EP*) programme was designed by the researchers to stimulate phonemic awareness through writing and spelling activities, and decoding strategies were directly taught. In other words, both programmes have a strong emphasis on phonological processing skills, but there was more instructional time spent reading and writing connected text with the EP programme. Statistically significant gains were made by both groups which were maintained at a two-year follow up assessment. Large effect sizes of 4.4 were shown for the ADD group, and 3.9 for the EP group. Reading rate was measured on the Gray Oral Reading III (an earlier version of the instrument used in the current study) and showed almost no change over the treatment. Similarly, in the current study, Rate was the variable with the smallest improvement over the Cellfield treatment.

This focus of addressing phonological processing skills in intervention as a foundation for reading success was also studied by Denton et al. (2006). Their intervention was designed to assist children who were shown to be have persistent reading difficulties. Taking into account the poor progress in reading rate in the Torgesen et al. (2001) study, Denton et al. (2006) incorporated a fluency intervention programme for eight weeks following the eight-week decoding programme. The intensive decoding intervention was conducted for two hours a day to 27 students in Grades 1 and 3. The *Phono-Graphix* programme (McGuiness, McGuiness and McGuiness 1996), based on the nature of the English grapho-phonemic system, was used for the first part of the intervention, and teaches students to blend, segment and manipulate sounds and apply these skills to reading and spelling. *Read Naturally* (Ihnot et al. 2001), which was used for the second part of the intervention, is designed to promote oral reading fluency by reading with a model. This model entails repeated reading, and goal-setting and progress monitoring of reading skill. Students received one hour per day of *Read Naturally* intervention for eight weeks following the *Phono-Graphix* training.

Assessments conducted following the *Phono-Graphix* phase were associated with large effects on Word Attack and Word Identification scores and moderate effects on Passage Comprehension and GORT-4 Comprehension. Following the *Read Naturally* phase, there were moderate to large effects on the TOWRE Sight Word Fluency and GORT-4 Fluency scores. Combining the outcomes of both interventions were associated with large effect sizes for all measures of reading and spelling. Denton et al.'s study demonstrated that remediating more than one skill at the same time is more impactful than addressing only one area, a finding that is supported by the present study.

The role of comprehension at the secondary schooling level becomes increasingly important as a tool for learning. Text becomes more complex, there is more reliance on independent reading and a higher level of engagement with the content through analysis and inference. Comprehension can be impacted when a student has difficulty in any of the following areas: phonological skills including decoding, fluency, vocabulary, background knowledge, language structures, comprehension strategies and verbal reasoning including understanding figurative language and inferring information.

The impact of intervention on comprehension for older struggling readers (Grades 6-12) was explored in a meta-analysis by Edmonds et al. (2009). Interventions that addressed decoding, fluency, vocabulary and comprehension that measured the effect on reading comprehension were included. Thirteen studies were included in the meta-analysis. Results indicated that older students' comprehension skills improved most when they received intervention that targeted comprehension, or a combination of components. Interestingly, interventions that targeted word reading strategies were associated with lesser gains in reading comprehension. This is in contrast to the findings of the current study, which showed strong correlations between decoding, word identification and comprehension outcomes, and which suggested that these correlations are strengthened following the Cellfield intervention. A large effect size in comprehension in both silent and out loud reading was seen following the Cellfield intervention. A possible explanation for this contradictory finding is that the participants in the current study were younger and drawing meaning from text does not require as much higher order thinking as for older children. Additionally, it is unclear what remediation aspects are addressed in the broad term of 'word-reading strategies' that were targeted in the Edmonds et al. (2009) study. The Cellfield not only addresses decoding, but also visual and auditory processing, and particularly also aims to improve reading fluency, that has been implicated in reading comprehension difficulties.

The Edmonds et al. (2009) study highlights that comprehension can extend beyond reliance on efficient decoding. This will be discussed in the context of Scarborough's (2001) rope in section 5.4.

Kim et al. (2020) conducted a meta-analysis in order to examine and identify effective variables related to single-study interventions for struggling readers. 84 research papers were selected where the interventions were categorised based on the stages of reading development, namely, phonological awareness, word recognition, fluency, vocabulary, and comprehension. The first stage is the pre-reading and decoding stage where children acquire phonological awareness by using visual and auditory processing mechanisms and develop word recognition. The second stage is the development of fluency where reading accuracy increases. New vocabulary is acquired, and children then move to the more complex comprehension stages of evaluation, inference and analysis of text. Each skill builds on the previous one, and Kim et al. (2020, 1) state that these "essential constructs of reading abilities…. cannot be underestimated in any parts of the reading process".

The results of the Kim et al. (2020) meta-analysis showed the overall effect size of all reading intervention studies was 0.77, representing large effects. The largest effect size was for interventions addressing word recognition, followed by reading comprehension, vocabulary acquisition, phonological awareness and reading fluency. Considering these stages of reading skills, the Cellfield intervention primarily addresses the first stage of phonological awareness, and to a lesser extent, word recognition and vocabulary. In the current study, decoding and word recognition were measured by the variables Word Attack and Word Identification and effect sizes (Cohen's d) were found to be 1.774 and 1.429 respectively (between the baseline and post-test). These effect sizes are higher than the Kim et al. (2020) effect sizes of 0.77 for phonological awareness and 0.83 for word recognition.

Kim et al.'s (2020, 5) meta-analysis also considers the age of children, and suggested that reading interventions had a larger impact on older learners (Grade 10-12) than on younger learners (Grade 7-9), but they concede that, despite this, "small-group instruction and individualized instruction types are both effective for all age groups". The current study supports this finding, as the overall effect of the Cellfield was large, despite the substantial age range of the participants in the present sample (7 to 18 years). It should nevertheless be noted that, in general, it would make sense to carefully consider the needs of older struggling readers, who tend to have more complex academic demands – particularly if they have already experienced repeated academic failure. Although it was not the focus of the present study, it would be interesting to determine whether the Cellfield intervention's impact is differentiated by age/grade level, and whether the long-term effect of this intervention is different, depending on the age/grade level and previous instructional experiences of the child. Even if reading interventions are more impactful in older children, this should not be seen as a reason not to remediate reading in young struggling readers. It is well-accepted that early intervention, that is implemented even *before* readers fail, is beneficial. Zentall and Lee (2012) and Vaughn et al. (2009), for instance, argue that reading intervention that happens early on is vitally important, as it can prevent incidences of substantial reading failure.

Another noteworthy, relevant point was made by Afacan, Wilkerson and Ruppar (2017), who found that reading interventions were less effective when applied to mixed-groups (i.e. to groups consisting of children who had various types of disorders) compared to small homogenous groups where the participants had the same disorder and similar academic needs. The advantage of the Cellfield intervention is that sessions are administered individually, thus the potentially diminishing effects of working in a mixed-group is not a factor. Also, because the Cellfield addresses multiple skills, there is, at least theoretically, less need to assess individual needs, as one may assume that the intervention will address delays in heterogenous samples. Afacan, Wilkerson and Ruppar (2017) argue that successful reading instruction (for children with learning disabilities) should consist of focused activities that address multiple skills, rather than a single skill. The results from this study clearly support this stance.

A final important variable to consider is the duration of a reading intervention. Kim et el. (2020) reported that instructional reading interventions should preferably adopt a long-term approach, as their meta-analysis showed that interventions of 21-30 sessions, or more than 31 sessions, had an effect size of 0.82, compared to interventions that consisted of 1-10 session, that had an effect size of 0.68. This conclusion supported earlier research by Gresham, Sugai and Horner (2001) and Wanzek and Vaughn (2008), that found that reading interventions that lasted for more than 10 sessions were significantly more effective than shorter interventions. The current study's findings do not support this stance, as the effect of the Cellfield (which could be considered a short-term approach), was large at both post-intervention assessment points. The present study supports previous studies (Wolff 2011; Solis et al. 2014) which argued that short interventions (completed in a two- to three-week period) consisting of fewer (high-intensity) sessions can be just as effective as a long-term approach. More importantly, the results of the present study showed that the effect of the intervention was sustained as long as two years after the original intervention, and that the treatment group continued to improve their reading skills long after the intervention. It is the researcher’s opinion that the design of an intervention is paramount – one could argue that short-term interventions that address only one or two skills, and that do not strengthen all the neurological pathways associated with reading are less likely to have a long-term impact. The Cellfield, due to its design, does exactly this, which could explain the lasting effect of this short-term intervention.

5.4 Interconnectivity of reading skills and the Cellfield intervention

It is possible for a child to have adequate decoding, but still have weak comprehension. Scarborough (2001) developed a visual representation of the components that comprise skilled reading. Commonly referred to as Scarborough’s reading rope (Fig.5.1), it is an elaboration of the Simple View of Reading that was discussed in section 2.3.

Figure 5.1 shows the two elements, ‘word recognition’ and ‘language comprehension’ intertwined 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 in order to be able to ‘decode’ graphemes back to phonemes by reading. As decoding becomes more automatic and a child’s mental lexicon grows, regular and irregular words are recognised by sight. 65-75% of children diagnosed with reading difficulties at this foundation phase continue to have weak reading throughout their school careers and beyond (Scarborough 2001). These staggering numbers highlight the importance of acquiring these foundation skills, and the importance of early intervention. Skilled reading requires that the processes involved in this word recognition strand happen automatically and fluently in order for cognitive resources to be available 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 adds that "fluency gives enough extra time to the executive system to direct attention to where it is most needed – to infer, to understand, to predict" (Wolf 2008, 131).

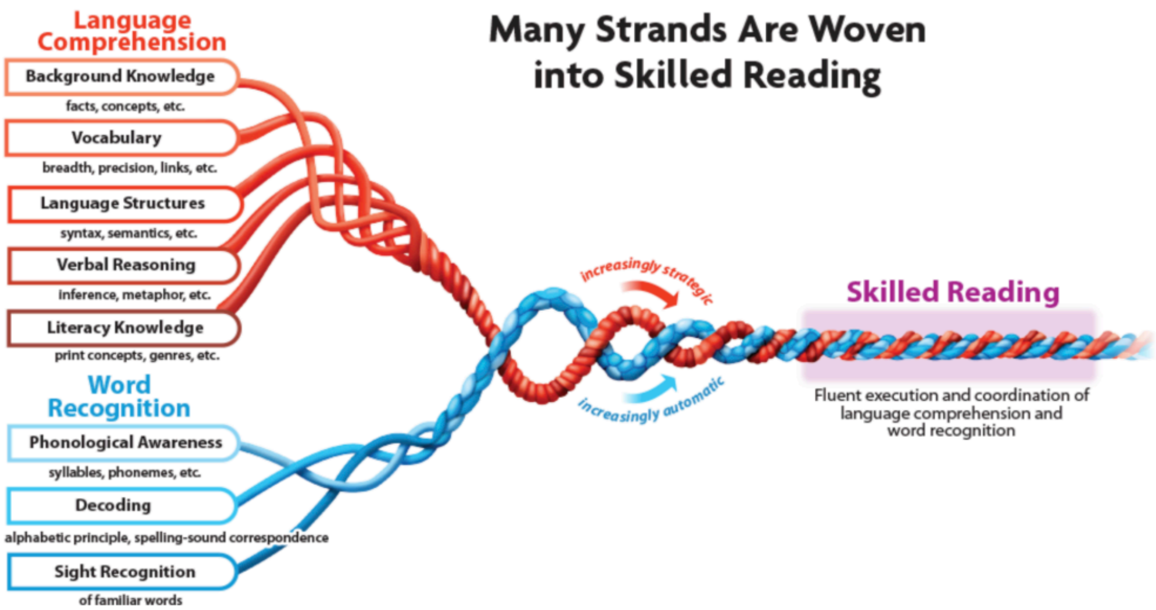


Fig. 5.1 Scarborough's rope (Scarborough 2001) (https://dyslexiaida.org/event/a-20th-year-celebration-of-scarboroughs-reading-rope/ Accessed 20 October 2021)

Although most reading difficulties are associated with the word recognition strand of Scarborough's rope, reading skill can be impeded by weaknesses in the language comprehension strand, especially in the higher grades when text becomes more complex. A child is required to have a more sophisticated vocabulary, understand the semantic and syntactic relationships between words, apply background knowledge to assist in understanding the material and apply higher order thinking skills in order to interpret metaphors, infer information and gain insight from text. As with the word recognition strand, the strands in language comprehension are all related. Scarborough (2001) notes that deficits in this strand are essentially oral language limitations. As shown in the Edmonds et al. (2009) meta-analysis in 5.3.2 above, remediating vocabulary and comprehension in older students improves reading comprehension outcomes.

Without the skills on the word recognition strand of Scarborough's rope, a child would not be able to read. This adds complexity to an already complex model of reading – what skills are necessary to acquire word recognition skills? The theories of reading difficulties attempt to understand and explain why a child would struggle to learn to read, or have persistent difficulty with reading. Although oral language proficiency was not measured in the current study, the results presented do support the notion put forward in the Simple View of reading that children will not become successful learners without properly developed decoding skills.

Proficiency in phonological processing, rapid naming, visual and auditory processing, and motor skills are essential for the word recognition strand to develop, and could potentially be added to that strand. As is addressed by the multi-deficit model of reading difficulties, many weak readers present with mixed profiles, with possible combinations of these areas of difficulty. This complicates both diagnosis and remediation. A child with a reading difficulty 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 have been found to be impactful on children with weak reading because they remediate multiple possible causes.

For example, in the Fälth et al. (2013) study (discussed in Section 2.5), the effect size for word decoding and sight word reading for the group receiving the combination intervention (decoding, phonological, word and sentence level training) was 2.97 compared to 1.85 for the phonological training only group, and 1.69 for the comprehension training only group. Additionally, the effect size for phonological abilities and non-word reading for the combination group was 1.87 compared to 1.38

for the phonological only training group and 1.43 for the comprehension only training group. In the current study, the effect sizes (Cohen's d) for Word Identification and Word Attack were 1.429 and 1.774 respectively.

The Cellfield programme, by its design, addresses phonological, motor, auditory, visual, and visual-to-phonological processing skills simultaneously. The successful outcomes presented in this dissertation lend support to previous research that addressing multiple skills is impactful and broadens the reach of remediating weak reading. It has also been established that by addressing decoding skills, comprehension (which is the main aim of reading) can be improved.

5.5 Limitations and future studies

Several limitations should be considered with regards to the results of the present study. These limitations determine the extent to which the results can be generalised. The participants were a convenience sample consisting of children whose parents had sought out 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 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 of the participants had English as LoLT, 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. It should also be noted that the researcher conducted all assessments as well as the intervention. Although all prescriptions in terms of testing and data analysis were followed, as provided in the various standardised guidelines, it is not impossible that the researcher's familiarity with the participants led to a more pronounced effect. Ideally then, the Cellfield should also be tested in the South African context using qualified research assistants, who would be more indifferent to the outcome. The risk that this limitation poses for the reliability of the current study is, however, very small, given that the intervention phase of the current study preceded the researcher's registration as postgraduate student (i.e. secondary data was used) and given that the researcher fully complied with the standardised test and data analysis procedures, as they are described in the Gray Oral Reading Test and Woodcock Reading Mastery Test.

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 for these factors could be an option for future research as well as a better matched group size between the treatment and control groups. The difference in size between the two groups (n = 41 for the treatment group and n = 11 for the control group) also needs to be considered when interpreting the outcomes for question three. A small sample can affect the reliability of the outcomes and may not be representative of the population. A different outcome may have been reached had the groups been more evenly matched in number.

In the current study, the groups were not divided into subgroups according to causes of reading difficulty, 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.

It was typically noted that the motivation of the participants improved over the duration of the Cellfield intervention. When the families were contacted for the delayed post-test, anecdotal feedback was received of improved self-esteem and confidence in reading, and a roll-over effect of willingness to read more and improved academic success. The contribution of person-centred factors can be analysed in conjunction with reading skill outcomes as a potential area for future research.

5.6 Recommendations

In the South African context where the majority of 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 the possible implementation of a treatment of this nature to the majority of students in a public-school system. Nonetheless, the impact of Cellfield as a multidimensional intervention on children behind their age-appropriate level in reading skill has been well established. There is clear value in expanding the reach of the Cellfield intervention for 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. It is also important to acknowledge the role of oral language skills, and the impact these skills have on comprehension, especially for second language learners.

5.7 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 in Section 5.5, 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 of 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 over the long term. The improvement in decoding skills following the Cellfield is particularly important, as this skill is critical – decoding has to 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 in order to experience academic success.

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ANNEXURES

Annexure A: Participant questionnaire

Assessment Questionnaire

The information provided here will remain confidential.

Date ____

Candidate's name ____

Age ____________________ Date of birth ______________

School and grade ____

Sibling's ages ____

Parent's name ____

Address ____

____

____

Contact h) ________________ w) ________________

c ________________ Email ________________

Home Language ________________________________

Language of instruction at school________________________

Does your child take any medications? Yes ○ No ○

Name(s) of medication(s)

____

____

Has your child had his/her hearing tested in the past 2 years? Yes ○ No ○

Has your child had his/her eyesight tested in the past 2 years? Yes ○ No ○

What was the outcome of these tests?

____

____

____

____

Psychometric Testing

Has your child had any psychometric testing done in the past 2 years? Yes ○ No ○

What was the outcome of these tests?

____

____

____

____

If any older psychometric testing has been done which provided significant results, please include these below:

____

____

____

Have any educational concessions been applied for or granted?
Yes ○ No ○

Please provide details

____

____

____

Family History
Has anyone in your child's immediate or extended family had difficulties with:

○ Articulation
○ Language skills
○ Stuttering
○ Dyslexia
○ Reading or learning

Has your child ever received special education help Yes ○ No ○
(e.g. special reading group, language support class)? Please specify

Special Education Help	**Duration**

Schooling

In your opinion, what is your child's current achievement at school in the following areas? Please tick the boxes.

	Above Average	**Average**	**Below Average**
Reading accuracy	○	○	○
Reading comprehension	○	○	○
Spelling	○	○	○
Written expression	○	○	○
Oral (verbal) expression	○	○	○
Handwriting	○	○	○
Mathematics	○	○	○

Is your child particularly anxious about tests and exams? Yes ○ No ○

Generally speaking, does your child finish tests and exams in the required time?
Yes ○ No ○

Please list past schools attended:

School	**Year**

Do any of the following apply to your child?

☐ Dislikes school
☐ Blames teacher for difficulties
☐ Complains school is boring

☐ Refuses to cooperate with teachers
☐ Teachers report 'discipline' problems
☐ Is not motivated to complete class or homework activities
☐ Frequently hands in 'sloppy' work or neglects to hand in assignments

Comprehension

Does your child have difficulties:

☐ Understanding questions
☐ Following instructions correctly
☐ Understanding indirect requests and sarcastic comments
☐ Following stories as a whole, drawing conclusions, making predictions
☐ Understanding that the meaning of a word can change depending on the context

Auditory Processing

Does your child have difficulties:

☐ Saying speech sounds (e.g. 'lellow' for 'yellow', 'fum' for 'thumb')
☐ Saying words of several syllables (e.g. 'hostipal' for 'hospital', 'puter' for 'computer')
☐ Understanding rhymes
☐ Identifying the number of syllables or sounds in words
☐ Confuse similar-sounding words (e.g. 'cone' for 'comb')

Behaviour

Please tick the behaviours that refer to your child.

Activity Level:
☐ Cannot keep still or stay quiet; 'hyperactive', restless
☐ Lethargic, often tired, fatigues quickly

Attention:
☐ Cannot concentrate on a task for long
☐ Needs to be called back to task continually
☐ Cannot ignore 'distractions'; overly aware of nearby sounds, sights and smells

Movement and Balance:
☐ Poor balance on play equipment
☐ Difficulties climbing or descending stairs
☐ Seems overly sensitive to movement; becomes carsick regularly
☐ Constantly moving; often swinging, twirling, bouncing and rocking

Visual Perception:
☐ Difficulties matching colours, shapes and sizes
☐ Difficulties completing puzzles, uses 'trial and error' to place pieces
☐ Reverses words, letters or number after Year One
☐ Skips words, phrases or lines when reading
☐ Loses place when reading or copying; needs finger or marker to keep place

☐ Difficulties with smooth eye-tracking (following objects with eyes)

Is there any other information relevant to your child's difficulties that you would like to tell us about?

____

____

____

Please state any event that has had a significant impact on your child's emotional well-being:

____

____

____

Has your child undergone the Cellfield intervention?

Yes ○ No ○

If 'yes', please complete the following section:

Date of intervention: ____

Has your child received any additional intervention or assistance since the Cellfield treatment?
If yes, please give details:

____

____

____

In signing below the parent(s) / guardian(s) confirm the above information is accurate and complete.

____________________	____________________
Parent/Guardian Name	**Signature**

Annexure B: Ethical clearance certificate

COLLEGE OF HUMAN SCIENCES RESEARCH ETHICS REVIEW COMMITTEE

04 March 2020

Dear Angela Charalambous

NHREC Registration # :
Rec-240816-052
2020_CREC_66089433
Staff Number: 66089433

Decision:
Ethics Approval from 01 March 2020 to 31 February 2024

Researcher(s): Angela Charalambous

66089433@mylife.unisa.ac.za

A Longitudinal Study of the Efficacy of the Cellfield Reading Intervention in the South African context.

Research Type: Project

Ethics approval is granted for four years.

The proposed research may now commence with the provisions that:

1. The researcher(s) will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
2. Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study should be communicated in writing to the **CREC Chair (dubeeen@unisa.ac.za)**
3. The researcher(s) will conduct the study according to the methods and procedures set out in the approved application.
4. Any changes that can affect the study-related risks for the research participants, particularly in terms of assurances made about the protection of participants' privacy and the confidentiality of the data, should be reported to the Committee in writing, accompanied by a progress report.
5. The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study. Adherence to the following South African legislation is

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Open Rubric

important, if applicable: Protection of Personal Information Act, no 4 of 2013; Children's act no 38 of 2005 and the National Health Act, no 61 of 2003.

6. Only de-identified research data may be used for secondary research purposes in future on condition that the research objectives are similar to those of the original research. Secondary use of identifiable human research data require additional ethics clearance.
7. No fieldwork activities may continue after the expiry date **(31 February 2024)**. Submission of a completed research ethics progress report will constitute an application for renewal of Ethics Research Committee approval.

Note:

The reference number ***2020_CREC_66089433*** *should be clearly indicated on all forms of communication with the intended research participants, as well as with the Committee.*

Yours sincerely,

EDube

Signature :

Dr. E.E.N Dube
Ethics Chair : CREC
Email: dubeeen@unisa.ac.za
Tel: (012) 429- 3892

Annexure C: Participant information and assent form

PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM

TITLE OF THE RESEARCH PROJECT:

A Longitudinal Study of the Efficacy of the Cellfield Reading Intervention in a South African context.

.

RESEARCHERS NAME: Angela Charalambous

What is RESEARCH?

- Research is something we do to find new knowledge about the way things (and people) work. This gives us information to help people. I will explain what will happen in the study and then, if you agree to participate, you will sign a form of agreement and I will give you a copy.

What is this research project all about?

- For the Experiment Group:
  When you did the Cellfield intervention on the computer, we measured your reading before and afterwards to see how it had changed. Now we want to measure your reading again to see how it is different to what it was before.
- For the Control Group
  You came and visited the reading centre some time ago, and we measured your reading. We want to measure again, to see how your reading has changed since then.

Why have I been invited to take part in this research project?

- **You have been invited to take part in this study because we have already done an assessment with you before and we want to be able to use the results to help other children with their reading.**

Who is doing the research?

- I am doing the research, and I will put all the results together for the research project.

What will happen to me in this study?

- We will spend some time together in the reading centre, as before, to do the reading assessments. It will take 45-55 mins. We will then have the results of where your reading is at the moment. There are no risks or danger involved in the study.

Will anyone know I am in the study?

- No one will have to know that your reading results are in the study. Everyone's names will be kept confidential or secret and your file will be locked away.

Who can I talk to about the study?

- You can speak to me any time about the study and ask me any questions that you have. You can also speak to your parents about the study. The study has also been discussed with your parents so that they can also give permission for you to participate in the study.

What if I do not want to do this?

- You can refuse to take part in the study if you want to. You can also change your mind at any time without getting into trouble.

Do you understand this research study and are you willing to take part in it?

YES	NO

Has the researcher answered all your questions?

YES	NO

Do you understand that you can pull out of the study at any time?

YES	NO

Participant's Name & Surname……………………………………(please print)

Participant's signature…………………………………………..

Date…………………

Researcher's Name & Surname……………………………………(please print)

Researcher's signature…………………………………………..

Date…………………

Annexure D: Parent/Guardian information and consent form

PARENT/GUARDIAN INFORMATION AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

A Longitudinal Study of the Efficacy of the Cellfield Reading Intervention in a South African context.

RESEARCHER: Angela Charalambous

Your child has been invited to take part in a research project for the purposes of a Masters in Linguistics undertaken through the University of South Africa. Please take some time to read the information presented here, which will explain the details of this project. Please ask me any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails. Also, your child's participation is entirely voluntary, and you are free to decline to participate without any consequences. You are also free to withdraw from the study at any point, without consequence, even if you do agree to take part.

This study has been approved by the Health Research Ethics Committee at the University of South Africa and will be conducted according to the ethical guidelines and principles.

What is this research study all about?

- The assessment will be conducted at the reading centre where your child's reading has previously been assessed.
- If your child has previously done the Cellfield reading intervention, we would like to measure the improvements in the long term.
- If your child did not do the Cellfield intervention, we want to measure how his reading outcomes have changed since the initial assessment.
- You will be asked to fill in a questionnaire to give us some background information and your input of where your child's strengths and weaknesses are. Your child will come into the reading centre where we will do an assessment to measure across 6 areas of reading.
- The assessment should take about 45- 55 minutes. The outcomes of this assessment will be used for the research project.

Why have you been invited to participate?

- Your child has been invited to participate in the study as your child has previously been assessed by the reading centre or has undergone the Cellfield intervention.

What will your responsibilities be?

- Your responsibility will be to complete the questionnaire and bring your child to the appointment time for the assessment.

Will you benefit from taking part in this research?

- The benefits from taking part in this research will be that we can have a better understanding of reading and the interventions that assist children who are behind in their reading ages.
- You will be issued with a brief report outlining the results of the assessment.

Are there in risks involved in taking part in this research?

- There are no risks involved in taking part in this research. As in previous assessments, the process will be clearly explained to your child and his/her comfort level monitored throughout. The assessment will be terminated if he/she becomes overwhelmed or stressed in any way.

Who will have access to your records?

- The information collected will be treated as confidential and protected. Hard copy files will be stored in a locked environment for a period of 5 years. The identities of all participants will remain anonymous. Only the researcher and staff at the reading centre will have any access to personal information. Anonymous outcomes will be shared with the UNISA supervisor and the statistician. Any published information will only contain group outcomes and no personal information will be published.

- You can contact the UNISA Ethics Committee if you have any concerns or complaints that have not been adequately addressed.
- You will receive a copy of this information and consent form for your own records.

- There will be no costs involved for you, if you choose take part.

I, __________________ (parent/guardian name), confirm that the person asking my consent for my child ___________________ (child's name) to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet.

I have had sufficient opportunity to ask questions and am prepared to participate in the study.

I understand that my child's participation is voluntary and that I am free to withdraw him/her at any time without penalty.

I am aware that the findings of this study will be processed into a research report, journal publications and/or conference proceedings, but that my child's participation will be kept confidential unless otherwise specified.

I agree to the recording of the outcomes of the reading assessments as explained, and for the outcomes from previous reading assessments to be used.

I agree to the outcomes of the assessment being shared anonymously with the UNISA supervisor and statistician.

I have received a signed copy of the informed consent agreement.

Parent/Guardian Name & Surname………………………………………… (please print)

Parent/Guardian Signature……………………………………   Date…………………

Researcher's Name & Surname……………………………………………..(please print)

Researcher's signature…………………………………………..   Date…………………