Learning to read and write: The role of handwriting fluency

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PUBLICATIONS ARISING FROM THIS THESIS

This thesis is presented in hybrid format with the inclusion of four articles and one policy brief, alongside three traditional chapters (1, 4 and 5). At the time of submission, one paper (Chapter 7) was published in a peer reviewed journal, two papers (Chapters 2 and 3) were under review, and one paper (Chapter 6) was a manuscript in development. Chapter 8 contains a policy brief in development.

Published Manuscript:

Ray, K., Dally, K., Colyvas, K. and Lane, A.E. (2021). The effects of a whole-class kindergarten handwriting intervention on early reading skills. *Reading Research Quarterly, 56*(S1), 193-207. https://doi.org/10.1002/rrq.395

Manuscripts Under Review:

Ray, K., Dally, K. and Lane, A.E. Impact of a co-taught handwriting intervention for kindergarten children in a school setting: A pilot, single cohort study. Manuscript submitted for review to *Journal of Occupational Therapy, Schools, & Early Intervention.*

Ray, K., Dally, K., and Lane, A.E. The relationship of handwriting ability and literacy in kindergarten: A systematic review. Manuscript submitted for review to *Reading and Writing.*

Manuscript in Development:

Ray, K., Dally, K., Colyvas, K., and Lane, A.E. Improving handwriting fluency and writing outcomes in kindergarten: The effect of Write Start-K. Manuscript in preparation for *American Journal of Occupational Therapy.*

Policy Brief in Development:

Ray, K. Dally, K., and Lane, A.E. Learning to Read the Write Way – A Policy Brief. Proposed publisher—Callaghan, NSW: The University of Newcastle, 2021.

PRESENTATIONS ARISING FROM THIS THESIS

One presentation was made during my candidature, with one abstract currently under review at an international conference.

National Conference Presentation:

Ray, K., Dally, K, and Lane, A.E. Effectiveness of Write Start-K, an embedded, therapeutic handwriting program for kindergarten students. Occupational Therapy Australia 28th National Conference and Exhibition, Sydney, Australia, 10-12 July, 2019, E-poster.

Under Review:

Ray, K., Dally, K. and Lane, A.E. Impact of a whole-class handwriting intervention on literacy in Australian kindergarten children. 18th World Federation of Occupational Therapy Congress, Paris, France, 27 – 30 March 2022.

DECLARATIONS

Statement of Originality

I hereby certify that the work embodied in the thesis is my own work, conducted under normal supervision. The thesis contains no material which has been accepted, or is being examined, for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made. I give consent to the final version of my thesis being made available worldwide when deposited in the University's Digital Repository, subject to the provisions of the Copyright Act 1968 and any approved embargo.

Signed:

Name: Karen Ray Date: 15th June, 2021

Contribution Statement

The work carried out throughout this PhD program of study has led to four papers, presented in this thesis in Chapters 2, 3, 6 and 7. I was the lead author on each of these papers and I was the sole PhD student involved in the studies on which each paper is based. A statement of contribution is provided at the beginning of each of these chapters. In addition, this thesis includes a policy brief in development (Chapter 8, Appendix 14) and I was the lead author for this publication.

Acknowledgement of Authorship

I hereby certify that the work embodied in this thesis contains one published paper and scholarly work of which I am a joint author. As part of the thesis I have included a written declaration endorsed in writing by my supervisor, attesting to my contribution to the joint publication/s/scholarly work.

Signed:

Name: Karen Ray Date: 15th June, 2021

By signing below, I confirm that Karen Ray contributed to the research questions, ethics approvals, intervention design, recruitment, data gathering, intervention implementation and write up for the publication entitled:

Ray, K., Dally, K., Colyvas, K. and Lane, A.E. (2021) The effects of a whole-class kindergarten handwriting intervention on early reading skills. *Reading Research Quarterly,* Wiley, *56*(S1), 193-207. https://doi.org/10.1002/rrq.395

Signed:

Name: Prof Alison E Lane Date: 15th June, 2021

TERMINOLOGY

"Kindergarten": throughout this thesis the term Kindergarten has been used to describe the first year of formal schooling. This term is used in New South Wales and the Australian Capital Territory, Australia; however, in other states in Australia, the term used for this Year is "prep" (Queensland, Victoria and Tasmania), "reception" (South Australia), "preprimary" (Western Australia) and "transition" (Northern Territory). The first year of formal schooling is also described as the "foundation year" by the Australian Curriculum, Assessment and Reporting Authority. In other countries terms for Kindergarten also include "elementary" and "preschool". The definition applied throughout this thesis was that children in Kindergarten were in their first year of compulsory education and formal instruction, in contrast to preschool environments which can be optional and where formal literacy and handwriting instruction are not prescribed. This definition was applied for inclusion of studies in the systematic review and when comparing and contrasting research findings relevant to this thesis.

"Year" and **"grade":** both terms **Year** and **grade** are used in this thesis to describe an educational year. In accordance with Australian conventions, the term "Year" is used predominantly. However, "grade" is used consistently in chapters that include a published paper, paper under review or a manuscript in development (Chapters 2, 3, 6 and 7). All of the papers included in these chapters are published in, under review by, or in development for, international journals where the term "grade" is conventionally used. For both Year and grade, numerals are used to describe year level, for example Year 1 or grade 1.

DEFINITIONS

Term	Meaning of term adopted in this thesis
Beginning writer	A student, generally in kindergarten, who is developing the foundation skills necessary for writing.
Component skills	A subset of skills with a known contribution to another skill, such as handwriting.
Decoding	Use of phonic knowledge to sound out written words.
Early reading	Foundation skills that enable the emergence of reading ability, including letter and sound knowledge, phonological skills and letter sound correspondence.
Fine motor skills	Hand skills that support the coordination and completion of manipulative tasks.
Handwriting	Use of letter formation patterns to transcribe written forms.
Handwriting fluency	Ability to transcribe legible written forms from memory, implying coordination of cognitive, perceptual and motor processes, also known as automaticity.
Kindergarten	The first year of formal schooling, characterized by the introduction of structured lessons for literacy.
Letter formation	The series of strokes and lines taught for writing individual letters.
Letter sound correspondence	Mental association between a letter form and its related sound, includes capacity to write a correct letter form in response to an auditory cue.
Literacy	Knowledge, understanding and skills in listening, reading, viewing, speaking, writing and creating multimodal texts.
Motor program	The underlying neurological sequences that support the successful completion of a planned motor action.
Orthographic coding	The mental generation of correct forms to represent letters and words.
Phonemes	The smallest units of sound, generally comprising one or two letters to create a single sound.
Phonemic awareness	Ability to hear, interpret and manipulate individual phonemes within words.
Phonics	Matching sounds of individual letters or groups of letters (orthographic codes) with the corresponding letter forms.

Term	Meaning of term adopted in this thesis
Phonological awareness	A broad range of skills that contribute to the ability to hear, manipulate and interpret sound units within words. Examples include identifying rhyme, alliteration, and segments of a word or sentence.
Process	Cognitive and motor program factors that contribute to handwriting fluency.
Product	The appearance of handwriting on a page.
Reading	Use of skills such as vocabulary, phonics, decoding and morphological knowledge to interpret and comprehend written text.
Sight words	Nondecodable words read by development of retrievable orthographic codes.
Transcription	Foundation skills used in translation, such as spelling and handwriting.
Translation	The process of converting ideas and thoughts to written text.
Visual memory and visual sequential memory	The ability to remember visual forms, either individually presented or presented as a sequence.
Visuomotor skills	The coordination of visual perception with motor skills to complete tasks requiring both elements, such as skilful use of the hands for writing tasks.
Visual motor integration	A more specific descriptor of visuomotor skills, pertaining to the ability to accurately copy shapes and forms.
Visual perception	The ability of the brain to perceive and interpret visual stimuli. Interpretation can include discrimination between stimuli and recognising orientation and form differences.
Write Start	An extant handwriting intervention program previously designed and tested for Year 1 students.
Modified Write Start	The Write Start program that was modified and piloted by the candidate for Kindergarten students, and retrospectively analysed in this research.
Write Start-K	The modified Write Start program for Kindergarten students that was revised and updated, by the candidate, and tested in a two-group study in this research.
Writing composition	Written, self-generated text produced generally in response to a stimulus or prompt topic.

CONTENT STRUCTURE

This hybrid thesis includes traditional chapters, papers (published, under review or in development) and a policy brief. Two papers are currently under review (Chapters 2 and 3). The paper presented in Chapter 6 is in development for submission to a peer reviewed journal. The published manuscript is presented in Chapter 7 (accepted version) and a copy of the published paper is included in Appendix 13. Chapter 8 is presented in part as a policy brief in development, which details the key findings and recommendations arising from the body of work. A copy of the draft policy brief is included in Appendix 14. As each of the papers and publications have been prepared for separate journals, there is some duplication of information across chapters. However, the thesis has been structured as much as possible to ensure that each chapter builds on preceding chapters.

The structure is detailed below:

Chapter 1	Introduction: An overview of the thesis topic, key concepts and a rationale for the research, and a concluding statement of the thesis questions and hypotheses.
Chapter 2	Systematic review: A systematic literature review identifying the relationships between handwriting and literacy, specifically in Kindergarten populations, reported as the following paper: Ray, K., Dally, K., and Lane, A.E. The relationship of handwriting ability and literacy in kindergarten: A systematic review. Manuscript submitted for review to *Reading and Writing.*
Chapter 3	Pilot study: A retrospective analysis of the effectiveness of a whole-class handwriting intervention (modified Write Start) and the impact of early literacy abilities on outcomes, reported as the following paper: Ray, K., Dally, K. and Lane, A.E. Impact of a co-taught handwriting intervention for kindergarten children in a school setting: A pilot, single cohort study. Manuscript submitted for review to *Journal of Occupational Therapy, Schools, & Early Intervention.*

Chapter 4	Theoretical model: A model for handwriting fluency acquisition synthesising the findings of Chapters 1 to 3 and proposed as the basis for a revised and updated whole-class handwriting intervention for Kindergarten (Write Start-K).
Chapter 5	Methods: Methods for a two-group pre- post-intervention comparison study to test the impact of Write Start-K on handwriting fluency, reading and writing composition.
Chapter 6	Results and Discussion Part 1: Results and discussion of the effect of Write Start-K on handwriting fluency and writing composition, presented as the following paper: Ray, K., Dally, K., Colyvas, K., and Lane, A.E. Improving handwriting fluency and writing outcomes in kindergarten: The effect of Write Start-K. Manuscript in preparation for target journal the *American Journal of Occupational Therapy*.
Chapter 7	Results and Discussion Part 2: Results and discussion of the effect of Write Start-K on reading, presented as the following published paper: Ray, K., Dally, K., Colyvas, K. and Lane, A.E. (2021). The effects of a whole-class kindergarten handwriting intervention on early reading skills. *Reading Research Quarterly, 56*(S1), 193-207. https://doi.org/10.1002/rrq.395
Chapter 8	Conclusion: A synthesis of the findings of the body of work in the thesis including key findings, recommendations, limitations and conclusions. Key findings and recommendations are presented as the following policy brief in development: Ray, K. Dally, K., and Lane, A.E. Learning to Read the Write Way - A Policy Brief. Proposed publisher Callaghan, NSW: The University of Newcastle, 2021.

ABSTRACT

Background:

Handwriting is a complex skill comprising aspects of literacy, fine and visuomotor skills and cognitive development (Dinehart, 2015). Handwriting fluency, the capacity to write recognisable letters and words from memory, is implicit in, and impacts, many typical academic tasks (Feng et al., 2019; McCarroll & Fletcher, 2017). Handwriting underpins writing composition (Kim, Gatlin, et al., 2018; Santangelo & Graham, 2016) and emerging evidence supports its role in facilitation of reading skills, including letter recognition and categorisation (James & Engelhardt, 2012; Li & James, 2016). However, less is known about supporting handwriting fluency acquisition of beginning writers (Cantin & Hubert, 2019; Santangelo & Graham, 2016), or the effects of handwriting fluency acquisition on literacy in beginning readers (James & Engelhardt, 2012; Longcamp et al., 2005). Children in Kindergarten, the first year of formal instruction for reading and writing, are noted to be an understudied group (Puranik, Petscher, et al., 2018). Further study of effective ways to support handwriting fluency acquisition and the impact of improvements in this skill on literacy in Kindergarten is warranted.

Objective:

The overall objective of this research was to examine the interrelationships between handwriting fluency in Kindergarten students and early reading and writing composition skills.

Method:

The objective of the research was addressed by:

1. Undertaking a systematic review of the current literature pertaining to the relationship between students' handwriting and literacy in Kindergarten.
2. Conducting a pilot study of a modification of the Year 1 Write Start program (Case-Smith et al., 2014) for Kindergarten children. The modified Write Start involved a whole-class, co-taught

handwriting intervention for Kindergarten students, and the pilot study retrospectively analysed impacts of this program on handwriting fluency and the impact of early literacy abilities on intervention outcomes. The pilot study included a single cohort of Australian Kindergarten students (n= 81) at a regional independent school. The candidate had delivered the modified Write Start program as part of routine clinical practice in the school and data were analysed retrospectively.

3. Development of a theoretical model of handwriting fluency acquisition in beginning writers through the integration of evidence from the literature and the pilot study results.
4. Implementing a prospective, two-group pre- post-test comparison study of the effectiveness of a revised and updated modified Write Start (Write Start-K) on the handwriting fluency and early literacy of Australian Kindergarten students. Write Start-K was tested in two Kindergarten classes in the intervention school (n = 38) and compared with Kindergarten children in a control school who received standard handwriting teaching (n = 39). Together with teachers and research assistants, trained in the intervention methodology, the candidate conducted the intervention in two 45-minute sessions per week for eight weeks. At both schools, handwriting, early reading and writing composition outcomes were measured at baseline, immediate post-intervention and follow-up (12 weeks post-intervention).

Results:

Systematic review: Relationships between handwriting and literacy in Kindergarten were reported in 15 articles involving 2049 unique participants. Relevant skills were grouped as: 1) handwriting— letter writing fluency and perceptual motor skills; and, 2) literacy—letter name and sound knowledge, phonological skills, word reading, writing composition, and spelling. There was moderate to strong evidence for a relationship between letter writing fluency and all literacy groupings, except phonological skills, for which weaker evidence was found. Weaker evidence was found for an effect of perceptual motor skills on spelling, letter name and sound knowledge, word reading and phonological skills.

Pilot study: Significant gains in handwriting fluency were observed for participants following the modified Write Start intervention ($Z = -4.457$, $p < 0.0001$). Higher or lower early literacy abilities did not impact intervention outcomes (phonics, $f_{(19, 50)} = 1.11$, $p = 0.36$; phonemic awareness, $f_{(19,50)} = 1.32$, $p = 0.21$; writing, $f_{(19,50)} = 0.59$, $p = 0.89$).

Theoretical model: The 4*Rs* model is a proposed model of handwriting fluency acquisition based on findings from the systematic review and pilot study. The model proposes that there are four processes involved in handwriting fluency acquisition: *Recall, Retrieve, Reproduce* and *Repeat*. These processes are underpinned by the cognitive and perceptual motor skills indicated in handwriting fluency and are conceived as a system that must work together for fluency acquisition.

Two-group study: Linear Mixed Models were used to assess the impact of group, time and the group by time interactions, with these three terms forming the base model. Amount of growth across the assessment time intervals and the differences in this growth between the intervention group, who received Write Start-K, and the control who received standard teaching, were analysed to determine significant effects. Significant group by time interactions in favour of the intervention group were observed for handwriting fluency ($p = .005$), letter sound correspondence ($p = .01$), number of words written ($p<.001$), word reading fluency ($p = .05$) and letter name knowledge ($p <.001$).

Conclusion:

Findings from the prior literature support a relationship between early handwriting and early literacy in Kindergarten students. The 4*Rs* model of handwriting fluency acquisition in beginning writers is proposed and highlights this relationship. Findings from the retrospective (pilot) and prospective (two-group) studies confirmed that the Write Start program can be successfully adapted and utilised as an effective intervention for handwriting fluency acquisition for Kindergarten children. Further, when compared with standard teaching, Write Start-K participants made greater gains in reading and writing composition skills. This finding adds to the emerging evidence for the impact of handwriting fluency on literacy in Kindergarten. Replication of these findings is required to confirm these conclusions. Results from this research were compiled in a policy brief to advise key stakeholders in health and education.

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Chapter 1 Introduction

1.1 Outline

The primary aim of this research was to investigate the relationship between handwriting and literacy for Kindergarten children. Handwriting has strong links to successful writing composition, and emerging evidence supports a role in reading development. The evidence of these relationships for Kindergarten has not yet been synthesised, and there is a paucity of research on methods to support handwriting development for this age group. The need for research in this field is evident as Kindergarten children continue to experience high levels of developmental risk factors which may impact foundation skill acquisition (Department of Education and Training, 2016). Further, despite improvements, literacy remains a crucial national agenda focus (Australian Institute of Health and Welfare, 2019). The interrelationship of handwriting and literacy, and methodologies that may impact Kindergarten handwriting abilities are, therefore, an important focus.

Chapter 1 presents an introduction to the work reported on in the thesis. Section 1.2 provides a rationale for the research and a statement of the research topic. Section 1.3 presents a review of the literature pertaining to the research topic. An analysis of intervention approaches is presented in Section 1.3 and leads to the introduction of the intervention approach modified, revised and tested in this research, Write Start (Case-Smith et al., 2011; Case-Smith et al., 2012; Case-Smith et al., 2014). Section 1.4 lists the specific thesis questions and hypotheses. The overall project structure is summarised at the conclusion of the chapter.

1.2 Rationale for Research

Despite increases in the use of technology in education, handwriting and written expression remain important tools by which primary school students document their knowledge (Malpique et al., 2017; McMaster & Roberts, 2016). It has been estimated that up to 50% of a typical school day is spent carrying out fine motor tasks, with handwriting accounting for half of that time (Marr et al., 2003). Approximately 10% to 30% school students experience difficulties with handwriting (Feder &

Majnemer, 2007; Karlsdottir & Stefansson, 2002; Overvelde & Hulstijn, 2011a) and skills known to underpin handwriting in Kindergarten may be declining in this general population (Sheedy et al., 2021). Teachers often refer students with handwriting difficulties to specialists such as occupational therapists when difficulties do not resolve with classroom teaching alone (Cantin & Hubert, 2019; Hammerschmidt & Sudsawad, 2004).

Literacy is a crucial life skill, with pervasive impacts on learning, employment and health (Arnaud & Gutman, 2020; Frolek Clark, 2016; Grajo et al., 2020; Grajo & Gutman, 2019). As noted, handwriting ability makes an important contribution to literacy as a foundation skill for documenting knowledge. In addition, handwriting fluency has surprising and important impacts on writing quality and reading. There is a well-established link between fluent handwriting and literacy, with seminal studies demonstrating that improvements in handwriting lead to improvements in writing composition (Berninger et al., 1997; Graham et al., 2000; Jones & Christensen, 1999). Further, handwriting automaticity, the ability to write fluently from memory, is a significant predictor of both reading and writing in children in the early grades of education (Malpique et al., 2020). It is evident that handwriting continues to be a significant skill for present day students, with effects across a wide range of typical classroom tasks.

The development of handwriting is a highly complex process, requiring maturation across perceptual motor and cognitive skills areas (Chu, 1997; Feder & Majnemer, 2007). Component skills important to handwriting ability have been identified, including visuomotor skills (Bara & Gentaz, 2011; Daly et al., 2003; Tseng & Chow, 2000; Volman et al., 2006; Weintraub & Graham, 2000), fine motor and kinaesthetic skills (Brossard-Racine et al., 2011; Cornhill & Case-Smith, 1996; Tseng & Chow, 2000; Volman et al., 2006; Weintraub & Graham, 2000), visual perceptual abilities (Tseng & Chow, 2000; Volman et al., 2006), and cognitive abilities that encompass literacy processes, memory and executive function (Abbott & Berninger, 1993; Langmaid et al., 2014; Rodriguez & Villarroel, 2017; Salas & Silvente, 2020; Valcan et al., 2020). Differences in many of these component skills have been observed between typical and slower speed handwriters (Brossard-Racine et al., 2011; Tseng & Chow, 2000; Volman et al., 2006; Weintraub & Graham, 2000). Similar relationships between component skills difficulties and handwriting deficits have been observed in children with atypical neurological development (Barnett & Prunty, 2021; Kushki, Chau, et al., 2011; Racine et al., 2008; Shen et al., 2012).

As previously noted, handwriting problems are prevalent in general populations, and research suggests that handwriting quality may have declined in recent years (Overvelde & Hulstijn, 2011a). In response to the significance of handwriting problems within the student population, researchers have begun to test models of intervention for handwriting problems that do not rely on withdrawing identified students from the classroom, rather the intervention is delivered to the whole class (Case-Smith et al., 2014; Pfeiffer et al., 2015). In these curriculum embedded models, adjustments to the regular handwriting curriculum are made to introduce specific strategies to promote the development of handwriting ability, based on current conceptualisations of component skills for handwriting. A further rationale for curriculum embedded methods, is changes to legislation in some countries that require students with identified disabilities to receive interventions in their naturalistic environments rather than being withdrawn from the mainstream curriculum (Bazyk et al., 2009). These methods often use a co-teaching approach, where specialty skills are combined in the classroom environment (Friend et al., 2010; Hang & Rabren, 2009). There is early evidence to suggest that these embedded methods are not only effective (Engel et al., 2018), but appear to improve aspects of student literacy (Bazyk et al., 2009; Case-Smith et al., 2014; Dolin, 2016). However, most of the extant research on effective curriculum embedded handwriting interventions relates to children from Year 1 and above, or on the development of component skills in the preschool years (Engel et al., 2018). Given concerning numbers of Kindergarten have difficulty writing the letters of the alphabet at the end of the school year (Malpique et al., 2017), a need for focus on this age group is indicated.

In Australia, the Australian Curriculum Assessment and Reporting Authority (ACARA) is responsible for the development of a national curriculum and the administration of national assessments and reporting (Australian Curriculum Assessment and Reporting Authority [ACARA], 2016). According to the Australian curriculum, by the end of the school year, Kindergarten students should be able to correctly form known upper and lowercase letters, use familiar words and phrases in writing, and demonstrate knowledge of letters and sounds (ACARA, 2014). However, ACARA does not specify the underlying component skills for handwriting that may require development in order for these writing abilities to emerge. Further, pedagogical changes to teaching practices have influenced the amount and focus of specific instruction for handwriting. Over the last two decades, explicit instruction for handwriting, such as accurate letter formation, has been de-emphasised in favour of process writing and whole language approaches (Graham, 1992; Graham & Harris, 1994; Graham & Weintraub, 1996; Medwell & Wray, 2008). This change in approach has resulted in a decreased focus on direct, explicit instruction for handwriting (Dinehart, 2015; Medwell & Wray, 2008). In addition to changes in pedagogy, teachers report varying levels of undergraduate training and preparedness in handwriting instruction (Collette et al., 2017; Donica et al., 2012; Nye & Sood, 2018). There is also wide variation in both the amount of time spent on specific instruction of handwriting, and instruction methods which teachers use (Cantin & Hubert, 2019; Graham et al., 2008; Puranik et al., 2014; Vander Hart et al., 2010). A survey of over 4000 New South Wales primary and high school teachers found that both handwriting and keyboarding were not emphasised in undergraduate training, with only 39% of primary teachers reporting explicit instruction in teaching handwriting (Wyatt-Smith et al., 2018). The same survey also found patterns related to the teaching of writing more broadly, with initial regularity in the early years, with a peak in years three to six, followed by a decline in the high school years. Overall, 49% of teachers reported feeling underprepared to "teach writing" (Wyatt-Smith et al., 2018). Within this context of prevalence of handwriting problems, specific expected students' abilities in Kindergarten, pedagogical change away from direct instruction and variation in teacher reported handwriting instruction skills and methods, it appears that handwriting may indeed be becoming "a forgotten language skill" (Medwell & Wray, 2008, p. 34).

Examination of the interrelationships of handwriting and literacy in Kindergarten children is warranted because:

- Significant skill development is expected during Kindergarten; therefore, it is important that the factors that contribute to handwriting acquisition, and effective handwriting intervention are understood (Dinehart, 2015);
- Little is known about the development of handwriting in the earliest years (Ritchey, 2008);
- There has not been a systematic analysis of the literature pertaining to the relationship between handwriting and literacy in Kindergarten children and, therefore, it is unknown if handwriting intervention impacts literacy abilities in this age group; and,
- If a relationship between Kindergarten handwriting and literacy is observed, and an effective handwriting intervention can be identified, it may be possible to positively impact both handwriting and literacy in the earliest stages of education.

1.2.1 Statement of Research Topic

This doctoral program of research is focussed on Kindergarten students, investigating relationships between handwriting ability and literacy for this age group. The research aims to gain an increased understanding of factors that contribute to handwriting ability in Kindergarten, potential links to literacy development and an effective approach to intervention. Specifically, the research aims to:

a) Identify the relationships between handwriting and literacy in Kindergarten.
b) Define a model of handwriting acquisition for Kindergarten to inform intervention practices.
c) Examine the effectiveness of a whole-class approach to handwriting fluency acquisition for Kindergarten children and the impacts on literacy.

The research will contribute to knowledge regarding understanding the impact of handwriting on literacy for Kindergarten students as well as effective means of early intervention for this age group.

1.3 Literature Review

1.3.1 Introduction

Section 1.3 provides a narrative literature review on handwriting acquisition, relationships of handwriting to literacy and handwriting intervention approaches, and prefaces the research aims, questions and hypotheses (Section 1.4). Each area discussed is synthesised in relation to implications for Kindergarten students. Section 1.3 concludes with an introduction to whole-class approaches to handwriting intervention and specifically describes Write Start (Case-Smith et al., 2014), the intervention approach used as the basis of the work reported on in this thesis.

1.3.2 Handwriting Development

The building blocks of handwriting are complex and interrelated (Feder & Majnemer, 2007; Rosenblum et al., 2004; van Galen, 1991). Children begin to write by scribbling, gradually increasing the intentionality of these marks (Feder & Majnemer, 2007). With typical development, precision of lines and movements emerge and this eventually leads to the ability to replicate letter forms as increasingly complex shapes and directional lines are mastered (Beery et al., 2010). Uni-directional, vertical line copying emerges at approximately two years of age, followed by horizontal and circle copying from two and a half years. Copying skills gradually increase in complexity until squares and triangles can be copied from five years of age (Feder & Majnemer, 2007). Whilst this process sounds simple enough, there are many processes at work that underpin the development of foundation skills for handwriting. Two specific and interrelated areas, perceptual motor and cognitive skills, have been shown to be influential in the development of handwriting ability (Dinehart, 2015; Feder & Majnemer, 2007). “Perceptual motor skills” is an umbrella term used to describe the range of abilities required to link incoming sensory information with a desired and appropriate motor action. Perceptual motor skills such as visual motor integration develop in the context of practising sensory-guided actions (Krakauer & Mazzoni, 2011). Cognitive skills for handwriting include processes that enable representations of letters and words to be created in memory (orthographic codes) which are then accessed for writing (Abbott & Berninger, 1993). Cognitive skills also relate to important executive function abilities that ensure sufficient attention is applied to handwriting tasks. These two skill areas are discussed separately in the following review; however, they cannot be considered in isolation due to their interdependent nature. Further, for Kindergarten students, the interrelated effects of development in both perceptual motor and cognitive skills areas are highly significant, as skill development in concurrent abilities such as reading and writing are emerging at this age (Castles et al., 2018; Ritchey, 2008). Handwriting abilities are generally measured by examining legibility (the appearance of letter forms), speed (the rate of writing such as in copying tasks), or fluency (the ability to write letters and words legibly from memory, such as when writing the alphabet).

1.3.2.1 Perceptual Motor Skills Contributors to Handwriting Development.

Perceptual motor skills variables that have been associated with handwriting legibility, speed and /or fluency include; visual perception, kinaesthesia, visuomotor and fine motor skills. Each perceptual motor skill is now described, including the evidence for relationships with handwriting.

1.3.2.1.1 Visual Perception.

Visual perception is the brain's ability to make sense of what the eyes see and is used to distinguish between letter forms (Tseng & Chow, 2000) and monitor performance whilst writing to check for errors (Laszlo & Bairstow, 1984). Visual perceptual abilities such as visual memory, form constancy, and figure ground perception have been found to be lower in children classified as poor handwriters compared with those classified as good handwriters, for children in the age range from seven to eleven years (Tseng & Chow, 2000; Volman et al., 2006). In addition, one aspect of visual perception, visual sequential memory (the ability to remember visual details in the correct sequence), was shown to be predictive of handwriting speed amongst seven- to eleven-year-old hand writers with poorer abilities (Tseng & Chow, 2000).

1.3.2.1.2 Kinaesthesia.

Kinaesthesia is the awareness of the body part position and is a sensory process informed by proprioceptors in the muscles and joints (Tseng & Cermak, 1993). Researchers have used various means to test kinaesthesia specific to finger function, including finger succession (timed test of touching thumb to each finger sequentially out of line of sight), finger lifting (raising a finger touched by examiner with a pencil) and finger recognition (identifying a finger touched whilst hand hidden from view) (Weintraub & Graham, 2000). Finger function tests such as those described have been found to contribute to a model that explained handwriting fluency for children from Years 1 to 6, mediated by cognitive processes such as orthographic coding (described in Section 1.3.2.2.3) (Abbott & Berninger, 1993). Similarly, finger function was found to be a unique and significant contributor to prediction of good or poor Year 5 handwriting status.

1.3.2.1.3 Visuomotor Skills.

Visuomotor skills is a term that encompasses the coordination of visual sensory input with motor skills. A number of terms are included in this descriptive category. Visual motor integration is the ability to combine motor and visual perceptual senses to enable skilful use of the hands, such as for handwriting (Beery et al., 2010). The Beery Buktenica Developmental Test of Visual Motor Integration tests ability to accurately copy increasingly complex shapes (Beery VMI; Beery et al., 2010), and has been shown consistently to be a strong indicator of handwriting ability for children ranging from Kindergarten onwards (Brossard-Racine et al., 2011; Cornhill & Case-Smith, 1996; Daly et al., 2003; Klein et al., 2011; Marr et al., 2001; Tseng & Chow, 2000; Volman et al., 2006; Weil & Amundson, 1994; Weintraub & Graham, 2000). In other measures, visual motor coordination, tested by drawing the outlines of familiar shapes, such as squares and triangles, was found to predict handwriting copying quality (Bara & Gentaz, 2011). Eye-hand coordination has also been shown to predict handwriting legibility in Year 2 children (Kaiser et al., 2009).

1.3.2.1.4 Fine Motor Skills.

For handwriting, fine motor skills enable graded and fluent movements of the pen or pencil to produce letter forms in a particular size and position (van Galen, 1991). Fine motor skills such as in-hand manipulation (precise and rapid movements of the intrinsic muscles of the hand to enable movement patterns when manipulating an item) have been shown to be positively associated with handwriting ability in Year 1 (Cornhill & Case-Smith, 1996). Other specific sub areas that are associated with handwriting ability include manual dexterity (Tseng & Cermak, 1993; Volman et al., 2006), praxis (or planning of motor movements) (Tseng & Cermak, 1993), and movement isolation, grading and timing (Kushki, Schwellnus, et al., 2011).

1.3.2.2 Cognitive Contributors to Handwriting Development.

In addition to perceptual motor skills, handwriting also requires the development of efficient memory representation and retrieval patterns for letters and words (Berninger et al., 1997). Specific aspects of cognition have been identified that have an association with handwriting, including memory (Section 1.3.2.2.1), phonological awareness (Section 1.3.2.2.2), orthographic coding (Section 1.3.2.2.3) and sustained attention (Section 1.3.2.2.4). Authors have observed that handwriting instruction that includes cognitive processing tasks are more effective than those that include only sensorimotor experiences targeting sensory abilities, such as kinaesthetic awareness (Denton et al., 2006; Weintraub et al., 2009; Zwicker & Hadwin, 2009), suggesting an important role for cognitive skills in handwriting ability.

1.3.2.2.1 Memory.

Retrieval of letter and word forms from memory appears to be important in developing automatic letter writing skills. One intervention study for improving handwriting showed that incorporating memory retrieval routines (whereby students first practiced accurately writing letter forms and then wrote the letters from memory) into the intervention had a greater effect on improving handwriting than interventions that only emphasised copying (Berninger et al., 1997). Working memory may be particularly important. A study of eight- to nine-year-old primary school children's handwriting demonstrated that poor handwriting was associated with lower working memory capacity (McCarney et al., 2013). In an interesting study, increasing a motor task demand (finger tapping) whilst concurrently writing pseudo-letters and recounting word lists had a direct relationship with decreasing handwriting performance, leading the authors to conclude that working memory and handwriting utilise a common cognitive resource (Tindle & Longstaff, 2021). A further study of children with identified handwriting difficulties reported similar associations between working memory and legibility (Rosenblum et al., 2010).

1.3.2.2.2 Phonological Awareness.

"Phonological awareness" is a broad term describing the ability to hear, recognise and manipulate sound units within words. A phoneme is the smallest unit of sound and can be represented by a written letter (grapheme) or group of letters. For example, the long vowel sound for the phoneme /e/ can be represented by the grapheme 'e' (as in me), 'ee' (as in seed) or 'ea' (as in bead). Phonemic awareness, the ability to manipulate individual phonemes within words, is associated with handwriting ability, especially in earlier Years, with phonemic abilities uniquely predicting handwriting fluency for Year 1 children (Berninger, Abbott, et al., 2006).

1.3.2.2.3 Orthographic Coding and Rapid Automatic Naming.

"Orthographic coding" is the creation of a mind image of a letter or word, or "representing a printed word in memory" (Abbott & Berninger, 1993, p. 490). This process can be tested by showing a word briefly, then asking a participant whether a letter, group of letters or the whole word is present in another example of the word (Berninger, Abbott, et al., 2006). The skill of orthographic coding can be seen functionally in a student's ability to write a modelled word from memory, and 'hold' the whole word, parts of the word or individual letters in mind during copying tasks (Abbott & Berninger, 1993). The degree of access to orthographic codes is a predictor of handwriting ability for students from Years 1 to 5 (Berninger, Abbott, et al., 2006). A separate but related skill, rapid automatic naming (RAN), measures the speed of letter naming. RAN has been shown to uniquely predict handwriting fluency in Year 1 children under timed conditions, and both RAN and orthographic coding predict the time taken to write the whole alphabet for the same age group (Berninger, Abbott, et al., 2006). Similarly, letter and sound naming fluency have been associated with handwriting fluency in Kindergarten children (Ritchey, 2008).

1.3.2.2.4 Attention and Executive Function.

Sustained attention and self-regulation are indicated in handwriting ability. In a study of students from 7 to 11 years old, researchers found that teachers' ratings of attention were significantly associated with handwriting ability, and noted the importance of finding methods of instruction for handwriting that promote attention, especially for children with handwriting difficulties (Tseng & Chow, 2000). A longitudinal study of children from Years 1 to 5 found that the skill of harnessing focus and attention, measured by the ability to inhibit and switch attention, was a unique predictor of handwriting ability for all ages tested (Berninger, Abbott, et al., 2006). A measure of attentiveness was included in a study which examined predictors of writing quality for Year 1 students (Kim et al., 2013), and was found to be uniquely related to both the quality of written work and the underlying writing conventions including letter writing automaticity, mechanics and spelling.

1.3.2.3 Implications of Handwriting Development Processes for Kindergarten.

Children entering Kindergarten have varying abilities which have been influenced by their personal development (Welsh et al., 2010), childhood exposure to specific skills (Ritchey, 2008), home literacy practices (Puranik, Phillips, et al., 2018) and early childhood education (Burger, 2010). As well as contextual variables, there are considerations for each of the component skills of handwriting that are particular to Kindergarten.

Beginning writers are more reliant on visuomotor and visual perceptual skills and the role of visual feedback is also much greater before letter formation has become automatic (Lee et al., 2016; Weintraub & Graham, 2000). Visuomotor skills are assessed through shape copying tasks, such as the

Beery VMI, as previously described (Section 1.3.2.1.3). Daly et al. (2003) reported that Kindergarten children who could accurately copy the first nine shapes on the Beery VMI had significantly better handwriting legibility than those who could not. This observation was explained in later research using head mounted eye-tracking, which confirmed a reduction in Kindergarten children's visual and motor efficiency as form complexity on the Beery VMI increased, characterised by more pen lifts when writing and visual fixations on the figure being copied (Fears et al., 2019). Other research using head mounted eye-tracking found that younger children (preschool and Kindergarten) needed more time to visually process letters before initiating writing (Fears & Lockman, 2018). Fears and Lockman (2018) also reported an increase in eye fixations when copying unusual, novel letter forms or less common letter forms when compared with common letter forms. The authors' view was that less familiar stimuli, such as new letters, influenced visual processing time and impacted visual motor integration.

Kindergarten students, with emerging fine motor skills (Daly et al., 2003), may also require significantly greater opportunities to practice and develop the fine motor skills specifically associated with handwriting. Broadly, fine motor activities relevant to Kindergarten include self-care such as eating, or manipulating fasteners and buttons on clothing, manipulating objects for play or learning, such as blocks, scissors and playdough, and paper and pencil activities for play or learning, such as writing with various implements and materials (Marr et al., 2003). Fine motor skills associated with handwriting have been described, and include in-hand manipulation skills such as translation (moving an object from the palm to the finger tips), rotation (spinning an object in the hands, such as rotating a pencil from end to end) (Cornhill & Case-Smith, 1996), and manual dexterity including the ability to manipulate objects accurately and with speed (Volman et al., 2006). Typically, Kindergarten children experience a marked increase in use of these fine motor skills in pencil and paper tasks from preschool to Kindergarten, engaging in these activities for up to a quarter of the day (Marr et al., 2003; McMaster & Roberts, 2016). Evidence suggests that Kindergarten children can benefit from fine motor skills development before or alongside handwriting instruction (Bazyk et al., 2009; Ohl et al., 2013).

Cognitive tasks for handwriting may also be more challenging for Kindergarten students, as they need to translate a relatively new orthographic code (mental picture) for a letter or word to a transcribed form (handwriting) (Puranik & Al Otaiba, 2012). For example, in one lesson, a Kindergarten student may learn the name, sound and letter formation pattern for a new letter, and then write this letter in a word. This process is distinct from older students, who have already assimilated knowledge about letter names, sounds and forms into precise orthographic representations, and are not retrieving this information for the first time (Abbott & Berninger, 1993). Competing demands on working memory may impact the processing of new orthographic and motoric information, significantly affecting the integration and performance of handwriting abilities for Kindergarten students (McCutchen, 1996).

Executive function includes capacities for solving novel problems, paying attention, switching focus and remembering instructions, with each skill entailing self-management or self-regulation abilities (McClelland & Cameron, 2019; Willoughby et al., 2017). Typical capacities for Kindergarten children include using working memory to hold two pieces of information in mind at once, inhibitory control such as making the opposite animal noise associated with a picture of a dog or cat, and attention shifting such as noticing similarities in two pictures such as colour, and when presented with a new picture, picking the best match (Willoughby et al., 2017). Executive function in Kindergarten may have important impacts on skills related to handwriting ability. Direct relationships between visuomotor skills (measured by copying shapes) and both working memory and self-regulation of behaviour have been observed (Becker et al., 2014). Executive function is proposed as a facilitator of automatisation of motor tasks, thereby enabling motor learning essential to typical class activities such as handwriting (McClelland & Cameron, 2019). Indirect impacts of executive function on handwriting may also be inferred in studies such as Kent et al. (2014), who found that attention related skills measured by teachers' ratings were uniquely related to Kindergarten writing composition quality.

The development of the necessary component skills for handwriting may be currently challenged by changes in play and teaching practices. For example, an increase in technology-based play has been linked with decreased fine motor ability for students (Gaul & Issartel, 2016; Lin et al., 2017; Sheedy et al., 2021). Further, there are concerns that early childhood education is being “schoolified” (Ring & O’Sullivan, 2018), consisting of more formal academic experiences rather than free play that encourages the development of manual skills such as in-hand manipulation (Brooks & Murray, 2018). It is possible, therefore, that in this context, many students starting Kindergarten will require additional targeted learning experiences to assist in component skill development for handwriting. Furthermore, as described, the requirements of ACARA for Kindergarten specifically note the ability to write letters and words (Section 1.2) and, given the complexity of contributing factors to handwriting development, a lack of systematic instruction and targeted experiences at this early age could have detrimental effects on students’ handwriting performance.

The preceding literature suggests that certain aspects of the process of handwriting require a greater emphasis while this skill is in early development, and that instructional methods and specific skill development for handwriting in Kindergarten require further investigation.

1.3.3 Handwriting and Literacy

Handwriting is more than simply the means of expressing knowledge, as researchers have found significant links between students’ handwriting ability and academic measures. Factors that contribute to the association between handwriting and literacy include the development of handwriting fluency, the role of orthographic coding, and the constraints of working memory explained by capacity theory.

1.3.3.1 Handwriting Fluency.

Handwriting is commonly assessed based on appearance or legibility (Hammerschmidt & Sudsawad, 2004). However, for handwriting to be functional it must be both legible *and* fluent. Handwriting fluency refers to the ability to transcribe legible written forms from memory, implying coordination of cognitive, perceptual and motor processes, and is also known as “automaticity”. Handwriting fluency requires a level of automatic processing whereby the motor patterns required to produce a legible letter form are readily retrievable and reproducible (Puranik et al., 2017). Handwriting fluency is generally measured via timed alphabet tests and timed copying tasks, as these skills require both recall and reproduction of letter and word forms (Berninger et al., 1997). This process is referred to as “orthographic motor integration” and requires the use of orthographic coding to create a representation of the letter or word in mind (Berninger et al., 1997).

1.3.3.2 Orthographic Coding and Handwriting.

There is a strong pathway between orthographic coding skill—mental representations of letters or words—and fluent handwriting (Abbott & Berninger, 1993). As noted previously, many researchers have found that the Beery VMI is a consistently strong predictor of handwriting ability (Section 1.3.2.1.3). Understanding this association may go some way to explaining the role of orthographic coding in handwriting fluency. In a study to distinguish between the effects of different components tested by the Beery VMI on academic outcome for children from 5 to 18 years of age, it was found that accurate copying of shapes was a predictor of both maths and writing ability (Carlson et al., 2013). However, Beery VMI tasks that measured visual motor coordination (tracing through increasingly complex mazes) were not a predictor for any academic measures. Shape copying can be conceived as a measure of orthographic coding ability, as this task requires the ability to hold an image in the mind’s eye. Shape copying approximates classroom tasks such as copying from the board, and even dictation or composing, as a word or sentence is generated in mind and must then be transcribed. In addition to shape generation and copying, handwriting requires letter name and sound knowledge. Handwriting therefore entails an interaction of letter knowledge, orthographic ability and perceptual motor skills.

1.3.3.3 Links Between Fluent Handwriting and Literacy.

There are strong indications that fluent hand writers are able to produce a higher level of written output, both in terms of quantity and quality (Medwell & Wray, 2007). The implication is that handwriting fluency, with its associated integration of perceptual motor and cognitive skills, is an integrated language skill, not just a motor skill (Berninger, Abbott, et al., 2006). The association also suggests that lack of fluent handwriting constrains written expression (Longobardi et al., 2018; Puranik et al., 2017). Researchers have demonstrated the handwriting-literacy link through studies of students from Year 1 and above by analysing the effect of improving automatic, fluent handwriting on written expression (Berninger et al., 1997; Graham et al., 2000; Jones & Christensen, 1999; Longobardi et al., 2018; Medwell et al., 2009; Olinghouse, 2008). These studies used a timed alphabet test (Berninger et al., 1997) to measure handwriting fluency and collected a writing sample based on a stimulus sentence or topic. Researchers compared the alphabet writing measure (including appearance and quality of letter forms, and number of letters) with measures of written expression (including measures of content and language quality). Researchers found increased use of elements of sophisticated language by fluent hand writers, and the effect has been shown through varying ages in students, from Year 1 and above. The conclusions drawn from this body of research is that handwriting fluency is not just associated with quantity, but with the quality of written expression. Handwriting also appears to impact reading, through the facilitation of letter representations (James & Engelhardt, 2012). Handwriting automaticity, or fluency, has been found to predict orthographic skills in Year 4 children, suggesting this facilitating effect (Wicki et al., 2014). The same relationships are also observed in younger children, with fluent, automatic handwriting in Kindergarten found to predict important reading skills in Year 1 (Malpique et al., 2020).

1.3.3.4 Capacity Theory.

The link between fluent, automatic handwriting and higher levels of literacy ability is based on capacity theory (Berninger, 1999). Capacity theory postulates that working memory is a space and time limited resource (McCutchen, 1996), and that automatising mechanical processes such as handwriting frees cognitive space for higher order processes such as composition (Berninger, 1999). Capacity theory has also been used to explain the impact of strong visuomotor skills, necessary for handwriting ability, on reading. Strength in this perceptual motor area allows resources to be directed to conceptual interpretation needed for reading (Cameron et al., 2016). Capacity theory is important, as researchers have found large variability in emphasis on handwriting practice in current curricula (Malpique et al., 2017; Puranik et al., 2014). With the increasing use of technology for writing, it becomes even more important to understand whether the act of developing readily retrievable motor patterns for letters, words and ultimately sentences, is instrumental in becoming a proficient reader and writer. If fluent, automatic handwriting is a crucial foundation for reading, and written expression for young students, educators will need to know if there are possible consequences of omission or reduction of handwriting instruction (Puranik et al., 2014). It will also be important to determine if alternate forms of transcription such as keyboarding have a similar effect on literacy (Connelly et al., 2007; Rogers & Case-Smith, 2002).

1.3.3.5 Current Research on Links Between Handwriting and Literacy for Kindergarten Students.

Recently, scholars have begun to examine the link between handwriting ability and literacy for Kindergarten students whereas, prior studies have focussed on students from Year 1 and above. A summary of the findings of these early, Kindergarten-focussed investigations follows.

Functional magnetic resonance imaging (fMRI) has been used to identify differences in activation of “reading circuits” (brain regions known to underlie successful reading) after exposures to letter forms. Pre-literate 5-year-olds (n = 15) either printed, typed or traced letters, and were then shown those letters whilst undergoing fMRI scans. The researchers found that activation of reading circuits on exposures to the letters only occurred in the children who had printed the letter by hand prior to the scan (James & Engelhardt, 2012). Typing or tracing the letter did not have the same effect. The motor act of writing a letter by hand appeared to have had a stronger effect on reading than did typing or tracing the letter.

Skills described as lower-level, handwriting and spelling, have been found to impact higher-level writing composition abilities, in studies of children from Year 1 (for example, Alves et al., 2016; Arrimada et al., 2018). Puranik and Al Otaiba (2012) have also reported a significant association between these lower-level transcription skills and written expression in Kindergarten students.

However, oral language and reading skills were not found to predict written expression abilities in this group. In fact, handwriting accounted for the greatest amount of unique variance in written expression, highlighting the important role of emerging handwriting for Kindergarten students as a constraint on written expression (Puranik & Al Otaiba, 2012).

Fine motor skills may also have a much greater influence in Kindergarten, with researchers finding strong links between Kindergarten fine motor skills and later academic success (Cameron et al., 2012; Grissmer et al., 2010). The association between fine motor skills and handwriting is significant, as there are specific fine motor component skills associated with handwriting, as previously noted. Therefore, insufficient fine motor development may impede handwriting fluency and consequent literacy.

1.3.3.6 Handwriting Fluency Measurement Issues.

Conclusions about the links between handwriting and literacy in Kindergarten may be constrained by difficulties in measurement of handwriting fluency for this age group. The alphabet test, as previously described, is commonly used as a measure of handwriting fluency, as it requires both memory of letter forms and legible writing of these forms. The alphabet test has typically been timed in order to establish a rate of handwriting. However, due to the stage of development of Kindergarten students, and the emerging processes that form the basis of fluent handwriting, it has been found that the only valid measure of handwriting for this age group is untimed alphabet testing and, further, that this test is a unique predictor of written expression. Despite the validity of this untimed assessment approach, floor effects are still observed, as some children are unable to recall and write any alphabet letters (Puranik et al., 2017). One possible explanation for floor effects is the need to remember and write letters in alphabetic sequence, which may be difficult for many Kindergarten children. Focussing on *accuracy* of letter formation rather than alphabetic sequence and speed of letter reproduction may be more important as a predictor of written expression in Kindergarten. An untimed measure of a student’s ability to replicate a letter form accurately, by recalling and writing the correct pattern of lines and strokes, reflects how well the student has been able to coordinate the component skills that contribute to handwriting, such as visual motor integration (Daly et al., 2003). At the Kindergarten age, accurate letter formation can be seen as the foundation of handwriting fluency. Many measures of *legibility* are available that assess the appearance of letters after they have been written. However, no measures of handwriting *fluency*, based on accurate letter formation, are currently available for Kindergarten. A focus on the ability to accurately form letters may be a useful basis for measuring handwriting fluency.

1.3.3.7 Intervention Implications.

A logical conclusion that can be drawn from the prior research is that teaching practices and interventions that promote the development of accurate handwriting in Kindergarten students should impact literacy skills associated with reading and writing development. Therefore, it can be hypothesised that, providing intervention that specifically targets foundation skills for handwriting will lead to improvements in foundations of literacy *beyond* development that typically would be expected with students' maturity and standard teaching practices. Similarly, a lack of handwriting practice in Kindergarten may compound difficulties with reading and written expression. Effective interventions for Kindergarten students must consider their stage of maturation due to the developing nature of all systems required for handwriting. Strategies that emphasise and support developing systems involving a range of processes including fine motor, visuomotor and kinaesthetic and orthographic integration may be indicated. Section 1.3.4 discusses features of effective handwriting intervention and their application to Kindergarten.

1.3.4 Handwriting Interventions

There is a body of evidence about interventions that improve handwriting skills for students over a range of primary school ages (Engel et al., 2018; Graham et al., 2012; Hoy et al., 2011). Effective interventions have common characteristics that emphasise the integrated nature of handwriting component skills (Hoy et al., 2011). Given the prevalence of handwriting problems for school students, intervention programs are often delivered in school settings, and there has recently been a trend towards whole-class, curriculum embedded models (Engel et al., 2018).

1.3.4.1 Features of Effective Handwriting Intervention.

Whilst perceptual motor (also referred to as sensorimotor) skills are strongly predictive of handwriting ability, it appears that intervention for these components or contributing skills in isolation from the task of handwriting is not effective in improving handwriting ability (Denton et al., 2006; Zwicker & Hadwin, 2009). In a study where the intervention was distinctly sensorimotor or cognitive; that is, the sensorimotor intervention did not include any handwriting practice at all, there was some improvement in the sensorimotor skills treated, and no effect on handwriting (Denton et al., 2006). However, in a study that compared handwriting practice through sensory (for example, writing letters in a tray of sand) or cognitive mediums (for example, using worksheets and practice of letter forms with feedback and self-monitoring) for Years 1 and 2 students, the multisensory practice of letter forms was effective for Year 1 students in improving letter legibility despite not reaching clinical significance (Zwicker & Hadwin, 2009). Conversely, letter legibility for Year 2 students in this study improved with a cognitive intervention but declined with a sensorimotor intervention. These studies suggest that suitable intervention may be influenced by age and stage, with younger students appearing to benefit from multi-sensory handwriting practice that promotes perceptual motor skills development.

As previously noted, “poor” handwriting has been associated with difficulties in visual sequential memory and visual motor integration (Tseng & Chow, 2000), reinforcing the highly integrated nature of sensorimotor and cognitive skills associated with the development of handwriting. The inclusion of cognitive or higher-level processing tasks such as memory retrieval of letters and words in intervention has been associated with improvements in handwriting in a number of studies (Berninger et al., 1997; Weintraub et al., 2009; Zwicker & Hadwin, 2009). Task practice emphasising memory of letters may need to be combined with perceptual motor skills development for Kindergarten children, as previously noted.

Instructional methods that include strategies to maximise self-regulation through self-monitoring, such as goal setting, have been shown to benefit writing for older students (Graham et al., 2012).

Improvements in writing composition were observed in Kindergarten classes using peer assisted learning, which enhanced skills that support self-monitoring and revising (Puranik, Petscher, et al., 2018). Whilst similar self-regulation strategies used in a handwriting intervention for Kindergarten students have not been studied, the inclusion of intervention design methods that promote reviewing and revising letter formation may be beneficial.

Improvements in handwriting legibility have been observed in interventions ranging from six to ten weeks. One systematic review identified that sufficient handwriting practice opportunities (twice a week for at least 20 sessions) were essential to the effectiveness of the intervention (Hoy et al., 2011). However, in a recent systematic review of curriculum embedded handwriting interventions for preschool through to Year 5, a small to medium effect on legibility and speed was apparent with interventions of as little as 6 weeks duration (Engel et al., 2018). An impact on handwriting fluency for Year 1 students was achieved with a 12-week curriculum embedded program (Case-Smith et al., 2014).

In conclusion, interventions for improving handwriting should include strategies to promote attention (Berninger, Abbott, et al., 2006; Berninger, Rutberg, et al., 2006; Kim et al., 2013; Tseng & Chow, 2000), orthographic coding (Abbott & Berninger, 1993; Berninger et al., 1997) and practice (Hoy et al., 2011). While a cognitive (practice-based) approach may be more beneficial for older students, sensorimotor handwriting instructional activities are indicated for younger students (Zwicker & Hadwin, 2009). Perceptual motor skills development may also be indicated for children in Kindergarten as part of intervention given the range of factors that may impact emerging handwriting ability.

1.3.4.2 Intervention Programs in School Settings.

Intervention for handwriting difficulties is a common practice in schools, and occupational therapy services have traditionally been delivered using consultative methods or withdrawal from class models (Case-Smith & Cable, 1996). However, there has been a recent trend towards curriculum embedded methods, sometimes referred to as *Response to Intervention* approaches (Asher & Estes, 2016; Engel et al., 2018).

1.3.4.2.1 Withdrawal from Class.

A number of specialists may be involved in the treatment of handwriting problems in school settings, and occupational therapy is commonly used by teachers as a point of referral for persistent handwriting problems (Collette et al., 2017; Donica et al., 2012; Hammerschmidt & Sudsawad, 2004). Students identified for intervention have commonly been withdrawn from class for specialised intervention, in addition to consultation provided to the teacher on methods of instruction or support that may benefit the student in class (Donica et al., 2012). Some of the problems cited with consultation and withdrawal from class methods include time away from the naturalistic class environment for the student, and additional pressure on teachers to provide specialty services as part of the regular classroom program (Case-Smith et al., 2012; Eckberg Zylstra & Pfeiffer, 2016)

1.3.4.2.2 Response to Intervention and Whole-class Programs.

Response to Intervention (RtI) programs have emerged as a promising approach for students with disabilities to receive intervention in naturalistic settings (Bazyk et al., 2009; Eckberg Zylstra & Pfeiffer, 2016). This approach to intervention has also been driven by legislative changes in the United States that focus on early intervention (Fuchs & Fuchs, 2006). The aim of RtI is to provide quality teaching and instructional experiences that accommodate learning needs for a diverse range of students, before problems arise (Barnes & Harlacher, 2008). RtI programs are typically tiered, with Tier 1 being universal or whole-class interventions, and Tiers 2 and 3 being small group or individual intervention, respectively (Ohl et al., 2013). In RtI models, students are assessed to determine whether the intervention has been effective for the identified goals. For those students for whom the intervention has not been effective, an additional adjustment or method of intervention may be indicated using Tiers 2 and 3 interventions (Fuchs & Fuchs, 2006). Therefore, RtI is both a way to provide timely and effective intervention to all students, and a means to identify students with additional needs (Barnes & Harlacher, 2008). A number of studies have examined the effect of providing curriculum-based handwriting interventions to whole classes under an RtI approach (Engel et al., 2018). Using a Tier 1 approach, whole classes receive an evidence-based instruction program that aims to both prevent the development of handwriting problems, and to identify students who may require a higher level of intervention (Ohl et al., 2013). One such method, Write Start, has been studied for effectiveness on handwriting legibility and fluency for Year 1 children (Case-Smith et al., 2011; Case-Smith et al., 2012; Case-Smith et al., 2014).

1.3.4.3 The Write Start Program.

As noted in the preceding literature review (Section 1.3.2), many factors are associated with the development of handwriting. Of note is the interaction of cognitive and sensory motor development for younger students. Write Start is a Year 1 handwriting intervention that has been devised to include all evidence-based principles for effective handwriting instruction. In the initial pilot of this program, the authors drew extensively on the literature and particularly noted the important role of cognitive processes of memory recall of letter forms, practice, feedback, and additional complementary skills development such as fine and visual motor abilities (Case-Smith et al. 2011). Further, in the Write Start program, teachers and occupational therapists collaborate to provide specialised instruction on handwriting, emphasising the development of important component skills. The Write Start pilot study clearly described the evidence for co-teaching, noting studies that reported both elements of successful co-teaching (planning time, clear roles, communication and administrative support) as well as studies that reported benefits for students including more individual attention and feedback and transfer of skills between the co-teaching professionals (Case-Smith et al., 2011). The pilot study of Write Start was subjected to a fidelity analysis following a reliability study in which the fidelity instrument was independently rated by two authors, with 90% agreement. The fidelity of the pilot program was found to be high, showing the Write Start program to be a feasible intervention. The pilot also found large gains in handwriting legibility and speed, and writing fluency, maintained at six months follow up. Writing fluency was measured by asking students to compose sentences from three words written beside a picture. These gains suggested that the intervention included important elements to promote handwriting, and supported the evidence for impacts of improved handwriting on writing composition fluency (Berninger et al., 1997). The authors noted greater gain scores using the co-teaching model when compared with studies using a similar cognitive and motor approach that used a single instructor (Denton et al., 2006; Zwicker & Hadwin, 2009), leading them to speculate that the co-teaching methodology was instrumental in these gains. Subsequent, more rigorous, study of the program included a one group pre- post-test study (Case-Smith et al, 2012) and a two group comparison study (Case-Smith et al., 2014). The one group study found significant gains in handwriting legibility, speed, writing fluency and writing composition. Writing fluency was measured as for the pilot study, and the additional writing composition test asked students to write a sentence using a picture prompt (Case-Smith et al., 2012). In the two group comparison study, the intervention group gained significantly more than the control in handwriting legibility and speed, and writing fluency was significantly higher at six months follow up.

In summary, the Write Start program includes carefully designed activities to promote skills with a known contribution to handwriting development including perceptual motor (fine and visuomotor) and cognitive application tasks. Write Start uses a co-teaching framework, in which educators and specialists collaborate to develop and conjointly implement a program of intervention (Friend et al., 2010). The studies of the Write Start program have reported positive, significant and enduring effects for both handwriting legibility and writing fluency in Year 1 students in the United States (Case-Smith et al., 2011; Case-Smith et al., 2012; Case-Smith et al., 2014). Positive outcomes were also noted for children with diverse learning needs and improvements in legibility and fluency observed across all levels of ability (Case-Smith et al., 2012).

The Write Start program, modified for a Kindergarten target group in Australia (modified Write Start), offers a possible model for the introduction of a curriculum embedded handwriting instruction program in Australian schools. Prior to the commencement of this research, modified Write Start was piloted for Kindergarten children in a New South Wales independent school by the candidate in her occupational therapy clinical role. The focus of the intervention was a structured handwriting program that increased exposure to letter forms, words and sentences through tailored activities, following the same structure as Write Start. Adjustments were made to tailor intervention activities to suit Kindergarten children. Retrospective analysis of this pilot work, further investigation of the literature to explore handwriting and literacy relationships for Kindergarten, and a prospective two-group intervention study are the focuses of this thesis.

1.3.5 Conclusion

It is evident that a range of factors impact the acquisition and fluency of handwriting in Kindergarten. Early investigations into the links between handwriting and literacy also indicate that the relationship mirrors that observed in older populations. This evidence however, is yet to be synthesised. Analysis of the current literature is required to progress the understanding of the role of handwriting in literacy for this age group. Whole-class, co-taught approaches to handwriting have demonstrated positive effects on handwriting, yet there is limited evidence for Kindergarten populations. Effective Kindergarten handwriting intervention may have downstream effects on literacy and further investigation is of great importance.

1.4 Thesis Questions

The overall objective of this research program was to examine the relationship between handwriting and literacy in Kindergarten. The thesis questions were:

> *Question 1: What is the relationship between handwriting and literacy for Kindergarten students?*
>
> *Question 2: How effective is a whole-class intervention in improving handwriting ability for Kindergarten students?*
>
> *Question 3: Does a whole-class handwriting intervention impact Kindergarten students' literacy?*

1.4.1 Hypotheses

Hypotheses were proposed for Questions 2 and 3, specifically:

1. A curriculum embedded, co-taught handwriting intervention will increase handwriting fluency in Kindergarten students who are beginning writers.

2. Improvements in handwriting fluency in Kindergarten students will be associated with improvements in early literacy skills.

1.4.2 Project Structure

The following research activities were conducted in order to address the research questions:

1. Systematic review

A systematic review of the literature answering the question *What is the relationship between handwriting and literacy for Kindergarten students?* was conducted (Chapter 2). The final searches for this review were conducted in January 2020. Included studies reported cross-sectional, longitudinal and intervention effects and results were analysed narratively. A key task in conducting this review was defining and categorising the measurement of handwriting and literacy for Kindergarten and the analysis drew on this categorisation to report relationships.

2. Pilot study

A single cohort, pre- post-test pilot study was conducted to examine the impact of a whole-class handwriting intervention, modified Write Start, on handwriting fluency in Kindergarten students (Chapter 3). A retrospective design was used, where data collected as part of usual practice in a large independent primary school in 2016, was analysed. The pilot study utilised a newly designed handwriting fluency assessment tool that aimed to eliminate floor effects common in the usual methods of handwriting fluency measurement in Kindergarten. Further, the pilot study aimed to determine the impact of early literacy abilities on intervention outcomes.

3. Model development

Many factors involved in handwriting have been identified, as discussed in this Chapter 1; yet, a practice model to guide the acquisition of handwriting fluency has not been developed. In Chapter 4, a new practice model to guide intervention to support handwriting fluency acquisition, the 4*Rs* model (*Recall, Retrieve, Reproduce,* and *Repeat)*, is presented. The model was informed by the findings of the systematic review and pilot study.

4. Two-group study

The modified Write Start intervention approach was revised based on the 4*Rs* model and the pilot study findings. Write Start-K, the revised and updated program, was tested in a two-group pre-post-test comparison study across four Kindergarten classes in two schools (n = 77) (Chapters 5 to 7). The two-group study examined the effectiveness of Write Start-K on improving handwriting fluency and early literacy in Kindergarten students as compared with standard teaching. One school received the intervention over eight weeks as a whole-class, co-taught program, and one continued with standard teaching and served as control.

Chapter 2 Systematic review

Preface:

Chapter 2 presents the results of a systematic review addressing:

> *Question 1: What is the relationship between handwriting and literacy for Kindergarten students?*

This review extends and augments the literature reviewed in Chapter 1 from which it was concluded that the emerging evidence for relationships between handwriting and literacy in Kindergarten is yet to be synthesised. Further, a thorough and systematic review of the literature on handwriting and literacy relationships in Kindergarten incorporating cognitive and perceptual motor factors that underpin Kindergarten handwriting development, was indicated.

The systematic review was completed in January 2020 and had the following aims:

a) Determine and classify handwriting and literacy measures used in Kindergarten;
b) Using these categories of measurement, analyse the evidence for interrelationships between handwriting and literacy in Kindergarten children; and,
c) Document the strength of evidence for interrelationships of Kindergarten handwriting and literacy.

After completion of the systematic review, the results were prepared and submitted to *Reading and Writing* in April 2021. The article is currently under review. The formatting and capitalisation conventions of the prepared article presented in Chapter 2 follows the journal requirements.

Contribution statement:

The candidate led the overall design, definition of search terms and implementation of the systematic review, with guidance from supervisors. In consultation with the University of Newcastle School of Health Sciences Faculty Librarian, the candidate developed and performed the search. The candidate led the screening of title, abstract and full text with assistance from Professor Alison Lane and Dr Kerry

Dally, and was responsible for all data extraction and narrative synthesis of results. The candidate drafted the manuscript arising from this review and made revisions in response to supervisors' comments. Coauthors of this manuscript include Professor Alison Lane and Dr Kerry Dally, who carried out the roles previously described, and Kit Iong Tam and Leah Rowlandson who carried out title and abstract and full text screening respectively as second reviewers. In addition, Dr Kerry Dally carried out the role of casting vote reviewer for conflicts arising from title and abstract and full text screening.

Authors and affiliations:

The relationship of handwriting ability and literacy in kindergarten: A systematic review

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Under review:

Reading and Writing

Keywords:

Kindergarten, beginning writing, beginning reading, emergent literacy, handwriting, literacy.

Naming conventions used in the article:

As explained in Chapter 1, relevant journal language conventions have been used to describe school class level for chapters presented as a paper. For the paper presented in this Chapter, terms used are: kindergarten; grade; and numerals for grade level, for example, grade 1.

Appendices to this Chapter:

- Appendix 1—Risk of bias assessment for systematic review—Johns Hopkins Evidence-Based Practice (Dang & Dearholt, 2017)

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2.1 Abstract

Evidence supports a link between handwriting and aspects of literacy, including both reading and writing. However, most evidence pertains to children from grade 1 and above, once foundation skills known to support emerging literacy have been established. The purpose of this systematic review is to synthesise the extant literature concerning measurement of handwriting and literacy and the relationships between these measures for kindergarten students (the first year of formal instruction). Following a systematic search of the literature, 15 studies involving 2049 unique participants were identified. Handwriting measures could be grouped into two categories—letter writing fluency and perceptual motor skills, while literacy measures addressed one or more of letter name and sound knowledge, phonological skills, word reading, writing composition, and spelling. Strong evidence was found for the impact of letter writing fluency on writing composition, and letter name and sound knowledge. In addition, there was moderate evidence for a relationship between letter writing fluency, spelling, word reading and phonological skills. Weaker evidence was found for the impact of perceptual motor skills proficiency on letter knowledge and spelling, word reading and phonological skills. However, as all intervention approaches focusing on letter forming fluency included perceptual motor skills practice or exposure, an important role for these skills in both letter writing fluency and literacy may be inferred. This review has found preliminary evidence to support the facilitating impact of handwriting on the foundations of literacy in kindergarten. Further research into the effects of handwriting interventions on kindergarten literacy is indicated.

2.2 Introduction

Literacy is an important life skill, with pervasive effects on access to education, work and the ability to carry out important tasks that are required for independent living. Literacy abilities encompass both reading and writing. Kindergarten is an important time for the development of foundation skills in reading, such as connecting letters with their sounds and decoding text using knowledge of the alphabetic principle, as well as writing (using the alphabetic principle and handwriting abilities to generate text) (Ritchey, 2008). The kindergarten year, therefore, is recognised as an important stage for acquiring the skills needed for successful reading and writing (Bingham et al., 2017; Kim et al., 2015). Thus, it is important to understand factors that may support literacy acquisition in this foundation year.

Researchers have theorised that handwriting skill impacts both reading and writing abilities (Vander Hart et al., 2010). For example, handwriting has been linked to the quantity and quality of written expression for children from the kindergarten year and above (Alves et al., 2016; Arrimada et al., 2018; Graham et al., 1997; Kent et al., 2014; Limpo & Alves, 2017; Limpo et al., 2018; Puranik & Al Otaiba, 2012). This relationship has been explained by a theory of cognitive load (McCutchen, 1996). This theory proposes that through automatisation of the mechanical tasks of writing, vis-à-vis handwriting, overall cognitive load is reduced and cognitive resources can be redirected to more complex authorial writing processes including planning, sequencing and ideation, thereby improving writing quality. The mechanical act of handwriting has also been found to activate brain regions associated with reading, whereas simply viewing letters does not (James, 2010). The possible impact of handwriting on reading has been described as "action perception coupling" (Kiefer et al., 2015). Writing letters may create stronger letter recognition through the coupling process, and thereby aid early reading. In addition, accurately categorising letter symbols has been shown to be facilitated by variations in letter forms produced through handwriting (Li & James, 2016). In the current context of general concerns about literacy acquisition in kindergarten students (Le et al., 2019), a clearer understanding of the role of handwriting is needed as handwriting development may serve as a facilitator of literacy ability in this age group.

Factors relating to fluent handwriting in kindergarten include cognitive skills such as the recall and retrieval of letter names and forms and their associated motor patterns, and perceptual motor skills involved in the execution or reproduction of the letter form (Fears & Lockman, 2018; Feder & Majnemer, 2007; Frolek Clark & Luze, 2014; Rosenblum et al., 2003; Weintraub & Graham, 2000). Handwriting curricula in kindergarten, therefore, are comprised of both the establishment of foundation skills that support fluent letter writing, as well as letter writing practice. Studies have reported associations between underlying perceptual motor skills and handwriting ability. For example, visuomotor ability has been associated with handwriting ability from kindergarten to grade 5 (Daly et al., 2003; Kaiser et al., 2009; Volman et al., 2006; Weintraub & Graham, 2000). Specific fine motor dexterity skills such as the speed of sequential finger movements and in-hand manipulation have also been associated with handwriting (Berninger & Rutberg, 1992; Cornhill & Case-Smith, 1996). Given the early stage of handwriting development in kindergarten the relationship of letter writing and perceptual motor skills to literacy may be important.

Similarly, kindergarten literacy is characterised by the establishment of foundation skills that are known to support both reading and writing composition (Treiman, 2000). As a result, literacy markers for kindergarten can include phonological skills, word reading and letter name and sound knowledge (Castles et al., 2018). Measures of literacy such as the following are specific to the emergence of these skills in kindergarten. Phonological skills can be measured using tests that ask students to listen to and identify sounds (letter sound fluency) or listen to a word, then say it without part of the word (elision or phoneme deletion). Reading skills can be assessed at the letter level, such as initial letter recognition tests, or by asking students to read both real and nonsense words. As for literacy, measures of handwriting ability in kindergarten vary, and may be complicated by the emergence of perceptual motor abilities that could impact letter writing. It is not clear at this stage whether current handwriting measures adequately account for these factors, with some researchers noting a floor effect in commonly used methods such as alphabet writing (Puranik et al., 2017). Therefore, in order to interpret relationships between handwriting and literacy, it is important to establish groupings of both handwriting and literacy measures based on similarity of the construct being measured.

2.2.1 Research Questions

The purpose of this systematic review is to determine the relationship between handwriting and literacy in kindergarten. A synthesis of measures for both handwriting and literacy, and an analysis of relationships and effects, are important steps in understanding the interactions between these factors. Specifically, this review sought to answer the following:

Question 1: What are the characteristics of handwriting and literacy measures in kindergarten?

Question 2: What are the observed relationships between handwriting ability and literacy in kindergarten?

2.3 Method

The methods and reporting of this review were guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al., 2009). The program Covidence was used to manage the search results and selection process.

2.3.1 Eligibility Criteria and Information Sources

A systematic search was undertaken of databases; CINAHL, Eric, A+ Education, PsychINFO and Scopus from 1998 to September 2017, and a rerun of the same search was completed in January 2020. The year 1998 was selected as the start date for the review as the following year the National Research Council in the United States published a comprehensive report describing the critical skills that beginning readers need to acquire (Burns et al., 1999). Terms used for the CINAHL search are listed in Table 2.1 and included literacy and handwriting concepts. The participant population was restricted to the first year of formal schooling. Where necessary, clarification from study authors was sought to confirm that the population studied were in their first year of formal instruction, and that this year included curriculum-prescribed academic activities. The inclusion criteria were: article published in or after 1998; English language publication available; studies conducted in language other than English where English language text was available; relationship between handwriting and literacy reported; participant population in first year of formal schooling; any study design. Exclusion criteria included narrative review or opinion, and studies prior to 1998.

Table 2.1

Search Strategy Used in CINAHL

#	Query	Results
S1	(MH "Handwriting") OR "handwriting"	1,108
S2	"pre writing skill*"	5
S3	"prewriting skill*"	7
S4	pencil* n3 control*	9
S5	"grapho-motor"	7
S6	grafo-motor	1
S7	"drawing proficiency"	1
S8	"fine motor skills"	246
S9	printing n3 skill*	2
S10	proficient at-risk non-proficient writer*	1
S11	(upper limb*) n3 (speed or dexterity)	58
S12	(word* or letter* or printing*) n3 (legib* or speed)	154
S13	"writing readiness"	8
S14	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12 OR S13	1,541
S15	(student* or school*) n5 (elementary or preschool* or early stage or kinder* or infant* or prep* or pre-k)	14,778
S16	"emergent writer*"	3
S17	"foundation phase learner*"	3
S18	"school beginner*"	10
S19	S15 OR S16 OR S17 OR S18	14,831
S20	S14 AND S19	90
S21	(school* or student*) n5 (primary or junior or secondary or high or middle or elementary)	39,632
S22	S19 OR S21	44,405
S23	S14 AND S22	130
S24	"early literacy skill*" OR (MH "Literacy")	4,587
S25	"emergent literacy"	177
S26	encoding	5,949
S27	grapheme phoneme	92

#	Query	Results
S28	letter* n3 (identification or naming fluency or recognition)	149
S29	"orthographic motor integration"	0
S30	"orthographic motor integration"	30
S31	phoneme segmentation	20
S32	phonological n3 (segmentation or awareness or processing or skill*)	1,118
S33	rapid naming	171
S34	(MH "Writing") OR "writing"	21,399
S35	"written expression" OR (MH "Written Language")	273
S36	"written productivity"	8
S37	S24 OR S25 OR S26 OR S27 OR S28 OR S29 OR S30 OR S31 OR S32 OR S33 OR S34 OR S35 OR S36	33,066
S38	S14 AND S19 AND S37	28
S39	S14 AND S22 AND S37	46

2.3.2 Study Selection

After duplicates were removed, two authors (KR and KT) reviewed the articles by title and abstract, and studies that met the search criteria were identified. A third author (KD) reviewed any studies where a conflict had occurred. In the second stage of the review, two authors (KR and LR) reviewed the identified articles that met the search criteria by reading the full text. Again, a third reviewer (KD) provided the casting vote for conflicts. After a full text review, a hand search of the reference lists of the included studies was conducted to identify any additional articles that met the search criteria.

2.3.3 Data Items and Collection Processes

Data from the included papers were extracted into Excel 2007 by KR and checked by KD for accuracy. Extracted data included:

- Study characteristics—design, year of publication, participant numbers, study quality
- Participants’ age range

- Intervention (if relevant)—intervention approach and duration
- Handwriting measures
- Literacy measures
- Significant results for relationships/associations between handwriting and literacy
- Risk of bias assessment.

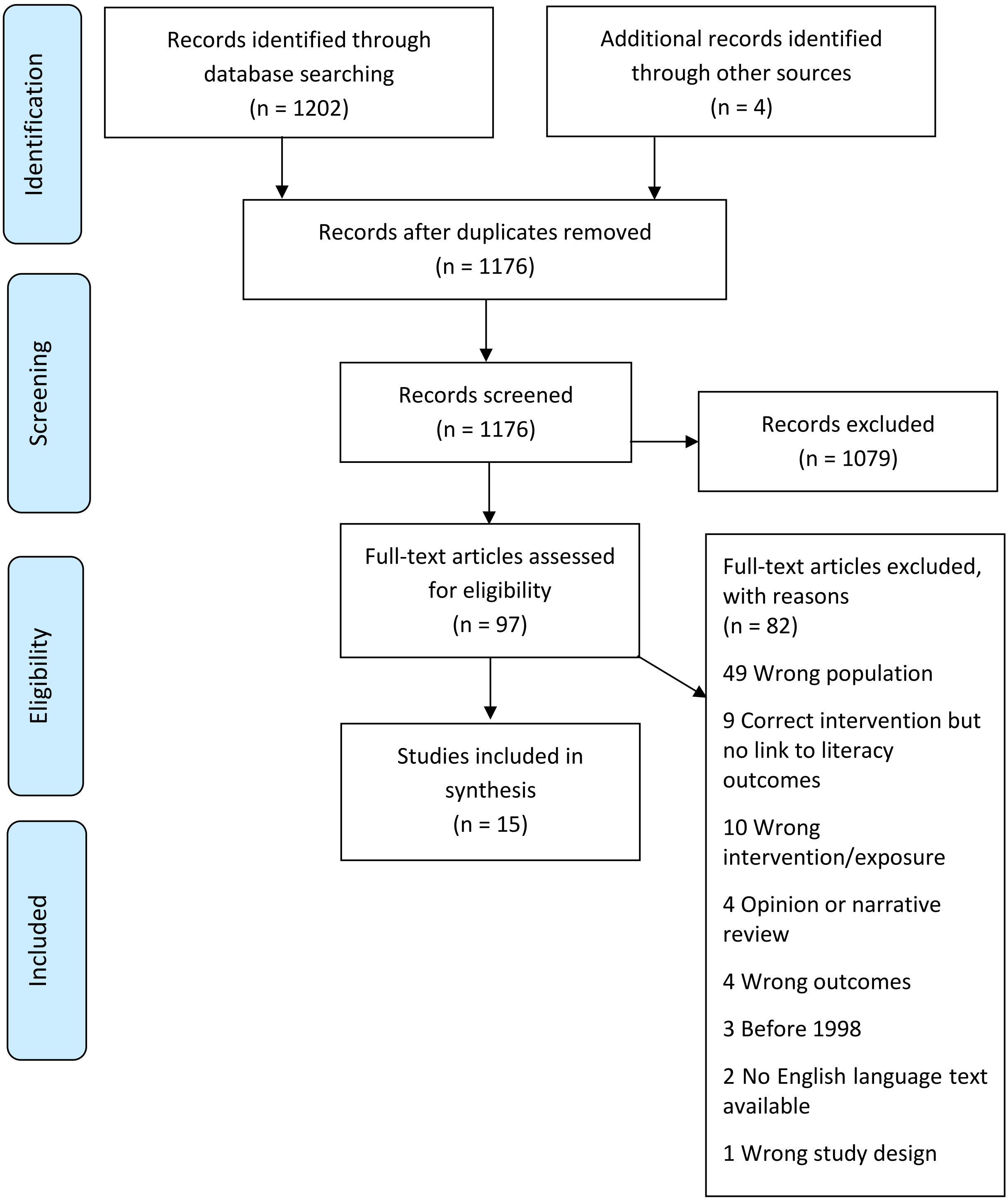
The Johns Hopkins nursing evidence-based practice rating scale (Dang & Dearholt, 2017) was used to assess included studies for quality. The rating scale uses a flow chart to establish evidence level and quality rating. Level of evidence is established through evaluation of three quality factors including independent variables, control and randomisation. The three levels of evidence are: randomised control trials (Level 1); quasi-experimental studies (Level II); and, non-experimental studies (Level III). Quality rating is determined using a 15-point checklist and studies are classified as high quality (A), good quality (B) or low quality (C) based on the quality assessment. The quality rating of studies included in this review was used to identify the weight of evidence, with evidence from higher rated studies noted in the results and discussion. All studies in this review were either quasi- or non-experimental, restricting evidence to Levels II and III. The quality of the included studies was generally good, with all being rated at Level B. Limitations in quality generally related to currency of the literature review, consistency between intervention and control groups and use of valid and reliable measurement instruments. Quality rating for theses (n = 2) was only applied to individual sub-studies relevant to the review question.

2.4 Results

From 1176 citations, 15 studies were identified for inclusion in the study (see Figure 2.1). The significant associations or effects between handwriting measures or interventions and literacy are shown in Table 2.2.

Figure 2.1

PRISMA Flow Chart



2.4.1 Characteristics of Included Studies

Fifteen studies were included in the review. Some studies used more than one study design. Designs comprised quasi-experimental (n = 4), longitudinal (n = 5) and cross-sectional research (n = 10). Theory testing was included in three studies. The mean age for participant populations in studies where age was reported (n = 11) ranged from 61.56 to 74.23 months. The total number of participants in the included studies was 2500 (unique participants n = 2049). Studies were conducted in the United States of America (n = 11), Australia (n = 2), Canada (n = 1), and Norway (n = 1). Study design description relates to outcomes that are the focus of this review. For example, in a two-group study, Dolin (2016) measured differences in handwriting legibility at pre- and post-test; however, written composition was a post-test measure only. As the subject of this review is the association and relationships between handwriting factors and literacy outcomes, this study has been described as a two-group post-test design. Table 2.2 summarises study characteristics including design, participant population details and describes handwriting intervention or measures. Not reported (NR) data are noted where applicable.

Table 2.2

Results by Author for Study Design, Quality Rating, Participants and Significant Effects/Associations

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy‡
1	Bazyk et al. (2009) *Integrating occupational therapy services in a kindergarten curriculum: A look at outcomes*	One-group pre- post-test (IIB)	37, 71.5 months (NR)	Embedded occupational therapy intervention two days per week for seven months, including teacher consultation (64%) and individual and group fine and visuomotor and sensory processing activities targeting participation in class activities and writing (36%).	Post intervention effects for correct letters in dictated sentence, $\eta^2 = 0.336$**; upper and lowercase letter identification (untimed), $\eta^2 = 0.696$***
2	Dolin (2016) *An analysis of the effectiveness of curriculum embedded handwriting instruction and its impact on student learning*	Two-group post-test (IIB)	313, NR (NR)	36 weeks of daily handwriting curriculum lessons (Handwriting Without Tears) using multi-sensory mediums (visual modelling, auditory cues and sensory practice for letter formation) and feedback delivered by teachers after 6.5 hours training. Control condition in regular classes not described.	Intervention group higher scores at post-test in writing composition measures including words spelled correctly, $f_{(1-311)} = 4.322$*; and number of ideas, $f_{(1-311)} = 6.298$*

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy[ǂ]
3	Eidlitz-Neufeld (2003) *Early letter form errors as a predictor of later literacy outcomes and the short- and long-term benefits of early instruction in proper letter formation*	Cross sectional and longitudinal (Study 1; IIIB) Two-group post-test intervention (Study 2b; IIB)	Study 1: Cohort A 52, NR (NR), cohort B 35, NR (NR) Study 2b: Cohort A 92 (40 experimental, 52 control), NR(NR)	**Study 1:** Dictated letter writing errors (13 letters dictated randomly, written from memory scored correct/incorrect based on legibility) **Study 2b:** Direct instruction in letter formation (Jolly Phonics) delivered by teacher over one year after two-hour teacher training program. Weekly instructional activities provided for one to four new sounds for graphomotor letter formation, phonological development, and letter sound correspondences using multi-sensory activities to practice letter formation. Home practice included. Control condition received standard teaching.	**Study 1:** Baseline dictated letter writing errors negatively associated with: 1. Kindergarten letter naming ability: Cohort A, r = -.796**; Cohort B, r = -.384** 2. Grade 3 (Cohort B) word reading, r = -.395* nonsense word reading, r = -.349*; reading comprehension, r = -.485**; reading speed, r = -.434**; and spelling, r = -.313* 3. Grade 5 (Cohort A) word reading, r = -.475**; nonsense word reading, r = -.429**; reading comprehension, r = -.458**; reading speed, r = -.567**; spelling, r = -.527**; and writing composition, r = -.509** **Study 2b:** Intervention group attained higher scores in grade 5 writing composition, assessed for conventions, linguistics and concepts, t = 2.122*

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy[ǂ]
4	Frolek Clark and Luze (2014) *Predicting handwriting performance in kindergartners using reading, fine-motor and visual-motor measures*	Cross-sectional (IIIB)	48, 74.23 months (4.23)	Dictated letter writing accuracy (26 randomly dictated alphabet letters, scored correct if all five features achieved, including phoneme grapheme correspondence, closure, line placement, no large gaps, and correct orientation) Dictated letter writing speed (time to write each dictated letter) In-hand manipulation (manipulation of objects in dominant hand) Visual motor integration (copy shapes) Visual perception (identify matching shapes) Motor Coordination (draw within boundary lines of a shape)	**Kindergarten associations between:** **Dictated letter writing accuracy and:** Initial sound fluency (ISF), r = .726**; letter naming fluency (LNF), r = .676**; phoneme segmentation fluency (PSF), r = .600**; nonsense word fluency (NWF), r = .633** **Dictated letter writing speed and:** ISF, r = .357*; LNF, r = .510**; PSF, r = .386**; NWF, r = .495** **In-hand manipulation and:** ISF r = .329*, LNF r = 410**, PSF r = .458**, NWF r = .329* **Visual motor integration and:** ISF, r = .465**; LNF, r = .529**; PSF, r = .465**; NWF, r = .453** **Visual perception and:** ISF r = .387**; LNF, r = .292*; PSF, r = .385**; NWF, r = .373** **Motor coordination and:** ISF, r = .361*; LNF, r= .353**; PSF, r = .357**; NWF, r = .374**

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy‡
5	Jones and Christensen (2012) *Impact of teacher professional development in handwriting on improved student learning outcomes and writing quality*	Two-group pre- post-test intervention study (IIB)	381 post-test, 275 delayed post-test, 65 months, (NR)	Intervention program of two different types of teacher training. Experimental condition received one-hour teacher professional development in handwriting explicit instruction including modelling, sensorimotor practice, directional arrows, memory retrieval and contextual writing. Control condition received one-hour training on standard curriculum.	Intervention group improved in quality of writing composition at post-test ($t = 6.79$***) and delayed post-test ($t = 12.55$***)
6	Karlsdottir and Stefansson (2003) *Predicting performance in primary school subjects*	Longitudinal (IIIB)	407, 84 months (NR)	Dictated letter writing (capital letters) Visual motor integration (copy shapes of increasing complexity)	Dictated letter writing predicted: 1. Grade 2 reading, r=.51 (99% CI .43, .58); and spelling r = .57 (95% CI .50, .63) 2. Grade 5 reading, r = .46 (95% CI .38, .53); and spelling r = .45 (95% CI .37, .52)

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy[‡]
7	Kent et al. (2014) *Writing fluency and quality in kindergarten and first grade: The role of attention, reading, transcription and oral language*	Cross sectional including theory testing, and longitudinal (IIIB)	265, 5.13 years (NR)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with: 1. Kindergarten reading, r = .51**, spelling, r = .54**, and writing composition (number of words, sentences, ideas, and correct word sequences) r = .47** 2. Grade 1 writing composition quality (text structure, ideas, word choice and sentence fluency), r = .31**, and writing production (correct word sequences), r = .34** Alphabetic letter writing fluency uniquely and positively related to kindergarten compositional fluency, β = .13*
8	Kim et al. (2014) *The contributions of vocabulary and letter writing automaticity to word reading and spelling for kindergartners*	Cross sectional including theory testing (IIIB)	242, 5.83 years (0.61)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with kindergarten phonological awareness, r = .48**; alphabet knowledge fluency (letter name and sound), r = .53**, word reading, r = .37**; and spelling, r = .48**, and marginally related to spelling in structural equation modelling (β = .11, p=.06)
9	Kim et al. (2011) *Componential skills of beginning writing: An exploratory study*	Cross sectional including theory testing (IIIB)	242, 5.83 years (0.61)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with latent kindergarten variables of reading, r = .36**; spelling, r = .47**; and composition writing (number of words, ideas and sentences), r = .46**, and uniquely and positively related to kindergarten written composition, γ = .26**

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy[ǂ]
10	Kim et al. (2015) *Kindergarten predictors of third grade writing*	Cross sectional and longitudinal (IIIB)	157, NR (NR) for kindergarten data collection point	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with: 1. Kindergarten letter and word reading, r = .32*; word attack (nonsense word reading), r = .30*; sight word efficiency (fluency), r = .31*; dictated spelling, r = .41*; real sight word spelling, r = .33*; real decodable word spelling, r = .39*; and literacy variable (composed of six measures of word reading and spelling), r = .35* 2. Grade 3 exposition idea development, r =- .23*
11	Malpique et al. (2017) *Handwriting automaticity and writing instruction in Australian kindergarten: An exploratory study*	Cross sectional (IIIB)	177, 5.82 years (0.35)	Alphabetic letter writing fluency	A one unit increase in word reading was associated with a .10 increase in alphabetic letter writing fluency, β = 0.10**
12	Puranik and Al Otaiba (2012) *Examining the contribution of handwriting and spelling to written expression in kindergarten*	Cross sectional including theory testing (IIIB)	242, 5.23 - 5.85 years (0.38 – 0.46)	Alphabetic letter writing fluency	Alphabetic letter writing fluency associated with kindergarten total number of words written in a composition, r = .44***; ideas expressed in a composition, r = .43***; spelling, r = .48***; word attack (reading nonsense words) and word identification, r = .24*** Alphabet letter writing fluency uniquely and positively related to kindergarten writing outcome, β = .24*** and accounted for the most unique variance (4.1%) in total number of words in kindergarten composition.

13	Puranik et al. (2017) *Examining alphabet writing fluency in kindergarten: Exploring the issue of time on task*	Cross sectional and longitudinal (IIIB)	134, 69 months (4)	Alphabetic letter writing fluency at beginning and end of kindergarten using timed - 15 seconds (15s) and 60 seconds (60s) or untimed (ut) tests	Cross-sectional correlations of alphabet writing fluency at beginning of year with words written in a sentence (15s, r=.42**; 60s, r = .63**; ut, r = .66***), sentence writing quality (15s, r = .41**; 60s, r = .63**; ut, r = .62***), composition words written (15s, r = .26**; 60s, r = .58**; ut, r = .61***), composition quality (15s, r = .37**; 60s, r = .59**; ut, r = .58***), spelling (60s, r = .47**; ut, r = .49***) and standardised assessment of writing (60s, r = .55**; ut, r = .55***) End of kindergarten alphabet letter writing fluency associated with end of year spelling (15s, r = .46**; 60s, r = .46**; ut, r = .45***), standardised assessment of writing (15s, r = .48**; 60s, r = .51**; ut, r = .57***), words written in a sentence (15s, r = .39**; 60s, r = .59**; ut, r = .52***), sentence writing quality (15s, r = .39**; 60s, r = .57**; ut, r = .56***), composition words written (15s, r = .41**; 60s, r = .63**; ut, r = .58***), composition quality (15s, r = .38**; 60s, r = .53**; ut, r = .60***). Alphabet letter writing fluency at beginning of kindergarten predicted end of year spelling (15s, β = .32**; 60s, β = .26*; ut, β = .48***), sentence writing words written (ut, β = .23*), sentence writing quality (ut, β = .36**), essay words written (ut, β = .37**) and essay quality (15s, β = .2*; ut, β = .54***) Beginning of year alphabet letter writing fluency significantly explained additional variance in end of year spelling (15s, ΔR^2 = .09**; 60s, ΔR^2 = .04*; ut, ΔR^2 =.13***), sentence writing number of words

Number	Author, year, title	Design (quality rating)	Participants N, Mean age (SD)	Kindergarten handwriting measures/interventions	Significant associations or effects of kindergarten handwriting skills on literacy[ŧ]
					written (ut, $\Delta R^2 = .03^*$), sentence writing quality (ut, $\Delta R^2 = .07^{**}$), essay words written (ut, $\Delta R^2 = .08^{**}$), and essay quality (15s, $\Delta R^2 = .04^*$; ut, $\Delta R^2 = .16^{***}$).
14	Reutzel et al. (2019) *Exploring the relationship between letter recognition and handwriting in early literacy development*	Cross sectional (IIIB)	48, NR (NR)	Alphabetic letter writing fluency Letter writing fluency (copying pseudo letters) Visuomotor skill – recognising and manipulating shapes to construct letters in order to copy a sample letter	Kindergarten associations between LNF and alphabetic letter writing fluency (r = .638***) and recognising and manipulating critical features of letters (visuomotor skill) (r = .363*)
15	Eckberg Zylstra and Pfeiffer (2016) *Effectiveness of a handwriting intervention with at-risk kindergartners*	Two-group pre- post-test (IIB)	Intervention 23, 68.7 (3.98); control 12, 71.8 (5.19)	Intervention group received handwriting program (Size Matters) based on direct instruction for letter formation using motor learning and cognitive principles and including practice and engaging activities twice a week for 16 weeks. Control condition received classroom handwriting instruction.	Greater gain for intervention group in uppercase letter name recognition, t = 2.34*; lowercase letter name recognition, t = 2.27*; and uppercase letter sound recognition, t = 2.46*

[ŧ] p values indicated as follows: * p <.05, **p <.01, ***p <.001;

2.4.2 Question 1 – What Were the Characteristics of Handwriting and Literacy Measures in Kindergarten?

Table 2.3 shows the measures authors used to assess handwriting and literacy. Handwriting measures could be classified into two sub-categories: letter writing fluency (dictated randomly or alphabetically sequenced) and perceptual motor skills. Literacy measures fell into one of five sub-categories: letter name and sound knowledge, phonological skills, word reading, writing composition and spelling. The measures used included the foundation skills known to impact kindergarten handwriting and literacy; for example, letter name and sound knowledge, phonological awareness skills, and visual and fine motor skills. Fluency was an important inclusion in measures. For handwriting, this was assessed using either dictated letter or alphabet writing tasks. Both required fluent recall and retrieval of the letter form from memory. Not all authors employed timed tasks that required recall, such as handwriting fluency or phonological skills, again, reflecting the emerging nature of these skills in kindergarten. Reading measures used in kindergarten included word and nonsense word reading, rather than continuous text reading. For spelling and writing, developmental scoring was often used to ensure that emerging skills, such as partially correct spelling based on phonological knowledge was incorporated.

Table 2.3

Groupings for Handwriting and Literacy Measures used in Included Studies

Grouping	Definition	Methods of measurement and references
Handwriting		
Letter writing fluency, either dictated (n = 4) or alphabetic (n = 10)	Dictated letter writing fluency is the ability to recall and write dictated, non-alphabetically sequenced letters.	Scoring combined aspects of appearance (legibility) as well as memory recall of dictated letter (fluency), for example, criteria used by Frolek Clark and Luze (2014) included: matches dictated letter, correct line placement, no large gaps, correct orientation, and recognisable out of context (Dolin, 2016; Eidlitz-Neufeld, 2003; Frolek Clark & Luze, 2014; Karlsdottir & Stefansson, 2003).
	Alphabetic letter writing fluency is alphabet writing from memory, with variations in the amount of time allowed for writing.	Methods for scoring included number of recognisable (legible), alphabetically sequenced letters written in varying time periods (15 seconds, 60 seconds and untimed). Features that were generally required included recognisability of the letter, correct orientation, and correct alphabetic sequence (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik & Al Otaiba, 2012; Puranik et al., 2017; Reutzel et al., 2019).
Perceptual motor skills (n = 4)	A range of abilities across visual, perceptual and motor systems including fine motor skills (movement skills of the small muscles of the hand, generally requiring manipulation of a tool or object), visual motor integration (VMI) (coordination of eye and hand skills to enable tasks such as copying), motor coordination (coordination of writing movements, such as tracing within lines) and visual perception (discrimination between shapes).	Fine motor (Bazyk et al., 2009; Frolek Clark & Luze, 2014). VMI (Bazyk et al., 2009; Frolek Clark & Luze, 2014; Karlsdottir & Stefansson, 2003; Reutzel et al., 2019). Motor coordination and visual perception (Frolek Clark & Luze, 2014).
Literacy		

Grouping	Definition	Methods of measurement and references
Letter name and sound knowledge (n = 8)	Verbal identification of as many mixed upper and lowercase and randomly ordered letter names and/or sounds as possible.	Performance was untimed or timed (generally one-minute duration). Timed (Dolin, 2016; Frolek Clark & Luze, 2014; Kim et al., 2014; Reutzel et al., 2019). Untimed (Bazyk et al., 2009; Eckberg Zylstra & Pfeiffer, 2016; Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003).
Phonological skills (n = 4)	The ability to hear and manipulate sounds, for example, identification of the first sound of a spoken word, breaking a word into its phonetic components, or blending segments of a word together to say the whole word.	Initial sound fluency (identification of first sound of a spoken word), phoneme segmentation fluency (breaking a whole spoken word into its phonemic components) (Dolin, 2016; Frolek Clark & Luze, 2014). Phoneme blending (joining individual sounds to say a word) (Kim et al., 2014; Puranik & Al Otaiba, 2012). Elision (listen to a word and then say it after deleting a part or sound) (Kim et al., 2014; Puranik & Al Otaiba, 2012).
Word reading (n = 9)	Nonsense word or pseudo-word fluency is the ability to read words that can be decoded by applying the alphabetic principle. Real word reading includes both decodable and non-decodable (sight) words.	Reading skills include timed or untimed sounding out of decodable real or nonsense word and recognition of sight or non-decodable words. Timed Nonsense word fluency (Dolin, 2016; Frolek Clark & Luze, 2014). Untimed nonsense word fluency (Eidlitz-Neufeld, 2003; Kent et al., 2014; Kim et al., 2014; Kim et al., 2015; Puranik & Al Otaiba, 2012). Timed and untimed real word reading (Eidlitz-Neufeld, 2003; Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik & Al Otaiba, 2012). Reading accuracy and comprehension (Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003).

Grouping	Definition	Methods of measurement and references
Writing composition (n = 9)	Composing a sentence, story or exposition based on a writing prompt (either picture and word or prompt topic).	Rubrics devised measured quantity and quality of writing and included a combination of number of words and/or sentences written (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012; Puranik et al., 2017), spelling (sometimes using partial scoring for phonetically correct attempts) (Dolin, 2016; Puranik et al., 2017), number of ideas or units of thought expressed (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012), sentence organisation, complexity or sequencing (Dolin, 2016; Eidlitz-Neufeld, 2003; Kent et al., 2014; Puranik et al., 2017), punctuation (Eidlitz-Neufeld, 2003; Jones & Christensen, 2012; Puranik et al., 2017), vocabulary (Kent et al., 2014), text structure/form/organisation (Eidlitz-Neufeld, 2003; Kim et al., 2015; Puranik et al., 2017), correct word sequences (use of punctuation to delineate one sentence from the next, syntactically and semantically correct ordering of words and adjacent words spelled correctly) (Dolin, 2016; Kent et al., 2014), and idea development, meaning or relevance of writing to the prompt (Kim et al., 2015; Puranik et al., 2017).
Spelling (word and sentence) (n = 10)	The ability to translate spoken, dictated words into writing. Can be single words or sentences.	For single word spelling, whole words were scored dichotomously as right or wrong (Dolin, 2016; Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003; Kent et al., 2014; Kim et al., 2011; Puranik et al., 2017) and/or on developmental scales that allowed for gradations based on phonemic correctness (Kent et al., 2014; Kim et al., 2014; Kim et al., 2015; Puranik & Al Otaiba, 2012). For dictated sentence writing, number of correct letter sounds written was recorded (Bazyk et al., 2009).

2.4.3 Question 2 – What are the Observed Relationships Between Handwriting Ability and Literacy in Kindergarten?

Overall, the strongest evidence was found for the relationship of letter writing fluency to literacy encompassing reading, writing and phonological skills. Evidence of lower strength was found for relationships between perceptual motor skills and literacy.

2.4.3.1 The Relationship of Letter Writing Fluency to Literacy.

Most support in the literature was found for an association between literacy and letter writing fluency measured in both dictated and alphabetic forms. Significant positive associations of letter writing fluency and significant effects of letter writing fluency intervention were found for literacy factors in controlled intervention, longitudinal and cross-sectional studies. The strongest evidence was found for the impact of letter writing fluency on writing composition and spelling, followed by reading (letter sound and name knowledge and fluency, nonsense word reading, real word reading). Further, a small amount of evidence was found for a relationship between letter writing fluency and phonological skills.

2.4.3.1.1 Writing Composition and Spelling.

Three intervention studies rated as the highest quality in this review explored the impact of a letter writing fluency-based intervention on writing, particularly on writing composition. The intervention in these studies was characterised by a focus on multi-sensory approaches to consolidating letter forming ability; that is, the ability to form letters from memory using a defined series of strokes and movements. In two studies, immediate post intervention effects on compositional writing were reported (words spelled correctly and number of ideas, Dolin (2016); and writing quality, Jones and Christensen (2012)). Additionally, two studies reported delayed effects of a letter writing fluency intervention on writing composition (grade 5, conventions and linguistic concepts, Eidlitz-Neufeld (2003); grade 1, recognizable words or sentences, number of sentences or thought units, basic punctuation, Jones and Christensen (2012)). The results of longitudinal studies supported intervention study findings. Alphabet writing fluency in kindergarten predicted grade 1 writing quality (text structure, ideas, word choice and sentence fluency) and production (quantity of correct word sequences)(Kent et al., 2014) and grade 3 exposition idea development (Kim et al., 2015). Beginning of year kindergarten alphabet letter writing fluency predicted and explained additional variance in end-of-year spelling, and sentence and composition writing quantity and quality.

In cross-sectional studies conducted at varying points in the kindergarten year, alphabet writing fluency was significantly correlated with compositional sentence or text writing quantity and quality, generally rated for number of words, sentences and ideas (Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012; Puranik et al., 2017). Additionally, Puranik et al. (2017) found beginning and end of year correlations of alphabet letter writing fluency with a standardised measure of writing. Three cross-sectional studies found alphabet writing fluency was uniquely and positively related to writing outcome (Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012) and accounted for the most unique variance in number of words written (Puranik & Al Otaiba, 2012).

Spelling was further explored in relationship to letter writing fluency. Kindergarten dictated letter writing fluency predicted spelling in grade 2 (Karlsdottir & Stefansson, 2003), grade 3 (Eidlitz-Neufeld, 2003) and grade 5 (Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003). Alphabet writing fluency at the beginning of kindergarten predicted end-of-year spelling (Puranik et al., 2017). Alphabet writing fluency measured using a range of times (15 second, 60 second and untimed) was significantly correlated with spelling in six studies (Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Puranik & Al Otaiba, 2012; Puranik et al., 2017). Note that for these results, four were drawn from the same data set (Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Puranik & Al Otaiba, 2012).

2.4.3.1.2 Reading.

Letter writing fluency intervention effects and associations were reported for foundation reading skills. Significant effects of a handwriting fluency intervention on letter name and sound knowledge were reported by Eckberg Zylstra and Pfeiffer (2016). This study was among the highest quality found in the review. Similar to the other intervention studies, this study was characterised by a focus on multi-sensory (motor learning and cognitive) approaches to consolidating letter forming ability. In support of this study, Eidlitz-Neufeld (2003) found that that letter form errors from dictated letter writing were significantly negatively correlated with letter name knowledge.

In other findings, kindergarten dictated letter writing fluency was found to predict grade 2 and grade 5 reading (Karlsdottir & Stefansson, 2003), as well as grade 3 and 5 word reading, nonsense word reading, and reading speed (Eidlitz-Neufeld, 2003). Further, dictated letter writing assessed for both legibility and speed was positively correlated with letter naming and nonsense word reading fluency (Frolek Clark & Luze, 2014). Alphabet writing fluency was also significantly associated with letter name or sound knowledge (Kim et al., 2014; Reutzel et al., 2019), nonsense word reading (Kim et al., 2015; Puranik & Al Otaiba, 2012) and word reading (Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Puranik & Al Otaiba, 2012). A one unit increase in word reading was significantly associated with a 0.1 increase in letter writing fluency (Malpique et al., 2017).

2.4.3.1.3 Phonological Skills.

Weaker evidence was found for the relationships between letter writing fluency and phonological skills. Dictated letter writing was positively correlated with initial sound fluency and phoneme segmentation fluency (Frolek Clark & Luze, 2014). Alphabet writing fluency was significantly correlated with phonological awareness (Kim et al., 2014; Puranik & Al Otaiba, 2012).

2.4.4 The Relationship of Perceptual Motor Skills to Literacy

Weaker evidence was found in support of a relationship between perceptual motor skills and literacy. The strongest evidence was found in an uncontrolled intervention study (Bazyk et al., 2009), however the weight of this evidence was lower than the letter writing intervention studies previously discussed. Evidence from cross-sectional studies was also found in support of the intervention study findings. No longitudinal data were identified.

Writing outcomes after perceptual motor skills intervention were identified by Bazyk et al. (2009).This study was a one group classroom based intervention focussed on the development of skills in fine and visuomotor areas that may impact participation in writing activities. Significant gains were reported in correct letters written in each word in a dictated sentence (sentence writing spelling).

Evidence was also found for a relationship between perceptual motor skills and aspects of reading. Bazyk et al. (2009) reported significant growth in letter knowledge after perceptual motor skills intervention as previously described. In cross-sectional analysis, visual motor integration was significantly correlated with nonsense word reading fluency (Frolek Clark & Luze, 2014) and letter naming fluency (Frolek Clark & Luze, 2014; Reutzel et al., 2019). Fine motor skills (in-hand manipulation and motor coordination) and visual perception were also significantly correlated with letter naming fluency and nonsense word reading (Frolek Clark & Luze, 2014).

The amount and weight of evidence for the relationship between perceptual motor skills and phonological skills was low, with cross-sectional evidence for a relationship between perceptual motor skills and phonological skills reported in one study. Specifically, visual motor integration, fine motor skills (in-hand manipulation), motor coordination and visual perception were associated with initial sound fluency and phoneme segmentation fluency (Frolek Clark & Luze, 2014).

2.5 Discussion

This systematic review sought to examine the relationship between handwriting and literacy for kindergarten students. The scope of the review included an analysis and grouping of measurements of both handwriting and literacy in kindergarten, and analysis of the relationships between handwriting and literacy factors. This study identified two categories of handwriting measurement (letter writing fluency and perceptual motor abilities) and five categories of literacy measurement (letter name and sound knowledge, phonological skills, word reading, writing composition and spelling). The findings of this review provide strong evidence for the associations with, and effects of, letter writing fluency on literacy, however, perceptual motor abilities also showed evidence of weaker relationships. These finding are instructive in progressing understanding of handwriting fluency measurement, the role of handwriting in literacy, and handwriting intervention approaches that may impact literacy in kindergarten.

2.5.1 Measurement of Handwriting and Literacy in Kindergarten

Measurement of handwriting ability in kindergarten is an important consideration, given the relationships with literacy identified in this review. By far the most common measure of handwriting used in the included studies was a measure of letter writing fluency, generally collected through timed alphabet testing. Timed alphabet writing generally relies on remembering and reproducing letters in alphabetic sequence, and combines aspects of letter legibility in scoring. For example, in a number of studies, letters received a score of zero for an illegible, out of order, cursive or uppercase letter, half a point for a poorly formed or reversed letter, and one point for a correctly formed and ordered letter (Kent et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017). Puranik et al. (2017) devised a coding system in which four identified errors contributed to the point score, based on the number or the type of errors made. Possible errors included poor form or control reversal or inversion, uppercase or unrecognisable letters. Floor effects, and limitations of timed alphabet measures as predictors of kindergarten literacy have been reported (Puranik et al., 2017). Dictated letter writing measures, or those that do not require alphabetic sequencing, partially address the limitations of alphabet knowledge and timing constraints. However, most measures using this method also used a rubric that combine accurate memory recall of the letter with aspects of letter appearance, as for the alphabet writing tests; for example, Reutzel et al. (2019). As scoring for memory recall and legibility of letters is combined, it is not clear from these rubrics which factor has the greatest impact on letter writing fluency—alphabet knowledge, letter sound knowledge, or the impact of perceptual motor factors such as fine and visuomotor skills that may produce legibility errors. Perceptual motor measures also aim to record fine motor, visuomotor, perceptual and motor coordination skills that may impact handwriting, but do not account for the cognitive processes inherent in fluent handwriting. Measures of handwriting fluency for kindergarten may need refinement to capture the contribution of all skills that impact fluency including phonemic ability, memory of letter forms, and perceptual motor skills including visuomotor ability. It is recommended that future research should use both alphabet and dictated letter measures of letter writing fluency to gain greater understanding of the effects of developing letter writing fluency on literacy. Measures may also need to be developed to capture the impact of both perceptual motor skills and fluency processes on handwriting in order to gain a clearer understanding of relationships with literacy.

2.5.2 Evidence for Handwriting as a Facilitator of Literacy in Kindergarten

Two distinct elements of handwriting were identified in this review—letter writing fluency and perceptual motor skills. Literacy measurement encompassed reading (letter name and sound knowledge and word reading), writing (writing composition and spelling), and phonological skills. Kindergarten letter writing fluency (writing legible letters from memory) was found to have a strong relationship to both reading and writing. Controlled studies that utilised a letter writing fluency development intervention reported significant gains in writing composition (Dolin, 2016; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012) and reading (letter identification; Eckberg Zylstra & Pfeiffer, 2016). Further evidence was found supporting these relationships in longitudinal and correlational studies. Letter writing fluency has an established relationship with written composition quantity and quality, explained by cognitive load theory in which automisation of handwriting, measured by timed alphabet writing, enables working memory to be available for more complex writing tasks such as ideating and planning. This review documents the evidence for this effect in kindergarten children. Weaker evidence was also found for letter writing fluency and reading. Evidence for the interrelationship of reading and handwriting is accumulating, with researchers finding that writing letters by hand activates reading circuits in the brain (James & Engelhardt, 2012). This suggests that handwriting has a role to play in facilitating relationships between letter names, sounds and forms, contributing to both reading and writing abilities. Further investigation of the impact of letter writing fluency on reading is indicated from this review, as the preliminary evidence documented here is supportive of the impact of letter writing fluency on both reading and writing in kindergarten.

Weaker evidence was found for relationships between perceptual motor skills (fine motor, visuomotor, perceptual and motor coordination) and literacy (letter knowledge, spelling, word reading and phonological skills). An uncontrolled study found that after perceptual motor skills intervention, gains were made in sentence writing and letter identification (Bazyk et al., 2009). As for letter writing fluency studies, further evidence supportive of the relationship was found in correlational studies. Similar associations between perceptual motor skills and literacy found in this review have been reported in preschool studies. For example, Suggate et al. (2019) found that for preschool children in Germany, fine motor skills (manipulation) did not play a role in early reading development, but graphomotor skills (copying pseudo letters) did. This suggests a role for a blend of perceptual and motor factors in letter writing fluency, with possible impacts on reading. Similarly, Cameron et al. (2012), measured fine motor skills prior to formal schooling and found that a combination of early fine motor abilities (building with blocks, copying shapes with a pencil, and drawing a person) predicted higher achievement on kindergarten entry tests including word reading and phonological skills. Further, literacy improvement across kindergarten was greater for children who had stronger design copy skills at preschool assessment. As noted, the weight of evidence for the role of perceptual motor skills in literacy for kindergarten is lower than for letter writing fluency; although, the findings suggest these skills warrant further attention as factors in literacy ability.

2.5.3 Handwriting Intervention Elements and Literacy in Kindergarten

In this review, studies with the highest level of evidence used a controlled, two-group evaluation of a handwriting intervention and reported improved literacy outcomes across reading and writing areas (Dolin, 2016; Eckberg Zylstra & Pfeiffer, 2016; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012). Each of the four studies used differing intervention methodologies, but all focussed on promoting letter writing fluency using age appropriate activities and including modelling (explicit instruction of letter, sound and form correspondences), multi-sensory activities to promote letter writing (for example, writing with finger in the air, tracing letters in sand), and engaging a range of sensory modalities to promote fluency (for example, auditory cues, directional arrows, visual modelling). What the description of methodologies suggests is that researchers combined both perceptual motor skills and letter writing fluency factors in intervention. It is possible that the nature of the activities facilitated the development of perceptual motor abilities necessary for handwriting. Given the evidence found in this review for strong relationships of letter writing fluency with literacy, and weaker, but significant, relationships of perceptual motor skills with literacy, it is possible that both intervention elements impacted the literacy outcomes to unspecified degrees. Another, lower level intervention study (one-group pre- post-test) focussed on development of perceptual motor contributors that may impact participation in writing (Bazyk et al., 2009). This study found greater than typical maturational development in the perceptual motor skill areas assessed and significant growth in sentence writing and letter identification. The impact of perceptual motor skills development on literacy is still unclear. In summary, intervention studies offer some support for inclusion of both perceptual motor skills development and letter writing fluency as part of effective handwriting intervention that may have positive impacts on literacy. The preliminary evidence found in this study, combined with learnings from younger age groups as previously discussed are supportive of a focus on perceptual motor skills development in the early years and in conjunction with the beginning stages of handwriting instruction. Further study of the role of perceptual motor skills in early handwriting acquisition is needed before any definitive conclusions can be drawn.

2.5.4 Proposed Mechanisms for the Relationships Between Handwriting and Literacy Found in This Review

The mechanism for the effect of handwriting on writing has been explained through capacity theory, whereby automaticity of some processes allows for application of cognitive resources to higher order tasks involved in written composition, such as generating ideas and planning. The effects of handwriting on writing composition found in this review are likely to be a result of the same mechanisms. Similarly, handwriting fluency was associated with improved spelling, and this association may relate to automaticity processes as well. As most studies used a developmental scale to assess spelling, rather than a dichotomous right or wrong method, the findings suggest that fluent letter writing is supportive of phonetic or invented spelling, as letter sound correspondences are more retrievable and therefore more readily available to be applied in invented spelling. Given the relationship of handwriting fluency to emergent spelling identified in this review, it may be possible that a strong basis of letter writing fluency in kindergarten is supportive of emergent spelling. This effect could also contribute to enhanced writing composition, as both elements of transcription—handwriting and spelling—enable more fluent writing, particularly in younger grades (Kim & Park, 2019). In effect, handwriting fluency may support and enable phonetic spelling; the beginnings of early writing.

The nature of a causal relationship of handwriting to reading is less understood. Yet, evidence from functional magnetic resonance imaging has shown that the act of writing by hand has an activating effect on brain regions associated with reading (James & Engelhardt, 2012). The majority of intervention studies in this review reported effects of handwriting intervention on writing outcome, with only one study of a higher quality reporting effects on reading. More kindergarten intervention studies are needed to explore the effects of handwriting on reading as well as writing.

Relationships of handwriting to literacy may be stronger in kindergarten than in subsequent years. For example, Kent et al. (2014) found that attention, higher order literacy (reading and spelling) and alphabet writing fluency were uniquely and positively related to kindergarten writing outcomes, but only attention and the higher order literacy factor predicted grade 1 outcomes. Also, Kim et al. (2015), found correlations at kindergarten level between alphabet writing and a literacy variable (six factors of reading and spelling combined) but only a combination of oral language and the combined literacy measure predicted grade 3 exposition writing. These studies may indicate that the relationships between alphabet writing and literacy are perhaps strongest in the kindergarten year as letter writing fluency directly impacts emerging abilities required for early reading and writing tasks, such as decoding and invented or phonetic spelling. More research is needed to understand the effect of handwriting in the kindergarten year.

Finally, it is conceived, and preliminarily supported by this review, that perceptual motor skills including fine motor and visuomotor abilities may facilitate and support the practice of letter writing. Through this practice, stronger relationships between letter name, sound and form may be made, possibly facilitating improvements in emergent spelling, reading and writing. Perceptual motor and cognitive skills development in kindergarten may impact handwriting skills, and addressing all factors in intervention approaches could lead to handwriting and subsequent literacy gains.

2.5.5 Study Limitations

This study sought to explore relationships between handwriting fluency and literacy in the first year of school. As such, some relevant factors that impact early literacy are not covered in this study. Clearly there are many factors at play in the development of literacy, however, this study clarifies understanding of the relationship of handwriting to literacy. The results of this systematic review can only be considered within the scope explored, in order to direct further study into the role of handwriting fluency in literacy. While there are other important contributors to literacy that were outside the scope of this review, the results nonetheless provide important direction to future intervention studies, by highlighting the role of automatic, fluent letter writing from memory in relation to a wide range of literacy outcomes. Future interventions should seek to combine the knowledge of contributors to handwriting for beginning writers, both from a perceptual motor and cognitive perspective in order to refine interventions and further explain the role that handwriting fluency, per se, may play in literacy development. Finally, it is noted that researchers have identified other contributing factors to writing outcomes including oral language (Kim et al., 2011) and attention (Kent et al., 2014) and that alphabet letter writing fluency is just one aspect of the models that have been devised to explain literacy outcomes. Given the accessibility of handwriting intervention approaches with a focus on foundation skills and fluency development, it is possible that attention to this one aspect could yield gains for emergent literacy. However, more evidence is needed to direct future intervention and classroom approaches. Handwriting, specifically letter writing fluency, appears to be a crucial contributor to kindergarten literacy.

2.5.6 Conclusion

This review sought to quantify and qualify the characteristics of measures used to assess handwriting and literacy in kindergarten, and to explore the relationships between different skills in these two areas. The results are supportive of the existence of a relationship between handwriting and literacy in kindergarten. While it appears letter writing fluency has the strongest relationship with literacy, evidence of relationships is also available for less frequently examined aspects of handwriting function such as perceptual motor ability. Intervention studies with the strongest research design showed that focussing on handwriting fluency can impact foundation reading skills such as letter identification, and writing skills such as composition. If the handwriting and literacy relationships reported in this review can be further substantiated in whole class intervention studies, it may be possible to support kindergarten literacy through a readily available classroom means—effective handwriting instruction.

2.6 Declarations

The authors received no financial support for the research, authorship and publication of this article.

Chapter 3 Pilot Study

Preface

Chapter 1 introduced whole-class methods of handwriting intervention and noted the positive effects of using this approach in conjunction with co-teaching (Section 1.3.4.2). The benefits of whole-class methods were described, including enabling early intervention and the prevention of handwriting problems. Co-teaching benefits were also described including the integration of therapy into classrooms through collaborative intervention approaches. The program, Write Start, was described as one whole-class, co-taught handwriting intervention for Year 1 students, with demonstrated positive impacts on handwriting fluency and literacy (Section 1.3.4.3).

In the present chapter, a retrospective analysis of a pilot of a modified Write Start program, adapted for Kindergarten, is presented as a manuscript. The retrospective analysis examined the impact of modified Write Start on the handwriting fluency of Kindergarten students in a single cohort, pre- and post-study. The impact of early literacy abilities on handwriting fluency outcomes was also examined. Data had been collected previously by the candidate as part of routine clinical practice in 2016 and were submitted for retrospective analysis for the purposes of this program of thesis work in 2018. Ethics approval and participant consent was obtained for the analysis of this data, as well as additional data that was retrospectively retrieved, in 2018 (H-2017-0415, Appendix 2).

Issues pertaining to the measurement of handwriting fluency in Kindergarten have been discussed in Chapter 1 (Section 1.3.3.6) and Chapter 2 (systematic review, Section 2.5.1). Of key concern was the conclusion from the systematic review, that one of the most used measures of handwriting fluency, timed alphabet testing, is impacted by floor effects. Alternate methods such as dictated letters, require scoring of both recall and legibility but these elements are not measured independently, thereby confusing interpretation. Consideration of alternate methods of measurement was recommended (Section 2.5.1). In the manuscript presented in this chapter, a new handwriting fluency measure, the Letter Form Assessment (LFA), is introduced and a rationale provided for its suitability as a measure of handwriting fluency for Kindergarten. Unique features of the assessment tool are described including assessment of level of individual letter writing ability including writing from memory, copying an example, or imitating a demonstration.

The pilot study presented in this chapter contributed to two thesis questions*:*

> *Question 1: What is the relationship between handwriting and literacy for Kindergarten students?*
>
> *Question 2: How effective is a whole-class intervention in improving handwriting ability for Kindergarten students?*

After completion of the study, the results were submitted to the *Journal of Occupational Therapy, Schools, & Early Intervention*, and the manuscript is currently under review.

Contribution statement:

The candidate coordinated and organised all processes related to retrospective data extraction for the pilot study analysed in this chapter. With supervisory guidance the candidate entered the data, conducted data cleaning and analysis and prepared the manuscript presented in this chapter to report the findings of this analysis, incorporating comments from supervisors' review.

Authors and affiliations:

Impact of a co-taught handwriting intervention for kindergarten children in a school setting: A pilot, single cohort study

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Under review:

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Keywords:

Kindergarten, handwriting fluency, literacy, beginning writing, handwriting

Naming conventions used in the article:

As explained in Chapter 1, relevant journal language conventions have been used to describe school class level for chapters presented as a paper. For the paper presented in this Chapter 3, terms used are: kindergarten; grade; and numerals for grade level, for example, grade 1.

Appendices to this Chapter:

- Appendix 2—Ethical approval and safety clearance for pilot study retrospective analysis

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[1] Discipline specific (occupational therapy) recommendations are included in the following paper, in accordance with journal requirements.

3.1 Abstract

The Write Start program is a co-taught, whole-class approach to handwriting instruction developed for students in grade 1 which teachers and occupational therapists deliver collaboratively. Write Start emphasises the development of handwriting fluency utilising evidence-based cognitive and perceptual motor strategies within a station-based teaching approach. This pilot study assessed the impact of a modified Write Start on handwriting fluency in Australian kindergarten students (their first year of formal schooling) and investigated the effects of early literacy on intervention outcomes using a retrospective analysis of existing clinical data. Participants were kindergarten students (n=81; mean age = 65.9 months) attending a large independent primary school in a regional metropolitan centre. Participants received the modified Write Start, over one school term, in two 45-minute sessions per week for eight weeks. Handwriting fluency was measured pre- and post-intervention using a researcher-designed tool, the Letter Form Assessment (LFA), based on and extending commonly used measures. LFA scores for the whole cohort were significantly higher post-intervention, indicating improved handwriting after the intervention ($Z = -4.457$, $p < 0.0001$). In order to determine if school entry ability impacted responsiveness to the intervention, students were assigned to a high- or low-performing tier based on scores from three early literacy skills tests measured by teachers as part of a routine assessment at school entry (n=70). There was no effect of Low or High Tier literacy skills groupings on change to LFA score for phonics ($f_{(19, 50)} = 1.11$, $p = 0.36$), phonemic awareness ($f_{(19,50)} = 1.32$, $p = 0.21$) or writing ($f_{(19,50)} = 0.59$, $p = 0.89$). The modified Write Start shows promise as an effective intervention for kindergarten handwriting, however, further revisions and testing should address the potential impact of literacy, and the interrelationship of perceptual motor and cognitive skills, on outcomes.

Keywords: Kindergarten; handwriting; early literacy; handwriting fluency

3.2 Introduction

Handwriting is the predominant method by which school students transcribe and document learning (Mackenzie & Spokes, 2018; McMaster & Roberts, 2016; Santangelo & Graham, 2016). A recent Australian study of nine classes from kindergarten to grade 5 found that fine motor tasks, usually handwriting, accounted for 30% to 50% of student time in a typical school day, with technology use making up 10% (McMaster & Roberts, 2016). It has been estimated that between 5% to 33% of school children have significant difficulty learning to write by hand (Overvelde & Hulstijn, 2011b). Many of these difficulties are associated with poor handwriting fluency, a key indicator of handwriting performance. Handwriting fluency measures not only the appearance or legibility of writing, but also the capacity to write from memory. Fluency is crucial for tasks commonly expected in early schooling such as spelling and compositional writing. Problems with handwriting fluency may constrain students' written expression with downstream effects on literacy acquisition, especially in early grades (Kim & Park, 2019; Malpique et al., 2020; McCarney et al., 2013). This may be attributed to the impact of cognitive attention or load being redirected to lower-level, mechanical aspects of writing rather than higher-level planning and text generation processes (McCutchen, 1996). In kindergarten (the first year of formal schooling in Australia), handwriting fluency is emerging, as relationships between letter sounds (phonemes) and forms (graphemes) are developing. As such, handwriting in kindergarten relies heavily on emerging phonological awareness skills, such as the ability to hear and recognise letter sounds (phonemic awareness), and the ability to attach or map these sounds to letter forms (graphemes) (Castles et al., 2018; Ehri, 2014). Given the interrelationship of phonological awareness skills with emerging handwriting in kindergarten, it is not surprising that there is accumulating evidence linking handwriting intervention to aspects of writing composition (Dolin, 2016; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012) and reading (Eckberg Zylstra & Pfeiffer, 2016). Handwriting appears to play an important role in a range of academic tasks and outcomes and perhaps acts to facilitate or support emerging phonological awareness, particularly phonics. Further, studies have found evidence for a facilitating relationship between handwriting and activation of brain regions associated with reading (James & Engelhardt, 2012), and letter recognition (Li & James, 2016). As such, there is an ongoing need to ensure that beginning students are receiving optimal handwriting instruction during their early years of schooling. In this article we describe the effect of a co-taught whole-class, kindergarten handwriting intervention on handwriting fluency. Further, we explore associations between early literacy skills and intervention outcomes.

3.2.1 Prerequisites for Handwriting Fluency

Handwriting is a complex, high-level task that combines cognitive with perceptual motor skills and relies on phonological awareness skills, as previously described (Berninger, Abbott, et al., 2006; Feder & Majnemer, 2007; Hooper et al., 2010; Klein et al., 2021). In terms of cognition, orthographic codes or mental representations for letters and words are created in memory and then accessed for writing (Abbott & Berninger, 1993). The process of mapping speech sounds to letter forms is known as phonics. Efficient memory representation and retrieval patterns for letters and words, therefore, are essential for handwriting fluency (Berninger et al., 1997). Fine motor coordination and visual motor integration have also been associated with, or are predictive of, handwriting skill and readiness, and transcription ability (spelling and letter writing fluency; Cornhill & Case-Smith, 1996; Daly et al., 2003; Feder & Majnemer, 2007; Graham et al., 1997; Jones & Christensen, 1999; Tseng & Cermak, 1993; van Hartingsveldt et al., 2015; Volman et al., 2006; Weintraub & Graham, 2000). Specifically, sequential thumb-finger tapping (Berninger & Rutberg, 1992; Weintraub & Graham, 2000), in-hand manipulation (translation and rotation; Cornhill & Case-Smith, 1996); unimanual dexterity (Volman et al., 2006), and upper limb coordination (Tseng & Chow, 2000) are considered especially important as predictors of handwriting ability. In the area of visual motor integration, shape copying is an established indicator of handwriting readiness and a predictor of legibility (Lee et al., 2016; Weil & Amundson, 1994; Weintraub & Graham, 2000). Further, for children with handwriting problems, visuomotor skills have been found to be significant predictors of handwriting quality (Volman et al., 2006).

The relative importance of the various prerequisite skills to handwriting *fluency*, is unknown. Similarly, the evidence for the interrelationships and relative weights of skills contributing to handwriting *legibility* is unclear. One study found that finger function and visuomotor skill predicted handwriting legibility (good or poor) in grade 5 children; whereas, orthographic ability and gender did not (Weintraub & Graham, 2000). In another study, perceptual motor skills (fine motor, visuomotor and visual perception) explained only a quarter of the variance in handwriting legibility for grades 3 to 6 children, suggesting a possible involvement of cognitive or other factors (Klein et al., 2011). One factor contributing to the lack of clarity in the literature is the absence of an accepted measure of handwriting fluency for beginning students.

3.2.3 Handwriting Fluency Measurement Issues in Kindergarten

Established measures of handwriting fluency combine aspects of legibility (for example, letter recognisability and orientation) with memory recall of letters, generally in alphabetic sequence (Abbott & Berninger, 1993; Graham et al., 1997). In kindergarten, fluency is commonly measured using either alphabet writing ability or the ability to write individually dictated letters (Dolin, 2016; Eidlitz-Neufeld, 2003; Frolek Clark & Luze, 2014; Jones & Christensen, 2012; Karlsdottir & Stefansson, 2003; Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik & Al Otaiba, 2012; Puranik et al., 2017; Reutzel et al., 2019). Speed is commonly used as the primary outcome of alphabet writing measures by counting the number of legible and correctly sequenced letters written in various time increments, with 60 seconds being commonly used as a cut-off point (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik & Al Otaiba, 2012; Puranik et al., 2017; Reutzel et al., 2019).

Floor or very low score effects have been reported in alphabet writing fluency measures for kindergarten both at the beginning and the end of the academic year, indicating the important role of memory recall in handwriting fluency (Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik et al., 2017; Reutzel et al., 2019). However, for both alphabet writing and dictated individual letter writing measures, factors other than memory recall may influence scoring. Perceptual motor abilities, as previously described, may impact legibility factors such as letter appearance, orientation and form accuracy. Further, retrieval of the correct motor pattern for letter formation may be facilitated by reducing cognitive load, such as by providing a model to copy. Commonly, in both alphabet writing and dictated letter writing methods, a correct score is only achieved when the letter can be both recalled *and* formed legibly on the first attempt (Dolin, 2016; Frolek Clark & Luze, 2014; Kent et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik et al., 2017). This approach of combining memory recall and letter appearance into the correct score for one attempt may mean that nuances of emerging handwriting fluency are not observed, and gradations of ability are missed.

Letter formation ability is the earliest handwriting skill taught and involves instruction in and reproduction of the correct sequence of the series of lines and strokes needed to form a letter. Whilst the amount of focus on handwriting instruction varies (Coker et al., 2016), writing the letters that match a sound is recognised as a basis to writing ability (Coker & Ritchey, 2010; Ritchey, 2008). A readily retrievable and reproducible motor pattern for a dictated letter suggests a strong orthographic letter representation and phoneme grapheme relationship, which has been described as a means of establishing memory traces (Kiefer et al., 2015). Limitations in letter formation patterns, such as incorrect formation when a letter is dictated (for example, reversals, additional lines and strokes or incorrect starting points), may, therefore, point to weaker orthographic and phoneme grapheme relationships, and impact emerging fluency (Graham et al., 2006). An accurate letter formation pattern may be impacted by cognitive demands, such as being required to write the letter from memory (van Galen, 1991). Further, visuomotor and fine motor abilities, with their known relationship with handwriting, may be especially important in letter forming due to a direct effect on legibility and accuracy, and a possible impact on the ability to control and sequence movements. It therefore follows that accurate letter formation is a measure of combined cognitive and perceptual motor abilities and a potentially useful indicator of emerging letter writing fluency for kindergarten children (Daly et al., 2003; Kushki, Schwellnus, et al., 2011). Therefore, observation of accuracy of letter formation may be a means of assessing fluency development for kindergarten children. Further, the degree of scaffolding needed to enable this skill (such as provision of a model to copy, or demonstration of how to write the letter) could indicate gradations of ability and measure variations in cognitive (memory recall of letters) and perceptual motor (fine and visuomotor) abilities.

To the authors' knowledge, there are currently no assessments of the fluency processes involved in accurate letter formation. This pilot study employed a newly designed tool, the Letter Form Assessment (LFA) that evaluates the fluency of letter forming ability by determining the degree of scaffolding (verbal, visual and modelled prompts) required to achieve accurate letter forms. The LFA is distinct from the alphabet test in that it is individually administered by an examiner, rather than administered to the whole class, as for the alphabet test. During the LFA, the examiner provides prompts to the participant to assess the level of fluency for each letter, so that it is clear whether a letter can be formed from memory, or from a visual prompt, or after a demonstration of letter formation. In contrast, the alphabet test requires participants to remember letters and write them in alphabetic sequence, and no prompting is provided if a letter cannot be remembered. These differences add a greater degree of complexity to the LFA, and provide for a more nuanced assessment of handwriting fluency for beginning writers.

3.2.4 Features of Effective Handwriting Intervention

As discussed, a combination of cognitive and perceptual motor factors influences handwriting. Given the impacts of development on emerging abilities, age and stage may influence effective intervention approaches. Traditional approaches to improving early handwriting skills emphasise the importance of improving perceptual motor factors, including fine motor, visuomotor and spatial relations skills (Kadar et al., 2020). However, treating perceptual motor skills in isolation from the task of handwriting is not considered effective in improving handwriting ability (Denton et al., 2006; Fancher et al., 2018). For beginning writers, evidence is supportive of the need for a balance between both cognitive and perceptual motor skills development. Multi-sensory and/or perceptual motor approaches have been found to have positive effects on kindergarten and grade 1 handwriting (for example, air writing, modelling letters from clay or playdough, tracing letters in sand, targeted development of fine and visuomotor skills within class tasks) (Bazyk et al., 2009; Case-Smith, 2002; Case-Smith et al., 2014; Dolin, 2016; Eidlitz-Neufeld, 2003; Jones & Christensen, 2012; Salls et al., 2013; Schneck et al., 2012).

Other effective interventions include memory retrieval of letters and words (Berninger et al., 1997; Weintraub et al., 2009; Zwicker & Hadwin, 2009) and are characterised by sufficient practice (Hoy et al., 2011). Specific teaching and learning strategies such as modelling, guided practice, repetition and opportunities for independent practice at retrieval of newly learnt information have been found to be important for the process of creating memory representations for letters and words (Engel et al., 2018; Ritchey, 2008; Vander Hart et al., 2010). For younger children, curriculum-based methods for whole classes, often including a blend of letter writing and perceptual motor skills development, have been found to be effective in eliciting small to moderate effects in handwriting legibility (Engel et al., 2018). Effect sizes in this study were considered to be lower as the control groups were also receiving regular instruction and were therefore likely to also gain in handwriting ability.

3.2.5 Whole-class Approaches to Intervention

Many handwriting interventions are delivered individually after handwriting difficulties have emerged; however, exposure to high quality handwriting instruction may prevent problems developing by meeting the needs of diverse early learners (Case-Smith et al., 2014; Engel et al., 2018). Multidisciplinary scholars have begun to research methods for assisting whole classes, through collaborative handwriting and writing programs with educators (Bazyk et al., 2009; Case-Smith et al., 2014; Dolin, 2016; Eckberg Zylstra & Pfeiffer, 2016; Pfeiffer et al., 2015; Puranik, Petscher, et al., 2018; Randall, 2018). Interdisciplinary approaches to handwriting instruction reflect the growing awareness of the complex interplay of cognitive and motor skills that contribute to handwriting fluency and, by combining professional skill sets, address students' needs for both educational and developmental supports (Case-Smith et al., 2012; Nye & Sood, 2019). Collaborative, whole-class handwriting and handwriting readiness programs have been developed and tested for grade 1 and preschool students (see Engel et al., 2018, for a review). However, many children are introduced formally to handwriting in their first year at school, which in most states in Australia is known as kindergarten. Investigation of effective methods for introducing letter learning in the kindergarten year is needed.

3.2.6 Write Start

Write Start is a co-taught, whole-class program for grade 1 students, developed in the United States (Case-Smith et al., 2011). Write Start was found to be effective in improving both handwriting and writing fluency for a compositional task (Case-Smith et al., 2014). Write Start includes effective elements of handwriting intervention for younger writers including visuomotor, fine motor and cognitive skills development within the context of explicit handwriting instruction and practice. The Write Start program is co-taught by the classroom teacher, an occupational therapist and an additional teacher or assistant who has been trained to deliver the program. Sessions are held twice a week, for 12 weeks, with the first session using station-based teaching and learning activities emphasising both letter forming and development of the evidence-based contributing skills to handwriting. The second session is designed to apply the learning of the first session in a writers' workshop, in which meaningful and contextual writing tasks occur with high levels of feedback from supporting adults. Whilst this model is effective for children in grade 1, it is not known if an adapted model for kindergarten, when letters are learnt for the first time, is effective in handwriting fluency development.

3.2.7 Research Questions

This article reports on the outcomes of a whole-class intervention program (modified Write Start) designed to improve the handwriting fluency of kindergarten children. For the present study, handwriting fluency was measured using the LFA (described in the Methods Section 3.3). We hypothesised that the modified Write Start intervention would result in improved handwriting fluency, as measured by the LFA. A secondary line of enquiry in this study was to determine the effect of differing early literacy ability on intervention outcomes. We hypothesised that, given the relationship between phonological skills and emerging handwriting, there would be significant differences in intervention effect between children with lower or higher literacy on school entry. As the intervention was not specifically targeting phonological skills, we speculated that children with higher levels of early literacy would have greater gains in handwriting fluency after the intervention, due to the advantage of stronger early literacy skills.

The research questions for the study were:

Question 1: Does a modified Write Start intervention improve handwriting fluency in kindergarten students?

Question 2: Were gains in handwriting fluency following a modified Write Start intervention impacted by early literacy ability?

3.3 Methods

3.3.1 Study Design

A retrospective analysis was used to address the study aims. The University of Newcastle Human Research Ethics Committee approved the study on 13 February, 2018 (H-2017-0415).

3.3.2 Participants

One school agreed to participate in the study by providing access to de-identified data that had been previously collected as part of routine assessment processes at the school. The school was a large independent primary school in regional New South Wales, with three kindergarten classes (n = 81; mean age = 66.1 months; males = 39, females = 42). All kindergarten students were included in the modified Write Start program conducted in the school as all were able to hold a pencil, follow simple instructions and attempt to replicate letter forms. Adjustments were made to the program during implementation for students with an identified disability, such as simplification of instructions, individual modelling of intervention tasks and variations to the amount and type of feedback to maximise positive participation. At all times, the emphasis was on providing an achievable level of challenge for each student. The kindergarten children were monolingual English speakers, which was reflective of the population of the region in which the study took place.

3.3.3 Procedure

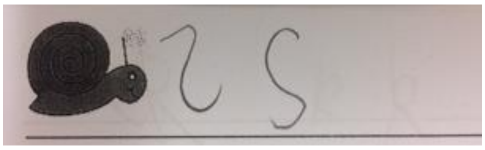
Data were obtained retrospectively from school records. Data comprised pre- and post-intervention (modified Write Start) handwriting fluency scores (LFA) and pre-intervention literacy scores for each participant. The literacy data were extracted retrospectively from school records of entry level assessments conducted by teachers at the start of the school year, as required by New South Wales Department of Education (Best Start Kindergarten Assessment; NSW Department of Education, 2021a). The data were retrospectively analysed for the effect of intervention on handwriting fluency and the relationship between pre-intervention literacy scores and intervention outcomes.

3.3.4 Letter Form Assessment (LFA)

The LFA is an untimed, individually administered paper and pencil assessment. Participants are asked to write individual lowercase letter forms one at a time, corresponding with a picture and verbal (letter name and sound) prompt for each letter. For each letter, a cascading series of prompts is used to facilitate letter formation, depending on the participant's ability. For example, for the letter *"a",* the examiner points to a picture of an apple and says *this is an apple, apple starts with "a" and the sound is /a/.* The examiner carefully observes the first attempt at letter formation and uses this observation to determine the need for subsequent prompts. Subsequent prompts include the provision of an example of the letter to copy, then a demonstration of how to write the letter (see Figure 3.1).

Figure 3.1

Sample LFA

In the first image, the participant's first attempt at the letter 's' from memory was reversed. The second attempt, when shown a model of the letter 's', was formed correctly. In the second image, the first two attempts at the letter 'b' (from memory, then copying a model) were reversed. The assessor modelled the third letter 'b' , and the participant was then able to reproduce the letter using correct formation (4th letter 'b'). The assessor determined if the correct formation was made at the time of writing based on observation of use of the series of strokes needed to form the letter as per classroom instruction.

In this study, 8 letters were assessed at each data collection point, with a maximum score of 32 points (8 x 4 points) possible. For each letter, four points were given for correct letter formation from memory, three points for correct letter formation when copying from an example model, two points for correct letter formation when imitating after a demonstration, one point for a recognisable letter with incorrect formation after a demonstration, and zero points for an unrecognisable letter. The letters assessed pre-intervention were learnt in the preceding eight weeks (m, a, t, s, p, n, c and d). The letters assessed post-intervention were learnt during the modified Write Start intervention (h, l, b, f, g, k, o and w). Each item on the pre and post test LFA was an individual letter, represented by a picture that was recognisable to kindergarten students, for example, an apple. The test was developed based on adaptation of commonly used dictated individual letter assessments, in which one letter verbal prompt is presented at time by the examiner, and the participant is required to write the letter from memory. The LFA extends this method by providing a visual and demonstration prompt after the initial verbal prompt. In addition, the LFA provides a familiar picture prompt for each randomly order letter in order to support writing from memory.

3.3.5 Early Literacy Measure—Best Start Assessment

In New South Wales schools, literacy measures are collected at the beginning of the kindergarten year using the Best Start Assessment (BSA) (NSW Department of Education, 2021a). At the time of data collection, the purpose of the BSA was to monitor progress across seven literacy domains—reading texts, phonics, phonemic awareness, concepts about print, comprehension, aspects of speaking and aspects of writing. Students individually completed the BSA with their teacher, with a score from one to four given for each domain, with one being the lowest score. As low scores are common on kindergarten entry, we selected literacy domains of highest relevance to our study and with balanced distributions between low and high ability (phonemic awareness, phonics and writing). A balanced distribution was defined as greater than 30% of participants allocated to each Tier. An exception to this rule was made for the domain of writing because of the high relevance of this domain to the study. Scores were dichotomised by the researchers into Low and High Tiers of ability level. Children with scores of zero or one were categorised in the Low Tier group, and children with scores greater than one were allocated to the High Tier group. In the BSA, phonemic awareness was measured through testing of awareness of speech sounds, syllables and rhymes. Phonics was measured using the ability to map sounds to letters and the measurement of writing included the ability to write one's name and any other known words. The full range of measures collected in the BSA and the distribution between Low and High Tiers are shown in Table 3.1.

Table 3.1

Mean, Median and Mode of Best Start Measures and Valid Percentages by Tier

Best Start Measure (n = 70)	Mean	Median	Mode	Low Tier valid percentages	High Tier valid percentages
Reading texts	1.099	1.000	1	93	7
Phonics	1.76	1.00	1	64.8	35.2
Phonemic awareness	1.49	1.00	1	62	38
Concepts about print	1.14	1.00	1	91.5	8.5
Comprehension	1.43	1.00	1	68.6	31.4
Aspects of speaking	1.87	2.00	1	40.8	59.2
Aspects of writing	1.10	1.00	1	91.5	8.5

3.3.6 Intervention

The intervention, modified Write Start, was implemented using a co-teaching approach twice a week, in two 45-minute blocks for eight weeks in the second half of the kindergarten year by the first author (KR), the class teacher and a trained school class assistant. The original Write Start designed for grade 1 consisted of two sessions. The first session included whole-class instruction on letter formation of a group of letters, followed by station-based activities emphasising cognitive, fine motor and visuomotor skills development. The second session also commenced with whole-class instruction and was then followed by writing tasks utilising a writers' workshop model. In the workshop, an authentic writing task was carried out and opportunities were provided for sharing and feedback. In both sessions, the emphasis was on fluent letter forming. For modified Write Start, adjustments were made to accommodate the unique stage of learning for kindergarten students including a reduction in the number of letters presented in each session, a focus on individual letter forming rather than on words and the inclusion of a modified writers' workshop that integrated a craft activity with a related guided sentence writing activity. The overall structure of whole-class instruction was followed by station-based activities. During the first session of each week (Session 1), as for Write Start, a workstation model was used with activities emphasising fine motor, visuomotor and cognitive skills. Activities frequently engaged the task of letter forming or writing for example, using fine motor skills to shape a letter correctly from playdough. During the second session of each week (Session 2) the emphasis was on meaningful writing experiences, approximating the writers' workshop approach, but being tailored for emerging writing skills. A summary of adjustments made in modified Write Start are in Table 3.2.

Table 3.2

Adjustments to Write Start for Kindergarten

Session	Write Start	Modified Write Start
Both Sessions 1 and 2	A group of focus letters presented each week.	One focus letter per week.
	Whole-class instruction in letter formation of a group of letters.	Whole-class instruction for letter formation of one letter.
Session 1	Station-based fine motor, visuomotor and cognitive-based activities included focus letters and words.	Station-based fine motor, visuomotor and cognitive-based activities generally included focus letters only, with some words included over time.
Session 2	Sentence copying, writing assignments (for example, story writing or assignments) and a writer's workshop (mini lesson on writing convention or concept).	A guided sentence was used and related to a craft activity to create an authentic writing experience, using strategies to promote memory recall for letter and word writing.
	Self-generated writing followed writers' workshop.	Extensions to guided writing were encouraged as skills developed.
	Feedback provided by station helpers to encourage a focus on 'best' handwriting and to promote letter forming skills and writing from memory.	Feedback from station helpers focussed on skills utilised in craft including manipulation of tools, following instructions and use of hands for complex tasks. Feedback in a related guided writing activity focussed on effective use of letter formation to write from memory with prompting as needed.

3.3.7 Analysis

To address the first research question, change in LFA score from pre- to post-intervention was assessed using the Wilcoxon Signed Ranks Test. This non-parametric analysis was chosen as the LFA scores were non-normally distributed at pre- and post-test. To address the second research question, one way ANOVA was conducted to determine if there was a significant difference in LFA change score by Low or High Tier for the three literacy measures included in the study (phonics, phonemic awareness and writing).

3.4 Results

3.4.1 Descriptive Statistics

Eighty-one participants (mean age = 65.9 months) had complete LFA data and were included in the analysis (see Table 3.3). A ceiling effect was observed at both pre- and post-testing for participants where pre- and/or post-data were available (n = 84 pre-test, n = 82 post-test). However, no floor effect was observed.

Table 3.3

Descriptive Data for LFA Pre, Post and Change Scores

Measures	Minimum	Maximum	Mean	Median	SD
LFA pre-score (n = 84)	10	32	26.0	28.8	5.3
LFA post-score (n = 82)	18	32	28.8	29.0	3.02
LFA change score (n = 81)	-6.00	15.00	2.7	2.0	4.6

Early literacy measures were available for 70 participants for whom full pre- and post- LFA data were available. Low and High Tier valid percentages were calculated to determine measures that demonstrated more balance between both Tiers, based on a distribution split of a minimum of one third of scores falling into each grouping (Table 3.1). As described in Methods, three measures were included in the analysis based on either valid percentages (phonics and phonemic awareness) or relevance of the measure to the study (aspects of writing).

3.4.2 Question 1—Did Modified Write Start Improve Handwriting Fluency?

A Wilcoxon Signed Ranks Test indicated that the median post-test LFA ranks were significantly higher than median pre-test ranks ($Z = -4.457$, $p < .0001$) indicating that fluency improved after the handwriting intervention.

3.4.3 Question 2—Were Fluency Gains Impacted by Early Literacy?

One way analysis of variance was used to determine differences in LFA change score between literacy groups (Low and High Tier) for phonics, phonemic awareness and writing. Although mean LFA change score was highest for High Tier groups in all literacy areas, no significant differences were observed (phonics: $f_{(19, 50)} = 1.11$, $p = 0.36$, phonemic awareness; $f_{(19,50)} = 1.32$, $p = 0.21$ or writing: $f_{(19,50)} = 0.59$, $p = 0.89$) (See Table 3.4). A higher degree of variation in mean LFA change score was noted for children in Low Tier groupings compared to High Tier groupings for all three literacy measures, demonstrated by the greater standard deviation.

Table 3.4

LFA Change Score by Tier Grouping, SD, Test Statistic and Significance

Literacy measure	Tier	Mean LFA change score	Std. Deviation	$F_{(df)}$, p value
Phonics	Low Tier (n=46)	2.30	5.10	$1.11_{(19, 50)}$, 0.36
	High Tier (n=24)	3.38	4.13	
Phonemic awareness	Low Tier (n=43)	2.49	5.42	$1.32_{(19,50)}$, 0.21
	High Tier (n=27)	2.96	3.63	
Aspects of writing	Low Tier (n= 64)	2.42	4.85	$0.59_{(19,50)}$, 0.89
	High Tier (n= 6)	5.33	3.33	

3.5 Discussion

This study examined the effect of an embedded, co-taught handwriting intervention, modified Write Start, on handwriting fluency in kindergarten students. The study also examined the effect of early literacy abilities on intervention outcomes. A significant improvement in handwriting fluency in kindergarten students was observed after implementation of the modified Write Start intervention. No significant effects of early literacy abilities on intervention outcomes were observed. However, higher variability was noted in handwriting fluency change scores for Low Tier (lower early literacy) students and greater, although non-significant, change scores for High Tier (higher early literacy) students on each literacy measure.

3.5.1 Effective Handwriting Fluency Intervention for Kindergarten

As hypothesised, handwriting fluency significantly improved following the implementation of the modified Write Start intervention. This intervention targeted developmentally appropriate cognitive and perceptual motor skills abilities of emerging writers and used a co-teaching, explicit instruction and activity-station framework. This study found preliminary evidence to support the use of the modified Write Start program with beginning writers.

The elements of the modified Write Start program are consistent with the original Write Start model designed and tested by Case-Smith et al. (2011), with adaptations made to both activities and approach to be developmentally suited to the kindergarten year. Strategies consistent across both Write Start and the modified Write Start include whole-class direct and explicit instruction of letter forms, and station-based groups that emphasise letter forming within the context of fine motor, visuomotor and cognitive development. Perceptual motor skills have an established relationship with handwriting development and may serve to enhance or impede handwriting practice (Klein et al., 2021). Explicit instruction, practice and direct feedback are emphasised in both Write Start and modified Write Start. Direct and explicit instruction has been linked to successful outcomes for writing, with explicit, written instruction for forming new movement patterns found to be superior to tracing or tracking a moving target (Overvelde & Hulstijn, 2011b). Feedback has also been identified as a crucial ingredient in kindergarten writing programs (Puranik, Petscher, et al., 2018) and was actively included in modified Write Start and facilitated by the program design of station-based teaching. The methodology allows for short bursts of focussed attention at each station, and through engaging activity, maximises the visual and motor self-monitoring needed when learning to write (Weintraub & Graham, 2000). Sufficient practice has also been identified as a key ingredient in handwriting interventions (Hoy et al., 2011) and practice that incorporates memory recall has been shown to be an effective means of improving handwriting (Berninger et al., 1997; Zwicker & Hadwin, 2009). The modified Write Start methodology concurrently developed memory recall and perceptual motor abilities through the station-based activities to facilitate developing handwriting fluency.

3.5.2 Early Literacy and Intervention Effects

We hypothesised that participants with a higher score on measures of early literacy would make greater gains in handwriting fluency as a result of the intervention. This hypothesis was based on the evidence for the impact of aspects of literacy such as letter name and sound knowledge on generation of mental representations of letters, and the important role of these representations in handwriting fluency development (Cartmill et al., 2009). We were interested in these effects as the results could give important insights into the focus of handwriting interventions for kindergarten children. We found there were no significant effects of early literacy (phonics, phonemic awareness and writing) on intervention outcomes. However, children grouped in the High Tier for each included literacy measure showed a trend for greater intervention effect. Additionally, children in the Low Tier groupings for each measure demonstrated higher variability in their response to the intervention.

For each of the three literacy variables included in the study, the change in handwriting fluency was greater for High Tier groupings than Low Tier groupings. This result suggests that, despite not being statistically significant, there may be clinically important trends to consider in relation to early phonics, phonemic and writing abilities. The capacity of the High Tier group, with higher early skills in these three areas, may have translated to greater integration of the phonemic, orthographic and motor skills indicated in writing (Costa et al., 2018; Hooper et al., 2010). This trend is supportive of models of handwriting fluency acquisition that incorporate the role of cognitive processes that lead to the coupling of letter names and sounds to letter forms (Berninger, 2000; Cartmill et al., 2009; Kim, Gatlin, et al., 2018). Future versions of modified Write Start may require a stronger focus on process models for handwriting fluency acquisition in order to support participants who have lower early literacy abilities. For example, the modified Write Start activities included fine motor, visuomotor and cognitive station-based activities. A revised program, utilising the trends noted in this study, could emphasise memory recall of letter names, sounds and forms within each activity station, whilst still retaining the activity theme, such as on fine motor skill development.

A second trend noted in this study was that the Low Tier groupings for the three early literacy measures demonstrated higher variability in intervention effects, as shown by a higher standard deviation of LFA change scores. This higher standard deviation may reflect the unique learning profile of students and suggests that the modified Write Start was more effective for some students with lower early literacy than others. A revised and updated modified Write Start, with a stronger focus on process approaches to handwriting acquisition as described above, may benefit more students.

3.5.3 Handwriting Fluency Measures in Kindergarten

The LFA was introduced in this study as an extension of current measures of handwriting fluency in kindergarten. It includes standard methods of dictation of individual letters, but this step is followed by a cascading series of prompts to assist accurate letter formation as needed (provision of an example of the letter to copy, then demonstration of the letter formation pattern). This method allows for assessment of emerging handwriting fluency, and focusses on accuracy in letter formation patterns. Learning formation patterns for letters is commonly taught in kindergarten as new letters are introduced (Ritchey, 2008) and may be a mechanism for coupling letter names and sounds with forms (Kiefer et al., 2015).

As previously described, letter formation ability, and the degree of assistance needed to achieve accurate formation may point to the degree of association between letter names, sounds and forms, and may therefore be an indicator of emerging fluency or limitations to fluency. For example, in many cases in the LFA, a participant may have been unable to demonstrate a correct letter formation pattern from memory, but was readily able to do this in the next step, when shown an example of the letter to copy. What this points to is the role of cognitive load in handwriting fluency development. Researchers have found that increasing handwriting fluency through training that promotes memory recall for formation of letters has resulted in enhanced story writing, both for quantity and quality (Arrimada et al., 2018; Berninger et al., 1997; Jones & Christensen, 1999; Limpo & Alves, 2018). The impact of overloaded mental processes (such as trying to recall how to write a letter) on working memory explains this effect. Similarly, it is conceived that, at the kindergarten level, the capacity for letter formation, as demonstrated through the level of prompting needed to support accuracy, is a measure of capacity to develop handwriting fluency. The amount of prompting needed to enable letter formation is therefore a measure of fluency abilities or limitations. The LFA was able to detect changes in emerging letter writing fluency in this study, and no floor effects were observed, suggesting it may be a useful methodology to utilise in groups with emerging and variable handwriting ability. This approach may be especially important for kindergarten due the emergence of, and variation in, cognitive and perceptual motor skills.

3.5.4 Limitations

While this study found a significant improvement in handwriting fluency in kindergarten students after the modified Write Start intervention, a control group was not employed and therefore, improvement in handwriting fluency due to natural development or standard teaching cannot be discounted as a contributor to the effects reported here. However, this study makes an important contribution with findings that may be able to be replicated in subsequent studies. Further testing using a matched two-group study would help to provide more substantial evidence for an intervention effect by comparing standard teaching alongside the intervention approach.

We found a trend towards greater intervention effects for participants with higher early literacy, although this was not statistically significant. It is possible that measurements of literacy taken prior to the commencement of kindergarten through Best Start Assessments were not sensitive enough for predicting the impact of the intervention program for students with differing levels of literacy ability. However, the trend towards greater impact for children with higher literacy supports a revision of the modified Write Start to ensure handwriting fluency processes are incorporated. Models for handwriting fluency acquisition may need to be used to guide and revise the intervention approach.

The LFA was used in this study as a handwriting fluency measure to extend the use of dictated, non-alphabetically sequenced methods by adding scaffolds to assist accurate letter formation. An advantage of this method was that no floor effects were seen; however, a ceiling effect was observed, suggesting the test needs to be extended to increase the range of outcomes. Further versions of the LFA should increase the number of letters tested to include the whole alphabet. The LFA was also not compared with a commonly used method of measuring fluency, alphabet writing testing. However, the tool is based on accepted methods of handwriting fluency assessment and extends these methods. Further study using the LFA should also incorporate additional measures of handwriting fluency. Examiner prompting of participants during assessment is one feature of the LFA. This aspect of the assessment should be addressed in future studies of inter-rater reliability.

3.5.5 Implications for Occupational Therapy Practice

The findings of this study have the following implications for occupational therapy practice:

- Preliminary evidence supports the use of the modified Write Start for kindergarten children as a whole-class, co-taught approach to handwriting fluency development. Further revisions of the intervention focussing on a model for handwriting fluency development are indicated to reflect the trend in this study for children with higher early literacy abilities to have greater intervention outcomes.
- Measurement of handwriting fluency for emerging or struggling writers may be assisted by measurement of the degree of prompting needed for successful letter formation. The LFA methodology has been introduced in this study as an extension of conventional measures of handwriting fluency in Kindergarten.

3.5.6 Suggestions for Future Research

The evidence found in this study is supportive of further investigations into the effect of whole-class handwriting interventions for kindergarten students. Three areas of research are proposed:

1. Further research of a revised and updated modified Write Start program using a two-group study should seek to determine if the intervention improves kindergarten handwriting fluency over and above standard teaching.
2. A relationship between early measures of literacy (phonics, phonemic awareness and writing) and intervention outcome was not detected in this study, however trends suggested that children with stronger early abilities in these measures had a greater response to the

intervention. Strengthening of letter name, sound and form relationships through intervention activity approaches could enhance the effectiveness of the modified Write Start program for all students and is indicated for further research.

3. Handwriting fluency is indicated in a range of literacy abilities, which have a profound impact on school participation and engagement. Handwriting fluency is an important area of study as occupational therapists increasingly integrate their practice into school settings and curriculum (Engel et al., 2018). Further, functional literacy is now included in occupational therapy scope of practice, given the major ramifications of literacy ability across the lifespan (Arnaud & Gutman, 2020; Frolek Clark, 2016; Grajo et al., 2020; Grajo & Gutman, 2019). Further research is needed to determine the effect of improved handwriting fluency on literacy abilities for Kindergarten children. Further research using an updated and revised modified Write Start is indicated by this study to identify whether the intervention approach, which demonstrated effects on handwriting fluency in this study, has the potential to impact both handwriting and literacy. Additional studies should analyse the effect of changes to handwriting fluency on literacy outcomes to increase understanding of the relationship between these factors.

3.6 Conclusion

Whole-class approaches are increasingly utilised to integrate therapy into naturalistic environments and to also work in a preventive way, meeting needs for children with undiagnosed or undetected difficulties. The findings of this study provide support for the use of a whole-class, co-taught Kindergarten approach for occupational therapy and teaching intervention to promote handwriting fluency. Whole-class handwriting interventions based on evidence driven programs such as modified Write Start have the potential to improve kindergarten handwriting fluency. The modified Write Start program piloted in this study is grounded in evidence and provides a possible model for occupational therapists and teachers working collaboratively to address the needs of children in present day classrooms. Handwriting fluency measures for kindergarten such as the LFA may provide clinicians with a more nuanced understanding of handwriting difficulties. Further research of both modified Write Start and the LFA are indicated.

Chapter 4 Theoretical model

4.1 Introduction

Findings described in Chapters 1 to 3 suggest that handwriting fluency in beginning writers is associated with early literacy skills and that coordination of cognitive and perceptual motor processes influence handwriting fluency acquisition. Chapter 1 described the factors that contribute to handwriting acquisition, including perceptual motor and cognitive abilities. The systematic review in Chapter 2 identified strong evidence for handwriting fluency (described in Chapter 2 as letter writing fluency for Kindergarten) and literacy relationships. Handwriting fluency integrates recall of letters with perceptual motor abilities. However, weaker evidence was found for a direct relationship between perceptual motor skills and literacy, suggesting that handwriting fluency may mediate handwriting-literacy links. Further preliminary support for this conclusion was found in the pilot study (Chapter 3), where a modified Write Start intervention emphasising perceptual motor (fine and visuomotor) and cognitive (recall of letter formation) skills development was shown to positively impact handwriting fluency. Also, children with higher early literacy abilities demonstrated better handwriting fluency outcomes, although this was not statistically significant.

In this chapter, a theoretical model for handwriting fluency acquisition is proposed. The model addresses all thesis questions by identifying the underpinnings of handwriting fluency acquisition for Kindergarten and by providing a guide for intervention approaches. First (Section 4.2), the theoretical base for the model is synthesised, drawing on the literature review from Chapter 1. Second, (Section 4.3), the proposed model for handwriting fluency acquisition is presented. The 4*R*s model consists of four quadrants—*Recall, Retrieve, Reproduce and Repeat* (4*Rs*). Each quadrant of the model is defined, and model assumptions are listed. Section 4.4 details the evidence in support of the definitions, key concepts and assumptions included in the model. In Section 4.4, research focussing on handwriting products and processes is reviewed and the section concludes with an analysis of how present day theories have been adapted to incorporate the interrelationship of both factors for beginning writers.

Sections 4.5 specifies relationships of process (the underlying cognitive mechanisms that enable the product) and product (the output of writing including appearance, legibility and formation) within each 4*R*s quadrant and provide specific evidence in support of the inclusion of each quadrant in the model. Section 4.6 reviews evidence relevant to the 4*R*s model from the systematic review (Chapter 2) and the pilot study (Chapter 3). The chapter concludes by recommending application of the 4*R*s model to Kindergarten handwriting intervention approaches.

4.2 Theoretical Base of 4*Rs* Model

As described in Chapter 1, handwriting is a complex skill consisting of perceptual, cognitive, and motor factors that need to work in synchrony. The acquisition of proficient handwriting is a multistage, multilevel process, requiring integration across and between sensorimotor, cognitive, and self-regulation abilities (Kushki, Schwellnus, et al., 2011; Medwell & Wray, 2007; Volman et al., 2006). Cartmill et al. (2009) suggest that handwriting comprises perception, cognition and action processes and requires a sequential process that includes sensory perception, letter-sound knowledge and correspondence with graphemes, motor program recruitment and planning and muscular execution of the motor plan. Smooth systematisation or "flexible orchestration" across these areas requires both sequential *and* concurrent development of all component skills (Berninger et al., 2001, p. 64). Acquisition of handwriting fluency can therefore be seen as a confluence of maturing skills. As discussed in Chapter 3, handwriting fluency is often measured by a timed test of writing alphabet letters from memory. Such tasks assess both the motor aspects of writing letter shapes as well as the ability to independently generate or recall the letter in the mind. Authors have recognised that handwriting fluency incorporates both the handwriting *product* (the output of writing including appearance, legibility and formation) and *process* (the underlying cognitive mechanisms that enable the product) (Graham & Weintraub, 1996; Rosenblum et al., 2003). The interrelationship of these process and product factors also appears to be a less tangible but an equally important aspect of fluency development.

A number of authors have described various contributors to handwriting fluency. Berninger et al. (1997) referred to lower-level skills in learning to write, the level in operation for Kindergarten students, and described these as drawing on "multiple component processes" (p. 652) and including "creating letter representations in memory, accessing and retrieving these representations in memory, motor planning and motor production" (p. 652). Alstad et al. (2015) referred to a measure of handwriting fluency, timed alphabet writing, as an "index of automatic letter access, retrieval and production" (p. 2). Graham and Weintraub (1996) also described the multiple processes contributing to handwriting, and explained that production of writing involves "semantic, syntactic, lexical and phonological factors" (p. 14). All of these factors are noted as having an impact on the output of handwriting—the production of letters or words. Whilst a lot has been learned about handwriting processes, synthesis of this knowledge into a practice model to facilitate fluency acquisition has not yet occurred.

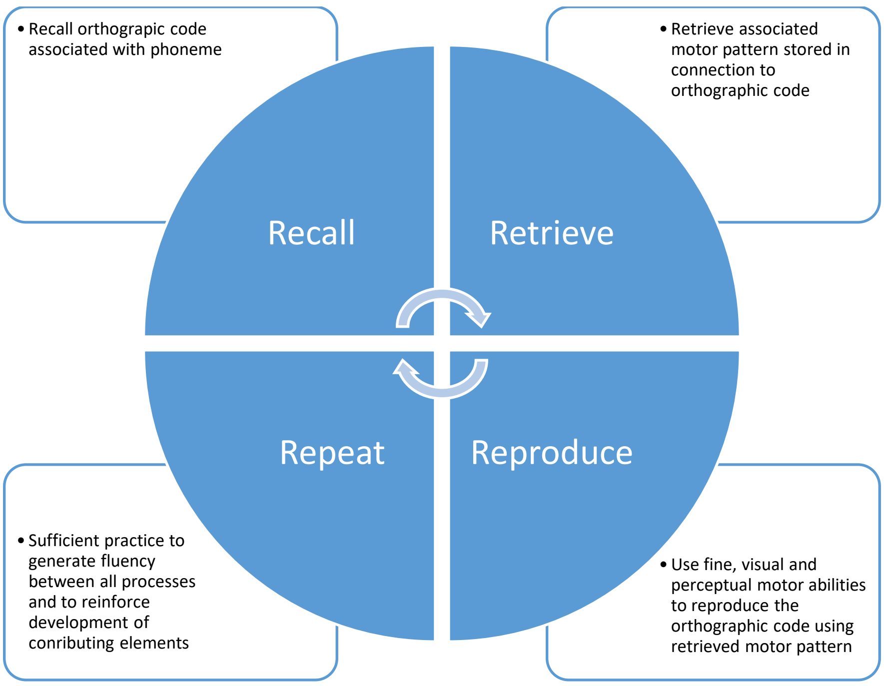
What, then, are the keys to handwriting fluency acquisition for beginning writers? It appears that both a strong, self-generated representation of a letter and the motor production of the letter are crucial elements (Berninger et al., 1997; Graham & Weintraub, 1996). Therefore, the key ingredients identified in fluency processes for beginning writers include the *creation* and recall of representations of letter forms (orthographic codes) in memory and the *creation* and retrieval of motor patterns. Product factors include perceptual motor components that may be a crucial constraint to handwriting fluency and practice that may be impeded or enhanced by the level of fine and visuomotor control and by the capacity to access letter representations. Thus, a model for handwriting fluency acquisition for beginning writers must include the cognitive and motor components of the fluency system, and also highlight the interrelationship of these components.

4.3 The 4*Rs* Model of Handwriting Fluency Acquisition

The 4*Rs* model proposes that the acquisition of handwriting fluency is reliant on four process and product factors (quadrants)—*Recall*, *Retrieve*, *Reproduce* and *Repeat*. Each quadrant is interdependent (Roux et al., 2013; van Galen, 1991) and smooth systemisation between quadrants is required to achieve automatic processing. This model is not hierarchical; rather the processes occur simultaneously, using the effect of cognitive "buffering" as a means to hold and store competing processes (van Galen, 1991). The four quadrants in the model work in a circular fashion, with continuous cycles required to create fluency (see Figure 4.1). Process elements include *recall* and *retrieve* and product elements include *reproduce* and *repeat*.

Figure 4.1

The 4Rs Model of Handwriting Fluency Acquisition



4.3.1 Foundational Definitions, Assumptions and Concepts

The definitions and assumptions of each quadrant are described in Table 4.1.

Table 4.1

Definitions of the 4Rs Quadrants and Related Assumptions

Quadrant	Definition	Assumptions
Recall	Recollection of the orthographic code for a letter or word (Abbott & Berninger, 1993; Berninger et al., 1997; Puranik & Apel, 2010; Rodriguez & Villarroel, 2017).	• Mapping phonemes to graphemes through letter formation practice creates strong, retrievable orthographic letter representations • Fluent handwriting of letters facilitates early writing through increasingly retrievable letter representations that support ability to encode words phonetically
Retrieve	Retrieval of the system of movements, or motor plan, associated with the recalled letter form (Grace et al., 2018; Graham et al., 2006; van Galen, 1991).	• Letter formation ability, the ability to learn and generate a specific series of lines and strokes to form a letter, activates cognitive processes essential for handwriting fluency • When a motor pattern for a letter is quickly retrievable, phonetic or invented spelling becomes more accessible
Reproduce	Recruitment of specific musculature to enable the retrieved letter form to be transcribed as planned, influenced by fine motor, visuomotor, visual perceptual and kinaesthetic abilities (Cornhill & Case-Smith, 1996; Graham et al., 2006; Kaiser et al., 2009; Kushki, Schwellnus, et al., 2011; Volman et al., 2006).	• Component skills that predict handwriting abilities are in development for beginning writers and will influence the writing system. • A combination approach is required to ensure that component skill development does not impede the emergence of handwriting fluency through cognitive and motor processes.
Repeat	Sufficient repetition or practice that specifically involves handwriting, rather than contributing component skills in isolation (Hoy et al., 2011; Santangelo & Graham, 2016).	• Letter formation practice is most effective when memory recall is activated • Graphemes are mapped to phonemes through sufficient handwriting repetition

The 4*Rs* model is conceived as a concurrent process and is influenced by the stage of learning. For example, when learning letters for the first time, a child in formal instruction is also learning how to use letters in combination for the first time, such as in newly learnt, phonologically simple words. It follows that, if orthographic representations and motor programs for letters are internalised, and easy

to recall, retrieve and reproduce, forming letters can occur more quickly and accurately—in essence, fluency is achieved. It also follows that phonological and graphical knowledge—that is the name, sound, appearance and formation pattern of a letter—is crucial information in the process of creating and executing a motor program. For Kindergarten students, the system is in the earliest stages of development, and visual feedback, visuomotor and visual perceptual skills appear to be important (Graham & Weintraub, 1996; Lee et al., 2016; Weintraub & Graham, 2000). In the 4*R*s model, the four quadrants work together to develop handwriting fluency whereby repeated opportunities to recall, retrieve and reproduce letter formation patterns are created. Through this continuous process, the various essential elements that underpin handwriting are able to be acquired and consolidated.

4.4 Evidence for Definitions, Assumptions and Concepts Included in the 4*R*s Model

A review of writing research since the 1970s is presented in the following section to explain the emergence of contemporary theories of writing and specific accommodations in these theories for beginning writers. Three phases of research are described: firstly focussing on product (how instructional methods impacted handwriting performance); secondly focussing on process (how a range of cognitive factors enhanced or constrained writing); and, finally blending product and process factors to understand combined impacts on writing. This review concludes with the key implications and adaptations of theory for beginning writers and relevance to the 4*R*s model.

4.4.1 Product Theory and Research of the 1970s

Historically, writing research has centred around the product, investigating the appearance of letters on the page and instructional methods that had the most impact on the appearance of letter forms. In 1980, Peck et al. (1980) summarised the previous decade of research including the most efficient letter forms (and more difficult letters to form), instructional techniques, effects of body positioning on writing performance, and the effects of different writing surfaces and materials. Certain instructional techniques were shown to be more effective than others. Of note, in this decade of research was that even though the output was the main outcome measured in terms of the appearance of letter forms, significant progress was made in understanding how instructional technique influenced the development of handwriting. A focus on perceptual motor interventions to improve handwriting reinforced the role of instructional methods in handwriting development. The discovery of lack of generalisability of improved letter forming for taught letters to novel letters pointed to underlying cognitive processes in handwriting acquisition.

4.4.1.1 Instructional Technique Research.

A key finding from the 1970s to the 1980s, which set the scene for future research into process, was the enhanced handwriting ability achieved when instruction included opportunities for modelling of letter formation, verbal guidance of the forming of the letter, and practice through copying. Peck et al. (1980) pointed to the potential of use of verbal and visual modelling combined with copying practice for both general instruction and for children with handwriting difficulties. For example, in one study reviewed by Peck et al. (1980), Sovik (1976) ,found that combining a modelled demonstration with verbal cues for the letter formation pattern was more effective in improving participants' copying performance (based on the accuracy of the letter form produced) than copying letters with no visual or verbal guidance, or with visual guidance alone. Of note is that many of the more effective instructional techniques Peck et al. (1980) reviewed, included aspects of instruction that may have promoted the creation of orthographic representations and retrieval of the associated motor patterns that have been identified in subsequent process-oriented research, such as copying tasks, as opposed to tracing over printed letters.

4.4.1.2 Perceptual Motor Skills Research.

Also of note in this era of research was a focus on identification of perceptual motor skills that were associated with handwriting ability, and some experimental attempts to improve handwriting via remediation of a component skill, such as visual perception. Peck et al. (1980) provided a review of studies using a perceptual motor skills approach which aimed to directly treat a component of perceptual motor skill and measure its effect on handwriting. For example, one experimental study on the effect of a handwriting readiness program using eye-hand coordination exercises, Fairchild

(1979), found that children participating in the experimental condition improved their visuomotor skills, but after a period of letter writing training, did not have improved letter writing skills compared with the non-experimental group. Studies such as this led authors to conclude that perceptual motor and handwriting skills were distinct and separable.

4.4.1.3 Generalisability.

In addition to the finding that perceptual motor skills improvement did not impact handwriting, studies reviewed by Peck et al. (1980) also concluded that, whilst handwriting could be improved for target letters, this skill did not transfer to unknown or untaught letters. Generalisability was conceived as possible in a perceptual motor framework, as handwriting was seen as a skill with component parts, which, if treated, would improve the handwriting product. Whilst the evidence did not support the hypothesis that component skills intervention could be generalised to impact handwriting, researchers were perhaps inadvertently adding to the evidence that handwriting could be acquired more readily through instructional methods that incorporated demonstration, modelling, verbal guidance and practice. What was not known at the time, and was discovered through later research, was the role of the underlying cognitive processes that may have been enacted through these instructional methods.

4.4.2 Process Theory and Research of the 1980s and 1990s

In 1996, Graham and Weintraub (1996) summarised handwriting research from the preceding decade and a half and noted the emergence of process theories and a decrease in focus on research into the effectiveness of handwriting instruction. The authors described that this shift was facilitated in part by the emergence of digitising tablets that enabled psychomotor researchers to explore features of handwriting, such as reaction time, in relation to different variables or under different conditions. This change in research focus towards digital technologies also coincided with the emergence of whole language theories of instruction which led to decreased interest in and focus on research into handwriting instruction in classrooms (Graham & Weintraub, 1996). Process theory centred around models that emphasised cognitive stages, recursive processes, the impact of cognitive effort on working memory and motor learning.

4.4.2.1 Stage Models.

The research of the 1980’s and 1990’s was informed by cognitive theorists, who proposed linear processing sequences facilitated by buffering or storage of one piece of information (such as visual recognition of the letter to be copied) with subsequent information (for example, allographic information such as the letter case). Ellis (1982) proposed a process of visual analysis and storage of visual information for writing in short-term memory, followed by activation of the graphemic system, with a series of steps or buffers to add information on the graphemic output such as allographic information (for example, choosing between upper or lowercase letter form) and motor pattern information. These steps then lead to the final step of writing, described as neuromuscular execution (Ellis, 1982). Whilst scholars such as Ellis described a linear, hierarchical process, other scholars pointed to the more recursive cognitive processes at play in writing.

4.4.2.2 Recursive Models.

Stage models, like the one proposed by Ellis (1982), investigating the internal processes of generating writing, contrasted with another influential model of writing for adult writers proposed by Flower and Hayes (1981), which described a recursive cognitive process occurring in written production, among “planning, translating and reviewing-revising” (Berninger et al., 1997, p. 652). Of note in this model were the subcomponents that contributed to planning and reviewing; however, processes that contributed to *translating*—getting thoughts onto the page—were not described. Flower and Hayes (1981) drew attention to the possible limitations of this model for beginning writers, noting that processes that contribute to translation could include a spectrum of contributing aspects such as syntax (use of words to create sentences), the mental lexicon (the vocabulary of a language) as well as the forming of letters through handwriting.

4.4.2.3 Capacity Theory.

An important development in understanding the processes that impacted writing development was the idea of working memory, and the impact of competing cognitive processes on the capacity to orchestrate multiple demands (McCutchen, 1996; McCutchen, 2000). McCutchen (1996) provided a capacity limiting model of working memory, whereby memory was seen as a limited capacity resource. In this model, writing ability was potentially enhanced by the creation of cognitive capacity through a decluttering process of automating lower-level skills. Specific skills that were seen as potentially limiting working memory were translational processes such as handwriting and spelling. Both stage and capacity theories were utilised in the study of psychomotor processes that contributed to handwriting ability, with ideas of cognitive constraint serving as a basis to study the impact of constraints on performance.

4.4.2.4 Psychomotor Research and Theory.

Psychomotor researchers investigating handwriting identified the motor program, an abstract concept to describe the neuromuscular activation resulting from processing of cognitive information for handwriting. Researchers identified how the motor program was influenced by different cognitive constraints—processing of cognitive information, manipulated through task constraints, impacted reaction times and product and indicated the role of cognitive load on execution of handwriting. Drawing on cognitive models, researchers of psychomotor behaviour devised models that incorporated process theory with models to explain the impact of process on neuromuscular activation of product.

4.4.2.4.1 The Motor Program.

Graham and Weintraub (1996), in reviewing psychomotor research, defined the motor program as "an abstract, non-muscle specific representation of a motor act" (p. 11). The motor program was defined as "non-muscle specific", based on studies that showed that various "effectors" (for example, the hand, or the wrist and shoulder) using different muscle groups could produce letter writing that was much the same in the same person regardless of which muscle group was used (see Graham &

Weintraub, 1996, for a review of studies). This research suggested that the motor program was common across different muscle groups. In effect, when using a muscle group to put a motor program into practice, it is the mind that is being trained, and by extension, the muscles.

4.4.2.4.2 Effect of Cognitive Constraints on the Motor Program.

It also became possible to understand how processes other than motor programs impacted handwriting by measuring reaction times and speed of word writing using digitisers, when different phonological, semantic, lexical and syntactic demands were made. Graham and Weintraub (1996) reviewed studies which showed that a longer processing time was required for longer words, more complex letters and more complex connections between letters when writing in cursive (for example, van Galen, 1990). Graham and Weintraub (1996) also reported evidence to suggest that there was an overlap between execution of the current letter and planning for the next one. That is, the planning for the use of the motor program was occurring ahead of time, but also in parallel.

4.4.2.4.3 Psychomotor Models for Handwriting.

Furthering the understanding of the role of the motor program, van Galen and Teulings (1983) proposed an influential three stage model for handwriting including: a response-choice phase, underpinned by linguistic knowledge; a retrieval phase in which a motor plan is searched for; and, a final phase where the motor program is translated to nerve impulses. After exploring digital data of letter forming by adults under various task constraints such as size of the letter and orientation of the baseline, van Galen and Teulings (1983) also added an additional component to their model, of parameter setting for the motor pattern. Parameter setting was thought to be the final stage before neuromuscular activation. Parameter setting was seen as an adjustment to allow for spatial and other constraints, such as the size of the lines to be written on, or the orientation of the lines.

4.4.3 Blending Product and Process Research for Beginning Writers

Despite the advances in understanding of cognitive processes for handwriting, scholars from a range of fields identified the limitations of cognitive processing models for beginning writers, due to the impact of developing neurological and motor processes on cognitive systems. Whilst cognitive process theories were useful for explaining processes used by and constraining skilled writers, factors impacting beginning writers were not fully addressed in these theories. Product and process interaction for beginning writers has since been explored to understand the relationship between different factors. Process theories have been adapted to accommodate the unique needs of beginning writers, considering the impact of process and product.

4.4.3.1 The Interaction of Product and Process for Beginning Writers.

Process factors that impede or enhance production are of interest to researchers in the field of beginning writers. Beginning writers have unique needs due to high cognitive demand on production factors (Graham et al., 1997). Scardamalia et al. (1982) highlighted the role of potentially constraining process factors, explaining that "both properties of the writer's knowledge and properties of the writer's psychological system" (p. 174) could limit the use of knowledge in writing. The authors also noted that children learning to write were likely to be constrained by production factors, and that these factors would limit what young children are able to write. Specifically, Scardamalia et al. (1982) identified that handwriting could take considerable attention in younger writers, and draw attention away from other process elements such as remembering words, plans and writing intentions. This was explained as a loss of information from short term memory storage, by a variety of production factors including mental activities (such as composing and storing the next sentence), which might limit transcription.

Scardamalia et al. (1982) and Graham (1990) studied the effect of removing mechanical demands from children's writing by having them compose in their normal handwriting, by dictation or by slow dictation (the researcher wrote the child's dictated prose at the child's normal handwriting pace). Whilst Scardamalia concluded that the effect of the mechanical demand of handwriting reduced with age, Graham concluded that this effect was sustained and important across a range of ages. Production factors causing limitations to writing were noted in both Scardamalia et al. (1982) research and the Flower and Hayes (1981) model of skilled writing; however, researchers interested in beginning writers and children with learning difficulties argued that there was not sufficient acknowledgement of the importance of handwriting for beginning writers, and the effect of limited handwriting fluency on text generation (Berninger et al., 1997; Graham, 1990).

These later researchers have seemingly combined the work of neuromotor developmental researchers and writing theorists with an identification that the role of translation for beginning writers has a significant impact on text generation, as the processes are in development and not fully formed (Berninger et al., 1995). As noted in Chapter 1 (Section 1.3.3.5), research explored the impact of lower-level skills included in translation (such as spelling and transcription), onto higher-level skills (such as generating a complex piece of written text requiring sequencing and ordering of ideas, planning, reviewing and revising). It identified that lack of handwriting fluency (as measured by timed alphabet writing) constrained written expression in both quantity and quality for children from Year 1 and above (for example, Berninger et al., 1997; Graham et al., 1997; Jones & Christensen, 1999). A foundation of letter writing fluency is proposed as being essential in order to release cognitive capacity for higher-level planning, reviewing and revising (McCarney et al., 2013). Perceptual motor skills, as previously described, are foundational to handwriting, and are likely to play a significant role for beginning writers in developing handwriting fluency. Therefore, this interrelationship between process and product is essential in understanding beginning writing, as developing subsystems influence each other.

4.4.3.2 Adaptation of Process Theories to Include Production Factors for Beginning Writers.

Incorporating the work of early theorists, and adding the research findings from behavioural research, models have been proposed to incorporate production factors for beginning and developing writers. The Flower and Hayes (1981) model was adapted to incorporate components of translation including spelling and handwriting that impacted text generation (Berninger et al., 1995). Capacity theories were expanded to incorporate the role of both short-term and long-term working memory in beginning writers, accounting for the limiting effects of translational processes (McCutchen, 2000).

Later developments in process theories noted the connection between handwriting, aural and oral language and reading (Berninger, 2000). More recent research has focussed on other constraining factors including self-regulation and the context of the writing task (Berninger & Winn, 2006; Kim & Park, 2019). Importantly, each of these theories has retained the significant contribution of foundation skills of translation including handwriting. Translation, and particularly handwriting, has a strong impact on the emergence of early writing. The application of process and product factors that influence beginning writing to the acquisition of handwriting fluency is therefore of key importance.

4.4.4 Summary

In conclusion, the instructional studies of the 1970s and 1980s, and the psychomotor and cognitive theories of the 1980s and 1990s have been combined to produce present day theories of writing that now include process knowledge, and for beginning writers, emphasise the role of production as part of a recursive process at the letter, word and text level (Berninger et al., 2009). This means that product informs process which informs product, enabling a beginning writer to use the act of writing, through effective practice, to consolidate motor and cognitive aspects of writing. In addition, researchers have found that production and process influence each other in beginning writers through the development and coordination of key components. These components impact the generation of writing. Components relevant to beginning writers include recall of letters, development and recruitment of motor programs and constraints caused by handwriting ability.

4.5 The Interrelationships of Process and Product Factors in the 4*Rs* Model

The 4*Rs* model incorporates the effects of process and product interactions for beginning writers. The following section discusses the interrelationships of these effects. Section 4.5.1 outlines how the two process quadrants, *recall* and *retrieve*, impact handwriting production. Section 4.5.2 discusses the influence of quadrants influencing the handwriting product, *reproduce* and *repeat*, on process factors. This discussion highlights the importance of interaction of process and product factors in the 4*Rs* model of handwriting fluency acquisition.

4.5.1 How Process Factors Impact Product for Beginning Writers

In the 4*Rs* model, process factors are defined as including all of the cognitive tasks leading up to, and including, activation of the motor program for letter writing, and include the quadrants *recall* and *retrieve*. The following section describes how these two process factors, the recall of the letter form and the retrieval of the motor program for the letter, impact the handwriting product.

4.5.1.1 Recall Quadrant: Impact of Recall of Letter Form on Product.

The ability to easily recall a letter form appears to have an impact on the written letter product, such as the legibility of the letter form. An example of this effect was seen in a study by Graham et al. (2006) who observed poorer legibility in alphabet writing and copying tasks than in composition (Graham et al., 2006). This was despite composition being conceived as a cognitively more challenging task than copying a sentence or writing the alphabet (and therefore more likely to show effects of cognitive overload through poorer writing). De-contextualised writing, such as copying tasks or alphabet writing from memory was suggested as the reason for the poorer appearance of handwriting (Graham et al., 2006). Contextual writing, such as composing a story, relies on recall of self-generated orthographic representations for letters and words. This appears to positively impact handwriting appearance and is supportive of the role of ease of recall (or access to an orthographic code) in influencing handwriting product. Motor patterns that support letter formation may be more accessible in a task where words are self-generated, such as in writing composition. During composition, children self-generate the words they wish to write along with the relevant spellings and use recall to support this process. Being constrained to write letters in sequence in the alphabet may create challenges to being able to recall (Rodriguez & Villarroel, 2017). This may interrupt the smooth access to the motor program that may be more achievable with independent word writing in composition, leading to poorer appearance of letters. Ease of recall therefore may impact product.

4.5.1.2 Retrieve Quadrant: Impact of Retrieval of Motor Plan on Product.

Beginning writers need to develop motor programs for letter writing (Palmis et al., 2017). A child in the first year of formal instruction is generally introduced to new letter forming patterns for each letter, and this process is unique as a specific series of lines and movements are taught, that may be different to previously learnt patterns. Graham et al. (2006) identified differences between good and poor writers in Years 1 and 2 through analysis of constructs for aspects of motor programming identified by van Galen and Teulings (1983). Processes of motor planning included the phases of response choice (which letter to select and write), retrieval of the motor plan, parameter setting (how large or small to write the letter, orientation to baseline) and then execution. Specific attributes of writing samples were hypothesised to represent each phase. For example, difficulties with letter placement on the line would indicate difficulties with parameter setting. Handwriting samples of alphabet writing from memory, word and sentence copying and independent composition tasks were analysed for: placement on the line, spacing between words and a range of visual measures of the appearance of letters. The authors argued that errors detected visually would be evidence of difficulties with executing the motor plan for the letters written. The authors found that poorer handwriters showed more features that were consistent with motor planning deficits for alphabet writing and sentence copying, as evidenced by errors in line placement, spacing and other measures. This indicates that better writers, with less visible errors, had more efficient motor programs for letter forming. The process of retrieving and executing a motor program for letters and words had a direct bearing on the product.

4.5.2 How Product Factors Impact Process for Beginning Writers

As previously described, the product of handwriting refers to the appearance of the writing on the page, which the quality of perceptual motor skills influences. The 4*Rs* model includes product factors in the *reproduc*e and *repeat* quadrants. The following discussion describes how perceptual motor components and repetition indicated in the *reproduce* and *repeat* quadrants of the 4*Rs* model impact process factors.

4.5.2.1 Reproduce Quadrant: Impact of Perceptual Motor Skills on Process.

In the 4*Rs* model, the term *reproduce* refers to the recreation of orthographic representations of letters and associated motor patterns through handwriting. Alstad et al. (2015) referred to this as letter production, described as the output arm of the handwriting fluency process. As noted in Chapter 1 (Section 1.3.2.1), perceptual motor skills predict or are associated with handwriting ability, including perceptual, kinaesthetic, visuomotor and fine motor capacities.

Abbott and Berninger (1993) used structural equation modelling to explore the contribution of perceptual motor and cognitive skills components to handwriting fluency as measured by a timed alphabet writing and copying task. The relative contribution of fine motor factors and orthographic coding to handwriting fluency was assessed. In this study, finger function was used to assess fine motor ability, using tasks such as timed tapping of thumb to fingers in succession, identification of finger tapped behind a screen, and lifting or spreading of fingers tapped by an examiner. Orthographic coding was found to be directly related to handwriting fluency for Years 1 to 6 students and the fine motor skills factor contributed indirectly to the fit of the model through orthographic coding. From these results, a constraining effect of fine motor skills on handwriting fluency processes can be inferred.

Strong visuomotor skills have interesting impacts on cognitive processes. For example, they have been observed to compensate for difficulties in social and emotional regulation, minimising impact on academic achievement (Cameron et al., 2015). Fine motor skills, particularly design copy, are known to predict higher achievement on school entry and are associated with greater literacy gains during Kindergarten (Cameron et al., 2012). Cameron et al. (2016) describes this effect in a similar way to capacity theories of writing, suggesting that strong perceptual motor skills means that attention can be deployed to more complex task demands, but also suggests the effects may be task specific. For example, four-year-olds with perceptual motor skills strengths who experience difficulties with executive functions, were able to make gains in print knowledge but not in language skills (Cameron et al., 2015). The perceptual motor skills strengths compensated for the executive function difficulties and enhanced the development of print knowledge. The suggestion is, that children who must attend to perceptual motor challenges, such as holding a pencil and monitoring the movements needed when handwriting will have slower progress in connecting letters with sounds (Cameron et al., 2012). Conversely, greater perceptual motor abilities release cognitive capacity for important processes of connecting letter names and forms. The impacts of perceptual motor skills difficulties on the 4*Rs* process factors of *recall* and *retrieval* can be observed. Higher levels of attentional demand on perceptual motor skills will limit cognitive capacity for focussing on recalling letter forms and retrieving related motor patterns. Therefore, perceptual motor capacities are included in the *reproduce* quadrant of the 4*Rs* model because of their potentially constraining effects on handwriting fluency processes.

4.5.2.2 Repeat Quadrant: Impact of Practice on Process.

As discussed, perceptual motor skills such as fine and visuomotor ability play a major role in process factors for handwriting fluency. Impairments in perceptual motor skills may impact handwriting fluency by appropriating cognitive resources primarily to task mechanics and away from important *recall* and *retrieve* processes (Cameron et al., 2012). Less opportunities to *repeat* handwriting may compound the impact of perceptual motor skills deficits on these process factors. Children who are slower at handwriting have been observed to have signficantly lower performacnce aross perceptual motor abilities (Tseng & Chow, 2000; Volman et al., 2006). In a circular relationship, reduced practice, such as in slower handwriting, may then compound deficits in perceptual motor skills. For example, a child who fatigues when holding a pencil through use of excessive grip or tension may have reduced practice opportunites, and consequently, reduced opportuntites to improve pencil grip and control.

Studies suggest that *repetition* of handwriting is also a means to facilitate interaction of process and product factors by enhancing *recall* which requires the development of an association between a phoneme and a grapheme, and entails letter recognition (Earle & Sayeski, 2017). Task constraints for beginner writers related to *recall* include the need to form new and unique orthographic codes for each letter learnt (Apel, 2009). Evidence suggests that handwriting practice, compared with viewing letters, enhances letter recognition (James, 2010; Zemlock et al., 2018). These effects are explained in part by the impact of enhanced visuomotor skills afforded through handwriting practice (Zemlock et al., 2018). Visually guided practice, such as in writing letters, is also observed to link visual (letter recognition) and motor brain systems (Vinci-Booher et al., 2016). Importantly, there is a need for repetition or practice to be novel and of varying nature, to maintain attention. Berninger (2009) noted that "too much repetition causes habituation, and the brain no longer attends to the task at hand and seeks novel stimuli or tasks to maintain attention over time" (p. 78).

4.6 Integration of Current Evidence into the 4*Rs* Model

In Chapter 2, a systematic review established associations of handwriting with literacy ability for Kindergarten children. In Chapter 3, a retrospective pilot study of the modified Write Start intervention demonstrated a primary effect of intervention on handwriting fluency. The key findings from both studies have been used to inform the model proposed in this Chapter 4 and are now described.

4.6.1 Systematic Review Results

The systematic review concluded that Kindergarten literacy was significantly associated with two types of handwriting measures—perceptual motor (visuomotor, fine motor and perceptual tests) and letter writing fluency (transcribing alphabetic or individually dictated letters from memory). Of note, these measurement types assess the key fluency elements identified earlier as being related to literacy (vis-à-vis, memory recall of letters and the ability to reproduce letter forms using perceptual motor skills; see Section 4.2) and encompass all quadrants of the 4*Rs*. Specifically, letter writing fluency requires *recall* and *retrieval* of the letter form, and sufficient perceptual motor abilities entailed in *reproduction* to enable legible formation. Perceptual motor skills clearly relate to *reproduction* factors, are enabled by handwriting *repetition* and impact processes of *recall* and *retrieval*. *Repetition* is also indicated in letter writing fluency, through impacts of practice on letter recognition via cortical visual and motor links. Therefore, the findings of the systematic review with regards to key handwriting measurement constructs are integrated into process and product factors identified in the 4*Rs* model.

The 4*Rs* can be seen to serve as proxies for both measurement types identified in the systematic review (letter writing fluency and perceptual motor skills) that are associated with literacy. Handwriting fluency has a clear association with literacy (Sections 1.3.3.3 & 1.3.3.6) as Kindergarten handwriting fluency is generally assessed at the letter level and this involves perceptual motor competencies. Thus, the measurement groupings (and by proxy, the 4*Rs*) identified in the systematic review are equated with *handwriting fluency* for Kindergarten. The 4*Rs* model is, therefore, proposed as a means to promote handwriting fluency acquisition for Kindergarten children.

In this Chapter 4, the interrelationships of process (*recall* and *retrieve*) and product (*reproduce* and *repeat*) factors for handwriting fluency have been described and a rationale for involvement of all processes in fluency acquisition has been detailed. These process and product factors were observed in both measurement groupings in the systematic review. However, relationship strength between measurement groupings and literacy varied in the systematic review. Evidence for a strong relationship between handwriting fluency and literacy was detected. A weaker relationship between perceptual motor skills and literacy was observed. The variation in strength of relationships suggests that these components are factors within a more complex whole. The systematic review evidence has informed the 4*Rs* model, in which components of the overall skill of handwriting fluency acquisition, are seen as factors of influence. A whole number can be factored into different combinations, by use of multiplication, and this is possibly a clearer way to understand what traditionally have been known as component skills. A multifactorial skill is not the sum of its parts, with each part requiring a specific amount of focus or development to create the whole. A component implies a part that must be in place for the whole to work. A factor however, can vary, and may take a number of forms in terms of size and importance in order to create the whole. Multiplication of factors to create a whole also infers a combining effect; that is, when all factors work in concert, the whole is achieved. The systematic review evidence confirmed the importance of all inclusions in the 4*Rs* model, as both handwriting fluency and perceptual motor skills were associated with literacy and, by inference, with handwriting fluency acquisition.

4.6.2 Pilot Study Results

As described in Chapter 3, a significant improvement was noted in Kindergarten students' handwriting fluency following implementation of the modified Write Start program. The modified Write Start included whole-class instruction of letter names and sounds, practice opportunities, and activity stations with either a fine motor, visuomotor or cognitive (memory) focus. As such, many features of the 4*Rs* model can be observed in the modified Write Start program which was specifically characterised by a focus on one specific component skill at each activity station. For example, a fine motor activity for the letter "f" such as a frog colouring in sheet (to identify the letter of the week), focussed on the *reproduce* quadrant, with a focus on pencil control, grip strength and hand strength. Cognitive activity stations including tasks such as writing words from memory focus on *recall*, *retrieve* and *reproduce* quadrants. The *repeat* quadrant was emphasised at various activity stations through letter writing practice. The positive effects of the modified Write Start on handwriting fluency observed in the pilot study support the inclusion of the four key elements proposed in the 4*Rs* model. Further, it was also observed that children with stronger early literacy abilities (phonics, phonemic awareness and writing) tended to have better handwriting fluency following the intervention. These results can also be interpreted through the lens of the 4*Rs* model. These children may have had an advantage in the process factors of *recall* and *retrieve*. The combined results of the pilot study, therefore, affirm the inclusion of process and product quadrants in the 4*Rs* model. The effects of the modified Write Start program on handwriting fluency suggest that an intervention approach based on the 4*Rs* model will improve handwriting fluency acquisition. Additionally, the trend for enhanced benefits for children with higher early literacy skills suggests that strengths in component areas can impact handwriting fluency acquisition. This result suggests that all quadrants of the 4*Rs* model are crucial to fluency acquisition.

4.6.3 Goals of the Model

A primary aim of this thesis was to establish a model for handwriting fluency acquisition for Kindergarten. Based on a review of extant literature and new evidence from a systematic review and pilot study, the 4*Rs* model has been developed. The model serves two key purposes:

1. To outline a method for ensuring acquisition of handwriting fluency in Kindergarten; and,
2. To elucidate the link between handwriting fluency and literacy outcomes through the development of strong grapheme phoneme relationships.

The novelty of the 4*Rs* model is its inclusion of both process and product factors when considering handwriting intervention approaches, and when understanding the link between handwriting and literacy. The 4*Rs* model offers an opportunity to strengthen the modified Write Start program. As described, intervention activities in the modified Write Start program included the 4*Rs* overall, but not necessarily in each individual activity. The modified Write Start intervention activities could be strengthened to ensure that each activity, whilst assisting to develop component skills, also support the development of handwriting fluency. For example, a handwriting activity in which playdough is used to make a letter using the correct form (*recall*), and then beads are pressed into the form following its motor pattern (*retrieve*), followed by tracing over the playdough letter with a toothpick (*repeat*), incorporates all aspects of the 4*R*s but is more heavily weighted to the *reproduction* quadrant, in which the muscles in the hands, wrist and shoulder are being activated. As shown in this example, many regular Kindergarten activities designed to promote handwriting can be modified easily to adopt the 4*Rs* model and can also be weighted towards one quadrant or another. Revisions to the modified Write Start are indicated based on the 4*Rs* model. Observed impacts of handwriting fluency on literacy may then be realised.

4.6.4 Summary

Prior studies have established that treating a component skill in isolation will not lead to improvements in the overall target skill of handwriting fluency; yet, component skills are needed for proficient handwriting. The systematic review (Chapter 2) showed that letter forming ability and perceptual motor skills link to literacy and are inferred in handwriting fluency acquisition. In the pilot study (Chapter 3), an improvement in handwriting fluency was achieved using modified Write Start, which included the 4*Rs* elements in intervention activities. Drawing from a theoretical basis, the results of the systematic review and the pilot study informed the proposed 4*Rs* model. Two outcomes of this model are a framework to ensure handwriting fluency acquisition in Kindergarten and opportunities to strengthen literacy impacts. A stronger focus on the whole fluency system in intervention *combined with* component skills development may be the most effective model for beginning writers.

4.7 Conclusion

This chapter has presented a newly conceived model for handwriting fluency acquisition for Kindergarten. Evidence for the model has been drawn from the extant literature pertaining to handwriting process and product and the findings of the systematic review reported in Chapter 2 and the pilot study reported in Chapter 3. The 4*Rs* model can now be used as a framework for intervention to support Kindergarten handwriting.

Chapter 5 Methods

Preface:

In this chapter, the methods used to conduct a prospective, two-group study examining the effectiveness of whole-class, co-taught handwriting intervention for Kindergarten students are described. Using the 4*Rs* model (Chapter 4) as a basis, revisions were made to the modified Write Start intervention described in Chapter 3. The revised and updated intervention, Write Start-K, was compared to standard teaching to examine impacts on handwriting fluency and literacy. This two-group study addresses thesis questions:

> *Question 2: How effective is a whole-class intervention in improving handwriting ability for Kindergarten students?* and
>
> *Question 3: Does a whole-class handwriting intervention impact Kindergarten students' literacy?*

The present chapter outlines the context for the two-group study including the basis for intervention revisions, research questions and aims, ethics processes, research design, participants, measures and assessment procedures, intervention approach and procedures, and data analysis methodology. Some of the methods described in this chapter are re-summarised in Chapters 6 and 7 that report results for primary (handwriting fluency) and secondary (literacy) outcomes for the study.

Appendices to this chapter:

- Appendix 3 – Ethical approval and safety clearance for two-group study
- Appendix 4 – Participant Information Statement for principal of intervention school
- Appendix 5 – Participant Information Statement for teachers at intervention School
- Appendix 6 – Participant Information Statement for parents and guardians of kindergarten children at intervention school
- Appendix 7 – Letter Form Assessment (LFA)-2
- Appendix 8 – Letter name and sound knowledge assessment sheet

- Appendix 9 – Procedure and scoring for alphabet test administered by teachers
- Appendix 10 – Writing composition task procedure and scoring
- Appendix 11 – Write Start-K session summary
- Appendix 12 – Fidelity measures

5.1 Context of the Two-group Study

The need for a more rigorous examination of the role of handwriting fluency in early literacy outcomes in beginning writers and readers has been established in the thesis work to date. First, a systematic review of the evidence (Chapter 2) found support for significant, positive relationships between letter writing fluency and perceptual motor skills and literacy, including reading and writing. Strong evidence was found for relationships between letter writing fluency and literacy. Letter writing fluency requires recall of letters and retrieval of associated motor patterns. This evidence supports the role of cognitive aspects of handwriting acquisition. Weaker evidence was found for relationships between perceptual motor factors and literacy; however, this evidence was supportive of the importance of these skills as facilitators of handwriting fluency. Second, a pilot, one-group pre- post-test study (Chapter 3) found that a whole-class, co-taught handwriting intervention, modified Write Start, improved handwriting fluency in beginning writers. This result demonstrates that handwriting fluency can be improved through a focus on component skills that underpin handwriting including fine motor, visuomotor and cognitive abilities. The analysis did not detect an effect of early literacy (phonics, phonemic awareness and writing) on handwriting fluency outcomes but trends were supportive of the role of these skills in handwriting acquisition. Also, the impact of improving handwriting fluency on literacy outcomes was not tested.

Based on these studies, a new model for handwriting fluency acquisition was proposed (4*Rs* model; Chapter 4). The 4*Rs* model proposes that four factors work cohesively for handwriting fluency acquisition—*recall* of the orthographic code for the letter, *retrieval* of the associated motor pattern, *reproduction* of the letter using a range of perceptual motor skills and based on the recalled and retrieved form, and *repetition* to consolidate the relationships between letter name, sound and form. As such, the 4*Rs* model provides an evidence-based framework for handwriting intervention for beginning writers. When compared against this framework, the strengths and weaknesses of the modified Write Start intervention, can be identified. Strengths relate to the inclusion of all of the factors indicated in the 4*Rs* handwriting fluency acquisition model across the program as a whole. While weaknesses may be less emphasis on some aspects of the 4*Rs* in some intervention activities; for example, fine motor activities without the inclusion of process factors of *recall* and *retrieval* of letter formation. On this basis, and considering the results of the pilot study, the modified Write Start intervention may be improved by incorporating factors that promote orthographic coding and recall and retrieval of motor patterns into all intervention activities, rather than only in one activity station (cognitive station). The findings also suggest that perceptual motor skills activities should be retained in intervention. Strengthening the intervention to systematically incorporate process (*recall* and *retrieval*) and product (*reproduce* and *repeat*) into all activities might also impact literacy, as, in the systematic review, both factors were found to have important effects on literacy. The 4*Rs* model informed a new version of Write Start, Write Start-K which is described in this Chapter 5 (Section 5.7).

A further finding of the systematic review pertained to the types of measures used to assess handwriting fluency in Kindergarten (Section 2.4.2). Measures of letter writing fluency were commonly used and generally consisted of timed alphabet testing from memory. The limitations of this methodology were presented in Chapter 3 (Section 3.2.3), and a method was proposed to extend measurement methods and address frequently reported floor effects. A new tool, the Letter Form Assessment (LFA), was found to be effective in eliminating floor effects. However, ceiling effects were observed which indicated a need for the assessment to be modified to increase its scope. The updates to the LFA (LFA-2), including reporting of psychometric testing, are described in this chapter.

5.2 Study Aims and Hypotheses

The primary aim of this study was to evaluate the effectiveness of Write Start-K in improving handwriting fluency in Kindergarten children. A two-group, pre- post-test comparison study was conducted to address the study aims. Two schools (one intervention, one control) were recruited to the study. Both schools followed a similar program for literacy instruction, comprised of regular morning sessions where reading and writing activities occurred. The intervention school (two Kindergarten classrooms; n= 38) received the Write Start-K program twice a week during this regular literacy instruction time, whilst the control school (two Kindergarten classrooms and one composite Kindergarten/Year 1 classroom; Kindergarten students n= 39) continued with standard teaching. The primary outcome, handwriting fluency, was measured using the researcher-devised LFA-2. Additional assessments of handwriting fluency (timed and untimed alphabet writing; alphabet writing 60 seconds [AW60] and alphabet writing untimed [AWU]), were included as these are established and frequently used measures. It was hypothesised that Kindergarten students receiving Write Start-K would demonstrate greater handwriting fluency following the intervention period when compared with Kindergarten students receiving standard teaching.

Two secondary aims were identified for the study. The first was to examine the impact of Write Start-K on early literacy skills in Kindergarten students when compared with standard teaching. Two categories of early literacy skills were identified: reading and writing composition. Reading measures relevant to Kindergarten were drawn from measurement groupings identified in the systematic review and included letter and sound knowledge, letter naming fluency, and word reading fluency. Writing composition features relevant to Kindergarten were also drawn from the literature and included writing composition quantity (number of words written) and quality (a composite score including significant writing features). Moderate and significantly greater gains were hypothesised for the intervention group as a result of the Write Start-K intervention for both reading and writing measures, based on the evidence for handwriting and literacy associations identified in the systematic review (Chapter 2, Section 2.4.3).

An additional secondary aim was to determine if Write Start-K impacted fine and visuomotor skills that are established predictors of handwriting proficiency (Chapter 1, Section 1.3.2.1). A small to moderate improvement was anticipated for the intervention group compared to the control.

Therefore, this prospective, two-group, pre- post-study aimed to establish if Write Start-K improved handwriting fluency, literacy and perceptual motor skills in Kindergarten students over and above the effects of standard teaching.

The research questions were:

Question 1: Does Write Start-K improve handwriting fluency for Kindergarten students compared with standard teaching?

Question 2: What effects, if any, does the program have on Kindergarten students' literacy including age-appropriate measures of reading and writing?

Question 3: What are the effects of the intervention, if any, on perceptual motor factors indicated in handwriting fluency development?

5.3 Ethics and Approvals

Ethics approval was obtained from the University of Newcastle Human Research Ethics Committee (HREC). This approval was obtained on 20 May, 2019 (H-2019-0049) (See Appendix 3). The State Education Research Applications Process (SERAP) reviewed and approved all proposed procedures and methods for the study on 24 May, 2019 (SERAP 2019110). Additional Research Assistants recruited to the study were approved by The University of Newcastle HREC as a variation. All Research Assistants provided Working With Children Check numbers to both schools as part of meeting statutory requirements for identification.

5.4 Study Design

The study used a two-group, prospective comparison design. Kindergarten students from two schools participated; one school received the intervention and the other served as control and received standard teaching. The criterion for allocation to intervention or control conditions are described in

Section 5.5. The phases of the study were: pre-intervention assessment, an eight-week intervention, an immediate post-intervention assessment and a follow-up assessment 12 weeks post-intervention. During the intervention period, standard teaching continued at the control school and the intervention school received Write Start-K.

5.5 Participants

Two schools in the suburbs of a large regional city in New South Wales (NSW), Australia, were approached for inclusion in the study. The schools had similar numbers of enrolments in the Kindergarten year and were selected because of their location in communities of lower socio-economic status. In NSW public schools, a school socio-economic index called the Family Occupation and Employment Index (FOEI), is calculated at the beginning of each year based on data parents of all enrolled children provide, including levels of parental education, non-school qualifications and occupational status, with scores ranging from zero to 300 and higher scores representing greater disadvantage (NSW Department of Education, 2021b). A two-year average of the FOEI for the control and intervention schools (133 and 134 respectively) identified both schools as having a similarly lower level of socio-economic status (NSW Department of Education, 2020). A second index, the Index of Socio-Educational Disadvantage, was also similar for the control and intervention schools, with both schools found to be below the national average of 1000 (947 and 935, respectively; ACARA, 2020). The schools were also matched overall for racial and linguistic diversity, with both schools having approximately equivalent numbers of Indigenous students (control 12%, intervention 16%) and students with a language background other than English (control 2%, intervention 3%) (ACARA, 2020).

All Kindergarten students, across all classes (two classes at the intervention school and two Kindergarten and one composite Kindergarten/Year 1 class at the control school) were invited to participate in the study. The allocation of the schools to the intervention or control condition was made by the thesis author in conjunction with supervisors and was based on the feasibility and accessibility of the identified school to participate in the intervention program. The allocation process was considered acceptable as Kindergarten teachers at both schools had similar experience and training in early education, schools were well matched for socio-economic background and diversity, and both schools followed the same curriculum. Neither school was aware of the condition they would be allocated to when expressing interest in study participation.

5.5.1 Informed Consent Processes

A rigorous, multi-step process of obtaining consent was followed. First, overall informed consent was requested from the schools' Principals for the school to participate (Appendix 4). Second, Kindergarten teachers were individually asked to consider an information statement including all information on the required contribution they would need to make to the study (Appendix 5). The process of asking teachers individually was considered crucial as the program of study followed a co-teaching model, requiring a significant contribution from each class teacher. In addition, teachers at both schools were asked to collect data samples at three time points in the study (see 5.6.1, Measures) and, as such, their consent to participate was essential. Last, once informed consent was obtained from Kindergarten teachers, a full information statement and consent form was provided to parents and guardians to seek individual consent for the participation of the Kindergarten children in the study (Appendix 6). The research team provided contact details to enable parents and guardians to seek extra information as required, and in addition, key teachers in a coordination role at the schools made themselves available for questions or concerns. Informed consent was obtained from both schools' Principals, all Kindergarten teachers at both schools and parents and guardians of all enrolled Kindergarten children at both schools.

5.5.2 Exclusion and Inclusion Criteria

Exclusion criteria included factors based on language and disability. For language exclusions, it was determined that if a child was unable to comprehend the English language instructions used in the assessments, then an exclusion would apply. For disability, it was determined that if a child had significant difficulty that would impact the ability to carry out the assessment tasks they would be excluded. It is important to note that a child with an identified disability would not be automatically excluded as the assessment tasks were selected with a range of abilities in mind, and with many tasks allowing for children to participate to their own level. For example, with fine motor assessment activities such as beading, card stacking and coin sorting, children are not required to complete a certain number of successful attempts, rather they are able to complete as many attempts as they can within a short time period. For literacy assessments, in some tasks the assessor provided prompts for items children could not complete such as naming letters, and in this way a range of abilities was accommodated. Inclusion criteria were the ability to comprehend the verbal instructions in the assessment activities, and consent received for participation.

5.5.3 Flow of Participants Through the Study

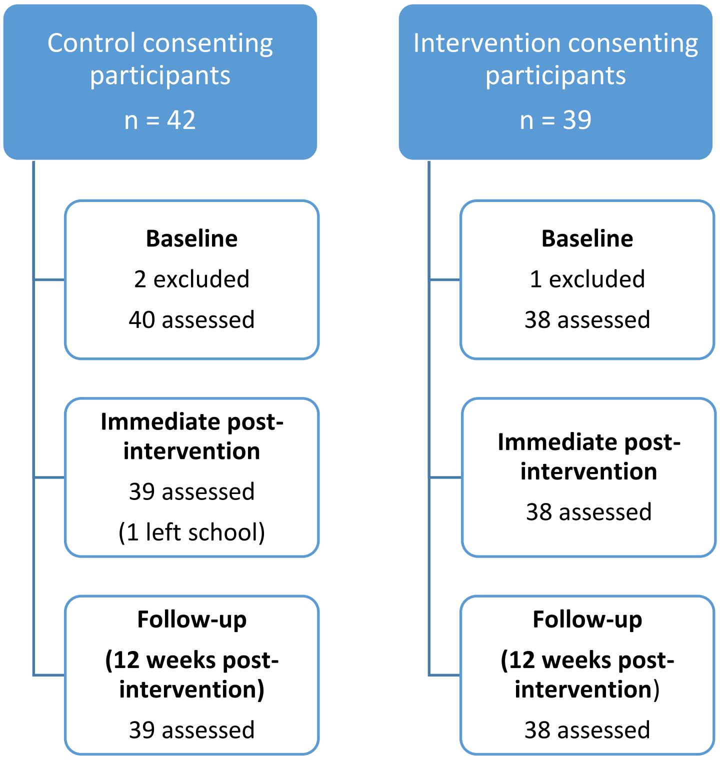
Consent was obtained for the participation of 39 children at the intervention school, which comprised all children enrolled in the Kindergarten year. One child was excluded at the baseline assessment phase due to significant developmental delays impacting the ability of the child to carry out the standardised assessments. For this participant, aspects of the assessments that were achievable were completed and a report was provided to the teacher and parents to enable follow up and further intervention outside of the study program. Further, the intervention was a whole-class program, and as such, adaptations to program activities were made to accommodate and include this participant in the intervention program. However, no data from this child was included in subsequent study analyses. The total number of participants at the intervention school with exclusions factored in was 38. During intervention and at post-intervention and follow-up time points all 38 participants remained in the study as no children left the school or withdrew from the study.

At the control school, consent was received for participation of 42 children, again constituting all enrolments in the Kindergarten year. Of these, two children were identified at initial assessment for whom the full assessment process was deemed inappropriate due to developmental delays impacting on their ability to carry out assessment activities. For both participants, the same process was followed as at the intervention school, where aspects of the assessments that were achievable were completed to allow for a summary report for parents and teachers to seek additional assessment and intervention. One additional child left the control school after the initial assessment round, leaving a total of 39 participants at post-intervention and follow-up assessment points.

At follow-up, both schools had the same participants enrolled as at the immediate post-intervention assessment. See Figure 5.1 for the flow of participants through the study. Summary reports on baseline assessment results were provided to parents and teachers for all children for whom consent to participate had been obtained, with modifications made to the extent of reporting for the children for whom exclusions applied, as previously explained. In this way important clinical information was conveyed at the outset of the study so that parents and teachers could offer ongoing support and follow up as required at both schools. This process ensured that children in both the intervention and control groups received the benefit of early screening information.

Figure 5.1

Flow of Participants Through the Study



5.6 Procedure

The study consisted of baseline data collection, implementation of Write Start-K at the intervention school for eight weeks, and two post-intervention data collection points—immediate post-intervention and follow-up at 12 weeks post-intervention. Each period of data collection was conducted over two weeks, with both schools receiving assessments within this time period. Prior to commencing the intervention, the intervention team (thesis author [KR], respective classroom teachers and undergraduate occupational therapy student Research Assistants) participated in half a day of training which the thesis author (KR) conducted with one of the thesis supervision team (KD). The intervention, Write Start-K was implemented as a whole-class, co-taught, eight-week program with two 45-minute sessions per week, in place of morning literacy sessions.

5.6.1 Measures

The following section details the assessment process and all measures used in the study. Some measures were collected at baseline only, to provide more data on the similarity between the groups. Standardised procedures were followed using either administration manuals or researcher designed procedures that drew on existing methodology documented in the literature. The measures collected at each time point are shown in Table 5.1, below.

Table 5.1

Assessment Schedule at Baseline, Immediate Post-Intervention and Follow-Up

Measure	Baseline (Weeks 9 and 10, Term 2, 2019)	Immediate post-intervention (Weeks 9 and 10, Term 3, 2019)	Follow-up (Weeks 9 and 10, Term 4, 2019)
Letter Form Assessment	x	x	x
Beery Buktenica Developmental Test of Visual Motor Integration (Beery VMI)[40]	x		x
Beery VMI visual perception sub test	x		
Beery VMI motor coordination sub test	x		
Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) fine motor and manual dexterity sub tests[95]	x	x	x
Dynamic Indicators of Basic Early Literacy (DIBELS) subtests of Letter Naming Fluency, Nonsense Word Fluency and Word Reading Fluency	x	x	x
Letter identification assessment (name and sound)	x	x	x
Timed and untimed alphabet test	x	x	x
Written composition quantity and quality	x	x	x

Assessments were identified in order to answer the research questions. They encompassed measures of handwriting fluency, factors that may contribute to the development of handwriting fluency, and measures of emerging or early literacy across both reading and writing. Each measure used in the study and the psychometric properties of the measures are described in the following section. Where researcher designed assessments were used, a rationale and basis in the literature is provided.

5.6.1.1 The Letter Form Assessment-2.

The Letter Form Assessment-2 (LFA-2) was used to measure handwriting fluency as the primary outcome of interest in this study. As previously described, (Chapter 3, pilot study, Sections 3.2.3 and 3.3.4) the LFA was developed in response to the documented limitations of common measures of handwriting fluency for Kindergarten, such as timed alphabet writing and dictated individual letter writing. Floor effects have been identified as a significant disadvantage of alphabet writing measures. In addition, the scoring procedures for both alphabet writing and dictated letter writing measures prohibit the discrimination of legibility from letter recall and, as a result, do not measure gradations of Kindergarten ability such as being able to copy a letter or imitate letter writing. The LFA-2 uses a series of cascading prompts to assess letter formation ability (conceived as an index of fluency), with scoring reflecting the level of prompting (verbal, visual or modelled) needed to achieve accurate formation. Floor effects were not evident in the pilot study of the original LFA; however, a ceiling effect was observed (see Section 3.4.1). In the pilot study, the scope of the LFA was limited by the curriculum of the participating school which specified the introduction of one new letter a week. Therefore, the LFA only tested fluency for the 12 letters learnt in class pre-intervention and the 12 letters learnt during intervention at post-intervention. Schools participating in the current study had already introduced all alphabet letter sounds prior to the commencement of the study procedures. Therefore, the LFA was revised (LFA-2) to include all letters of the alphabet in order to give a more complete picture of emerging handwriting fluency and to address ceiling effects in the piloted version.

5.6.1.2 Administration and Scoring.

The LFA-2 is a paper and pencil assessment, with a series of small pictures representing each letter of the alphabet and a line next to each picture (see Appendix 7). The letters are ordered non-alphabetically down the page and follow common sequencing for the introduction of letter sounds used in Kindergarten based on simplicity, as some letters are known to be more difficult to write (Graham et al., 2001; Ritchey, 2008). The procedure for administration is as follows:

- The assessor points to the first picture prompt, says the name of the picture and the letter name and sound the picture begins with, and asks the participant to write the letter from memory in lower case, for example, "This is an apple, apple starts with 'a', the sound is /a/. Can you please write a lower case 'a' next to the apple?"
- The assessor carefully observes letter formation. If a formation error is made, or the student is unable to recall the letter, they are shown a model of the letter and asked to write it.[2]
- If a further error is noted, the examiner demonstrates the formation of the letter on the line on the assessment sheet and asks the participant to write the letter "just like me".

As noted for the original LFA (Chapter 3), the premise of the LFA-2 is that individual letter formation may vary depending on the ability to access orthographic representations, and the emergence of perceptual motor abilities. The integration of these factors demonstrates emerging fluency. Scoring is based on the level of prompting needed for the participant to form the letter correctly. Two scores are recorded in the LFA-2: LFA-Formation (LFA-F) and LFA-Letter Sound Correspondence (LFA-LSC).

LFA-F is a score of letter formation accuracy. Scoring is calculated based on the number of prompts needed to correctly form the letter, with four points given for correct formation from memory, three points for correct formation when shown a model, two points for correct formation after a demonstration of the letter form and one point for a recognisable attempt after demonstration regardless of the formation pattern used. For unrecognisable attempts after demonstration, no points are awarded. A score is obtained for each letter and tallied to obtain a score out of 104.

[2] In this study, judgements about formation errors were made based on the conventions for NSW Foundation Font which is used in NSW primary schools. Similarly, models of the letter were presented based on NSW Foundation Font format.

LFA-LSC is a score of letter sound correspondence. A score (one for correct, zero for incorrect) is recorded for the first attempt at each letter. This is a measure of ability to write a matching letter after a verbal prompt, irrespective of the use of upper or lowercase or incorrect letter formation pattern. LFA-LSC is scored out of 26.

The LFA-2 has excellent inter-rater reliability (agreement between individual letter scores, ICC estimate 0.83, 95% CI [.78, .88]; agreement between total scores, ICC estimate 0.95, 95% CI [.75 , .99]) (Evans et al., 2019). Coefficients for concurrent validity of the LFA-2 with measures of visuomotor ability and alphabet writing fluency are fair to moderate (r = 0.32 – 0.55) (Daly et al., 2020).

5.6.1.3 Bruininks-Oseretsky Test of Motor Proficiency Fine Motor and Manual Dexterity Sub Tests.

Fine motor and manual dexterity skills were measured using two sub tests of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2, Bruininks & Bruininks, 2005). The BOT-2 is a standardised tool that is norm referenced for those whose ages range from four to 21, allowing for a standard score in each sub test as well as an overall score for the full form. The full form of the BOT-2 has eight sub tests: fine motor precision, fine motor integration, manual dexterity, upper limb coordination, bilateral coordination, balance, running speed, and agility and strength. For this study, only two sub tests were selected—fine motor precision and manual dexterity—as they included skills that have been shown to have had an association with handwriting ability such as in-hand manipulation and fine motor precision (Cornhill & Case-Smith, 1996). The BOT-2 fine motor precision sub test includes activities such as tracing inside lines, folding paper and cutting out. For the manual dexterity sub test, activities include precisely marking inside dots on a page, transferring coins to a container, sorting cards into piles and threading beads. Inter-rater reliability for the BOT-2 complete form and sub tests was found to be > 0.90 with the exception of the fine motor sub test which was 0.87 and coefficients for concurrent validity were moderate to strong, ranging from r = 0.51 to r = 0.74 (Deitz et al., 2007).

5.6.1.4 Beery-Buktenica Developmental Test of Visual Motor Integration and Supplemental Tests (Beery VMI and Supplemental Tests).

The Beery-Buktenica Developmental Test of Visual Motor Integration (Beery VMI, 6th Edition; (Beery et al., 2010) was used to assess visuomotor skills. The Beery VMI is a norm referenced and frequently used test with established evidence for relationships between performance on the test and handwriting ability, as detailed in Chapter 1 (Section 1.3.2.1.3). The Beery VMI is an individually administered assessment in which the participant copies lines and shapes of increasing complexity. Scoring is based on accuracy of shape copying. For this test, a cut off is made when a participant makes three consecutive errors. The Beery VMI has consistently high inter-rater reliability and validity (Beery et al., 2010)

Two supplemental tests were also administered—the Visual Perception Test and the Motor Coordination Test. The supplemental tests were used in this study as measures of baseline ability rather than outcome measures. In the Visual Perception Test, participants are shown a shape and then asked to identify the matching shape from a group. This test is stopped when three consecutive errors are made or on completion. In the Motor Coordination Test, participants are asked to draw lines inside the outline of shapes of increasing complexity. The Motor Coordination Test has a time cut off of five minutes.

5.6.1.5 Dynamic Indicators of Basic Early Literacy (DIBELS).

The DIBELS is a frequently used test of literacy skills and measures early literacy abilities including Letter Naming Fluency, Phoneme Segmentation Fluency, Nonsense Word Fluency, Word Reading Fluency and Oral Reading Fluency (University of Oregon, 2018 - 2020). For this study, three sub tests were used—Letter Naming Fluency (LNF), Nonsense Word Fluency (NWF) and Word Reading Fluency (WRF), based on relevance to the study aims and questions. The DIBELS follows standardised procedures, with each sub test administered for one minute and scored based on the number of correct items. The standard procedures were followed in this study; however, the test materials were modified to be consistent with the New South Wales Foundation font, which was being taught in class.

The modified test materials matched the DIBELS forms, with the only difference being the font used. For LNF, students were shown a sheet of randomised upper and lowercase letters and asked to name as many as they could within a minute. The examiner provided a visual cue by tracking along each line with their finger, to ensure that children with scanning difficulties were not disadvantaged. The examiner read letters which the participant could not name, and the child was encouraged to keep going. For NWF, two practice items were used to teach the task. Children were then asked to read short decodable nonsense words, either reading the word as a whole, or saying each sound. Points were awarded for each correct sound, or for the whole word if it was read. Word Reading Fluency (WRF) was assessed using a page of decodable and irregular words of increasing complexity. As for LNF, the examiner read words which the participant could not read and the child was encouraged to continue. A point was awarded for each correctly read word. Inter-rater reliability for scoring of DIBELS sub tests has been reported as excellent (ICC 0.982, 95% CI [0.982, 0.996]) with moderate to good concurrent validity coefficients (LNF, $r = 0.27$ - .60; NWF, $r = 0.27 – 0.65$; WRF $r = 0.26 – 0.73$) (University of Oregon, 2018 - 2020).

5.6.1.6 Letter Name and Sound Knowledge.

A test of letter name and sound knowledge was devised, based on measures used in the literature, to obtain a baseline of skill ability and to measure growth in letter name and sound knowledge (Eckberg Zylstra & Pfeiffer, 2016; Karlsdottir & Stefansson, 2003; Larsen et al., 2015). Larsen et al. (2015) devised a comprehensive test of letter sound knowledge, including all single letter sounds and digraphs; however, this method was modified to allow for the stage of Kindergarten of the study participants, who had only learnt single letter sounds at the outset of the assessment period. As such, only single letters were presented. In a further modification from Larsen et al. (2015) an example of both the upper and lowercase letter was provided to ensure the maximum opportunity to recall names and sounds. A sheet of randomised letters (matched upper and lowercase) was shown to the participants one row at a time, and they were asked to say the letter name and sound. Participants scored one point for each correct letter name and/or sound, with a total of 26 points possible in each category. A similar procedure was followed to Larsen et al (2015), with the assessor providing the correct name and sound if the participant was unable to respond, and then encouraging the participant to move onto the next letter. The assessment sheet is in Appendix 8.

5.6.1.7 Timed and Untimed Alphabet Writing.

As seen in Chapter 3, measures of timed alphabet writing are commonly employed in the literature as a way to assess handwriting fluency for Kindergarten children. The method used by Puranik et al. (2017), who explored the relationship of timed and untimed alphabet testing to literacy, was used as the basis for devising an alphabet writing fluency test in the present study. A script was written and teachers were trained in the administration of the test at both the control and the experimental schools (see Appendix 9). Teachers were asked to administer the test as a whole class in order to reduce the impact of individual assessment time on participants and to reflect established practices for alphabet testing. Teachers reported they followed the script accurately and data were collected at the same time point at both schools. The participants were asked to write the lowercase alphabet as quickly and carefully as they could, and were asked to put their pencils down at the 60 second point. Teachers then drew a line next to the last letter written to show the amount completed at 60 seconds and asked the children to then carry on writing until they were finished, or could no longer remember any letters. The alphabet test was scored using a rubric devised by Puranik et al. (2017). Two highly experienced early education teachers completed the scoring of the alphabet tests, and independently scored the same samples until 100% agreement was reached for five consecutive samples. In this rubric, each letter received a score of zero points, half a point or one point, giving a total score out of 26. Scores were based on four possible errors:

- Letter form/control
- Reversal/inversion
- Uppercase
- Unrecognisable

If none of the four errors were made, the letter received a score of one point. If only one error from form, reversal or uppercase was made, the letter received a score of half a point. Multiple errors, unrecognisable letters or omitted letters were scored zero points. Repeated letters were not scored more than once and letters in random order (i.e. not in alphabetical sequence of at least two letters) did not receive a score. Using the scoring matrix, a score was given for letters written at 60 seconds (AW60), and letters written in the untimed condition (AWU). Assessment of letter form, the appearance of the letter on the page, was based on NSW Foundation font lower case. A "more than half" rule was used to make decisions for form/control for letters such as *h*. In applying this rule, assessors considered if the form was incorrect by more than half to decide on form/control errors, for example, the "bump" of the *h* more than half way up the length of the downward stroke would be considered an error of form as the letter would then look more like an *n*.

5.6.1.8 Writing Composition.

Class teachers administered a scripted, whole-class composition task which was devised to assess participants at all three assessment time points (see Appendix 10). A simple topic relevant to all children was conceived and used at all three time points. The topic was to write freely using the prompt "I like…". A procedure was adapted from studies that use composition in Kindergarten as a measure of literacy. The procedure was for each class teacher to lead a class discussion on the topic, following the set script. Children were prompted to discuss things they like, such as things to eat, do or play. Ideas were not written down; however, the prompt phrase "I like" was written on the board. Children were then asked to write their name at the top of their page. The page was divided into an upper third and lower two thirds, with the upper third used for drawing. Prior to commencing writing, children were given six minutes to draw their idea/s of things they like. This procedure was common to both schools, and was used as a strategy to assist children to conceive and record their ideas visually prior to writing. After six minutes, children were asked to cease drawing and begin writing their story using the prompt "I like…" which the teacher wrote on the board. Prior to commencing writing, children were reminded of the prompt phrase, and encouraged to write as many things as they wished. Children were then given ten minutes to write their composition.

The writing samples were then collected and coded for scoring. Scoring was based on a rubric devised specifically to suit Kindergarten children. Scoring included the number of words written (WW) and a composite score of writing quality compiled from scores and ratings on six areas (WQ). Scoring was completed by two highly experienced early education teachers and inter-rater reliability was established by comparing marks for the first five samples. The scorers then discussed the discrepant ratings to ensure a common understanding of each criteria and independently marked five more samples. For the second batch of five samples 100% agreement was reached.

For the writing composition sample, an individual score was calculated for WW. For this score, the total number of words written was counted. Spelling did not have to be correct, but the word had to be recognisable and able to be phonetically determined, rather than being a string of unrelated letters. This method reflects developmental scoring of spelling seen in other studies of Kindergarten writing (Kent et al., 2014; Kim et al., 2014; Puranik & Al Otaiba, 2012). WW score did not include the child's name or the prompt phrase "I like". If "I like' was repeated after the first sentence, these words were counted.

Composite scores out of 26 were also calculated for the writing composition sample based on scores from six aspects; quality of ideas, spelling, punctuation, sentence structure, vocabulary and handwriting. The writing composition sample rubric was conceived from a number of tools and rating scales suitable for Kindergarten writing. The features of the rubric were adapted from Mackenzie et al. (2013) who used categories including text structure, sentence and grammar features, spelling, punctuation and handwriting/legibility to develop a writing analysis tool for Year 1 students. The descriptive categories for the quality of ideas and handwriting were also adapted from this tool. The Harrison Writing Assessment and Moderation Tool for Kindergarten (Harrison School, n.d.) was used to create a scoring system relevant for Kindergarten children for spelling, punctuation, sentence structure, vocabulary, handwriting. The scoring matrix is presented in Table 5.2.

Table 5.2

Scoring for Quality of Writing Composition Items

Category	Score	Description
Quality of ideas	Rating scale 0 -4 points	0 points for no message, 1 point for one idea, 2 points for more than one idea that may be unrelated, 3 points for one or more ideas elaborated, and 4 points for a coherent story connecting ideas.
Spelling	Mark out of 5	1 mark for each of 5 items: correct spelling of most decodable one syllable words; correct spelling of most common irregular one syllable words (e.g. was, the); incorrect medial but mostly correct initial and final sounds; correct spelling of one or more irregular words containing complex medial vowels; and attempts at one or more sound blends such as consonant digraphs.
Punctuation	Mark out of 4	1 point given for each of: consistent use of capital at beginning of sentence; consistent use of full stop at end of sentence; consistent use of uppercase letters for pronoun ‘I’ and or their own name within a sentence; and use of capitals for a range of proper nouns but may not be consistent and/or experimentation with further punctuation
Sentence structure	Mark out of 4	1 point given for each of the following—use of sentence starters such as “I am”; use of compound sentences with simple conjunctions; varied sentence beginnings; and use of appropriate conjunctions to add ideas or give additional information.
Vocabulary	Rating scale 0 – 4 points	0 points were given for no words written; 1 point for use of mostly simple words such as nouns; 2 points for use of nouns and some verbs or describing words; 3 points for use of nouns, verbs and some precise or subject specific describing words; and 4 points were given for choice of words that included nouns, verbs, describing words and may show feelings.
Handwriting	Rating scale 0 – 5 points	0 was given for writing that was not recognisable as letters; 1 point for letter like forms with some recognisable letters; 2 points for a mix of upper and lowercase letters and/or some reversals or distortions; 3 points for mostly correct letter forms but with poor spacing, positioning or corrections; 4 points for correct letter forms, mostly well positioned and spaced; and 5 points for regularity of letter forms and letter size, well positioned and spaced.

5.6.2 Administration Procedures

Assessments at each data collection point were conducted by a team of Research Assistants (RAs) who were in 2nd, 3rd and 4th year undergraduate occupational therapy programs at the University of Newcastle. The RAs were required to apply for the role and were selected based on their level of paediatric experience and availability for each assessment time period throughout the study. The RAs were rigorously trained in the use of all assessment tools included in the study and during the training were given the opportunity to practice each assessment tool to ensure accuracy of its use and to clarify any procedures and rules which were specific to each tool. Written procedures were provided for non-standardised tools, and scripts and procedures of standardised and published tools were followed as written. The RAs were rostered to each school at each time period and were blinded as to which school received the intervention. Supervision of the RAs was provided onsite by a member of the research team (candidate and supervisors). Onsite supervisors carefully monitored the implementation of each assessment tool, providing additional on the spot training of aspects of assessment if required. Supervisors also provided a support role in ensuring participants were managing the assessment demands, and problem solving with the RA if any difficulties arose. In the vast majority of cases, participants were easily able to manage the assessment tasks and appeared to enjoy the activities and the one-to-one time with an RA. As the RAs were highly trained in practices to support participants, in using developmentally appropriate language, in rapport building and giving feedback, there were very few instances where modifications to the assessment process were needed. Modifications, where they occurred, did not alter assessment tasks, rather they included accommodations, for example, breaking a participant's assessment activities over recess or lunch to allow for some rest time in between assessments.

The assessments were administered in a carefully designed sequence at each time point, to ensure participants were given a mixture of activities and built-in breaks between cognitive and motor tasks. The order of assessments was chosen in order to balance literacy assessments with motor tasks, and to present the LFA-2 first, so that subsequent letter identification tests did not influence the capacity to remember letters unprompted. Minimal changes to the sequence were made at post-intervention and follow-up time points, in order to ensure a balance of tasks was maintained. The sequence was followed by each RA at all times and a checklist was used to monitor progress. The checklist was also used as a tool to assist participants with the assessment process, as they were encouraged to independently mark the list when an item was completed. This strategy not only ensured the integrity of the assessment sequence, it provided the participant with visual feedback of their progress and an opportunity to take ownership of the tasks being completed by ticking each step along the way. The assessment sequence at each data collection point is shown in Table 5.3.

Table 5.3

Assessment Sequence at Each Data Collection Point

Baseline*	Immediate post-intervention**	Follow-up***
Beery VMI	BOT-2 fine motor precision subtest (plus item one of manual dexterity)	Beery VMI
LFA	LFA	LFA
Beery visual perception	Letter identification assessment	Letter identification assessment
Letter identification assessment	DIBELS	BOT-2 fine motor precision subtest (plus item one of manual dexterity)
BOT-2 fine motor precision subtest (plus item one of manual dexterity)	BOT-2 manual dexterity subtest	DIBELS
DIBELS		BOT-2 manual dexterity subtest
Beery Motor Coordination subtest		
BOT-2 manual dexterity subtest		

*Baseline assessments were conducted prior to the intervention period over a two-week period. A two-week school holiday period followed the baseline assessment phase after which the eight-week intervention commenced
** Immediate post-intervention assessments were conducted over a two-week period immediately after the conclusion of the eight-week intervention period
***Follow-up assessments were conducted over a two-week period, at 12 weeks post the conclusion of the intervention

5.7 Intervention—Write Start-K

The Write Start-K intervention was developed from the modified Write Start approach detailed in the pilot study (Chapter 3, Section 3.3.6). Write Start-K was informed by the 4*R*s model described in Chapter 4, which incorporated the findings of the systematic review (Chapter 2) and the pilot study (Chapter 3).

5.7.1 Intervention Overview

Write Start-K was delivered in each Kindergarten classroom in two 45-minute sessions per week for eight weeks. Each session was co-taught by the class teacher, the primary researcher and one RA. An additional teacher, a specialist instructional leader, was available as reserve for the class teachers if required. The RA for each session was one of two occupational therapy undergraduates recruited for the study. These two RAs were not part of the assessment RA team and were not involved in any assessment procedures. A comprehensive training program was conducted with the RAs, the participating Kindergarten teachers and the instructional leader teacher to ensure the key aspects of the intervention approach were utilised throughout the program. Intervention plans and activities were reviewed at a weekly meeting of the intervention team. A summary of the intervention program is in Appendix 11.

5.7.1.1 Contrast of Intervention to Standard Teaching.

Morning literacy sessions were observed at both schools, and at each school these sessions comprised a mix of reading and writing activities. Examples of typical instruction in these sessions included whole-class instruction of a new letter, letters or words (with or without modelling and practice), followed by literacy in small group rotations, supported by a teacher and an aide, such as copying words onto a whiteboard from a picture, cutting and sorting letters to match a reading rule, cutting and pasting coloured squares onto “bubble” letters to fill in the shape, use of iPads to practice a literacy task, practising a new word on a worksheet, tracing letters on a worksheet or reading with the teacher. As described, Write Start-K was conducted at the intervention school twice a week, and replaced two of these regular literacy teaching sessions. Write Start-K lessons were characterised by a focus on developing handwriting fluency for the whole alphabet, using activities that developed perceptual motor skills and linked knowledge of letter names, sounds and forms. In the control school, the standard teaching approach included typical handwriting and literacy teaching. Literacy methods included teachers demonstrating a letter or letters; for example, the letters *u* and *e* together make the /u/ sound. Small-group rotations or individual activities followed the demonstration, such as pasting colored squares onto printed bubble letters, copying words, tracing letters on a worksheet, cutting and sorting words that fitted under headings (e.g., words with and without a silent *e*), and use of an iPad for literacy activities. Handwriting lessons at the control school used standard procedures, such as modelling of letter formation and provision of worksheets for practice. A key difference in the approach at the intervention school was the focus on handwriting fluency and consolidation of letter-forming patterns for each letter through visuomotor, fine-motor, and cognitive-themed activities. This was a distinct difference, as usually at this stage of the curriculum, after all letters have been introduced, attention would turn to reading and spelling in literacy lessons, rather than reemphasizing letter forming of all letters through handwriting. The instructional approaches at the intervention and control school are summarised in Table 5.4.

Table 5.4

Contrast of Instructional Approaches at Intervention and Control Schools

Intervention	Control
Regular morning literacy sessions, with two of them replaced by the Write Start-K program.	Regular morning literacy sessions, following standard curriculum.
Regular literacy sessions on non-Write Start-K days included phonics, understanding blends and digraphs, writing practice, and reading.	Regular literacy sessions followed standard curriculum and included phonics, blends and digraphs, handwriting, writing practice and reading.
Write Start-K lessons focussed on letter formation, letter names and sounds, and perceptual motor skills development related to handwriting.	Perceptual motor skills may have been included in general classroom activities such as craft.
All letter sounds had been introduced by the end of Term 2, prior to commencement of Write Start-K.	All letter sounds had been introduced by the end of Term 2, as at the intervention school.
Focus on revision of handwriting fluency for whole alphabet and emphasis on letter formation for similar groups of letters.	Handwriting instruction as part of literacy was not explicitly attached to letter groups or families with similarities based on directional properties.
Daily morning writing practice	Daily morning writing practice

5.7.2 Write Start-K Revision Approach

Write Start-K included four major revisions: adoption of the 4*R*s model as a basis to each intervention activity, interaction of cognitive and perceptual motor processes, revising and reteaching letter formation based on letter groups or families, and a reduced number of sessions from the original Write Start.

5.7.2.1 Adoption of the 4*Rs* Model for Each Activity.

The 4*Rs* model of handwriting fluency acquisition presented in Chapter 4 emphasises the coordination of four factors to enable handwriting fluency: *Recall, Retrieve, Reproduce* and *Repeat*. As previously described, this model is based on literature explaining the interaction of process and product factors that impact beginning handwriting. In the 4*R*s model, process factors include recall and retrieval of letter form representations, and motor patterns and product factors include perceptual motor abilities that impact handwriting. Sufficient repetition is seen as key to facilitating coordination between product and process factors. In the modified Write Start tested in the pilot study (Chapter 3) station-based activities emphasised three target areas—cognitive, fine motor or visuomotor development. Each station activity emphasised one of the three target areas as foundational to handwriting fluency, but a link between process and product factors in each activity was not always explicit. In Write Start-K, small but significant changes were made to incorporate the 4*R*s model within each activity. The stations continued to be themed into fine motor, visuomotor and cognitive areas, reflective of the established role of each of these areas in handwriting acquisition. However, the 4*R*s model was applied to each activity to ensure the coordination of all processes. Few changes were made to cognitive station activities, because in the modified Write Start these were more likely to include all aspects of the 4*R*s model. Fine and visuomotor activities were generally revised as these were less likely to include all aspects of the 4*R*s model. For example, in the modified Write Start, playdough might be used for hand strength development. In Write Start-K, the fine motor themed station used playdough to make the target letter, and novel ways of writing the letter onto the playdough such as rolling a marble, driving a toy car or using a chopstick as a pencil. These modifications ensured that foundation skills indicated in emerging handwriting continued to receive focus, with the fluency processes that underpin handwriting being accentuated. Examples of typical revisions from the modified Write Start to Write Start-K are in Table 5.3. Descriptions of all activities included in the program are in Appendix 11.

Table 5.5

Examples of Revisions from Modified Write Start to Write Start-K to Incorporate 4Rs Model

Activity focus	Modified Write Start	Write Start-K
Fine motor, letter *p*	Make a playdough pizza by rolling a ball, flattening it and then adding toppings made of small pieces of playdough. Emphasises the letter *p* as the starting letter.	Roll a long playdough snake, break into two parts and form the letter *p*. Use a marble to roll on the shape of the letter using the correct starting point and formation pattern. Repeat using different tools to 'write' the letter on the playdoh such as a toy car or a chopstick.
Visuomotor, letter *j*	Dot to dot of a picture of a jellyfish, noting that it starts with the target letter.	Dot to dot of the letter *j* in upper and lowercase. When finished, use rainbow crayon colours to write the letter inside the outline of each letter, using correct formation.
Cognitive, various target letters in short words	Use laser pointer to find target letters or words on classroom word wall. Students copy words onto a blank page, emphasising target letters.	Use a laser pointer to identify target letters or words on the classroom word wall. Demonstrate letter formation of each letter in a word using coloured paper themed with 'sky, grass and dirt' colours to show line placement for each letter. Ask students to attempt on own themed paper from memory. Monitor and encourage letter formation and support with looking at example as required.

5.7.2.2 Interaction of Cognitive and Perceptual Motor Processes.

As reported in Chapter 2, the systematic review highlighted a link between handwriting and literacy, and identified that interventions impacting handwriting fluency generally used sensorimotor-based learning activities. This finding was applied when revising Write Start-K, through an emphasis on multi-sensory methods throughout instruction such as the use of consistent mnemonics to guide letter formation. In addition, materials with different sensory modalities were used in intervention activities to diversify sensory input whilst learning letter formation. Materials included, chalk and chalkboards, various writing tools such as crayons and pencils, and different writing surfaces such as whiteboards, chalkboards and paper.

5.7.2.3 Revising and Reteaching Letter Formation Based on Letter Groups or Families.

In the pilot study (Chapter 3) handwriting fluency improvements were observed based on teaching one letter per week. The systematic review (Chapter 2) identified that letter writing fluency had the strongest relationship with literacy outcomes. These two findings informed a revision to Write Start-K, emphasising letter writing fluency by linking letters into families with similar directional properties and teaching them in the same session. For example, the letters *r*, *n*, *m* and *h,* all begin with a downward stroke and finish with a "bump". The reason for approaching the letters in this way was to maximise the repetitions of letter forming patterns within each session and to also assist in building associations between letter forming patterns, letter names and sounds. For the first week of the program, as there was no revision, a larger number of letters were introduced in the "magic *c* family" (all letters in this family starting with the letter *c* shape, such as *a, o, d, g* and *c*). For subsequent weeks, the letter family sizes were reduced as much as possible to allow time in whole-class instruction for revision of letters from previous weeks. Appendix 11 (Write Start-K session summary) lists the letter families learnt each week.

5.7.2.4 Dose Intensity and Practice Repetition.

The pilot study of modified Write Start (Chapter 3) found that an effect on handwriting fluency was possible after an eight week, twice weekly intervention program emphasising one letter per week. The 4*Rs* model proposed that fluency would be enhanced by repeated exposure to process and product factors within handwriting activities. These two findings informed an increase in intensity of Write Start-K, through an increase in the number of letters learnt each week, and by maximising repetition of letter formation in each activity. As described in Chapter 1, dose and practice repetition are significant factors in determining the effectiveness of a handwriting intervention (Engel et al., 2018; Hoy et al., 2011). This number of Write Start-K sessions (16) was slightly short of the recommended dose of practice found in the literature, of 20 practice sessions (Hoy et al., 2011); however, the evidence from the pilot study and application of the 4*Rs* model suggested that an intervention effect would still be observed. In addition, the practicalities of delivering the program within a 10-week school term was important. A further hypothesis was, that by delivering the intervention in a co-taught method, the “flow over” effect would be increased, with teachers taking opportunities to emphasise elements taught and emphasised within the program at additional times through the week, thereby adding to practice opportunities in addition to the programmed activities. This hypothesis proved to be correct, with teachers either reusing some of the station-based activities during regular weekly tasks such as literacy rotations, or adding novel experiences to emphasise letter practice. One teacher explained that on a sunny day, she and the class went outside and used paint brushes and water to paint letters on the walls and concrete.

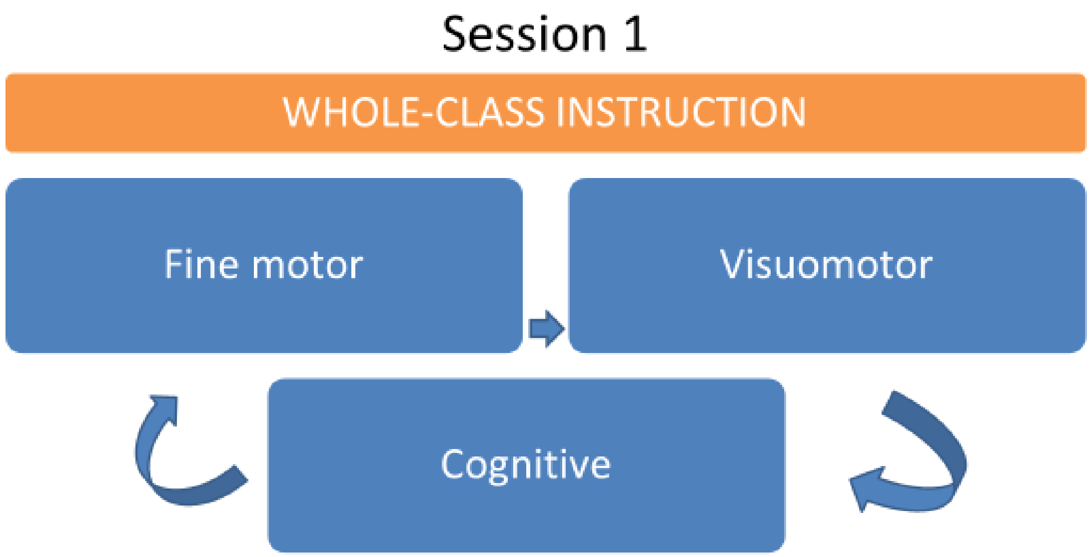
5.7.3 Session Outline

5.7.3.1 Session 1.

Session 1 consisted of two components—whole-class instruction followed by small group station-based activities (see Figure 5.2).

Figure 5.2

Flow of Intervention Session 1



5.7.3.1.1 Whole-class Instruction.

Whole-class instruction was of 15 minutes duration and was generally led by the class teacher. Children were seated on the floor in a structured seating plan that allowed room for the use of small, individual whiteboards. Key features of whole-class instruction were to introduce the new focus letter family and conduct a short revision of the previous week's letters using multi-sensory modelling (such as air writing, or tracing letters on the carpet), consistent mnemonics to guide letter formation and whiteboard practice of correct formation. Multi-sensory practice aimed to support internalisation of and associations between letter name, sound, letter formation pattern and motor pattern. Self-talk of the mnemonic was encouraged to support development of motor patterns for each letter. Letter formation practice was supported by direct and positive feedback from the intervention team, and invited self-monitoring, such as children circling their best example of practice letters.

5.7.3.1.2 Session 1 Activity Stations.

Three activity stations were included in Session 1, themed on fine motor, visuomotor or cognitive activities. The class was divided into three groups and each group rotated through the stations, spending approximately ten minutes in each activity. Each station was led by one of the intervention team. Features of activity stations were: variety to maximise novelty and engagement; encouragement of self-monitoring and active assistance; and, support from an intervention team member at each station. Each activity integrated all aspects of the 4*Rs* in addition to the thematic focus area.

Fine motor theme

Fine motor activities emphasised hand and finger strength and coordination as well as repetition of letter formation using recall, retrieval and reproduction processes. For example, making a playdough letter *a* and tracing the formation of the letter using beads required the use of fine motor skills whilst concurrently and repeatedly recalling the letter, and retrieving and reproducing the motor pattern. Variation and repetition were created by using different tools or methods to trace around the playdough letter, such as toothpicks or marbles.

Visuomotor theme

The emphasis of visuomotor activities was on learning to replicate motor patterns wherever possible, and making links to the letters of the week and the 4*R*s model. Examples include: following a guided drawing pattern using sequential drawings with added features to notice; remember and copy; explicit visuomotor development, such as mazes; and playing noughts and crosses in pairs on whiteboards or chalkboards using two letters of the week. In this game each child chose a letter from the pair and then played with a partner to complete the game. In each activity, visuomotor skills were emphasised through activity design, and the 4*Rs* were included by incorporating letters of the week in writing activities related to that task. Activities also used high levels of repetition of letter formation and variations, for example, for the noughts and crosses' game.

Cognitive theme

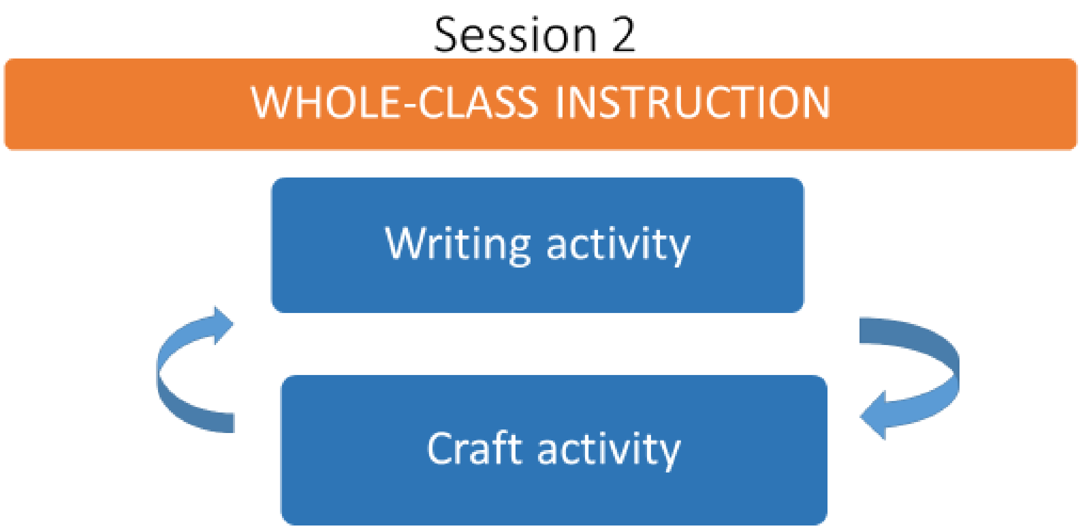
Cognitive activities emphasised all aspects of the 4*R*s model; however, activities were weighted towards the recall of letter forms and retrieval of associated motor patterns for formation. Focus letters were incorporated into short consonant-vowel-consonant words (CVC) and used for station activities. For example, in a "roll and write" game, six pictures on a large soft dice were used as the trigger for recall of the associated word, with children writing the word on a sheet of paper with corresponding picture. To make the activity more enjoyable, a game was created to see which picture would "win", i.e. be written the most times. Adjustments to the cognitive demand were made by providing modelling of the word on a small whiteboard for those children who needed it, or adjusting the number of letters to be recalled at a time by modelling and then hiding sequential letters in each word.

5.7.3.2 Session 2.

Session 2 emphasised the repetition of the whole-class instruction element, using the same principles as used in Session 1. This whole-class instruction element was then followed by two group stations, comprised of half the class rotating through each group (see Figure 5.3).

Figure 5.3

Flow of Intervention Session 2



5.7.3.2.1 Writing Activity.

The writing activity station incorporated practice of writing the letters learnt in the week within a meaningful, modelled and guided sentence and/or individual words. The weekly intervention team meeting decided on a modelled sentence or word writing activity to ensure that it was achievable by the Kindergarten children, and used words of an appropriate level. In order to embed the 4*R*s model, the writing activity focussed on recall of newly learnt letters rather than only copying from a model. Strategies that were employed to achieve increased use of memory for accurate letter formation included modelling one word at a time on a small whiteboard, and then encouraging children to look, say and remember, then write. The teacher might then hide the word, but show it to any children who might need an extra prompt. A game-like approach was encouraged to build fun and confidence for the children in writing letters and words from memory. An additional strategy utilised in the writing activity was to only use words and sentences formed from letters learnt in the program, either in that week's session or in preceding weeks. This ensured maximum opportunities to practice letters learnt using correct and fluent formation and the development of mastery, over time.

5.7.3.2.2 Craft Activity.

The craft activity was related to the writing task and the letters of the week and emphasised use of many skills needed for successful writing which were indicated in the 4*Rs* model. For example, when the focus letter was *w*, children made a paper plate whale and the sentences and words used in the writing activity related to the craft activity. All craft activities were selected based on the ability to break the task into a series of simple steps, and were graded to gradually increase the challenge of components such as following a series of instructions, or manipulating scissors. The craft activities were weighted towards *reproduction* factors in the 4*Rs* model, such as an emphasis on bilateral hand use, use of the dominant hand with support from the "helper hand", and visually monitoring task performance. For example, in the first week, children folded a paper plate in half, using firm pressure from their dominant hand and then cut the plate in half to make two face masks. In a subsequent week, the challenge was increased for visual monitoring, bilateral hand use and cutting skills by asking the children to trace around their non-dominant hand and then cut around their hand shape to make feet for a frog. The level of visual monitoring needed for this second task was higher, as children had to carefully observe and sustain the position of their non-dominant hand while they traced around each finger. Children enjoyed the craft aspect of the second session greatly, often playing with their creations on completion.

5.7.4 Intervention Fidelity

The fidelity of the intervention program was determined through both the planning of the program delivery, training of all interventionists and independent assessment of the adherence to the program.

5.7.4.1 Planning of Program Delivery.

The content and dose of the intervention were determined from both the systematic review (Chapter 2) and from the pilot study of modified Write Start (Chapter 3). The underlying theoretical framework for intervention (Chapter 4) has been previously outlined, and includes the factors that have been identified as contributors to handwriting fluency for Kindergarten students, as well as the research findings on sufficient dose of intervention.

5.7.4.2 Training of Interventionists.

Standardised training procedures using a purpose-written manual were conducted by the thesis author (KR) and one supervisor (KD) for an initial half day pre-intervention training session. The thesis author (KR) is an experienced occupational therapist, and the thesis supervisor (KD) has significant experience in early childhood education. Ongoing training throughout the intervention to prevent deviation from procedures was provided by the thesis author (primary interventionist). The ongoing training took the form of weekly review and planning meetings, previously described, during which the intervention team reviewed the preceding session and referred to the manual to re-train specific aspects as required.

All three teachers (one teacher for each class and an instructional leader teacher as reserve) and two RAs were the primary co-facilitators of the intervention program and all received the half-day training program. Both RAs had also previously completed a clinical placement that used Write Start-K on a once weekly basis in Kindergarten classes. As a result, the RAs were familiar with the principles of the program and were skilled at facilitating small group activities for Kindergarten students. The RAs participated in the training workshop to gain up-to-date information on the revised methodology for the twice weekly Write Start-K program. The training consisted of three modules and one application activity:

1. Module one provided a rationale for the use of a whole-class approach to handwriting for Kindergarten students. The key points were the continued role of handwriting in early

schooling, the impact of handwriting ability on literacy, the prevalence of handwriting difficulties, the potential decline in students' foundation skills on school entry and the impacts of insufficient direct instruction.

2. The second module provided an overview of the 4*Rs* handwriting fluency acquisition model as a framework. In this module, a video example of a child completing the LFA-2 was used to demonstrate the varying levels of fluency for different letters typical of a Kindergarten student. This video showed only the child's hand, and had been collected as part of a supplementary study being conducted by an undergraduate Honours student, and release of the video was consented to by the participant's parent (Evans et al., 2019).
3. The third module provided an overview of the two sessions in Write Start-K, as described above.
4. Video of teachers conducting the whole-class instruction element of the program and managing transitions between small group stations was observed and rated for adherence to the fidelity measure from the original Write Start program (see Section 5.7.4.3). This video had been obtained from a school using the Write Start-K program and the teachers involved had consented to use for educational purposes. During video analysis, an emphasis was placed on the co-teaching nature of the program, and specific instruction was provided to the Kindergarten teacher participants on how to introduce and instruct each section of the program.

The key principles emphasised in the training program for participating teachers and RAs were: to have an understanding of the basis of handwriting fluency; to exercise the co-teaching approach to intervention delivery; to implement methods for maximising attention and focus; and to support the creation of fluent letter reproduction. Managing transitions between activity stations was emphasised as a means to maintain task focus and attention, to ensure maximal opportunities for students to engage and self-monitor their handwriting. Previously described methods for maximising multi-sensory, whole-class instruction were emphasised. The adoption of strategies to promote use of memory during all writing activities was encouraged.

5.7.4.3 Fidelity Studies of Intervention Delivery.

A fidelity tool was sourced which had been used in the study of Write Start (Case-Smith et al., 2014) and was applied to Write Start-K (Weaver, 2019, personal communication). The fidelity assessment of Write Start-K implementation is in Appendix 12. One observation of each classroom was made for each session by an independent rater who was an occupational therapist with expertise in delivering the Write Start-K program in school settings. The observations were made in each classroom during week five of the program, and ratings were provided as per the fidelity tool. A high degree of intervention fidelity was recorded in both classrooms for Session 1. In this session, instructors were observed modelling and demonstrating target letters, providing visual and verbal cues, monitoring practice and assisting students to engage in station activities. Of note in both classrooms, high fidelity was achieved for ensuring the relationship of the activities to the letter was clear and verbal cueing was consistent between instructors. A lower degree of fidelity was observed for Session 2. This can be explained by the significant modification of Session 2 from a writer's workshop in the original Write Start, which was designed for older Year 1 students. Write Start-K significantly modified this approach to allow for the stage of writing development for Kindergarten children. For example, aspects of the fidelity tool that were not met related to story writing and sharing of writing with instructors or peers. Aspects that were met in Write Start-K included application of writing to other projects in the curriculum; in this case, direct application to the craft activity in Session 2.

5.8 Data Analysis

Data were examined for errors and descriptive and summary statistics were generated for all study variables. Baseline differences for three measures were assessed using t-tests—age, visual perception and motor coordination. Linear Mixed Models (LMM) were used to examine the research questions by assessing all outcomes for the impact of group, time and the group by time interaction, with these three terms forming the base model. LMM are useful for analysing non independent data, such as repeated measures in the same participant. Residual covariance structures were used for the modelling to allow for possible differences in variability at each time point and differences in correlation between time periods. Differences between groups at baseline for all remaining variables were assessed as part of the post hoc tests from the mixed models. Non-standardised effect sizes were calculated for the growth differences between groups across three time intervals—baseline to post-intervention, baseline to follow-up and post-intervention to follow-up. For all outcome measures, differences in mean scores between time points and 95% confidence intervals were estimated by use of the mixed models. Statistical significance was set at 0.05.

5.8.1 Finding the Best LMM

Multiple analyses were conducted using the base model for each outcome by varying the choice of residual covariance structure to determine the best fitting structure for each outcome measure. Two important modelling assumptions were addressed by this process. Firstly, to test the equality of variances assumption, three residual covariance structures were used whereby the variability at different time points was constrained to be the same (compound symmetry). Two additional alternatives were tried where the variability at each time point could vary (compound symmetry and unstructured). Secondly the independence assumption of no correlation between time periods was tested by using structures with constant correlation over time (either of the compound symmetry structures) and variable correlation using the unstructured form. The compound symmetry pattern of variance assumes that all variances and covariances are equal to each other. Compound symmetry heterogeneous allows the variance to differ, but the covariances must be equal. The unstructured pattern allows all variances and covariances to differ. In most cases either compound symmetry heterogeneous or unstructured were used reflecting the tendency for variability to change over time. For example, differences between scores varied considerably at baseline but were less variable at later time periods due to general improvement in students' performance, leading to the scores being more similar to each other. The decision as to the most appropriate covariance structure was made by using Akaike's Information Criterion (AIC). The structure with the lowest AIC was chosen, with a lower AIC of ten or more needed before a more complex structure was considered better than a simpler one (Burnham & Anderson, 2004). This process ensured that appropriate adjustments were made when the two most important modelling assumptions, constant variance and independence of observations, failed.

5.9 Summary

In this chapter the methods for the two-group study have been described. Chapters 6 and 7 provide the results and discussion in the form of two papers which present the research outcomes. Primary and secondary aims are addressed in each paper, and are divided into outcomes related to handwriting fluency, writing composition, and perceptual motor factors (Chapter 6) and outcomes related to measures of reading (Chapter 7). As both papers have been prepared as stand-alone manuscripts, some repetition of the overall methods has been necessary for reader context.

Chapter 6 Results and Discussion Part 1

Preface:

Chapter 6 presents Part 1 of the findings of a two-group study, examining the impact of the Write Start-K program on handwriting and literacy outcomes. The methods for this study were described in Chapter 5. Write Start-K is a revised and updated version of the modified Write Start, which was retrospectively analysed for effect on Kindergarten handwriting (Chapter 3). The 4*Rs* model (Chapter 4), drawing on both the literature and the pilot study results were used to inform the Write Start-K revisions. Two chapters report the results and discussion of the findings from the two-group study of Write Start-K. First, this Chapter 6 details the impact of Write Start-K on handwriting ability, including fluency and perceptual motor skills related to handwriting, as well as the effects on writing composition. Following, Chapter 7 details the impact of Write Start-K on reading abilities. The findings of the impact of Write Start-K on handwriting fluency and writing outcomes reported in this Chapter 6 are presented as a manuscript that will be submitted to the *American Journal of Occupational Therapy*.

The thesis questions addressed in this chapter are:

> Question 2**:** *How effective is a whole-class intervention in improving handwriting ability for Kindergarten students?* and
>
> Question 3**:** *Does a whole-class handwriting intervention impact Kindergarten students' literacy?*

Contribution statement:

With guidance from supervisors, the candidate was responsible for the design and implementation of the two-group study reported in this chapter. This involved recruitment of participants, training and supervision of all Research Assistants (RAs) and teachers involved in the study, coordination of scheduling of assessments by RAs at each data collection point, intervention design and implementation in collaboration with teachers. The candidate carried out all data entry and data cleaning. With the assistance of a statistical consultant the candidate organised the data into suitable forms for analysis, and carried out the analysis, interpretation and reporting of results. Both supervisors provided comments on drafts of the paper presented in this chapter. The statistical consultant provided comments on these drafts, primarily on aspects that related to statistical matters.

Authors and affiliations:

Improving handwriting fluency and writing outcomes in kindergarten: The effect of Write Start-K. Karen Ray[a], Kerry Dally[a], Kim Colyvas[a], Alison E Lane[a, b]

[a] The University of Newcastle; [b] La Trobe University

In preparation:

American Journal of Occupational Therapy[3]

Keywords:

Kindergarten, beginning writing, emergent literacy, handwriting, literacy.

Naming conventions used in the article:

As explained in Chapter 1, relevant journal language conventions have been used to describe school class level for chapters presented as a paper. For the paper presented in this chapter, terms used are: kindergarten; grade; and numerals for grade level, for example, grade 1.

Feedback to participants:

The results of the two group study were shared with the study participants at the conclusion of the final assessment period and after data analysis was conducted. Both the intervention and control school received information on the study outcomes and impacts on each measure. In addition, the control school received information on the theoretical model guiding the intervention as well as a

[3] Discipline specific (occupational therapy) recommendations are included in the following paper, in accordance with journal requirements.

detailed account of the intervention program. A summary of the intervention program activities was made available to both schools.

6.1 Abstract

Background: Children in the first year of formal schooling (kindergarten) are frequently instructed in handwriting but there is no consensus regarding the most effective teaching method to develop handwriting fluency, the ability to write letters legibly from memory, in beginning writers. Co-teaching methodologies in which teachers and occupational therapists collaborate to implement a handwriting curriculum emphasising literacy, cognitive and perceptual motor skills that underpin proficient handwriting, have been found to be effective from grade 1, but are as yet untested for kindergarten. Write Start-K is one such program, and the effectiveness of this kindergarten intervention on handwriting and writing composition is the focus of this article.

Methods: A two-group, pre- and post-test, comparison study was conducted. Participants were kindergarten students from two schools matched for socioeconomic status. Participants at the intervention school received Write Start-K delivered using a co-teaching approach in two 45-minute sessions per week for eight weeks. The intervention sessions replaced two of the regular class literacy sessions. Participants at the control school received standard instruction comprised of regular class literacy sessions. Measures included handwriting fluency (letter formation, LFA-F; letter sound correspondence, LFA-LSC; timed alphabet writing, AW60; and untimed alphabet writing, AWU), perceptual motor skills (visual motor integration, VMI; fine motor precision, FMP; and manual dexterity, MD) and writing composition (words written, WW; and writing quality, WQ). Data were collected at baseline, immediate post-intervention and follow-up (12 weeks post-intervention).

Results: Growth differences between the two groups were analysed using Linear Mixed Models (LMM). Significantly greater growth for the intervention compared with the control was observed from baseline to immediate post-intervention for LFA-F (5.9, 95% CI [2.2, 9.7]), LFA-LSC (2.6, 95% CI [0.9, 4.3]) and AW60 (2.4, 95% CI[0.2, 4.6]), from baseline to follow-up for LFA-LSC (2.3, 95% CI[0.7, 0.4]) and WW (14.4, 95% CI [8.4, 20.4]), and from immediate post-intervention to follow-up for WW (15.9, 95% CI [10.0, 21.7]). LMM showed a significant group by time interaction, indicating the change

over time for the intervention group, differed significantly to that of the control for LFA-F ($p = .005$), LFA-LSC ($p = .01$) and WW ($p <.001$).

Conclusions: The findings of this study indicate that Write Start-K impacted handwriting fluency and writing composition in beginning writers. Write Start-K shows promise as a means to impact both handwriting and writing composition for kindergarten students. Further research is needed to replicate these findings before practice guidelines can be amended.

6.2 Introduction

Despite increases in technology use, handwriting continues to feature in typical educational settings, comprising up to 20% of a typical day in the first year of schooling (kindergarten) and increasing to over 30% by grade 3 (McMaster & Roberts, 2016). Handwriting problems have been reported in up to 37% of children in early grades (Overvelde & Hulstijn, 2011a) and recent evidence suggests that important motor foundations of handwriting may be lacking for children due to reduced exposure to manual play (Gaul & Issartel, 2016; Sheedy et al., 2021). Handwriting proficiency has been linked to writing composition quantity and quality in grades 1 and 2 (Alves et al., 2016; Berninger et al., 1997; Graham et al., 2018; Graham et al., 2000; Jones & Christensen, 1999; Limpo & Alves, 2018). Further, an emerging body of evidence has reported similar associations between handwriting and writing composition in kindergarten children (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011; Kim et al., 2015; Puranik & Al Otaiba, 2012; Puranik et al., 2017). Capacity theory is one possible explanation for the role of handwriting in compositional writing. This theory proposes that, when working memory is liberated from the transcription demands of handwriting through the development of automatic processing, space becomes available for ideas, content and elaboration (McCutchen, 1996). Importantly, the impact of handwriting on writing composition appears to be more pronounced in the early years (Kim & Park, 2019). Given the continued role of handwriting in education, the prevalence of problems and the impacts on handwriting proficiency on writing composition, effective, early instruction in handwriting is critical (Limpo & Graham, 2020; Santangelo

& Graham, 2016). Handwriting instruction has been found to impact quantity and quality and fluency of student's compositional writing skills (Santangelo & Graham, 2016). Therefore Interventions to improve handwriting in kindergarten may provide a means to impact both handwriting and writing composition.

Predictors of handwriting ability include perceptual motor skills (visual perception, kinaesthesia, visuomotor and fine motor) (for a summary, see Feder & Majnemer, 2007) and a range of cognitive skills including orthographic coding (mental representations of letters or words) (Abbott & Berninger, 1993), memory (McCarney et al., 2013; Rosenblum et al., 2010; Tindle & Longstaff, 2021), phonological awareness (Berninger, Abbott, et al., 2006) and attention (Kim et al., 2013; Tseng & Chow, 2000) . These skills impact handwriting differentially. Handwriting legibility refers to the appearance of letter forms in terms of appearance, spacing and orientation, and it is impacted by perceptual motor abilities (Cornhill & Case-Smith, 1996; Daly et al., 2003; Fears et al., 2019; Fears & Lockman, 2018). Handwriting fluency refers to the ability to write legible letter forms from memory and is commonly assessed using measures such as timed alphabet writing or dictated letter writing (Puranik et al., 2017). As fluency generally requires both legibility and the activation of memory for letter names, sounds and forms, both perceptual motor and cognitive factors are likely to impact proficiency in this area (Berninger et al., 1997; Cartmill et al., 2009; Graham & Weintraub, 1996; Rosenblum et al., 2003). Alongside spelling, handwriting fluency is considered to be a key component of transcription, and together, these two components form the foundation for functional, compositional writing (Berninger, 1999). It has been suggested, therefore, that handwriting fluency is more important to writing composition than legibility alone (Limpo & Graham, 2020; Santangelo & Graham, 2016).

The range of perceptual motor and cognitive skills implicit in handwriting fluency for beginning writers has been identified, and development in these areas is considered to contribute to writing readiness (Dinehart, 2015; van Hartingsveldt et al., 2014). Kindergarten is a unique time when many of these skills are in active development and not yet consolidated (Ritchey, 2008). However, little is known about the impact of intervention for handwriting fluency for this age group on handwriting and writing composition outcomes (Engel et al., 2018). Studies of handwriting fluency acquisition in older children have found that a combination of explicit instruction and practice is an effective approach. For example, an intervention for grade 5 children that included letter writing practice, alphabet activities promoting fast written recall, and copying tasks that promoted the use of letters in words and activities, led to gains in both handwriting fluency and aspects of writing quality (Limpo et al., 2018). In another study, Limpo and Alves (2018) contrasted self-regulation (task planning, reviewing and revising) and transcription (handwriting and spelling) training with self-regulation only and standard instruction. The authors found that, while both groups with self-regulation training had greater impacts on writing composition, the addition of transcription had an even greater impact on both handwriting fluency and writing outcome. In particular, the combined intervention approach was found to positively impact the writing quality of poorer writers, suggesting an important role for foundation skills such as handwriting. For younger students (grade 1) Graham et al. (2000) reported improvements to both handwriting fluency and writing composition using an intervention approach that combined letter formation, sentence copying and application activities such as writing the letter as part of a picture. For the same age group, Case-Smith and colleagues reported significant impacts on handwriting legibility, fluency (making sentences out of provided words under a time constraint), and sentence writing (writing words or sentences in response to a picture prompt) of an intervention approach, Write Start, that combined explicit letter writing instruction with perceptual motor and cognitive skills development (Case-Smith et al., 2014). Similarities in instructional approach were evident in all of the grade 1 studies described, including a small number of focus letters each week, explicit instruction in letter formation, the use of target letters in all sentence copying and writing activities, and the inclusion of activities that explicitly or implicitly promoted perceptual motor skills such as fine motor control. For these younger children, it appears that repetition and consolidation of letter formation at the letter level was an important focus for facilitating fluency, as was facilitating motor control. The grade 1 studies also included instructional activities that engaged attention, such as writing letters in an unusual way, or using craft materials in letter writing or perceptual motor skills development activities.

The available evidence for supporting handwriting fluency acquisition is instructive; however, there are few studies that investigate the best methods of instruction for kindergarten children. Further, many interventions that target younger children report on outcomes for legibility, or on perceptual motor skills as precursors to writing instruction, with few reports of handwriting fluency available for this age group (Engel et al., 2018).

6.2.1 Elements of Effective Intervention

Traditional methods of intervention emphasise cognitive (top down) and perceptual motor (bottom up) approaches. In cognitive approaches, memory of letter formation is emphasised and activities include repeated practice using visual and verbal prompts to support fluency (Berninger et al., 1997). These approaches have been shown to be effective for children from grade 1 and above for fluency or legibility (Denton et al., 2006; Howe et al., 2013; Pfeiffer et al., 2015). Interventions explicitly addressing perceptual motor skills, generally in conjunction with multi-sensory letter writing practice, have also been shown to impact handwriting fluency and legibility (Case-Smith, 2002; Case-Smith et al., 2012; Case-Smith et al., 2014; Donica, 2015; Kaiser et al., 2011; Roberts et al., 2014). However, at this stage, it is unclear how to combine cognitive and perceptual motor skills in effective intervention in kindergarten to promote handwriting fluency.

As discussed, evidence suggests that both perceptual motor and cognitive factors may be especially important for beginning writing, suggesting that the effectiveness of top down and bottom up approaches may be influenced by age and stage. In one study, a sensorimotor approach (such as tracing letters in sand) was contrasted with a cognitive practice approach (such as following numbered arrow cues to imitate letter formation), with differences seen for older and younger children. Although there were no significant differences between the intervention approaches, grade 2 children showed greater gains in legibility after cognitive intervention; whereas, grade 1 children showed greater gains, after sensorimotor intervention (Zwicker & Hadwin, 2009). It is important to note that both intervention methods used handwriting practice; however, in the sensorimotor condition this practice used multi-sensory means. This type of intervention may be particularly relevant for beginning writers whose cognitive and perceptual motor skills are actively developing. For example, younger writers have a greater need for visual monitoring of letter writing than older writers (Weintraub & Graham, 2000) and there is evidence that older children with poor handwriting rely on visuomotor skills to a greater degree than do proficient hand writers (Tseng & Chow, 2000). For kindergarten children, 20% of the variance in alphabetic writing fluency has been explained by the ability to manipulate letter shapes (such as semi-circles or varying length straight lines) to form pseudo letters, also indicating high levels of visuomotor skill involvement (Reutzel et al., 2019). Studies such as these support the inclusion of perceptual motor skills development as part of handwriting fluency intervention; however, the evidence also indicates that crucial cognitive skills must also be integrated. In this article, we present a model of handwriting fluency acquisition that combines top down and bottom up intervention approaches and incorporates repeated practice of both perceptual motor and cognitive components.

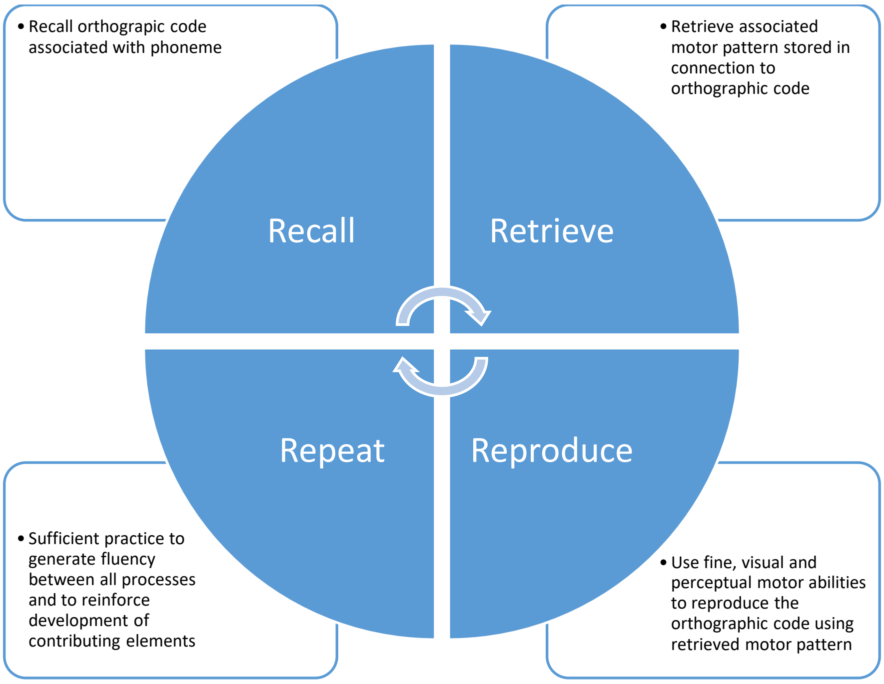
6.2.2 The 4Rs Model of Handwriting Fluency Acquisition

The 4*Rs* model[4] synthesises both the top down and bottom up elements implicated in handwriting processes (Cartmill et al., 2009; Hoy et al., 2011) and presents a practice model for application to Kindergarten handwriting fluency intervention. In the 4*Rs* model, four elements—*Recall, Retrieve, Reproduce* and *Repeat*—are viewed as components of a circular process, with each element influencing the others (Figure 6.1).

[4] Chapter 4

Figure 6.1

The 4Rs Model of Handwriting Fluency Acquisition



This model applies to the sub-word level, where letter writing is emerging (Puranik et al., 2017). In *recall*, the orthographic code for a letter is recollected based on the emergence of an association between a letter sound and its form (Abbott & Berninger, 1993; Berninger et al., 1997). A motor plan is then *retrieved* and paired with the recalled letter and orthographic code (Graham et al., 2006; Tseng & Murray, 1994; van Galen, 1991). *Reproduction* of the letter form involves perceptual motor abilities including fine motor, visuomotor, perceptual and kinaesthetic skills (Cornhill & Case-Smith, 1996; Graham et al., 2006; Kushki, Schwellnus, et al., 2011; Reutzel et al., 2019). Sufficient *repetition* of letter formation allows opportunities for component elements to develop and to work in cooperation (Berninger et al., 2009) and may also enhance perceptual motor skills and release working memory to aid *recall* (Zemlock et al., 2018). The 4*Rs* model of handwriting fluency acquisition recognises that this ability will not develop without handwriting practice but accommodates the contribution of orthographic knowledge (based on phonemic awareness), motor program development, and perceptual motor skills. This approach is important for the kindergarten age group, and perhaps for older children with handwriting difficulties, as the relative weights of the factors identified in the 4*Rs* model in overall fluency are not known. The 4*Rs* model provides a plausible explanation of why practice is indicated in all effective handwriting interventions (Hoy et al., 2011), as repetition enlists and develops component factors that are needed, and reinforces the circular relationships between elements. The 4*Rs* model is proposed as an approach to handwriting intervention to target handwriting fluency for beginning writers.

6.2.3 Curriculum-based Approaches

Current evidence supports the use of curriculum-based (whole-class) approaches to handwriting intervention as well as foundation skills development. Curriculum-based approaches are a response to the observed prevalence of handwriting and handwriting foundations problems, as previously described, as well as a method of integrating interventions into naturalistic classroom environments (Case-Smith et al., 2012). Curriculum-based interventions, often blending top down and bottom up approaches, have been shown to be effective for handwriting legibility for children from grade 1 (for a review, see Engel et al., 2018). Other curriculum-based approaches aim to support the development of foundation skills known to impact handwriting or participation in writing activities (Engel et al., 2018). For example, Bazyk et al. (2009) conducted an integrated intervention for kindergarten that emphasised development of fine motor, visuomotor, and sensory processing performance skills which were identified as important to classroom participation. The intervention approach aimed to enable participation in writing activities through perceptual motor skills development and, therefore, impact emergent literacy. Intervention was both direct (classroom activity based) and indirect (curriculum learning and teacher education). Direct intervention included provision of adapted writing materials and equipment to promote motor control, and the development of co-taught classroom programs to enhance perceptual motor skills. Gains in both fine motor and emergent literacy observed in this study suggested a positive impact of the intervention on participation in classroom writing activities, providing important support for the role of perceptual motor skills as an element of intervention to support fluency development in kindergarten.

Write Start is one whole-class approach with documented positive impacts on handwriting and writing fluency (Case-Smith et al., 2014). In this intervention, teachers and occupational therapists work collaboratively through co-teaching as a means of integrating intervention into classroom settings. Write Start includes both whole-class instruction on letter formation and station-based activities that separately emphasise key skill areas indicated in handwriting development—fine motor, visuomotor and cognitive skills. This co-teaching approach to handwriting intervention was found to be effective for grade 1 students for improving both handwriting and writing fluency, suggesting improvement in the transcription skills that are foundational to written expression (Case-Smith et al., 2011; Case-Smith et al., 2012; Case-Smith et al., 2014).

6.2.3.1 Write Start-K.

A revised Write Start program (Write Start-K) was developed to improve its applicability to Kindergarten students. Write Start-K follows the same format as Write Start, of explicit instruction for a group of letters followed by station-based activities. However, Write Start-K adopts the 4*Rs* model by introducing all four aspects of fluency into each intervention activity, rather than focussing on one of three target areas identified in the Write Start program (fine motor, visuomotor or cognitive activities). This means that activities which previously emphasised perceptual motor skills development as important contributors to handwriting, were adjusted to include recall of letter forms and motor patterns for formation into the intervention activities. In a pilot study of an early version of Write Start-K (Ray, Dally, & Lane, 2021), we found that a modified Write Start, tailored for kindergarten, was feasible and effective; however, we determined that intervention effects favoured children with higher early literacy abilities, which reinforced the need to adopt a framework to promote fluency acquisition. The modified Write Start was therefore revised and updated to incorporate the 4*Rs* model to become Write Start-K.

While the pilot work involving early versions of Write Start-K is promising, this approach to handwriting intervention for beginning writers is yet to be tested in a controlled study. If Write Start-K is found to be an effective method of improving handwriting fluency in kindergarten students, it will provide further support for the adoption of frameworks such as the 4*Rs* model which integrates top down and bottom up elements in their approach to handwriting acquisition.

6.3 Current Study and Research Questions

The aim of the present study is to determine if Write Start-K impacts handwriting fluency and writing composition over and above the effects of standard instruction in kindergarten.

Specifically, the study sought to address the following research questions:

Question 1: Did Write Start-K improve handwriting fluency for kindergarten children when compared with standard instruction?

Question 2: What was the effect of Write Start-K, if any, on the writing composition of kindergarten children?

Question 3: What was the effect of Write Start-K, if any, on perceptual motor skills associated with handwriting acquisition in kindergarten children?

Based on the prior review of literature, our pilot work and the assumptions underpinning the 4*Rs* model, we hypothesised that Write Start-K would improve handwriting fluency as a result of the blend of top down and bottom up approaches, improve writing composition by building and consolidating transcription skills with a known effect on literacy, and beneficially impact component perceptual motor skills with a known relationship with handwriting ability.

6.4 Methods

6.4.1 Study Design

The study used a non-randomised prospective two-group pre- post-design comparing Write Start-K to standard teaching. A convenience sample of two kindergarten cohorts from two schools (intervention and control schools) was employed. Ethics approvals for the study were obtained from the University of Newcastle Human Research Ethics Committee (H-2019-0049) and both school principals, teachers involved in the study and parents of participating children gave written informed consent. The New South Wales State Education Research Applications Process (SERAP) also approved the study (SERAP 2019110).

6.4.2 Participants

This study involved two schools with approximately equal numbers of kindergarten enrolments (intervention school n = 39; control school n = 42). The schools were from similar regions in the suburbs of a large regional city in New South Wales (NSW). A comparison of school socioeconomic status was made using the Family Occupation and Employment Index (FOEI; NSW Department of Education, 2021b). This measure is calculated for each school at the beginning of each year based on parents' reporting their level of parental education, non-school qualifications and occupational status. It provides a score from zero to 300, with higher scores representing higher levels of disadvantage. The FOEI for the control (133) and intervention (134) schools were similar and indicated low socio-economic status (NSW Department of Education, 2020). The schools were also matched overall for racial and linguistic diversity, with both schools having approximately equivalent numbers of Indigenous students (control 12%, intervention 16%) and students with a language background other than English (control 2%, intervention 3%; ACARA, 2020). The mean age (SD) and age range for participants was: intervention = 5.7 years (4.5), 4.8 – 6.4 years; control = 5.7 years (3.9), 5.2 – 6.4 years.

Written consent was provided by parents of all kindergarten children at both schools to participate in the study. Inclusion criteria were: current enrolment in the kindergarten year at either school, capacity to carry out developmental assessments and sufficient English language to complete assessment tasks. Exclusion criteria included inability to comprehend the English language instructions used in the assessments or having a significant disability that would impact participation in assessments. Two children from the control school and one child from the intervention school were excluded as a result of significant disability that prevented them from completing assessments. These children still participated either in the intervention or the standard teaching conditions with appropriate accommodations; however, their data was not included in analysis. Final participant numbers at baseline were: intervention (n = 38), control (n = 40). At immediate post-intervention one child had left the control school. No other participant changes occurred throughout the duration of the study.

6.4.3 Procedures

Write Start-K was delivered in two 45-minute sessions per week for eight weeks, during a standard ten week school term, to all children at the intervention school as whole-class, co-taught lessons. The intervention team consisted of the first author (KR), the classroom teacher and a Research Assistant who was an occupational therapy student. Half a day of intervention training for all participating teachers and Research Assistants (RAs) was conducted by the first and second authors (KR and KD) who have combined experience in school based occupational therapy and early childhood education. During the intervention period, standard literacy instruction continued at the control school, with handwriting integrated into literacy instruction. The intervention school also continued with standard literacy instruction during the intervention period, with handwriting being replaced by Write Start-K. Both schools conducted regular morning literacy sessions that comprised handwriting, phonemic awareness, and reading activities, and Write Start-K replaced two of these routine sessions at the intervention school. Baseline, immediate post-intervention and follow-up (12 weeks post-intervention) assessments were conducted by a team of trained, blinded RAs who were selected from 2nd, 3rd and 4th year undergraduate occupational therapy student volunteers at the University of Newcastle, Australia. Written procedures were provided for researcher designed tools, and scripts and procedures of published tools were followed as written. Supervision of the RAs was provided on site by a member of the research team (first, second and last authors). Classroom teachers administered two tests in a whole-class format using a scripted procedure—alphabet writing (timed and untimed) and writing composition. The baseline measures were collected in the last two weeks of the second school term and were followed by a two-week holiday period. The intervention occurred in Weeks 1 to 8 of Term 3 with the immediate post-assessment data collected in the last two weeks of that term. The follow-up measures were collected in the second last week of the fourth and final term of the year.

6.4.4 Measures

All assessments described below were conducted at baseline, immediate post-intervention and follow-up, except the Beery VMI which was conducted at baseline and follow-up only, in accordance with standardised procedures for this measure, and two perceptual motor measures were collected at baseline only (visual perception and motor coordination). Four outcome measures were used to measure handwriting fluency—the Letter Form Assessement-2 (LFA-F and LFA-LSC), alphabet writing 60 seconds (AW60) and alphabet writing untimed (AWU). Writing composition was measured using analysis of a writing sample for words written (WW) and writing quality (WQ). Three perceptual motor outcome measures included fine motor precision (FMP), visual motor integration (VMI) and manual dexterity (MD). Measures were defined as primary or secondary outcomes.

6.4.4.1 Primary Outcome Measure—The Letter Form Assessment-2.

The Letter Form Assessment-2 (LFA-2) is an untimed pencil and paper test of alphabet writing administered individually. Letters are presented in non-alphabetic order, reflecting the typical sequence for introducing new letters in kindergarten. For each letter, participants are shown a picture prompt which is named and participants are then told the name and sound of the first letter in the word. They are then asked to write the letter in lowercase. For example, for the letter *a* the examiner points to a picture of an apple and says *this is an apple, apple starts with a and the sound is /a/. Can you write a lower case a?* The examiner observes the first attempt and if letter formation errors are made, the participant is shown an example of the letter to copy. If further errors are made when copying, the examiner demonstrates the letter formation and asks the participant to *watch me write the letter and then write the letter just like me.* Handwriting fluency was measured by the LFA-2 which consists of two sub tests: Letter formation (LFA-F) uses a series of graded prompts (verbal, visual model and demonstration) to assess the ability to accurately form letters and, letter sound correspondence (LFA-LSC) rates the ability to write a recognisable letter after a verbal prompt, irrespective of formation pattern or case. The LFA-F scores letter formation accuracy as an indicator of emerging or consolidating letter writing fluency and the LFA-LSC scores the ability to recall the orthographic code associated with a letter name or sound, and reproduce a recognisable letter form. A score of from 0 to 4 is possible for each alphabet letter, with 4 points given for a correct first attempt, 3 points for a correct copy, 2 points for a correct imitation, 1 point for an incorrect imitation of formation pattern but a recognisable letter, and 0 points for an unrecognisable imitation attempt. The total possible LFA-F score is 104. LFA-LSC is assessed on the first attempt at reproducing a letter after the verbal prompt. The task is scored out of 26 with 1 point given for each letter that is recognisable regardless of the formation pattern used in either upper or lowercase.

A preliminary version of this test, the LFA, was developed as a new method of measuring kindergarten handwriting fluency to address floor effects seen in standard measures of fluency assessment, timed and untimed alphabet writing (Ray, Dally, & Lane, 2021). Adaptations were made to the LFA for the current study, including the extension of testing to include all alphabet letters (LFA-F), and inclusion of a measure of letter sound correspondence (LFA-LSC). Inter-rater reliability was determined using a sample of 16 participants for whom consent to video their assessment was obtained. These videos were segmented with pause screens to allow trained, blinded assessors to score each letter response at each stage of assessment. An expert rater and two additional trained raters scored all samples, and agreement was evaluated for both individual letter scores and total scores. The LFA-2 has excellent inter-rater reliability (agreement between individual letter scores, ICC estimate 0.83, 95% CI [.78, .88]; agreement between total scores, ICC estimate 0.95, 95% CI [.75 , .99]) (Evans et al., 2019). Concurrent validity was evaluated utilising baseline data from the 78 participants in the present study. The data was collected by trained and blinded research assistants using the procedures outlined previously. LFA-2 scores were compared with tests of alphabet writing and visual motor abilities, described below. Coefficients for concurrent validity of the LFA-2 with timed alphabet writing and measures of visual motor integration are fair to moderate (r = 0.32 – 0.55) (Daly et al., 2020).

6.4.4.2 Secondary Outcome Measures.

6.4.4.2.1 Timed and Untimed Alphabet Writing.

Alphabet writing from memory was tested under timed—60 seconds (AW60), and untimed (AWU) conditions. In whole-class groups, participants were asked by the class teacher to write the lowercase alphabet as quickly and carefully as they could. At the 60 second point participants were asked to pause and the page was marked to show completed letters. Participants were then asked to carry on writing the alphabet until they were finished or could no longer remember any letters. The alphabet letters were scored using a procedure adapted from Puranik et al. (2017). Each letter was given a score of zero points, half a point or one point. Scores were given based on four possible errors – letter form/control, reversal/inversion, uppercase or unrecognisable. If none of the four errors were present, a point was given. If only one error from form/control, reversal/inversion or uppercase was present, half a point was given. If multiple errors were present or a letter was unrecognisable, zero points were given. Repeated letters were only scored once. Letters out of alphabetical sequence of at least two letters did not receive a score. Using the scoring matrix, a score was given for AW60 and AWU.

6.4.4.2.2 Fine Motor Skills.

Fine motor precision (FMP) and manual dexterity (MD) skills were measured using two sub tests of the Bruininks-Oseretsky Test of Motor Proficiency (BOT-2) (Bruininks & Bruininks, 2005). The BOT-2 is a standardised tool that is norm-referenced for those whose ages range from four to 21. The FMP subtest includes activities such as tracing inside lines, folding paper and cutting out. The MD sub test activities include precisely marking inside dots on a page, transferring coins to a container, sorting cards into piles and threading beads. Interrater reliability for the BOT-2 complete form and sub tests was found to be > 0.90 with the exception of the fine motor sub test which was 0.87. Coefficients for concurrent validity with other standardised measures of fine motor and visuomotor ability were moderate to strong, ranging from r = 0.51 to r = 0.74 (Deitz et al., 2007).

6.4.4.2.3 Visual Motor Integration, Visual Perception and Motor Coordination.

Visual motor integration was assessed using The Beery-Buktenica Developmental Test of Visual Motor Integration (Beery VMI, 6th edition; Beery et al., 2010). In this test, the participant copies lines and shapes of increasing complexity. Scoring is based on the number of accurately copied shapes. Two supplemental tests were also administered at baseline only– the Visual Perception Test and the Motor Coordination Test. In the Visual Perception Test participants are shown a shape and then asked to identify the matching shape from a group. This test is stopped when three consecutive errors are made or on completion and the score is the number of correctly matched shapes. The Motor Coordination Test assesses accurate outlining of shapes of increasing complexity and is scored based on the number correct. The Beery has consistently high inter-rater reliability and validity (Beery et al., 2010).

6.4.4.2.4 Writing Composition.

A whole-class composition task, administered by class teachers using a set procedure, was adapted from Puranik et al. (2017). The procedure followed was a whole-class discussion of ideas on the writing prompt "I like…", followed by six minutes to individually draw idea/s and ten minutes to write a composition. Paper was divided into one third for drawing and two thirds for writing. A score was calculated for the total number of words written (WW). Spelling did not have to be correct, but the words had to be phonetically recognisable, rather than a string of unrelated letters. This method reflects developmental scoring of spelling seen in other studies of kindergarten writing (Kent et al., 2014; Kim et al., 2014; Kim et al., 2015; Puranik & Al Otaiba, 2012). A composite score out of 26 was also calculated for writing quality (WQ) from six items; quality of ideas, spelling, punctuation, sentence structure, vocabulary and handwriting. Descriptive categories for the quality of ideas and handwriting were adapted from a writing analysis tool for grade 1 students (Mackenzie et al., 2013). A scoring system for spelling, punctuation, sentence structure and vocabulary was devised using the Harrison Writing Assessment and Moderation tool for Kindergarten (Harrison School, n.d.). Rating scales were devised for quality of ideas (number of ideas and coherence; zero to four points), vocabulary (complexity of word choice; zero to four points) and handwriting (legibility features; zero to five points). Lists of desired features were identified for the remaining categories and a mark was awarded for each feature present in the writing sample. This included spelling (spelling of five types of words of increasing complexity; mark out of five), punctuation (four different types of punctuation used in the writing sample; mark out of four) and sentence structure (use of variation and complexity in sentence structure; mark out of four). Scoring was completed by two highly experienced early education teachers and inter-rater reliability was established by comparing marks for the first five samples. The scorers then discussed the discrepant ratings to ensure a common understanding of each criteria and independently marked five more samples. For the second batch of five samples 100% agreement was reached.

6.4.5 Intervention

Write Start-K was delivered in two, 45-minute sessions per week. The goal of the first weekly session was to introduce a new group of letters, and apply 4*Rs* fluency acquisition principles to station-based activities that concurrently emphasised perceptual motor skills development. The goal of the second weekly session was to revise the newly learnt letters, and use both perceptual motor and writing skills in a craft and guided writing activity. Each week, Write Start-K consisted of the introduction and/or revision of letter formation for small groups of letters with similar directional properties. Each session was conducted using whole-class instruction (explicit instruction, modelling and practice utilising multi-sensory methods) followed by small group, station-based activities. There were three small group activity stations in the first session of the week and two in the second session, reflecting the differing goals of each session. A weekly team meeting decided on a mnemonic (series of auditory cues to support letter formation) that would be used consistently for each letter, any letters from previous sessions that should be revised and a modelled sentence or word writing activity which would be used in Session 2. In the control school, the standard teaching approach continued during the intervention period and included typical handwriting and literacy teaching. Literacy methods included teachers demonstrating a letter or letters; for example, the letters *u* and *e* together make the /u/ sound. Small-group rotations or individual activities followed the demonstration, such as pasting colored squares onto printed bubble letters, copying words, tracing letters on a worksheet, cutting and sorting words that fitted under headings (e.g., words with and without a silent *e*), and use of an iPad for literacy activities. Handwriting lessons at the control school used standard procedures, such as modeling of letter formation and provision of worksheets for practice. A key difference in the approach at the intervention school was the focus on handwriting fluency and consolidation of letter-forming patterns for each letter through visuomotor, fine-motor, and cognitive-themed activities. This was a distinct difference, as usually at this stage of the curriculum, after all letters have been introduced, attention would turn to reading and spelling in literacy lessons, rather than reemphasizing letter forming of all letters through handwriting. Details of the intervention approach are described below.

6.4.5.1 Explicit, Whole-group Instruction.

Explicit, whole-group instruction was led by the teacher. Using the agreed mnemonic, focus letters were modelled on the class whiteboard. This was followed by student multi-sensory practice, such as writing letters in the air or tracing onto the carpet and then individual whiteboard practice of correct formation. The intervention team provided feedback and support and encouraged the use of the mnemonic during letter writing practice. Strategies to promote self-monitoring were used, such as asking students to write three examples and then circle their best one.

6.4.5.2 Session 1 Activity Stations.

Session 1 included three activity stations, themed around fine motor, visuomotor and cognitive skills development. Each activity, regardless of theme, integrated recall, retrieval, reproduction and repetition of letter formation patterns for the focus letters. For example, a fine motor themed activity used playdough to make the letter *a*, concurrently targeted orthographic coding for the letter, memory recall for formation by pressing beads into the letter following the formation pattern and repetition by using different tools to write the letter into the playdough model, such as a toothpick or a marble. Other activity examples included playing noughts and crosses on a chalkboard using a pair of focus letters (visuomotor theme) and using a large dice with pictures to prompt writing of simple words using focus letters (cognitive theme). Station activities were varied to maximise novelty and engagement which encouraged high levels of attention to the task and self-monitoring of performance. The role of the intervention team member at each station was dynamic, working at the level of each child to provide support, additional guidance and direct feedback.

6.4.5.3 Session 2 Activity Stations.

Session 2 included two activity stations, craft and writing. A craft item was made related to the letter/s of the week. Craft activities were graded to gradually increase the challenge of components such as following a series of instructions or bilateral hand use. Children enjoyed the craft aspect of the second session greatly, often playing with their creations on completion and engaging positively in the related writing activity. The writing activity emphasised practice of the letters of the week using the sentence planned by the intervention team related to the craft activity. Strategies used to promote fluency and accuracy practice included writing letters from memory rather than copying, modelling one word or letter at a time, and only using words and sentences formed from letters learnt in previous weeks.

6.4.5.4 Intervention Fidelity.

A fidelity tool was sourced which had been used in the study of Write Start (Case-Smith et al., 2014) and was applied to Write Start-K (Weaver, L., 2019, personal communication). One observation of each classroom, and of each session, was made by an independent rater, an experienced occupational therapist with expertise in the delivery of Write Start-K in school settings. A high degree of intervention fidelity was recorded in both classrooms for Session 1. In this session, instructors were observed modelling and demonstrating target letters, providing visual and verbal cues, monitoring practice and assisting students to engage in station activities. Of note in both classrooms, high fidelity was achieved for ensuring the relationship of the activities to the letter was clear and verbal cueing was consistent between instructors. A lower degree of fidelity was observed for Session 2. This can be explained by the significant modification of Session 2 from a writer's workshop in the original Write Start, which was designed for older Year 1 students. Write Start-K significantly modified this approach to allow for the stage of writing development for kindergarten children. For example, aspects of the fidelity tool that were not met related to story writing and sharing of writing with instructor or peers. Aspects that were met in Write Start-K included application of writing to other projects in the curriculum, in this case, direct application to the craft activity in Session 2.

6.4.6 Data Analysis

Data were examined for errors and descriptive and summary statistics were generated for all study variables. Baseline differences for three measures were assessed using t-tests – age, visual perception and motor coordination. Linear Mixed Models (LMM) were used to examine the research questions by assessing all outcomes for the impact of group, time, and the group by time interaction, with these three terms forming the base model. LMM are useful for analysing non-independent data, such as repeated measures in the same participant. Residual covariance structures were used for the modelling to allow for possible differences in variability at each time point and differences in correlation between time periods. Differences between groups at baseline for all remaining variables were assessed as part of the post-hoc tests from the mixed models. Non-standardised effect sizes were calculated for the growth differences between groups across three time intervals—baseline to post-intervention, baseline to follow-up and post-intervention to follow-up. For all outcome measures, differences in mean scores between time points and 95% confidence intervals were estimated by use of the mixed models. Statistical significance was set at 0.05.

6.4.6.1 Finding the Best LMM.

Multiple analyses were conducted using the base model for each outcome by varying the choice of residual covariance structure to determine the best fitting structure for each outcome measure. Two important modelling assumptions were addressed by this process. Firstly, to test the equality of variances assumption, three residual covariance structures were used whereby the variability at different time points was constrained to be the same (compound symmetry). Two additional alternatives were tried where the variability at each time point could vary (compound symmetry and unstructured). Secondly, the independence assumption of no correlation between time periods was tested by using structures with constant correlation over time (either of the compound symmetry structures) and variable correlation using the unstructured form. The compound symmetry pattern of variance assumes that all variances and covariances are equal to each other. Compound symmetry heterogeneous allows the variance to differ, but the covariances must be equal. The unstructured pattern allows all variances and covariances to differ. In most cases either compound symmetry heterogeneous or unstructured patterns were used reflecting the tendency for variability to change over time. For example, differences between scores varied considerably at baseline but were less variable at later time periods due to a general improvement in students' performance leading to the scores being more similar to each other. The decision as to the most appropriate covariance structure was made using Akaike's Information Criterion (AIC). The structure with the lowest AIC was chosen, with a lower AIC of ten or more needed before a more complex structure was considered better than a simpler one (Burnham & Anderson, 2004). This process ensured that appropriate adjustments were made when the two most important modelling assumptions, constant variance and independence of observations, failed.

6.5 Results

6.5.1 Summary Statistics

No statistically significant differences between groups were found for baseline attributes (Table 6.1) or for the primary outcome measure, LFA-F (Table 6.2). For secondary outcome measures, the intervention group had significantly higher mean baseline scores, mean differences being for AW60 (4.4, 95% CI [1.9, 6.9]), WW (9.4, 95% CI [5.9, 13.0]) and WQ (2.8, (95% CI [1.1, 4.6]) (Table 6.2). Means and standard deviations for all outcome measures at each time point are presented in Table 6.3. These scores were used to conduct the analysis using LMM, as previously described. A trend of greater means for the intervention group than the control for most measures at immediate post-intervention and at follow-up assessment was observed. However, the analysis method used assessed the impact of growth, and differences in this growth between groups, both to account for any baseline differences, and to determine intervention effects.

Table 6.1

Baseline Characteristics by Group (Intervention and Control) and Group Baseline Differences for Participant Attributes

Baseline attributes		Intervention n = 38		Control n = 40		Baseline difference
		Mean (SD)	*Median (min, max)*	*Mean (SD)*	*Median (min, max)*	*Test statistic, p value, [95% CI]*
Baseline age and perceptual motor skills attributes	Age	68.7 (4.5)	68 (57, 77)	68.2 (3.9)	68.5 (62, 77)	t = 0.482, p = 0.63 [-1.4, 2.4]
	Visual perception	98.6 (15.7)	98 (47, 140)	100.7 (15.0)	99 (47, 146)	t = -0.620, p = 0.54 [-8.8, 4.6]
	Motor coordination	91.8 (10.0)	93 (72, 112)	90.8 (12.4)	92.5 (58, 109)	t = 0.430, p = 0.67 [-4.0, 6.1]

Table 6.2

Baseline Characteristics by Group (Intervention and Control) and Group Baseline Differences for Outcome Measures

Outcome variables at baseline		Intervention n = 38		Control n = 40		Baseline difference
		Mean (SD)	*Median (min, max)*	*Mean (SD)*	*Median (min, max)*	*Mean difference [CI 95%]**
Handwriting fluency measures	Letter Form Assessment - Formation (LFA-F)	85.7 (10.6)	86.5 (55, 100)	82.6 (10.9)	84 (43, 97)	3.5 [-1.3, 8.3]
	LFA Letter Sound Correspondence (LFA-LSC)	19.8 (4.3)	21.0 (10, 25)	20.3 (4.3)	21.5 (9, 26)	-0.4 [-2.3, 1.5]
	Alphabet Writing 60 Seconds (AW60)	10.8 (7.1)	10.0 (0.5, 25.5)	6.3 (3.6)	6.3 (0.5, 16.0)	4.4 [1.9, 6.9]*
	Alphabet Writing Untimed (AWU)	16.1 (8.4)	20.5 (0.5, 25.5)	13.5 (6.1)	14.0 (1.0, 24.0)	2.8 [-0.5, 6.1]
Writing composition measures	Words Written (WW)	14.8 (10.4)	14.5 (0, 39)	5.4 (4.0)	4.0 (2, 26)	9.4 [5.9, 13.0]*
	Writing Quality (WQ)	12.6 (4.7)	14.0 (2.0, 20.0)	9.8 (3.2)	10.0 (3.0, 17.5)	2.8 [1.1, 4.6]*
Perceptual motor measures	Visuomotor Integration (VMI)	15.8 (2.0)	16 (11, 20)	15.4 (2.2)	15 (9, 20)	-0.4 [-1.3, 0.5]
	Fine Motor Precision (FMP)	13.8 (4.5)	13.5 (5, 22)	13.1 (3.4)	13.0 (6, 22)	0.7 [-1.2, 2.5]
	Manual Dexterity (MD)	14.8 (4.2)	14.0 (6, 24)	13.1 (4.2)	12.5 (6, 21)	1.6 [-0.4, 3.7]

*If CI 95% does not cross zero, difference is significant.

Table 6.3

Means and Standard Deviations for Outcome Measures by Group at Each Time Point

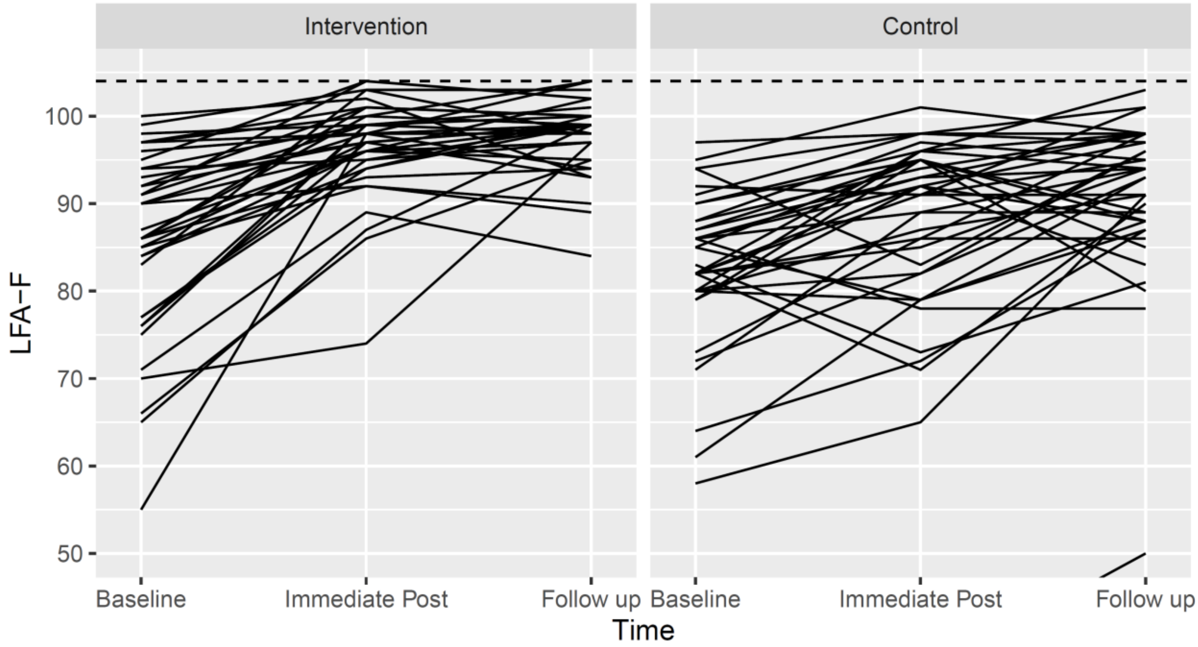
Outcome measures	Baseline Mean (SD)		Immediate post Mean (SD)		Follow-up Mean (SD)	
	Intervention	Control	Intervention	Control	Intervention	Control
Handwriting fluency measures						
Letter Form Assessment-Formation	85.7 (10.6)	82.2 (10.9)	96.6 (10.6)	87.0 (12.0)	97.9 (4.1)	91.2 (9.0)
LFA Letter Sound Correspondence	19.8 (4.3)	20.3 (4.3)	23.0 (2.7)	20.9 (2.8)	24.1 (2.2)	22.1 (2.3)
Alphabet Writing 60 Seconds	10.8 (7.1)	6.3 (3.6)	14.8 (7.8)	8.0 (5.0)	16.6 (6.7)	11.4 (5.5)
Alphabet Writing Untimed	16.1 (8.4)	13.5 (6.1)	20.1 (6.0)	16.3 (6.0)	19.5 (5.5)	18.3 (4.9)
Writing measures						
Words Written	14.8 (10.4)	5.4 (4.0)	15.8 (9.6)	7.9 (4.4)	36.5 (21.0)	12.7 (6.6)
Writing Quality	12.6 (4.7)	9.8 (3.2)	14.4 (4.2)	12.9 (3.4)	16.1 (4.3)	13.7 (3.2)
Perceptual motor measures						
Visuomotor Integration	15.8 (2.0)	15.4 (2.2)	-	-	16.6 (2.0)	16.5 (2.0)
Fine Motor Precision	13.8 (4.5)	13.1 (3.4)	12.5 (4.6)	12.6 (3.4)	13.6 (4.5)	13.1 (4.3)
Manual Dexterity	14.8 (4.6)	13.1 (4.2)	16.3 (4.7)	13.4 (4.4)	16.3 (5.2)	17.0 (4.1)

6.5.2 Question 1—Did Write Start-K Improve Handwriting Fluency for Kindergarten Children When Compared with Standard Instruction?

A trend of greater growth for the period from *baseline to immediate post*-intervention for the intervention group was observed for all four handwriting fluency measures, suggesting an immediate intervention effect (see Table 6.3). For three out of these four measures the size of the differences in growth between groups was statistically significant, including LFA-F (5.9, 95% CI [2.2, 9.7]), LFA-LSC (2.6, 95%CI [0.9, 4.3]) and AW60 (2.4, 95% CI [0.2, 4.6]; Table 6.4). An illustration of this trend for LFA-F is shown in Figure 6.2, which demonstrates individual scores at each time period for each group. Figure 6.3 illustrates the trend for greater mean growth for the intervention group from *baseline* to *immediate post*-intervention for each handwriting fluency outcome measure. This trend was repeated in the period from *baseline to follow-up* for all handwriting fluency measures (see Figure 6.3 and Table 6.3). The size of the differences in growth between groups in this time interval was statistically significant for LFA-LSC (2.3, 95% CI [0.7, 4.0]; Table 6.4). Of interest is the pattern for greater growth for the control group for one period, from immediate post-intervention to follow-up. This observation, combined with the immediate and overall gains to handwriting fluency for the intervention group points to an immediate intervention effect that consolidated over time and contributed to greater overall growth. That is, the intervention group's growth in handwriting fluency was enhanced across the intervention period, and growth was generally greater overall. The period of time after intervention appears to be a time in which the control group was able to make some gains (catch up) in handwriting fluency; however, these gains did not lead to a significant overall group by time effect as shown in LMM analysis for each measure, detailed below.

Figure 6.2

LFA-F Score (Maximum Score 104) for Each Participant at Each Time Point at Intervention or Control School



6.5.2.1 LFA-F.

As seen in Table 6.3, and illustrated in Figure 6.3a, the *baseline* mean LFA-F for the intervention group was 85.7 and the *immediate post*-intervention mean was 96.6. The difference between these means, or amount of growth for the period from *baseline* to *immediate post*-intervention was 10.9, 95% CI [8.2, 13.5] (Table 6.4). Growth for the control group for the same time period was 4.9, 95% CI [2.3, 7.7] (Table 6.4). Overall study effect size for LFA-F for this time period, therefore, was 5.9, 95% CI [2.2, 9.7], indicating the intervention group growth significantly exceeded that of the control. LMM showed a significant group by time interaction indicating that the change over time for the intervention group differed significantly to that of the control group (Table 6.4; $p = .005$).

6.5.2.2 LFA-LSC.

Differences in growth between groups were observed across two time intervals for LFA-LSC – *baseline* to *immediate post*-intervention and *baseline* to *follow-up* (Table 6.4 and Figure 6.3b). The *baseline* mean for LFA-LSC for the intervention group was 19.8, the *immediate post*-intervention mean was 23 and the *follow-up* mean was 24.1 (Table 6.3). The difference between these means, or the amount of growth for the periods *baseline* to *immediate post*-intervention and *baseline* to *follow-up* were 3.2, 95% CI [2.0, 4.4] and 4.2, 95% CI [3.0, 5.4], respectively. Growth for the control group for the same time periods were 0.6, 95% CI [-0.6, 1.8] and 1.9, 95% CI [0.7, 3.0], respectively (Table 6.4). Overall study effect size for LFA-LSC for *baseline* to *immediate post*-intervention was 2.6, 95% CI [0.9, 4.3] and for *baseline* to *follow-up* was 2.3, 95% CI [0.7, 4.0], indicating growth for the intervention group significantly exceeded that of the control group (Table 6.4). LMM showed a significant group by time interaction indicating that the change over time for the intervention group differed significantly to that of the control group (Table 6.4; p = .01).

6.5.2.3 AW60 and AWU.

Growth across time intervals for AW60 and AWU is shown in Table 6.3 and Figures 6.3c and 6.3d. A significant intervention effect was observed for the period from *baseline to immediate post*-intervention for AW60 with an effect size of 2.4 letters 95% CI [0.2, 4.6], with the growth for the intervention group exceeding that of the control group (Table 6.4). However, LMM did not show a significant group by time interaction (Table 6.4; p = .10). As previously discussed, an effect of greater growth for the control group was observed for one measure, AWU for the period from *immediate post*-intervention to *follow-up* of 3.5 letters [CI 95% -6.1, -.09]. LMM modelling showed a significant group by time interaction for AWU (Table 6.4; p = 0.03).

Figure 6.3

Handwriting Fluency Measures Means and 95% Confidence Intervals at Baseline, Immediate Post-Intervention and Follow-Up

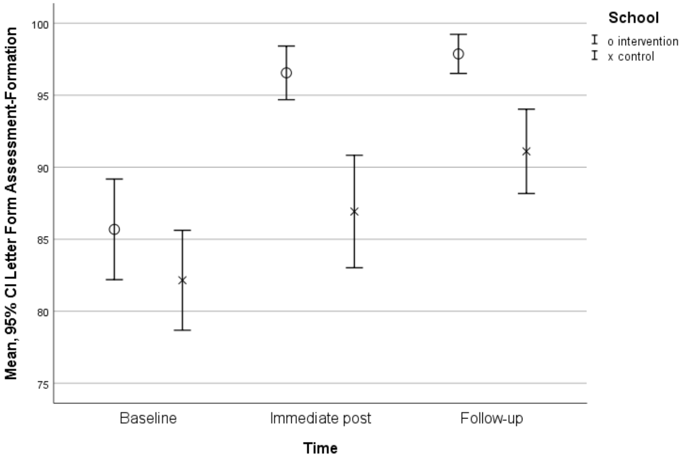


Figure 6.3a - LFA-F

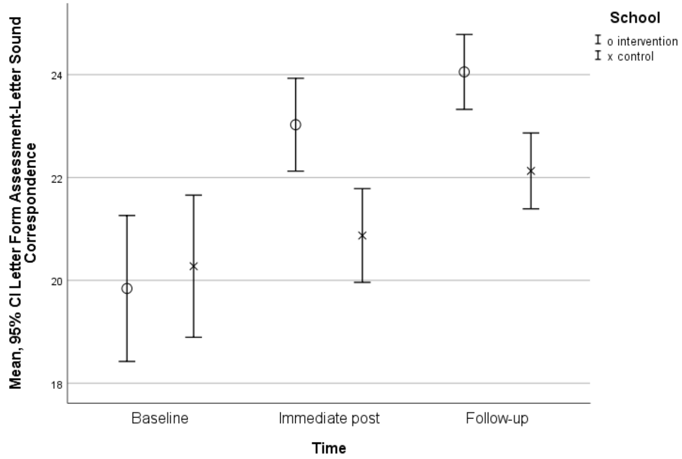


Figure 6.3b - LFA-LSC

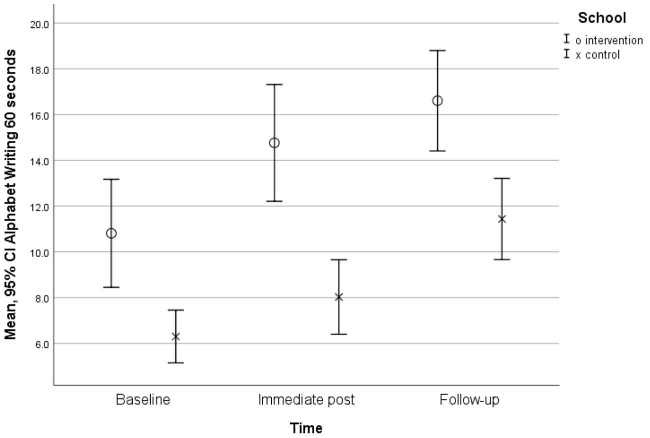


Figure 6.3c – AW60

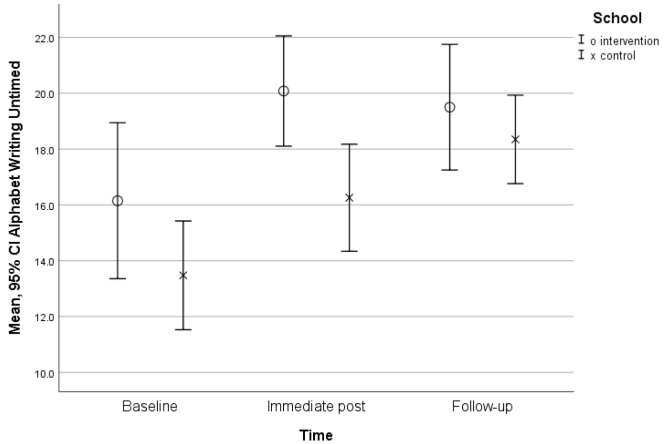


Figure 6.3d - AWU

6.5.3 Question 2—What Was the Effect of Write Start-K, if Any, on Writing Composition of Kindergarten Children?

Growth differences between groups across each time period for WW and WQ are shown in Table 6.3 and Figure 6.4. A pronounced pattern of greater growth for the intervention group was observed for WW (Figure 6.4a) across two time periods - *immediate post*-intervention to *follow-up* (15.9 words, 95% CI [10.0, 21.7] and *baseline* to *follow-up* (14.4 words, 95.5% CI [8.4, 20.4] (Table 6.4). LMM confirmed a significant group by time interaction for these effects for WW (Table 6.4; p < .001). A pattern of improvement was observed for both groups for WQ (Figure 6.4b). The growth for the intervention group for WQ from *immediate post*-intervention to *follow-up* was higher than the control, reflecting the trend for post-intervention gains (Table 6.4); however, the differences in growth across time periods between groups was not significant and no overall significant effect was observed (Table 6.4, p = 0.262).

Figure 6.4

Writing Composition Words Written and Writing Quality Means and 95% CI at Baseline, Immediate Post-Intervention and Follow-Up

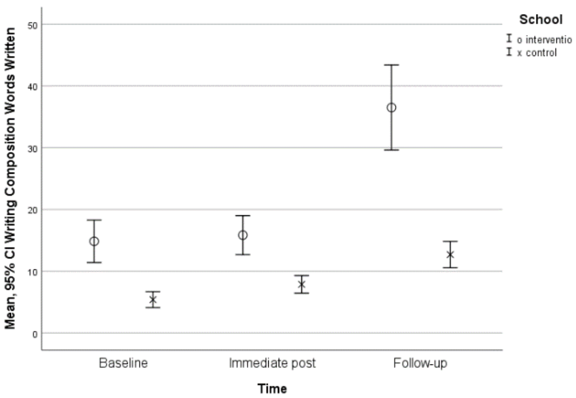


Figure 6.4a - WW

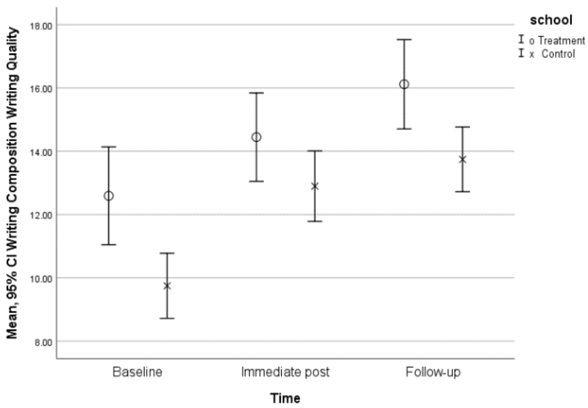


Figure 6.4b - WQ

6.5.4 Question 3—What Was the Effect of Write Start-K, if any, on Perceptual Motor Skills Associated with Handwriting Acquisition in Kindergarten Children?

Figure 6.5 and Table 6.3 show growth across each time interval for three perceptual motor measures – Visual Motor Integration (VMI), Fine Motor Precision (FMP) and Manual Dexterity (MD). Significantly greater growth for MD for the period *baseline* to *immediate post*-intervention was observed for the intervention group (Figure 6.5a and Table 6.4, 1.6, 95% CI [0.3, 2.8]). Growth for the control group on this measure across this period was observed to plateau, with no significant change detected (Table 6.4, 0.4, 95% CI [-1.0, 1.7]). However, for other time periods (*baseline* to *follow-up* and *immediate post*-intervention to *follow-up*) significant growth was observed for the control group, resulting in a significant overall effect (Table 6.4, $p < .001$). The significant growth of MD from *baseline* to *immediate post*-intervention for the intervention group was not matched by growth in this period for the control, suggesting a positive intervention effect (Figure 6.5a). Rather, the control improved more after the intervention period, in effect catching up with the earlier, significant growth observed for the intervention group. For the other perceptual motor measures, a pattern of growth was observed for VMI (Figure 6.5b); however, FMP for both intervention and control appeared to be relatively stable across time (Figure 6.5c). LMM confirmed no significant differences in the amount of growth between groups in VMI and FMP (Table 6.4; $p = 0.646$ and 0.591, respectively).

Figure 6.5

Perceptual Motor Measures Means and 95% Confidence Intervals at Baseline, Immediate Post-Intervention and Follow-Up

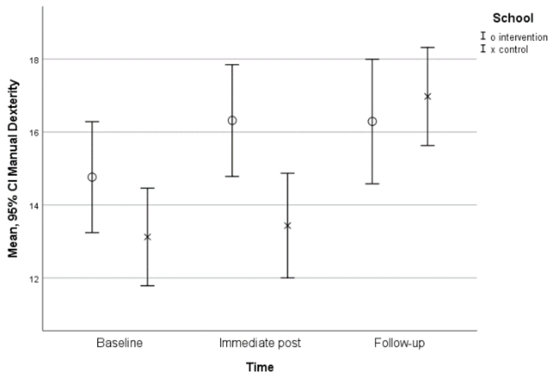


Figure 6.5a - MD

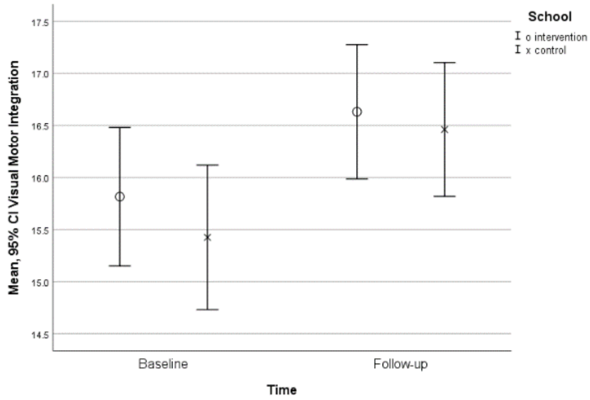


Figure 6.5b – VMI

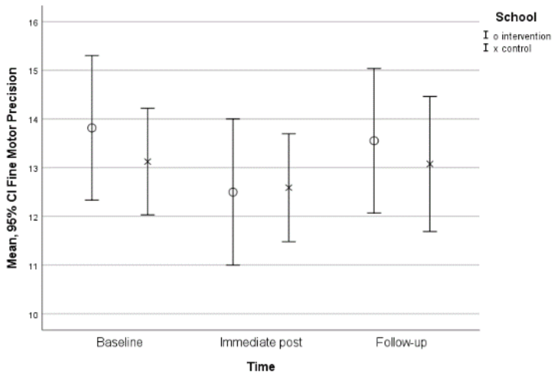


Figure 6.5c - FMP

Table 6.4

Effect Sizes for Changes in Outcome Scores Over Time by Group – Baseline to Post, Immediate Post to Follow-Up and Baseline to Follow-Up

Variable	Group*time interaction (*p* value)	Intervention change score [95% CI] (n = 38)			Control change score [95% CI] (n = 40)			Effect size for intervention–control change scores [95% CI]		
		Baseline to immediate post	Immediate post to follow-up	Baseline to follow-up	Baseline to immediate post	Immediate post to follow-up	Baseline to follow-up	Baseline to immediate post	Immediate post to follow-up	Baseline to follow-up
LFA	0.005	10.9 [8.2, 13.5]	1.3 [-0.98, 3.6]	12.2 [9.0, 15.4]	4.9 [2.3, 7.5]	4.1 [1.8, 6.4]	9.0 [5.9, 12.2]	5.9* [2.2, 9.7]	-2.8 [-6.0, 0.4]	3.2 [-1.4, 7.7]
LFALSC	0.010	3.2 [2.0, 4.4]	1.0 [0,2, 1.9]	4.2 [3.0, 5.4]	0.6 [-0.6, 1.8]	1.3 [0.4, 2.1]	1.9 [0.7, 3.0]	2.6* [0.9, 4.3]	-0.2 [-1.4, 1.0]	2.3* [0.7, 4.0]
AW60	0.100	4.1 [2.5, 5.6]	1.8 [0.2, 3.4]	6.0 [4.4, 7.4]	1.7 [0.2, 3.2]	3.4 [1.8, 5.0]	5.1 [3.6, 6.6]	2.4* [0.2, 4.6]	-1.6 [-3.8, 0.7]	0.8 [-1.2, 2.9]
AWU	0.029	3.8 [1.7, 6.0]	-1.4 [-3.4, 0.6]	2.4 [0.2, 4.7]	2.8 [[0.8, 4.9]	2.1 [0.4, 3.8]	4.9 [3.0, 7.0]	1.0 [-2.0, 3.9]	-3.5* [-6.1, -0.9]	-2.5 [-5.5, 0.5]
WW	<.001	1.0 [-1.5, 3.5]	20.7 [16.5, 24.8]	21.7 [17.3, 26.0]	2.5 [-0.01, 5.0]	4.8 [0.7, 9.0]	7.3 [3.0, 11.5]	-1.5 [-5.0, 2.1]	15.9* [10.0,21.7]	14.4* [8.4, 20.4]
WQ	0.262	1.9 [0.8, 2.9]	1.7 [0.6, 2.8]	3.5 [2.4, 4.6]	3.1 [2.0, 4.2]	0.8 [-0.2, 2.0]	4.0 [2.9, 5.0]	-1.2 [-2.8, 0.3]	0.8 [-0.7, 2.4]	-0.4 [-1.9, 1,1]
VMI	0.646	-	-	0.8 [0.1, 1.5]	-	-	1.0 [0.4, 1.7]	-	-	-0.2 [-1.1, 0.8]
FMP	0.591	-1.3 [-2.4, -0.2]	1.1 [-0.1, 2.2]	-0.3 [-1.4, 0.9]	-0.5 [-1.6, 0.6]	0.5 [-0.6, 1.6]	-0.03 [-1.1, 1.1]	-0.8 [-2.4, 0.8]	0.6 [-1.0, 2.1]	-0.2 [-1.8, 1.3]
MD	<.001	1.6 [0.3, 2.8]	-0.03 [-1.3, 1.3]	1.5 [0.2, 2.8]	0.4 [-1.0, 1.7]	3.5 [2.3, 4.8]	4.0 [2.7, 5.2]	1.1 [-0.6, 2.9]	-3.6* [-5.4, -1.8]	-2.4* [-4.2, -0.6]

*If 95% CI does not cross zero, difference between change scores is significant. Effect size calculated by subtracting control change scores from intervention change scores for each time interval.
Abbreviations: LFA-F, Letter Form Assessment – Formation; LFA-LSC, Letter Form Assessment - Letter Sound Correspondence; AW60, Alphabet Writing 60 seconds; AWU, Alphabet Writing Untimed; WW, Words Written; WQ, Writing Quality; VMI, Visuomotor Integration; FMP, Fine Motor Precision; MD, Manual Dexterity

6.6 Discussion

The aim of this study was to determine the effectiveness of Write Start-K on handwriting fluency and writing composition, compared with standard instruction. We observed that kindergarten students who received Write Start-K made significantly greater gains in handwriting fluency, and writing composition compared with those students who received standard handwriting teaching. Write Start-K is a whole-class, co-taught program based on Write Start which has been found effective in improving handwriting legibility, speed and writing fluency in grade 1 students (Case-Smith et al., 2014). The 4*Rs* handwriting fluency acquisition model (*Recall*, *Retrieve*, *Reproduce* and *Repeat*) informed Write Start-K content and methodology, and was a basis for developing an approach that incorporated bottom up and top down intervention strategies. The findings of this study support the notion that a focus on handwriting fluency acquisition in kindergarten can have positive benefits for both handwriting fluency and writing composition.

In this study, participants received either Write Start-K (intervention group) or standard teaching (control group). Therefore, as expected, positive effects were observed for the vast majority of variables for both groups as both were receiving continued instruction. However, significant differences in overall effect sizes for both handwriting and writing composition in favour of the intervention group were observed. These overall effects were determined by calculating differences in growth for each measure between groups across different time intervals (baseline to immediate post-intervention, baseline to follow-up and immediate post-intervention to follow-up). Variation in the strength of the effects differences were observed across the three time intervals, indicating fluctuating patterns of growth and intervention effects. This can be explained by the possibility that intervention effects might be immediate, delayed or cumulative. In general, effects across handwriting fluency, writing composition and perceptual motor abilities were noted immediately, or were observed as greater growth in the period following intervention. A particular trend for the intervention group was immediate gains at post-intervention for handwriting fluency and manual dexterity measures, and a cumulative effect of intervention on writing composition.

A general observation across all variables was that the modelling assumption of constant variance was broken as variability in scores for different scales differed over time. For example, in some later periods, variability decreased as scores approached the scale ceiling, given children were improving their skill levels. In contrast, variability also increased in the later time periods for some measures, as some participants approached the ceiling whilst others stayed relatively stable. The inconsistent variance problem was overcome by use of appropriate residual covariance structures in the modelling.

6.6.1 Handwriting Fluency Effects—Immediate Gains

Handwriting fluency growth was measured with the LFA-2 and a frequently employed alphabet writing test (AW60 and AWU). Positive intervention effects were seen immediately across both measures in favour of the intervention group. The LFA-2 has two components, formation and letter-sound correspondence, and significant, positive intervention effects were observed for each. LFA-F assesses letter formation ability using cascading verbal, visual and demonstration prompts. Lower scores indicate that more prompting is needed for a participant to be able to accurately form a letter. LFA-LSC measures letter sound correspondence, with higher scores indicating that more letters can be recalled and written from memory, regardless of formation or case. Both LFA-F and LFA-LSC are important in fluency as they require coordination of known cognitive and perceptual motor factors that impact handwriting (Cartmill et al., 2009). As previously described, fluency requires each of the features identified in the 4*Rs* model of handwriting acquisition, including sufficient repetition in recalling the letter form in memory, retrieving the motor pattern for formation and reproducing the letter using perceptual motor skills. Fluency gains were seen in a reduced need for prompting to remember letter formation (LFA-F) and an increased number of letters that could be remembered and written from a verbal prompt only (LFA-LSC). Growth in both measures indicates stronger mental representations, associated motor programs and perceptual motor abilities. We propose that the repeated practice of letter formation during the intervention and the emphasis on concurrent development of all handwriting contributing factors were key to the gains seen in both LFA-F and LFA-LSC. In support of this result, significantly greater growth was also seen for the intervention group for AW60 from baseline to immediate post-intervention; however, an overall group by time effect was not significant. This result is not surprising as the focus of intervention was on promoting letter formation for letters with similar patterns, and on linking these patterns to name and sound in writing activities, rather than on writing alphabetically. More surprisingly, untimed alphabet writing also showed no significant overall effects and in fact showed significantly lower growth across the post-intervention to follow-up time period. This result may have occurred as the intervention group had already made significant growth, as seen in AW60 growth across the first time period. The enhanced early growth in handwriting fluency suggested by these results may have contributed to the later and perhaps, cumulative, effects seen on writing composition.

6.6.2 Writing Composition Effects—Cumulative Gains

The gains made in handwriting fluency for the intervention group appeared to translate to gains in writing, with significantly greater growth in the number of words written in a composition and a trend towards greater growth for writing composition quality in the post-intervention period. These observations lend support to previous reports of the positive effects of handwriting fluency intervention on writing composition for kindergarten (Dolin, 2016; Jones & Christensen, 2012). Spelling and handwriting fluency have been proposed as the key transcription ingredients that underlie writing composition, with a more significant constraining impact in the early years (Kim & Park, 2019). Given the important of transcription skills, the handwriting fluency gains made as a result of Write Start-K may have contributed to longer story writing as detected in the effects on WW. The sensorimotor task of writing has been suggested as a facilitator of letter name, sound and form relationships through a process known as “action-perception coupling” (Kiefer et al., 2015, p. 136). In contrast to typing, learning to form letters requires the creation of a motor program, and this may be an additional link, or provide an additional information source, in order to access the orthographic representation of a letter (James & Engelhardt, 2012). Write Start-K focussed on developing motor patterns for letters supported by perceptual motor and cognitive skills development as well as practising writing in meaningful tasks. By creating efficient and reproducible motor patterns, new and retrievable memory traces may have been generated—an additional source of information for generating letter representations to aid writing composition. Therefore, the growth in handwriting fluency seen through the significant growth in LFA-F, LFA-LSC and AW60 may have enabled children to generate more words. Writing quality effects are expected with enhanced handwriting fluency by lessening the impact of mechanical tasks on working memory (McCutchen, 1996). In our study, greater growth was observed for the intervention group in the period from post-intervention to follow-up; however this difference was not significant. As noted, Kim and Park (2019) have observed that handwriting constraints may have a greater impact on writing composition in earlier grades. Our findings suggest that task constraints of handwriting in kindergarten remain high, despite improvements in fluency. Gains in quality of writing may only be afforded at later stages once fluency has consolidated. Further, writing research recommends that both low order (spelling and handwriting) and high order (planning and revising) skills contribute to writing quality and should be taught together as early as Kindergarten (Graham et al., 2012). The distinct contribution of handwriting fluency to writing composition quality may require further analysis to increase understanding of Write Start-K's impact on measures of quality.

6.6.3 Impact of the Intervention on Perceptual Motor Skills

The trend for greater immediate effects of intervention on handwriting fluency (LFA-F, LFA-LSC and AW60) was reflected in one perceptual skills motor measure, MD, although the growth of the intervention group across this period was not significantly different from the control group. During this same time period, growth for MD for the control group was minimal. However, the growth in MD was greater for the control group from baseline to follow-up and immediate post-intervention to follow-up, with a significant group by time effect detected. This was surprising, as generally, gains made by the control group, either in the period following intervention or overall from baseline, did not match the sustained gains of the intervention group. Two other perceptual motor outcomes reported in this study, FMP and VMI, did not show any significant difference in growth between groups. FMP remained relatively constant across the assessment periods and a pattern of growth was observed for both intervention and control for VMI. These results are similar to those of Pfeiffer et al. (2015) and Case-Smith (2002) who found that gains in handwriting after intervention were not reflected in improvements in visual motor integration. This is despite consistent evidence for the relationships of perceptual motor skills to handwriting legibility (Case-Smith, 2002; Engel et al., 2018; Klein et al., 2011; Tseng & Murray, 1994). However, the trend for immediate growth in MD combined with the comprehensive gains seen across three out of the four handwriting fluency measures is supportive of the inclusion of perceptual motor skills in handwriting intervention for kindergarten.

6.6.4 Reflections on Intervention Approach

Write Start-K adopted a whole-class, co-teaching approach. By delivering the intervention in a co-taught method, a flow-over effect was anticipated, with teachers taking opportunities to emphasise elements taught and emphasised within the program at additional times through the week. This proved to be correct, with teachers either reusing some of the station activities during regular weekly tasks such as literacy rotations or adding novel experiences to emphasise principles of the program. One teacher explained that on a sunny day, she took the class outside and they used paint brushes and water to paint letters and words on the walls and concrete. It was apparent that the co-teaching approach involving the development of suitable resources was beneficial and supportive of teachers for times outside of the program sessions. Co-teaching offers promise as a means of introducing programs to whole classes and enabling effects both during intervention and after intervention is complete. Some of the effects observed in our study such as the significant growth in writing composition from post-intervention to follow-up, suggest that the intervention approach provided a sound basis on which subsequent teaching could have maximum effect. By ensuring a solid foundation, both through perceptual motor skills that support handwriting and application of these skills to fluency for individual letters, words and sentences, access to literacy gains afforded by classroom teaching may have been enhanced. Write Start-K provides a possible approach to influencing key factors that impact transcription and text generation in the kindergarten year.

6.6.5 Limitations

Randomisation within schools was considered but was not feasible due to the risk of contamination of intervention knowledge across groups within schools as the intervention approaches may have been evident. Randomization of participants into intervention and control groups was also not possible because the intervention was intended to trial an approach that could be potentially adopted by whole classes, using the Write Start–K coteaching approach. However, the significant effects in this study warrant further research in a larger, randomised study. Write Start-K was compared to standard teaching in the study; however, the intervention method was not tested against other intervention approaches. The intervention approach in the study had a positive effect on handwriting fluency and writing composition; however, future study should contrast Write Start-K with alternative handwriting intervention approaches.

It is inevitable in small-scale studies with limited randomization that baseline differences will occur. Further, small nonrandomised studies run the risk of both positive and negative results potentially due to sampling error. In this study, we sought to minimize the effects of no randomization between groups by using a control group to provide partial matching on factors such as socioeconomic status. The control group nevertheless enabled the measurement of growth of key markers of handwriting fluency and writing. Comparing the groups using differences in amount of growth from baseline, controlled for the group differences at baseline.

In terms of effects, the Write Start–K intervention may have provided additional handwriting instruction over that allocated in standard teaching, and there is a possibility that the study effect was partly or wholly due to the extra guidance provided by two additional adults leading the small-group handwriting activities rather than the nature of the handwriting approach. Future study designs will need to address this possible mismatch in intensity of teaching between groups. Similarly, the program effects may have been impacted by differences between teachers and teaching practices at the intervention and control schools that we were unable to measure or discern. Although the teachers followed the same curriculum and had similar years of experience in teaching kindergarten, given the small number of students and teachers, pedagogical differences between the intervention and control teachers could have either inflated or reduced the program's effects.

Due to the low numbers of enrolled students at the participating schools with English as a second language, we were unable to assess the effectiveness of this approach with a more linguistically diverse student group. The use of multisensory activities in Write Start–K within a model that promotes fluency through use of memory, developmental skills support, letter formation, and practice, however, is expected to be an accessible methodology for emerging bi/multilingual learners. Further, the principles of the 4*R*s framework could be incorporated into both regular and tailored activities to support multilingual or emergent bilingual learners. For example, an application of this research into more diverse practice could include adaptation of learning activities to incorporate the 4*R*s framework with individuals or small groups with specific needs.

6.6.6 Recommendations for Further Research

This study provides preliminary evidence that Write Start-K is an effective method to support handwriting fluency acquisition in kindergarten, with benefits for writing composition. This study compared Write Start-K with standard teaching. Further research could also incorporate comparison with other intervention methodologies in a randomised trial. It may also be possible to apply the 4*Rs* model of handwriting fluency acquisition to other intervention approaches, especially those where effect was small to moderate such as in curriculum-based interventions as described by Engel et al.

(2018). As described, the modified Write Start tested in an earlier pilot study was updated and revised in Write Start-K, and only small adjustments in activity focus were needed to adopt the principles of that intervention model. Further research of the 4*Rs* model is also indicated to determine the relative weights of the elements indicated in handwriting fluency acquisition. This type of research would assist those working with children with handwriting difficulties to understand the strength and focus needed for the different fluency elements, and for children with profound difficulties, it would help to understand if a basis in certain skills was a prerequisite for successful handwriting.

6.6.7 Key Points for Occupational Therapy

- Write Start-K is a promising whole-class, co-taught approach to kindergarten handwriting fluency acquisition.
- The effects seen in this study are consistent with findings from studies of other age groups and adds to the evidence for a facilitating relationship between handwriting and writing composition.
- Perceptual motor skills' activities were specifically included in the intervention approach and the findings of this study are supportive of a balanced approach to handwriting intervention, facilitating both handwriting fluency and component skills acquisition.
- The LFA-2 is proposed as measure of kindergarten handwriting fluency. Further psychometric testing of the tool will assist practitioners in its ongoing use.
- The 4*Rs* model of handwriting fluency acquisition provides a format for revising and updating current intervention approaches. We used the 4*Rs* model as the basis for Write Start-K and we found significant gains for handwriting fluency and writing composition. Application of this model to whole-class, small group or individual intervention may warrant further investigation.

Chapter 7 Results and Discussion Part 2

Preface:

Chapter 7 presents part 2 of the findings of the two-group study of the effectiveness of Write Start-K. Specifically, this Chapter 7 presents the findings of the two-group study related to the impact of Write Start-K on early reading skills, specifically, word reading fluency, letter naming fluency and letter name and sound knowledge, and addresses thesis question 3:

> *Question 3: Does a whole-class handwriting intervention impact Kindergarten students' literacy?*

This material has been prepared for and published in a peer-reviewed journal, *Reading Research Quarterly*, and was included as part of a special edition on the science of reading. A copy of the accepted version of the paper is included in this Chapter 7, and the published version is reprinted with permission as an appendix to this thesis (Appendix 13). The published article was submitted on 16 July, 2020, revised on 23 February 2021 and published online in early view format on 15 April 2021.

Contribution statement:

With guidance from supervisors, the candidate was responsible for the design and implementation of the study reported in this chapter. This involved recruitment of participants, training and supervision of all Research Assistants (RAs) and teachers involved in the study, coordination of scheduling of assessments by RAs at each data collection point, intervention design and implementation in collaboration with teachers. The candidate carried out all data entry and data cleaning. With the assistance of a statistical consultant the candidate organised the data into suitable forms for analysis, and carried out the analysis, interpretation and reporting of results. Both supervisors provided comments on drafts of the paper presented in this chapter. The statistical consultant provided comments on these drafts, primarily on aspects that related to statistical matters.

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Keywords:

Kindergarten, beginning writing, beginning reading, emergent literacy, handwriting, literacy.

Naming conventions used in the article:

As explained in Chapter 1, relevant journal language conventions have been used to describe school class level for chapters presented as a paper; hence, terms used are: kindergarten; grade; and numerals for grade level, for example, grade 1. Specific conventions for hyphenation have been applied by the publisher that may not be used elsewhere in this thesis. American spelling is also used throughout the article included in this chapter.

Appendices to this Chapter:

- Appendix 13 – Published article, reprinted with permission

Feedback to participants:

Feedback on study outcomes and intervention approaches were made available to control and intervention schools as described in this section in Chapter 6.

7.1 Abstract

The ultimate goal of reading is to comprehend written text, and this goal can only be attained if the reader can decode written words and understand their meanings. The science of reading has provided compelling evidence for the subskills that form the foundation of decoding. Decoding words requires understanding of the alphabetic principle and letter–sound, or grapheme–phoneme, correspondence. In the first year of formal schooling (kindergarten), this same understanding is also required for young learners who are learning to write the letters of the alphabet. In this article, we examine the effectiveness of a handwriting intervention, Write Start–K, that emphasizes the recall, retrieval, reproduction, and repetition (the 4*R*s model) of grapheme–phoneme relations. We conducted a two-group, pre- post-test study at two Australian schools across four kindergarten classes ($n = 77$ students). One school received the intervention, and the other continued with standard teaching. Participants (mean age = 5 years 8.45 months, standard deviation = 4.18 months) at both schools were assessed at baseline, immediately after the eight-week intervention period, and at 12 weeks following the end of the intervention (follow-up). We used Linear Mixed Models to determine the statistical significance of effects over three time intervals. We identified statistically significant Group × Time effects for letter name knowledge and word reading, whereas changes in letter sound knowledge and nonsense word–reading fluency approached statistical significance. These results indicate that a handwriting intervention, incorporating repeated practice in recalling and reproducing letter forms, had a statistically significant impact on early reading skills.

7.2 Introduction

The science of reading has provided clear evidence that knowledge of letter names and sounds is one of the most important foundation skills when learning to read (Hulme & Snowling, 2013). Learning how sounds (phonemes) are associated with, or attached to, letter shapes (graphemes) leads to understanding of the alphabetic principle (Apel, 2009; Castles et al., 2018). Mastery of the alphabetic principle enables young learners to begin to decode written language by using phonemic knowledge and phonics skills to sound out words (Castles et al., 2018). In order for alphabet knowledge to support decoding and word reading, the names and sounds of all 26 letters need to be memorized and then retrieved not only accurately but also fluently (Clemens et al., 2017). Ample research from the science of reading has shown that many beginning readers face challenges in learning the arbitrary connections between letter forms and their names and sounds (Castles et al., 2018), and Roberts et al. (2019) described this process as a form of paired-associate learning.

Paired-associate learning serves to secure in long-term memory the link between orthographic information (the letter form) and its corresponding sound or name (Ehri, 2005). Mastery of alphabet knowledge is typically not acquired naturally, or by exposure only (Castles et al., 2018), and for 30% of kindergartners, difficulties in establishing these links have been resistant to targeted reading instruction (Paige et al., 2018). Studies in early literacy instruction have shown that the motor-perceptual links and sensory integration involved in writing letters enhance spelling (Cunningham & Stanovich, 1990) and support letter recognition through repeated exposure to letter variants (Li & James, 2016). Despite the fact that the beginning stages of both reading and writing require this same kind of alphabet knowledge, the sciences of reading and writing have typically been conducted separately, and there is a need for integrated research investigating how reading and writing can support each other (Graham, 2020).

Studies of the relation between reading and writing have reported both uni- and bidirectional effects. For students in the second year of formal schooling or higher, writing can influence reading (Graham & Hebert, 2011); however, other studies have suggested that reading may have a stronger impact on writing (Berninger et al., 2002; Kim, Petscher, et al., 2018). During kindergarten, the phonological aspects of reading (through understanding the alphabet), and writing (handwriting letters using grapheme–phoneme correspondences [GPCs]) are taught concurrently (Moats, 2020; Ritchey, 2008). A small body of evidence points to an association between handwriting fluency and reading building blocks (letter-naming fluency, initial sound fluency, nonsense-word reading, and word reading) in kindergarten (Frolek Clark & Luze, 2014; Malpique et al., 2017). A number of studies involving preschoolers have found modest effects on alphabet knowledge from interventions that emphasize the pairing of printed letters with their corresponding names and sounds (Castles et al., 2011; Roberts et al., 2019). In these studies, the students were shown a visual representation of the letter form while the teacher provided the verbal label. It was hypothesized that the orthographic information provided by repeated exposure to a grapheme (printed letter) aided the storage and retrieval of both the visual form of the letter and its verbal labels (Castles et al., 2011). Given that, in preliterate learners, brain regions associated with reading are activated by writing letters as opposed to merely viewing them (James, 2010), it is timely to investigate whether handwriting instruction in kindergarten can impact the phonological skills required for reading acquisition.

7.2.1 Handwriting as an Aid to GPCs in Kindergarten

Handwriting is an aural, cognitive, and motor skill, combining phonetic knowledge, retrievable orthographic representations for letter forms, and the creation and execution of associated motor patterns (Alstad et al., 2015; Berninger, 1999; Berninger et al., 1997). Many of these skills are emerging in kindergartners (Berninger & Rutberg, 1992; Graham & Weintraub, 1996; Weintraub & Graham, 2000). Based on the literature, four features of handwriting fluency development have been identified. First, fluent handwriting requires recall of the orthographic code or mental representation for a letter or word (Abbott & Berninger, 1993; Berninger et al., 1997). Second, retrieval entails accessing the system of movements, or motor plan, associated with the recalled letter form (Graham et al., 2006; Tseng & Murray, 1994; van Galen, 1991). Third, reproduction factors may impede or enhance fluent handwriting and include fine-motor, visuomotor, visuoperceptual, and kinesthetic abilities (Cornhill & Case-Smith, 1996; Graham et al., 2006; Kushki, Schwellnus, et al., 2011). Finally, repetition or sufficient practice is crucial to developing handwriting fluency (Hoy et al., 2011).

These four factors—*recall*, *retrieval*, *reproduction*, and *repetition*—are conceived as a handwriting fluency development model (the 4Rs model; Ray, Dally, et al., 2021b) and may provide an explanation for the potential role of handwriting as a mediator of GPC knowledge and acquisition of the alphabetic principle, which in turn leads to improved word-reading accuracy and fluency. Recall of letter forms is potentially facilitated by, and demonstrated through, writing from memory. Memory recall as part of handwriting instruction has been shown to increase fluent alphabet writing and contextual word and sentence writing, indicating enhanced access to mental representations of letters and words (Berninger et al., 1997; Wolf et al., 2017). Recursively, writing (or written fast-mapping) has been used to indicate the development of mental orthographic representations of novel, nonsense words in kindergartners (Apel, 2009). Mental processes may be more efficient when motor programs for letter writing are easily retrievable. For example, when learning a new letter symbol and reproducing it, learners with good handwriting are found to activate fewer brain regions than those with poor handwriting do (Palmis et al., 2017). Importantly, reproduction of the recalled and retrieved letter form pattern may aid visual letter recognition and categorization (James, 2010; Li & James, 2016). Finally, sufficient repetition underpins the circular relation between identified handwriting fluency factors and may contribute to the creation of stable mental images of letters (James, 2010; Palmis et al., 2017). Sufficient, developmentally suitable repetition within an intervention that promotes handwriting fluency may therefore be indicated in both phoneme–grapheme mapping and automatic letter identification.

7.2.2 Handwriting Intervention in Kindergarten

Handwriting instruction generally follows a prescribed path of demonstrating the method used to form a particular letter (the letter formation pattern) followed by student practice. Explicit, direct instruction of a new motor pattern has been found to be more effective than following a prompt line on an electronic application, or tracing the pattern (Overvelde & Hulstijn, 2011b). An effective handwriting intervention approach based on the 4*R*s model of handwriting fluency development (Ray, Dally, et al., 2021b) should also ensure that all aspects of the handwriting system are activated and supported to work in synchrony. For kindergarten-age students, this may include a focus on factors such as fine-motor and visuomotor skills that impact letter reproduction.

Write Start–K is a whole-class, co-taught (teaching and occupational therapy) handwriting intervention devised for kindergarten based on Write Start for grade 1 students (Case-Smith et al., 2012; Case-Smith et al., 2014). Write Start–K includes explicit instruction and practice of letter formation both in isolation and in words and sentences, through a combination of whole-class instruction and themed, station-based activities. Using the 4*Rs* model to guide intervention, each instructional activity encourages students to recall mental or orthographic images and retrieve and reproduce related motor patterns while utilizing different task elements that support emerging writing, such as fine-motor, visuomotor, and cognitive skills. In addition to supporting factors that contribute to fluency, engagement in a variety of themed, station-based authentic writing and crafts activities, ensures sufficient repetition, with the aim of students automatically associating the orthographic representation of a letter with its verbal label and then retrieving and executing the correct motor pattern for its formation. Because of the repeated practice in recalling, retrieving, and reproducing letters, we hypothesized that participation in Write Start–K would promote stronger GPCs and greater letter recognition, thereby facilitating greater gains in reading than would be made from standard instruction alone.

7.3 Research Question

In the current study, we examined whether participation in Write Start–K alongside standard literacy instruction would improve early reading skills in kindergartners when compared with participation in standard teaching of handwriting and literacy. We drew the data for this study from a larger study examining the impact of Write Start–K on the handwriting fluency and writing abilities of kindergartners. One research question guided the current study:

Does the addition of a handwriting fluency intervention, Write Start–K, to standard teaching of reading and writing impact early reading skills as compared with standard teaching of reading and writing alone?

7.4 Method

We used a two-group, nonrandomized, prospective comparison study design. Students from two schools participated; one school received the intervention, and the second school continued with standard teaching and served as the control. Ethics approval was obtained from the relevant bodies.

7.4.1 Participants

The two schools included in the study were from suburbs of a large regional city in New South Wales, Australia. Both schools had similar numbers of enrolments in the kindergarten year and were selected because of their location in community areas of lower socioeconomic status. In New South Wales public schools, a school socioeconomic index, the Family Occupation and Employment Index (FOEI), is calculated at the beginning of each year based on data provided by parents of all enrolled children on level of parental education, nonschool qualifications, and occupational status. The FOEI weights and combines parent information into an index that allows comparison among all public schools in New South Wales (NSW Department of Education, 2021b). The FOEI for the control and intervention schools identified both schools as having a similarly low level of socioeconomic status. The schools were also matched overall for racial and linguistic diversity, with both schools having approximately equivalent numbers of Indigenous students (control 12%, intervention 16%) and students with a language background other than English (control 2%, intervention 3%; ACARA, 2020). No students from either school had a diagnosis of dyslexia or learning difficulty.

Informed consent was received from all parties approached for inclusion in the study, including principals, teachers of the kindergarten classes, and parents of the children in each class. At the intervention school, parental consent was received for all 39 enrolled kindergartners and for all 42 enrolled kindergartners at the control school. Included participants at the intervention school (n = 38) had a mean age of 5 years 8.7 months (range = 57–77 months). Included participants at the control school (*n* = 39) had a mean age of 5 years 8.2 months (range = 62–77 months). There was no statistically significant difference between the schools in participant ages.

All kindergartners at the intervention school received the Write Start–K program, as it allowed for individual adjustments and used a range of strategies for providing instructions for activities such as visual modeling, demonstration, and specific feedback where needed. Pre- and post-assessments on some students (*n* = 1 at the intervention school, *n* = 2 at the control school), however, were not able to be completed due to a significant disability that impacted the ability of the students to understand and/or carry out assessment activities. The first author, a registered occupational therapist, assisted the research assistants (RAs) conducting the assessments to make judgments about whether assessments could be completed in a valid way. Where partial assessment data were collected, this was provided to class and specialist learning support teachers for the purposes of educational program and support planning; however, we did not use the data in the study analyses. No students were excluded from the study because of English-language difficulties.

7.4.2 Procedures

All participants in both schools were assessed at baseline, immediately after the intervention phase (eight weeks), and at 12 weeks following the end of the intervention (follow-up). Participants were assessed individually, and each assessment session, including breaks, took approximately 45 minutes per participant. After baseline data collection, Write Start–K was administered to all kindergartners at the intervention school in two 45-minute sessions per week for eight weeks. Kindergartners at the intervention school were distributed evenly across two classes. During the intervention phase, the control school continued with standard teaching according to the curriculum, including introduction to the alphabetic principle, handwriting, phonics instruction, and reading. This regular instruction also continued at the intervention school, with the exception that handwriting lessons and some aspects of the curriculum, such as crafts, were replaced by Write Start–K. Assessments were conducted by a team of 12 trained, supervised, and blinded RAs, who were selected from a pool of undergraduate occupational therapy students. RAs were randomly allocated to schools and participants, with all RAs working across both schools at each data collection point. Training for the RAs was conducted by the first and second authors and included face-to-face instruction, written procedures for nonstandardized tools, developmentally appropriate use of language, and on-site supervision by the first, second, or last author. Scripts and procedures of standardized and published tools were followed as published by the test developers. Integrity of the RA blinding was maintained, as only the supervising research team member interacted with school teaching staff involved in the study.

7.4.3 Measures

Measures collected and relevant to the current study are summarized in Table 7.1. The Dynamic Indicators of Basic Early Literacy Skills (DIBELS) is a frequently used test of literacy skills (Goffreda & DiPerna, 2010). For this study, three subtests were administered: Letter Naming Fluency, Nonsense Word Fluency, and Word Reading Fluency (Good & Kaminski, 2002). Each subtest was administered for one minute. An intraclass coefficient of .99, 95% confidence interval (CI) [0.982, 0.996], has been reported for inter-rater reliability for kindergarten DIBELS subtests (University of Oregon, 2018 - 2020). Concurrent validity ranges of the kindergarten subtests with measures of reading have been reported: for letter-naming fluency, r = .27–.60; for nonsense word-reading fluency, r = .27–.65; and for word-reading fluency, r = .26–.73 (University of Oregon, 2018 - 2020).

Table 7.1

Assessment Measures Description and Scoring

Assessment	Description	Scoring
DIBELS Letter Naming Fluency subtest	The student is shown a sheet of randomized upper and lowercase letters and asked to name as many as possible.	The total number of letters named correctly in one minute
DIBELS Nonsense Word Fluency subtest	A list of simple nonsense words is presented, and the student can pronounce either the whole word or individual sounds.	The number of correct letter sounds identified in one minute
DIBELS Word Reading Fluency subtest	The student reads words from a page of decodable and irregular words of increasing complexity.	The number of words read correctly in one minute
Letter name and letter sound knowledge	A sheet of randomized, matched upper and lowercase letters is shown one row at a time, and the student is asked the letter name and sound.	A point is awarded for each correct name and correct sound, totalling 26 for each category.

Note. DIBELS = Dynamic Indicators of Basic Early Literacy Skills.

In addition to the DIBELS, a researcher-designed test of letter name and sound knowledge was administered to obtain a baseline of skill ability in an untimed condition. Because we anticipated that accurate retrieval of letter names and sounds would be a likely key outcome of the writing intervention, it was important to gain a measure of letter name and sound knowledge for all 26 letters of the alphabet, and the timed DIBELS Letter Naming Fluency subtest did not provide this score. Both letter names and sound were included in this task because each type of knowledge makes a unique contribution to reading (Clemens et al., 2017). This untimed test mirrored tests used in studies with kindergartners (Eckberg Zylstra & Pfeiffer, 2016; Karlsdottir & Stefansson, 2003), in which participants are presented with a page of randomly sequenced upper and lowercase letter pairs and asked to name the letter and sound of the matched upper and lowercase letter pair. Clay (2002) reported a split-half reliability of .97 for a similar Letter Identification task that is part of the Observation Survey of Early Literacy Achievement. Names and sounds were given by RAs for any letters not known, and participants were invited to move on to the next letter.

7.4.4 Intervention

This study was conducted during the second half of the kindergarten school year. At the commencement of the intervention phase, all participants at both schools had received preliminary instruction in the alphabetic principle and had been introduced to all letters as part of standard teaching. Write Start–K was delivered in the classrooms by the first author, the classroom teacher, and one of two additional RAs who were undergraduate occupational therapy students and had experience in, and received additional training in, Write Start–K. Write Start–K was conducted in two 45-minute sessions per week for eight weeks. The structure of each session was explicit, whole-class instruction in the formation of a group of letters, followed by station-based activities, which were based on use of the letters, and related words and sentences.

Mnemonics to describe the formation patterns of each letter were introduced during the initial whole-class instruction and then used consistently and repetitively during session activities; for example, the mnemonic for the letter *a* was “around, up, and down.” All alphabet letters were revised over the course of the eight-week intervention by grouping letters with similar patterns of formation and using the groupings to establish fluency in writing for letters, words, and sentences. The focus of activity stations varied between session 1 and 2. Each activity station was led by one member of the intervention team and was themed through activity design based on the 4*Rs* model. For session 1, activities focused on fine-motor, visuomotor, and cognitive aspects of the handwriting task, and for session 2, the stations used crafts and writing tasks to create an authentic writing task. In each session, high levels of support and feedback were provided by station leaders, with the aim of consolidating the letter-forming patterns taught. In effect, each activity station engaged all four elements of the 4*Rs* model while also emphasizing foundation skill development.

In the first weekly session, the focus was on letter forming using a range of sensory and motor mediums, with a strong focus on the recall of letter formation patterns. The activity stations in session 1 emphasized repeated practice of letter forms using recall, retrieval, and reproduction routines through the medium of fine-motor, visuomotor, and cognitive station-based activities. Intervention activities were designed to be engaging to kindergartners and to include authentic writing tasks, wherever possible. Fine-motor-themed activities emphasized finger and hand skills that support writing, such as pressing Play-Doh flat to make a page and writing letters in the Play-Doh with a pencil tip. Visuomotor-themed activities emphasized the coordination of eye and hand skills, such as drawing a mirror image of half a face and writing the theme words *sad* or *glad* to represent the facial expression in the picture. Cognitive activities emphasized the use of memory recall in games and tasks, such as a “look, say, cover, write” activity in which flaps on folders were lifted one at a time to first reveal and then cover a letter or word, write the word, and then check and correct as needed. This meant that important foundation skill development for writing, such as fine-motor and visuomotor skill, and memory recall skill could develop at the same time as consolidation of letter name, sound, and form relations, as well as writing being embedded in authentic and relevant tasks.

In the second session of the week, letter formation practice was repeated through whole-class instruction and then facilitated through two activity stations: an authentic writing activity and a crafts activity. This approach approximated a writer's workshop model often used with older students. For example, at the crafts station for making a paper plate hat, using cutting, paper-tearing, and pasting skills was the basis for the related writing task. At the writing station, a guided and prompted sentence, "I can run and put on my hat," was used to apply the newly learned letter-forming knowledge and consolidate foundation skills indicated in handwriting fluency. In many cases, students were encouraged to extend their writing following the guided sentence and were encouraged to use their developing handwriting skills.

In the control school, the standard teaching approach included typical handwriting and literacy teaching. Literacy methods included teachers demonstrating a letter or letters; for example, the letters *u* and *e* together make the /u/ sound. Small-group rotations or individual activities followed the demonstration, such as pasting colored squares onto printed bubble letters, copying words, tracing letters on a worksheet, cutting and sorting words that fitted under headings (e.g., words with and without a silent *e*), and use of an iPad for literacy activities. Handwriting lessons at the control school used standard procedures, such as modeling of letter formation and provision of worksheets for practice. A key difference in the approach at the intervention school was the focus on handwriting fluency and consolidation of letter-forming patterns for each letter through visuomotor, fine-motor, and cognitive-themed activities. This was a distinct difference, as usually at this stage of the curriculum, after all letters have been introduced, attention would turn to reading and spelling in literacy lessons, rather than reemphasizing letter forming of all letters through handwriting.

It is important to note that the teachers at both the control and intervention schools had comparable levels of qualifications (a bachelor's degree in education) and that at each school, there was one teacher with more than 15 years of experience in teaching kindergarten and one teacher with three to five years of experience. Classroom observations at each school indicated that the regular literacy activities were similar at both schools. All kindergarten classes in Australia follow the same Early Stage 1 curricular objectives. Literacy instruction in kindergarten follows a balanced approach by which students develop reading and comprehension skills through exposure to written, visual, and digital texts from a variety of cultures. By the end of kindergarten, students are expected to have developed sound and letter knowledge, be able to identify letter patterns and sounds in words, and be able to read short, predictable printed texts on familiar topics with some fluency and accuracy (ACARA, 2014). Observations of literacy lessons at the control and intervention schools revealed that teachers at both locations adopted a similar blend of direct teaching of GPC and phonics strategies with story reading and class discussions. Write Start–K was time-tabled into the usual time allotted for handwriting and crafts activities and did not replace standard literacy and reading groups.

7.4.5 Data Analysis

We used linear mixed models (LMMs) to assess all outcomes for the impact of group, time, and the Group × Time interaction, with these three terms forming the base model. LMMs are useful for analyzing nonindependent data, such as those collected with repeated measures within a subject. The aim of the analysis was to determine the amount of growth for each measure as compared with each individual's own baseline score, and whether there was a difference between the groups in this growth. These changes from baseline score (i.e., growth) provided a way to adjust for potential nonequivalence of the groups due to the nonrandomized study design so only the growth differences between the groups were being compared. This type of analysis ensured that group differences at baseline would have minimal impact in assessing the size of the growth in the intervention, relative to the control. We assessed potential differences in variances and correlations between timepoints using residual covariance structures for each outcome measure. Three structures were tried, beginning with the simplest, compound symmetry, but to check for variability and/or correlation differences between time periods, we generally chose either heterogeneous compound symmetry or, the most general, unstructured.

We decided on the best structure based on the structure with the lowest Akaike Information Criterion. We chose a lower Akaike Information Criterion of 10 or more before we considered a structure better (Burnham & Anderson, 2004). We calculated nonstandardized effect sizes and 95% CIs for each measure for growth over time for each group and also for comparing the size of the difference in growth between the treatment and control groups. These were based on the fitted values from the LMMs. We set statistical significance at the .05 level.

7.5 Results

A general observation across all variables was that the modeling assumption of constant variance was broken, with variability in scores differing over time. In some cases, the variability decreased in the later time periods due to scores approaching the ceiling for each scale as students improved their skill levels. In other cases, the variability increased in the later time periods as some participants approached the ceiling for a measure while others stayed relatively stable. We overcame this nonconstant variance problem by using appropriate residual covariance structures in the modeling.

7.5.1 Baseline Comparison

We determined differences between baseline measures using LMMs (see Table 7.2). Statistically significant baseline differences were detected for letter-naming fluency (mean [*M*] = −9.6, 95% CI [−17.6, −1.5]), letter name knowledge (*M* = −9.0, 95% CI [−12.2, −5.6]), and letter sound knowledge (*M* = −2.5, 95% CI [−4.7, −0.2]), with the intervention group identifying fewer letters and sounds. The baseline differences for word-reading fluency and nonsense word–reading fluency were not statistically significant.

Table 7.2

Baseline Characteristics by Group (Intervention and Control) and Baseline Differences

Variable	Intervention (n = 38)		Control (n = 39)		Baseline difference	
	Mean (*SD*)	Median (min, max)	Mean (*SD*)	Median (min, max)	Mean	95% confidence interval[a]
Letter-naming fluency	16.6 (20.0)	7.0 (0, 64)	26.2 (15.5)	26.0 (0, 59)	−9.6	[−17.6, −1.5]
Nonsense word–reading fluency	30.2 (16.1)	32.5 (0, 63)	24.9 (13.5)	25.0 (0, 57)	5.3	[−1.3, 12.0]
Word-reading fluency	7.2 (7.7)	6.0 (0, 43)	8.6 (4.9)	8.0 (0, 18)	−1.3	[−4.2, 1.6]
Letter name knowledge	13.71 (9.24)	13.0 (1, 26)	22.7 (4.8)	25.0 (9, 26)	−9.0	[−12.2, −5.6]
Letter sound knowledge	21.6 (6.6)	25.0 (2, 26)	24.1 (2.6)	25.0 (15, 26)	−2.5	[−4.7, −0.2]

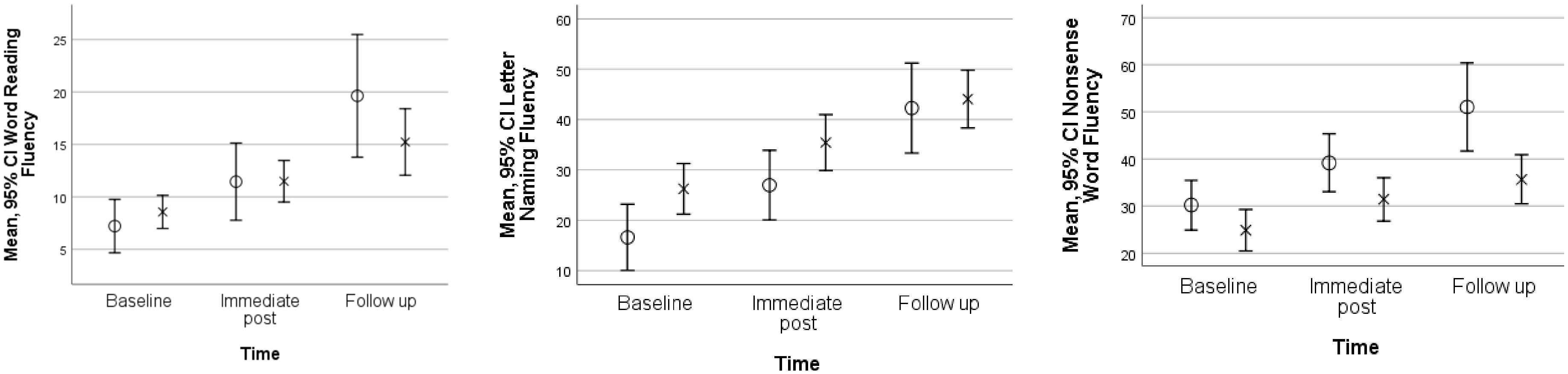
Note. *SD* = standard deviation. [a]If the 95% confidence interval does not cross 0, the difference between mean scores is significant at $p < .05$.

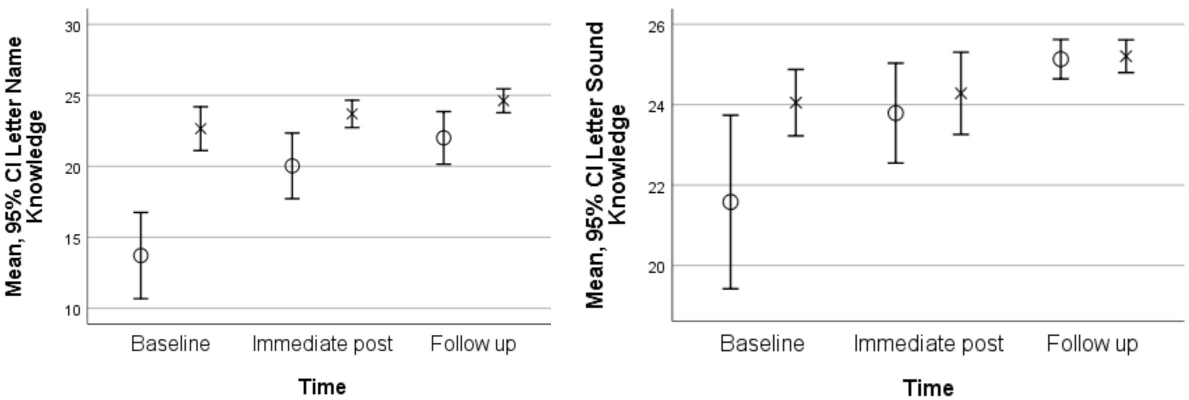
7.5.2 Reading Measures

Visual inspection of means with 95% CIs for each data collection point indicated the pattern of change in the means, within and between groups across the three timepoints—baseline, post-intervention, and follow-up—for all variables in the study (see Figure 7.1). We conducted statistical analysis using LMMs to determine the statistical significance of effects. Estimated marginal means from the models were used to assess the difference between groups in the differences between means across the three time intervals (baseline to post-intervention, post-intervention to follow-up, and baseline to follow-up) and the overall study effect sizes (see Table 7.3). For each measure and each group, a subtraction of means (e.g., mean at post-intervention—mean at baseline) yielded a difference in means (e.g., for word-reading fluency for the period from baseline to post-intervention, the mean difference for the intervention group was 4.2 more words read, 95% CI [3.0, 5.5], whereas the mean difference for the control group was 2.9 more words read, 95% CI [1.6, 4.1]). For all variables and both groups, the difference in means for each time interval were positive, indicating improvement over time regardless of group. This could be expected because the intervention and control groups received the intervention program and standard teaching, or standard teaching alone, respectively, and were therefore likely to gain in reading skills.

Figure 7.1

95% CI for Reading Markers and Word Reading Fluency for Intervention and Control Group at Time 1 (Baseline), 2 (Immediate Post) and 3 (Follow-Up)





O Intervention

X Control

Baseline: 0 weeks

Immediate post: After 8 week intervention period

Follow-up: 12 weeks after immediate post measures

Table 7.3

Effect Sizes for Changes in Means of Outcome Scores over the Three Time Intervals by Group

Variable	Group*time interaction (*p*)	Intervention difference in means [95 % CI] (n = 38)			Control difference in means [95% CI] (n = 39)			Effect size for intervention–control [95% CI]		
		Baseline to post-intervention	Post-intervention to follow-up	Baseline to follow-up	Baseline to post-intervention	Post-intervention to follow-up	Baseline to follow-up	Baseline to post-intervention	Post-intervention to follow-up	Baseline to follow-up
LNF	0.15	10.3	15.3	25.6	9.4	8.6	18.0	0.9	6.6	7.6
		[6.4, 14.2]	[9.9, 20.7]	[20.0, 31.3]	[5.5, 13.3]	[3.3, 14.0]	[12.4, 23.6]	[-4.6, 6.5]	[-0.9, 14.2]	[-0.4, 15.5]
NWF	0.09	9.0	11.9	20.8	6.3	4.2	10.5	2.6	7.7	10.3*
		[4.0, 14.0]	[5.2, 18.5]	[14.3, 27.4]	[1.4, 11.3]	[-2.4, 10.7]	[4.0, 17.0]	[-4.4, 9.7]	[-1.7, 17.1]	[1.1, 19.6]
WRF	0.05	4.2	8.2	12.4	2.9	3.7	6.6	1.3	4.5*	5.8*
		[3.0, 5.5]	[5.3, 11.1]	[9.1, 15.8]	[1.6, 4.1]	[0.8, 6.6]	[3.3, 9.9]	[-0.4, 3.1]	[0.4, 8.5]	[1.1, 10.5]
LNK	<.001	6.3	2.0	8.3	1.1	0.9	2.0	5.2*	1.1	6.3*
		[4.4, 8.2]	[1.0, 3.0]	[6.4, 10.2]	[-0.8, 3.0]	[-0.05, 1.9]	[0.1, 3.8]	[2.6, 7.9]	[-0.3, 2.4]	[3.6, 9.0]
LSK	0.07	2.2	1.3	3.6	0.2	0.9	1.2	2.0	0.4	2.4*
		[0.5, 4.0]	[0.2, 2.5]	[2.1, 5.0]	[-1.5, 2.0]	[-0.2, 2.0]	[-0.3, 2.6]	[-0.5, 4.4]	[-1.2, 2.0]	[0.4, 4.4]

This notation is only applied to the study effect sizes, i.e. intervention – control. If 95% CI does not cross zero, difference between means for overall study effect size is significant. The overall study effect size was calculated by subtracting control difference in means for each time interval from intervention difference in means for each time interval.

Abbreviations: LNF, Letter-Naming Fluency; NWF, Nonsense Word-Reading Fluency; WRF, Word-Reading Fluency, LNK, Letter Name Knowledge; LSK, Letter Sound Knowledge

We then determined the overall study effect size for each variable by subtracting the control group difference in means from the intervention difference in means at each of the time intervals. For example, for word-reading fluency (follow-up—baseline), the difference in intervention—control was 12.4 − 6.6 = 5.8, 95% CI [1.1, 10.5], in this case a statistically significant effect because the CI did not contain zero. All effect sizes were positive, indicating greater improvement for the intervention group relative to the control group for each variable across each time interval. Although not all of these effects were statistically significant as judged by their 95% CIs, it points to a general pattern in which the intervention group tended to outperform the control group. This indicated that the intervention was effective in impacting early markers of reading and word-reading fluency, over and above effects of standard teaching. We conducted statistical analysis to determine the statistical significance of these greater mean differences for the intervention group. Unstandardized effect sizes have been reported because they provide a more meaningful metric (i.e., number of letters or words) by which to judge the effects of the intervention and are recommended for primary research reporting (Pek & Flora, 2018).

LMM analysis showed a statistically significant Group × Time interaction for the variables word-reading fluency (p = .05) and letter name knowledge (p < .001), indicating that there was sufficient difference between groups across varying intervals to establish statistically significant effects. For word-reading fluency, greater change occurred for the intervention group relative to the control group in the period from baseline to follow-up, with an estimated mean difference in effect of 5.8 words, 95% CI [1.1, 10.5]. A statistically significant difference was also seen for word-reading fluency for the time interval from immediate post-intervention to follow-up, with an effect size of 4.5 words, 95% CI [0.4, 8.5]. Given that both schools continued with standard curriculum instruction in reading, this effect on word-reading fluency suggests a benefit to word-reading fluency for the intervention group as a result of the intervention. For letter name knowledge, there were two time intervals in which the intervention group statistically significantly outperformed the control group. From baseline to post-intervention, the effect size was 5.2 letters, 95% CI [2.6, 7.9], and from baseline to follow-up, the effect size was 6.3 letters, 95% CI [3.6, 9.0]. Because instruction in the alphabetic principle continued at both schools during the intervention phase, these results suggest an enhanced effect of the intervention on letter-naming ability.

For comparison purposes, Hedges' *g* is reported for the two measures where the Group × Time interaction was significant: letter name knowledge and word-reading fluency. We calculated Hedges' *g* by subtracting the mean of the change score for the control group from the mean of the change score for the intervention group and dividing by the pooled standard deviation. As a small sample correction, we applied Hedges' (1981) formula (multiplying the Hedges' *g* by a factor of $\omega = [1 - 3/(4N - 9)]$, with *N* being the total sample size) to produce an unbiased effect size estimate (What Works Clearinghouse, 2020). Use of change scores (see Table 7.3) allowed adjustment for differences in the baseline performance of each group. For letter name knowledge, baseline to post-intervention, the Hedges' *g* corrected for small-sample bias was 0.88, and for this same measure, the baseline to follow-up corrected Hedges' *g* was 1.05, indicating a large standardized effect size across both time periods. For word-reading fluency, the corrected Hedges' *g* from post-intervention to follow-up and from baseline to follow-up was 0.54 and 0.49, respectively. These standardized effect sizes suggest that the medium improvement in word-reading fluency that was evident at the end of the intervention was maintained over time.

Other measures that approached statistical significance for Group × Time interaction were letter sound knowledge ($p = .07$) and nonsense word–reading fluency ($p = .09$). For both of these measures, a statistically significant effect was detected favoring the intervention group for the period from baseline to follow-up; however, this was not sufficient for a statistically significant Group × Time interaction. For the period from baseline to follow-up, unstandardized effect sizes were 10.3 words (95% CI [1.1, 19.6]) for nonsense word-reading fluency and 2.4 letter sounds (95% CI [0.4, 4.4]) for letter sound knowledge. One measure, letter-naming fluency, did not demonstrate a statistically significant Group × Time interaction or a statistically significant effect size at any of the three timepoints. However, as shown in Table 7.3, all effect sizes were greater for the intervention group across each time interval for all measures, including letter-naming fluency.

7.6 Discussion

In this study, we sought to determine whether the introduction of Write Start–K, a handwriting fluency development program, into a kindergarten curriculum would result in growth of measures of reading greater than the growth that could be expected from standard teaching. To answer this question, we used two groups: one that received Write Start–K and regular literacy instruction and one that received regular teaching of handwriting and literacy. The key difference between the groups was the methodology used in the intervention group for handwriting fluency development, which was grounded in theory of how handwriting fluency develops in kindergarten. We hypothesized reading gains because of the development of GPCs facilitated through handwriting fluency processes. The method for analysis we used was to determine the growth (change over time) for each group and to compare differences in the growth between groups at varying time intervals with the aim of determining whether the growth in the intervention group exceeded that of the control group. Our purpose in using this approach was to determine how effective the intervention was in facilitating change and eliciting growth in commonly used markers of early reading. The benefit of analyzing differences in amount of change contributes to the science of reading by clearly showing whether intervention can impact emerging literacy by enhancing growth. Also, this method adjusts for any differences between groups at baseline.

The intervention had a statistically significant impact on two of the literacy measures, word reading and letter name knowledge, and the effect on two other measures, letter sound knowledge and nonsense word reading, approached statistical significance. Simply stated, the group that received the intervention, irrespective of baseline similarities or differences, made greater gains, or showed greater growth, than the gains made by the control group. We expected the control group to make some gains because they were receiving continued handwriting and literacy instruction, using standard and commonly used teaching methods. The intervention group also continued with similar literacy instruction but received a carefully designed handwriting intervention, designed to facilitate fluency in letter writing. We were interested in whether Write Start–K would have an impact on reading by strengthening GPCs. The statistically significant effects for letter naming and word reading and the finding that the effects for letter sound naming and nonsense word reading approached statistical significance suggest that this may have been the case.

A range of literacy markers, including letter naming and word reading, have a demonstrated relationship with early reading development (Schilling et al., 2007). We detected statistically significant intervention effects for the intervention group in letter-naming and word-reading skills. The greatest gains in knowledge of letter names occurred both immediately (from baseline to post-intervention) and overall (from baseline to follow-up). This suggests a rapid and immediate gain in letter-naming ability for the intervention group. Greater gains in word reading occurred in the period from post-intervention to follow-up and overall from baseline to follow-up. This suggests that most of the change in word reading occurred in the period from the end of intervention to the follow-up point. Word reading in grade 1 has been found to be predicted by letter naming (Stage et al., 2001) and letter–sound correspondence (Speece & Ritchey, 2005). The growth in letter naming immediately after intervention and in word reading over time points to a cumulative effect of enhanced letter recognition on word-reading fluency.

In this study, improvement in fluency in reading nonsense words, a predictor of reading (Fien et al., 2008), and knowledge of letter sounds, the basis of decoding (Earle & Sayeski, 2017; Treiman et al., 2019), both approached statistical significance. A timed measure of letter identification, used to measure fluency and accuracy, also followed the trend of greater gains across each time period made by the intervention group, but did not reach statistical significance. It is important to note that for the intervention group, these combined results indicate that all mean differences for all measures across all time periods were greater than the mean differences for the control group. This result is important in terms of the efficacy and potential benefit of the intervention, as growth effects were not limited to one or two measures.

We suggest that the overall positive trend for all literacy measures and specific statistically significant effects indicate that the handwriting fluency intervention, Write Start–K, impacted letter identification and GPCs and contributed to greater growth in word reading for the intervention group over the control group. Ehri (2014) explained that the process of learning to read is aided by both forming connections between graphemes and phonemes and understanding the alphabetic principle. When combined with phonemic skills, alphabetic and grapheme–phoneme knowledge enable bonding of spellings of words in memory and, ultimately, the ability to read words by sight. Decoding is another means used to read unfamiliar words, and this skill is in frequent use for students learning to read and also requires alphabetic and GPC knowledge (Castles et al., 2018; Rastle, 2019). Both sight word reading and decoding are therefore dependent on the establishment of alphabetic knowledge and GPCs. Further, rapid automatic naming, a measure of letter-naming fluency, has been found to predict spelling and word reading for kindergartners and first graders (Bar-Kochva & Nevo, 2019). The growth shown in this study may point to a stronger base in GPCs and more efficient retrieval of letter names and sounds, which may have contributed to the intervention group's statistically significant gain scores for reading, and gains in nonsense word reading that were close to statistical significance.

Why might an intervention for handwriting have impacted reading? We suggest that the handwriting intervention focus in this study impacted the mechanisms that underlie GPCs and alphabetic knowledge. For preschoolers, neuroimaging studies have demonstrated enhanced activation in visual processing of letters and brain areas associated with reading after letter printing (James, 2010; James & Engelhardt, 2012). Further, in experimental studies with preschoolers, letter writing has been found to facilitate letter recognition (Kiefer et al., 2015; Longcamp et al., 2005). It is possible that the Write Start–K methodology activated reading circuits by associating a letter name, sound, and form. Similar to Roberts et al. (2019) paired-associate learning intervention for preschoolers, Write Start–K uses station-based small-group handwriting activities to reinforce and repeatedly expose students to the relation among letter names, sounds, and forms. This consolidates the circular relation among cognitive representations of letters, motor patterns for letter formation, and reproduction of the cognitive representation using the correct motor pattern.

Reproduction factors that may limit handwriting ability, such as fine-motor and visuomotor skills, are also specifically targeted through Write Start–K, thereby enhancing effective practice. As previously noted, researchers have found a facilitating relation between letter writing and letter recognition (James, 2010; James & Engelhardt, 2012; Kersey & James, 2013). Participation in Write Start–K resulted in greater letter knowledge and word recognition automaticity. Also, enhanced visuomotor and fine-motor practice of letter writing is a feature of Write Start–K. Li and James (2016) found that both writing practice and visual studying of novel letter forms contributed to increased form recognition in kindergartners. Li and James therefore advocated increased handwriting practice as one means of promoting letter recognition. The practice element in Write Start–K, combining visuomotor, cognitive, and fine-motor skills in a fluency development model, may therefore underpin the enhanced reading gains made by students participating in the handwriting intervention. The coteaching features of Write Start–K may also be instrumental in the results, as the combination of teaching and occupational therapy specialties supports the use of specific, direct feedback and adjustment of intervention activities to ensure accessibility for all students based on developmental and cognitive needs.

In summary, these results demonstrate a key difference between the groups across a range of reading markers, despite both groups receiving ongoing literacy instruction, and we suggest that the repeated practice of retrieving letter forms from memory and writing the letters during the intervention was the contributing factor. We propose repeated practice through developmentally tailored handwriting fluency activities in kindergarten as the means by which a greater connection was established among the letter names, sounds, and forms, resulting in stronger letter identification and GPCs. Further, we see the use of the 4*R*s model of handwriting fluency (Ray, Dally, et al., 2021b) as a basis for designing the intervention activities as key to the gains made in reading for the intervention group. This literature-informed model emphasizes four aspects of fluency: recall of the letter form, retrieval of the motor pattern, reproduction of the retrieved form through handwriting, and sufficient repetition. Each factor was considered within the instructional model of Write Start–K. Activities based on the 4*R*s model may be able to stand alone; however, the coteaching framework of Write Start–K ensured sufficient feedback, monitoring, and practice time and allowed for both educational and developmental knowledge to inform the intervention.

7.6.1 Limitations

This translational research was conducted rigorously in an authentic classroom and, as such, was impacted by the natural variations that occur when working in the field. Randomization of participants into intervention and control groups was not possible because the intervention was intended to trial an approach that could be potentially adopted by whole classes, using the Write Start–K coteaching approach. Although the findings in the present study are supportive of the use of handwriting interventions as a means to promote reading acquisition in kindergarten, the results need to be confirmed through a larger, randomized study with more evenly matched control and intervention groups.

It is inevitable in small-scale studies with limited randomization that baseline differences will occur. In this study, we sought to minimize the effects of no randomization between groups by using a control group to provide partial matching on factors such as socioeconomic status. The control group nevertheless enabled the measurement of growth of key markers of reading when using regular teaching. Comparing the groups using differences in amount of growth from baseline, controlled for the group differences at baseline.

In terms of effects, the Write Start–K intervention may have provided additional handwriting instruction over that allocated in standard teaching, and there is a possibility that the study effect was partly or wholly due to the extra guidance provided by two additional adults leading the small-group handwriting activities rather than the nature of the handwriting approach. Future study designs will need to address this possible mismatch in intensity of teaching between groups. Similarly, the program effects may have been impacted by differences between teachers and teaching practices at the intervention and control schools that we were unable to measure or discern. Although the teachers followed the same curriculum and had similar years of experience in teaching kindergarten, given the small number of students and teachers, pedagogical differences between the intervention and control teachers could have either inflated or reduced the program's effects.

Due to the low numbers of enrolled students at the participating schools with English as a second language, we were unable to assess the effectiveness of this approach with a more linguistically diverse student group. The use of multisensory activities in Write Start–K within a model that promotes fluency through use of memory, developmental skills support, letter formation, and practice, however, is expected to be an accessible methodology for emerging bi/multilingual learners. Further, the principles of the 4*R*s framework could be incorporated into both regular and tailored activities to support multilingual or emergent bilingual learners. For example, an application of this research into more diverse practice could include adaptation of learning activities to incorporate the 4*R*s framework with individuals or small groups with specific needs.

7.6.2 Implications for Policy and Practice

The findings from this study indicate that a classroom-based kindergarten handwriting intervention had a positive impact on reading outcomes. We hypothesize that this might occur through consolidation of the foundational phonological knowledge of GPCs, which in turn support automatic word recognition (Moats, 2020). As noted by Moats (2020), most young readers require explicit instruction and sufficient practice to gain this knowledge. Moats recommended that beginning reading instruction should "focus on teaching students how to read and write words, following a systematic and logical sequence" (p. 7). Similarly, Rastle (2019) called for an integrated approach to the teaching of reading and writing, arguing that the nature of the reading system is a reflection of the writing system and that understanding how information is transmitted through written language facilitates skilled reading. The Write Start–K coteaching methodological approach tested in the current study provides one possible pathway to achieve integration between early writing and reading. Based on our results, we hypothesize that with repeated practice, beginning writers establish an efficient, accurate cognitive representation of a letter that contributes to the consolidation of the grapheme–phoneme relation, which in turn supports word-reading fluency. Replication of these results is needed, however, before practice guidelines can be amended. The findings of our study also support the further consideration of methods used to integrate specialty services in education, with indications that collaborative, interdisciplinary, whole-class models may be a means to address a wide range of developmental and instructional needs. The feasibility of one such model was tested in our study. The school and teachers involved found that the collaborative model worked effectively, strengthened and consolidated relationships, and allowed for early identification of issues as the intervention was progressing.

7.6.3 Contribution to the Science of Reading

This study contributes to the science of reading and the science of reading instruction (Shanahan, 2020), by providing empirical evidence that the repeated practice of recalling, retrieving, and reproducing letters through the act of writing serves to establish strong GPC knowledge, which leads to more efficient word-reading skills in beginning readers. Castles et al. (2018) proposed that instruction in GPCs and alphabetic decoding will have maximum benefit for higher order reading and text comprehension if this instruction is situated in the early stages of learning to read. These findings have implications for policymakers and practitioners in terms of teacher professional development in understanding how reading and writing processes can be integrated as part of effective early reading instruction. The current study meets recent calls for translational research that advances the science of reading through the implementation of instructional practices in classroom settings (Solari et al., 2020). The results will help equip kindergarten teachers with the knowledge and skills they need to support students' early reading and writing.

To read effectively and with comprehension, young learners first need a basis in the subskills that form the foundation of decoding. The science of reading has established the importance of phonological skills and alphabet knowledge in the early stages of learning to read. In this study, we found that a co-taught handwriting intervention, Write Start–K, led to statistically significant gains in these components. We speculate that the tailored handwriting intervention, emphasizing the 4*R*s (recall, retrieval, reproduction, and repetition of letter forms) model, facilitated stronger GPCs, resulting in enhanced letter and word recognition. This research contributes to the emerging evidence for the role of handwriting fluency in reading acquisition. Future research with larger samples is needed to further substantiate these results and guide practice.

Note:

We acknowledge the enthusiastic participation of the schools, teachers, and students in this study and also the voluntary involvement of the occupational therapy students who assisted in the delivery of the intervention and the student participants' assessments.

Chapter 8 Conclusion

Preface:

The final chapter in this thesis is a synthesis of all studies included in the body of work and is presented as the content of a policy brief in development (Sections 8.1 to 8.6), followed by thesis limitations (Section 8.7) and concluding remarks (Section 8.8). The Chapter content drawn from the policy brief is also included as an Appendix (Appendix 14). This policy brief has been reviewed by Joanne Geary, Subject Matter Expert at the NSW Education Standards Authority, and the recommendations have been included in the teacher practice guidlelines for handwriting which accompany the new Kindergarten to Year 2 English Curriculum.

Contribution statement:

The candidate prepared the policy brief with revisions as advised by supervisors, who are coauthors of this publication in development.

Authors and affiliations:

Learning to Read the Write Way – A Policy Brief

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Conventions used in the article:

The included policy brief uses terminology consistent with the NSW Department of Education, including Kindergarten, Year and numerals to describe Year levels.

Appendices to this chapter:

Appendix 13 - Learning to Read the Write Way – A Policy Brief

8.1 The Challenge

Children who struggle with literacy from the outset of their schooling are at risk of long-term difficulties in education, with potentially pervasive effects across their lifetime. In 2020, a new report “Nurturing Wonder and Igniting Passion”, was published by the NSW Education Standards Authority (2020), after a major NSW education review which commenced in 2018, in response to community and professional concerns about curriculum overcrowding and a loss of focus on foundation skills. Crucially, the report recognises Kindergarten as a critical time for building strong foundation skills for literacy, including reading and writing.

Handwriting has been identified as a core Kindergarten foundation skill requiring renewed focus because of its central role in creating written texts (NSW Education Standards Authority, 2021). Recently, it has been reported that handwriting fluency, which entails the ability to write legible letters from memory, may also impact the equally foundational and vital phonic knowledge that contributes to reading (Ray, Dally, et al., 2021a). However, children entering Kindergarten may be at a new level of disadvantage for acquiring handwriting skills, impacted by a profile of increasing developmental risk, particularly children in areas of socio-economic disadvantage (Department of Education and Training, 2016). Decreases in manual play stemming from increasingly early use of digital devices may contribute to developmental risk factors for handwriting acquisition (Gonski Institute for Education, 2019; Sheedy et al., 2021). There is also a paucity of evidence for curriculum-based ways to support Kindergarten students to develop handwriting skills, and wide variation in instructional practices (Engel et al., 2018; Malpique et al., 2017). The NSW Government has committed to a new K-2 curriculum by 2022 (NSW Government, 2020) based on the recommendations of the “Nurturing Wonder and Igniting Passion” report, which include a renewed focus on foundation skills in the early years and the need for capacity building for teachers to ensure they can implement the new curriculum. In this context, it is timely and essential to consider effective methods for supporting the foundation skill of handwriting. Focussing on effective instruction and intervention for handwriting may be a means to address pervasive developmental risk, support curriculum implementation through teacher capacity building, and facilitate transfer effects of fluent handwriting to literacy.

8.2 Problems

8.2.1 Risk for Difficulty with Handwriting is Increasing and Writing Readiness is Reducing

Kindergarten is a critical time for handwriting development, which requires the integration of cognitive and motor processes. However, a decline in handwriting-related motor skills in "digital natives" has recently been reported (Sheedy et al., 2021). Other reports speculate that increasing use of digital technologies is the cause of teacher observations of declining student ability to concentrate and focus on learning, suggesting a pervasive impact of early childhood experiences on learning across all foundation skills, including handwriting (Gonski Institute for Education, 2019). These problems may be compounded in areas of high socio-economic risk, with a widening gap in developmental vulnerabilities reported between children in advantaged and disadvantaged areas (Department of Education and Training, 2016). The confluence of these factors may explain the concerning numbers of Kindergarten children who have low abilities in handwriting fluency at the end of their first year of school. For example, in an Australian study, Malpique et al. (2017) found that nearly a quarter of Kindergarten children (42 out of n=177) were only able to write five or fewer alphabet letters in a minute .

8.2.3 High Expectations for Output Without a Solid Base

According to the Australian curriculum, by the end of the school year, Kindergarten students should be able to correctly form known upper and lowercase letters, use familiar words and phrases in writing and demonstrate letter and sound knowledge (ACARA, 2014). However, as observed in the recent NSW Education review, time spent on foundation skill development may be compromised by overall curriculum pressure (NSW Education Standards Authority, 2020). Further, explicit skills for handwriting, such as accurate letter formation, have historically been de-emphasised in favour of process writing and whole language approaches (Graham, 1992; Graham & Harris, 1994; Medwell & Wray, 2008). This shift in pedagogy may have compounded the impact of curriculum pressure.

8.2.3 Handwriting Instruction May be a Lost Art

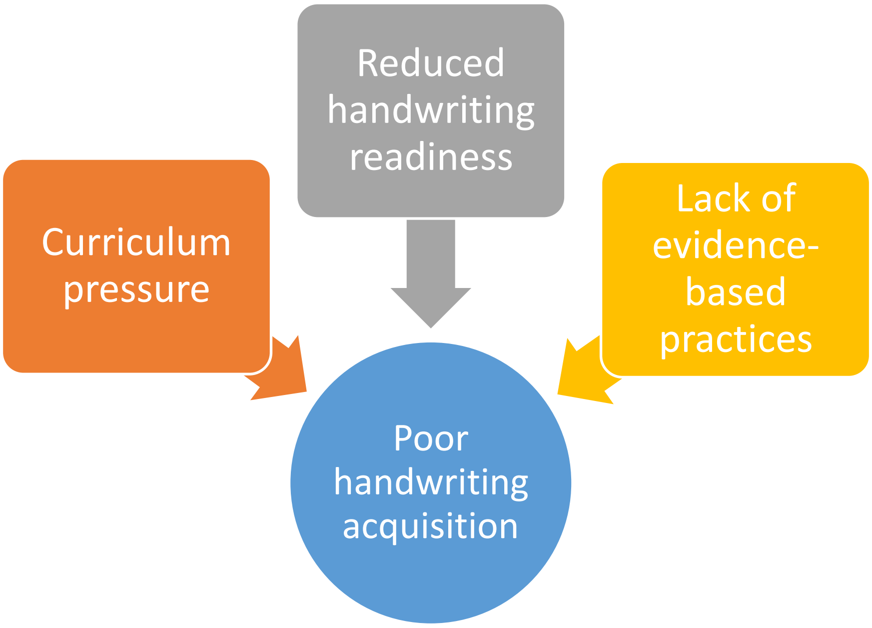
Teachers report varying levels of undergraduate training and preparedness in handwriting instruction (Collette et al., 2017; Donica et al., 2012; Nye & Sood, 2018) and there is a wide variation in both time spent on specific instruction, and instruction methods used by teachers (Cantin & Hubert, 2019; Malpique et al., 2017; Puranik et al., 2014). Further, evidence for effective curriculum-based handwriting intervention or early intervention programs is clustered in the pre-school years, or from Year 1 on, crucially lacking in the Kindergarten year (Engel et al., 2018). Within this context, it appears that handwriting may indeed be “a forgotten language skill” (Medwell & Wray, 2008, p. 34).

8.2.4 Impacts on Handwriting Acquisition

The three proposed factors impacting handwriting acquisition, handwriting readiness, curriculum pressure and insufficient knowledge on effective instruction may converge and lead to poor handwriting acquisition (Figure 8.1). This is of major concern as lack of development of handwriting fluency may contribute to an insufficient solid base for literacy tasks.

Figure 8.1

Factors Impacting on Handwriting Acquisition



Addressing the current problems requires an approach that acknowledges the complexities of the issues for teachers and students, including:

- Many students in Kindergarten are impacted by developmental risk factors that may impede the acquisition of vital foundations for learning, including handwriting.
- Children with increased developmental risk factors may not necessarily respond to standard teaching of handwriting, contributing to general concern about literacy development and progress.
- Wide variation exists in time and focus spent on Kindergarten writing, suggesting a lack of clarity on the nature of effective instruction.
- There is a need for evidence on handwriting fluency acquisition and effective instructional and intervention methods to support both typically developing children, and children with increased developmental risk factors.

…kindergarten presents a window of opportunity for preventing future reading and writing difficulties through early intervention (Kim et al., 2015, p.29)

8.3 Potential Gains—Handwriting Fluency Impacts on Literacy

Handwriting develops gradually, combining emerging knowledge of letter names, sounds and forms with developing fine and visuomotor skills. This skill is a recognised basis for writing texts (NSW Education Standards Authority, 2021). Handwriting fluency refers to the ability to form upper and lowercase letters automatically from memory, and is implicit in many typical school tasks. There are also downstream impacts of handwriting fluency on writing quantity, writing quality, and reading.

8.3.1 Handwriting Fluency Releases Working Memory From Mechanical Task Demands During Writing Composition

Being able to recall the image of a letter and reproduce it in writing enables legible handwriting, and with practice, leads to *automaticity*, or fluency in the act of writing a letter or word. When children are able to form letters correctly and quickly, vital memory resources are directed away from mechanical handwriting processes, and are available for spelling, generating ideas and using writing structures (Berninger et al., 1996; Graham et al., 1997; Kim et al., 2011; McCutchen, 1996). Strong evidence exists for impacts of handwriting fluency in Kindergarten on writing composition, specifically:

- Number of recognisable words, sentences or ideas (Dolin, 2016; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2011; Puranik & Al Otaiba, 2012; Puranik et al., 2017; Ray, Dally, et al., 2021b).
- Writing quality such as use of structure for text and complexity of word choice (Eidlitz-Neufeld, 2003; Jones & Christensen, 2012; Kent et al., 2014; Kim et al., 2015; Puranik & Al Otaiba, 2012).
- Spelling from dictation (Eidlitz-Neufeld, 2003; Karlsdottir & Stefansson, 2003; Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Puranik & Al Otaiba, 2012; Puranik et al., 2017).

8.3.2 Handwriting Enhances Grapheme–Phoneme Correspondences (GPC)

Understanding the alphabetic principle, the relationship between letter names, sounds and forms, is crucial in reading acquisition (Castles et al., 2018). Handwriting interventions that focus on development of fluency have reported downstream benefits for early reading skills known to support the acquisition of the alphabetic principle (Eckberg Zylstra & Pfeiffer, 2016; Ray, Dally, et al., 2021a). These effects are explained by the role of handwriting in creating strong grapheme-phoneme correspondences. Handwriting aids visual letter recognition and categorization (James, 2010; Li & James, 2016). Sufficient repetition of letter writing contributes to the creation of stable mental images of letters (James, 2010; Palmis et al., 2017).

Equally strong evidence exists for the impact of handwriting fluency on reading, including:

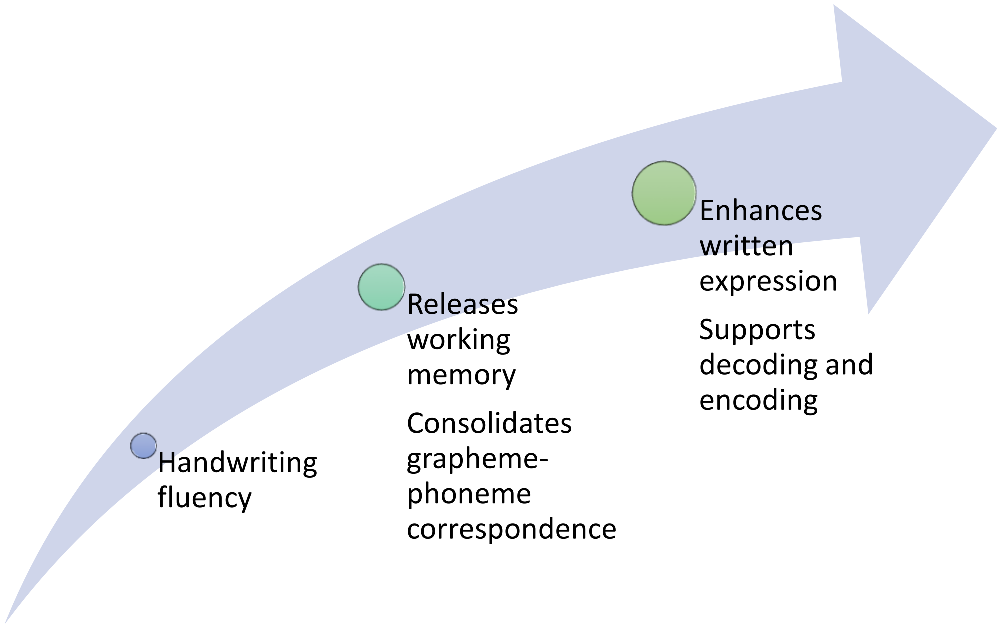
- Letter name and sound knowledge (Eckberg Zylstra & Pfeiffer, 2016; Eidlitz-Neufeld, 2003; Frolek Clark & Luze, 2014; Kim et al., 2014; Ray, Dally, et al., 2021a; Reutzel et al., 2019)
- Text reading (Karlsdottir & Stefansson, 2003)
- Real word reading (Eidlitz-Neufeld, 2003; Kent et al., 2014; Kim et al., 2014; Kim et al., 2011; Kim et al., 2015; Malpique et al., 2017; Puranik & Al Otaiba, 2012; Ray, Dally, et al., 2021a)
- Nonsense word reading (Eidlitz-Neufeld, 2003; Frolek Clark & Luze, 2014; Kim et al., 2015; Puranik & Al Otaiba, 2012)

8.3.3 The Impact of Perceptual Motor Skills on Literacy

Perceptual motor skills such as fine and visuomotor skills have traditionally been associated with handwriting abilities (Feder & Majnemer, 2007) and are associated with improved spelling (Bazyk et al., 2009), letter knowledge (Bazyk et al., 2009), letter naming fluency (Frolek Clark & Luze, 2014; Reutzel et al., 2019) and nonsense word reading (Frolek Clark & Luze, 2014). The development of these skills provides a crucial underpinning to handwriting fluency.

Figure 8.2

The Downstream Impacts of Handwriting Fluency on Literacy



8.4 The 4*Rs*—A Handwriting Fluency Acquisition Model

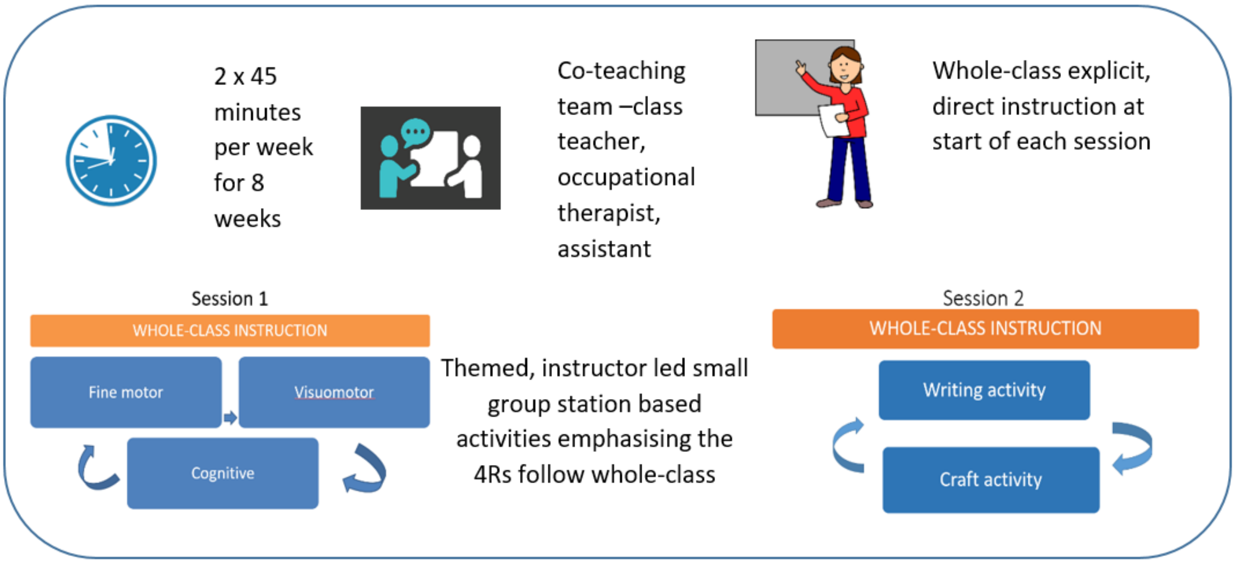
Relationships between literacy, perceptual motor skills and handwriting fluency, which entails key cognitive skills such as memory, are evident. Handwriting intervention approaches for Kindergarten that include both perceptual motor and cognitive factors, impact literacy (Bazyk et al., 2009; Dolin, 2016; Jones & Christensen, 2012). The 4*Rs* model (*Recall, Retrieve, Reproduce, Repeat)* (Ray, Dally, et al., 2021b) for handwriting fluency acquisition incorporates both cognitive and perceptual motor processes for beginning writers. Fluent handwriting requires: *recall* of the orthographic code or mental representation for a letter or word (Abbott & Berninger, 1993; Berninger et al., 1997), *retrieval* of the system of movements, or motor plan, associated with the recalled letter form (Graham et al., 2006; Tseng & Murray, 1994; van Galen, 1991), efficient letter *reproduction* using adequate perceptual motor abilities such as fine and visuomotor skills (Cornhill & Case-Smith, 1996; Graham et al., 2006; Kushki, Schwellnus, et al., 2011) and sufficient *repetition* (Hoy et al., 2011). These four factors are suggested as the key elements needed to work together to create handwriting fluency. Importantly, this model integrates the evidence for impacts of memory, motor plans and perceptual motor skills in emerging handwriting. The 4*Rs* model is proposed as a practice model to enable evidence-based classroom instruction. The 4*Rs* model is also a basis for revising and updating handwriting intervention approaches.

8.4.1 Write Start-K: A Test Case

The authors of this brief, through the University of Newcastle, partnered with teachers at two New South Wales regional schools to test the effectiveness of Write Start-K. The schools were identified as being from lower socio-economic areas. Write Start-K is a whole-class, co-taught Kindergarten handwriting intervention, revised using the 4*Rs* model, and adapted from Write Start, a Year 1 intervention program (Case-Smith et al., 2011; Case-Smith et al., 2012; Case-Smith et al., 2014) (Figure 8.3). Co-teaching, was used as a key strategy in this intervention approach to address the potential impacts of developmental risk on handwriting fluency acquisition, by embedding occupational therapy services into the handwriting instructional sessions. The co-teaching team consisted of the class teacher, an occupational therapist and a trained assistant. Key benefits of co-teaching include the blend of skills that each partner brings to the intervention approach, information exchange and capacity building that results from working in collaboration (Case-Smith et al., 2012). Occupational therapy focusses on use of meaningful, age-appropriate activities to support participation in tasks, in this case, handwriting fluency acquisition.

Figure 8.3

Write Start-K Eight-Week Intervention Program



The intervention consists of two 45-minute weekly sessions for eight weeks, introducing and/or revising letter formation for small groups of letters. Whole-class instruction is followed by small group, station-based activities. Session 1 stations emphasise foundation fine motor, visuomotor and cognitive skills during letter writing activities that activate *recall*, *retrieval*, *reproduction* and *repetition* of letter formation. Session 2 includes craft and writing activity stations, adapting a writing workshop approach used for Year 1. Write Start-K is informed by extensive evidence for:

- Multisensory instruction and practice to facilitate handwriting fluency (for example, mnemonics, air writing, use of a range of mediums for writing) (Dolin, 2016; Jones & Christensen, 2012).
- Embedding letter name, sound and form relationships through sensorimotor processes in handwriting (Kiefer et al., 2015).
- Interaction of both cognitive and perceptual motor processes in handwriting fluency (Abbott & Berninger, 1993; Berninger et al., 1997; Cornhill & Case-Smith, 1996; Graham et al., 2006; Hoy et al., 2011; van Galen, 1991; Volman et al., 2006).

- Enhancing mental representations of letters and letter recognition by handwriting (Berninger et al., 1992; James, 2010; James & Engelhardt, 2012; Li & James, 2016).
- Role of novel, varied and graded tasks direct, and dynamic and explicit feedback to support skill development (Case-Smith et al., 2014).
- Sufficient amount of intervention to ensure an effect.

In our study, we administered Write Start-K to two Kindergarten classes (n=38) and compared outcomes with Kindergarten students (n= 39) in another school who received usual handwriting instruction. Both the intervention and control classes continued with similar literacy instruction. We measured the differences between groups in amount of change in handwriting fluency and literacy. We found:

Handwriting fluency gains: The intervention group made greater gains in handwriting fluency and letter sound correspondence. The intervention group made greater gains in writing recognisable letters from memory using correct letter formation and with less reliance on visual, verbal or demonstration prompts. Both of these skills were influential in the gains seen in writing composition and reading.

Writing composition gains: The intervention group made greater gains in the number of words they could write in a story. This significant growth can be explained by increased handwriting fluency, which released working memory, and allowed more attention to be given to generating ideas, spelling and writing.

Reading gains: After the 8 week program, the gains in key reading skills of letter name knowledge and word reading fluency were significantly greater for the intervention group than the control. This effect is a downstream impact of handwriting fluency on reading, and supports the evidence for the broader impacts of handwriting fluency on literacy in Kindergarten.

8.5 Implications

Our study tested a whole-class, co-taught intervention for Kindergarten, which was revised and updated using the 4*Rs* model of handwriting fluency acquisition. Our results, indicate that Write Start-K shows promise as method to impact handwriting fluency acquisition in Kindergarten classrooms, and may be particularly relevant in schools where socio-economic disadvantage is high. Further, Write Start-K is a promising approach to facilitating capacity building in teachers through skills exchange. More broadly, the 4*Rs* model is a potential framework to:

- Integrate handwriting instruction with reading and writing outcomes.
- Devise activities that promote letter name, sound and form relationships through handwriting.
- Strengthen the relationships between letter names, sounds and forms to support writing, spelling and reading.
- Underpin teacher practice guidelines to support curriculum goals and outcomes for Kindergarten.

8.6 Key Policy Options

On the basis of the existing literature and new data from the study described in this brief, we recommend a range of policy options for a broad range of stakeholders including education standards authorities, government departments, professional bodies and tertiary institutions. Specific policy options are detailed for each.

Policy options for **education standards authorities** at a state and national level include:

- Ensure evidence informed practices are included in teacher practice guidelines for handwriting instruction, specifically:
    1. Outline factors that contribute to handwriting fluency acquisition, including memory of letters and associated correct formation patterns, skills that impact letter writing

such as hand and eye-hand skills, and the need for sufficient repetition to develop these skills and embed letter form relationships.

2. Differentiate between handwriting legibility and fluency, by explaining the role of memory in handwriting fluency, in contrast to copying or tracing tasks.
3. Report evidence for relationships between handwriting fluency and literacy, both reading and writing.
4. Emphasise evidence from frameworks that integrate knowledge of both cognitive and motor processes that underpin handwriting fluency acquisition such as the 4*Rs.*

- Seek out and approve professional development opportunities for teachers that provide evidence-based instructional methods for handwriting fluency acquisition.
- Identify effective handwriting instruction as an important inclusion in priority professional development areas.

Policy options for **departments of education** responsible for funding and resourcing of schools include:

- Address potential for large proportions of children in lower socioeconomic schools to be impacted by issues of developmental risk, with potential for flow on difficulties with handwriting acquisition through:
    1. Upscaling access for schools in high areas of need to co-teaching partnerships, such as with occupational therapy, to support handwriting fluency acquisition in Kindergarten.
    2. Increase access to professional development for teachers to upskill and capacity build in the area of handwriting fluency acquisition, such as through the identification of and training in courses that target handwriting fluency acquisition.

3. Consider research partnerships with tertiary institutions to build the knowledge base for effective handwriting fluency intervention approaches that can be delivered to whole classes in areas of need.

Policy options for **tertiary institutions** include:

- Increase interdisciplinary training at undergraduate level to upskill teachers in mechanisms for promoting handwriting fluency.
- Embed instruction on handwriting fluency acquisition into undergraduate teaching programs.
- Increase interdisciplinary practice experiences as part of educational training, such as collaboration between student occupational therapists and student teachers.
- Collaborate with education departments in researching handwriting instruction, intervention and benefits of different methodologies for both.

Policy options for **professional organisations** include:

- Generate a practice guideline for occupational therapists for working in schools collaboratively with teachers to support handwriting fluency acquisition.
- Ensure accessible resources on effective handwriting fluency acquisition instruction and intervention, relevant to professional disciplines.

8.7 Thesis Limitations

This Section 8.7 discusses the limitations of the thesis overall. This thesis included a systematic review, a pilot study and a two-group study. Limitations of each study are discussed.

The systematic review explored relationships between handwriting fluency and literacy in Kindergarten, with these terms informing the search strategy. Other important contributors to literacy have been identified such as attention, oral language and spelling (Section 2.5.4 and 2.5.5). The focus of the systematic review was only on relationships of handwriting fluency to literacy, and as such impacts of these other contributing factors were not incorporated into findings and conclusions. It may be the observed relationships of handwriting fluency to literacy seen in the systematic review may be mediated by other important contributing factors. Further reviews and study should aim to understand how handwriting fluency impacts or enhances other known predictors of literacy, such as spelling, in addition to continued exploration of the unique impacts of handwriting fluency on literacy. It should be noted that none of the studies included in this review were randomised control trials, with the highest level of evidence for studies included in this review found in two-group studies. Further, many of the included studies reported associations and relationships between variables, rather than the impact of an intervention on outcome, either controlled or uncontrolled. Evidence for the specific relationships studied in this review is emerging, and this is reflected in the design of included studies, such as small-scale two-group studies, one-group studies or studies reporting relationships or associations. The smaller scale two-group studies limit the generalisability of these study findings. Further, a causative relationship cannot be inferred from the studies reporting associations between handwriting and literacy. Given the limitations of the studies included in the review, overall findings of the review should be interpreted with caution. Studies were also characterised by a broad range of designs and different measures for both handwriting and literacy, which were grouped into categories as part of the study. This heterogeneity meant that a meta-analysis was not possible, and the results were synthesised narratively. Increased studies reporting the impacts of handwriting fluency intervention on Kindergarten literacy would strengthen future reviews, and contribute to a greater understanding of the impact of this skill on literacy.

The pilot study was a one-group pre- post-test, retrospective analysis, of a modified Write Start program. The retrospective analysis found significant gains in handwriting fluency post intervention. A major limitation to this study was clearly the lack of a control group, and it was therefore not possible to infer that the observed impacts on handwriting fluency were a result of the intervention. In addition, this study measured handwriting fluency with a previously untested and newly developed measure, the LFA. The LFA extended existing methods of handwriting fluency measurement for Kindergarten, and addressed the observed floor effect of the commonly used alphabet testing method; however, a ceiling effect was observed in the new tool. The ceiling effect, through limitations on the range of data collected, may have impacted the accuracy of measurement of handwriting fluency changes. Modifications to the tool were proposed based on this observation and were incorporated into the two-group study.

A two-group, quasi experimental study, Write Start-K, was based on implementation of the intervention tested in the pilot study, revised and updated using the 4*Rs* model as a framework. In this controlled study, Write Start-K resulted in significant gains for handwriting fluency and literacy outcomes, providing preliminary support for the intervention approach. However, this study was non-randomised and small scale, and a larger, randomised study is required to substantiate these findings. A possible impact of the small, non-randomised nature of this study was also the risk that results were due to sampling error. Outcome measures used in the two-group study including the LFA-2, revised and updated from the pilot study, and the writing outcome measure also need further testing before use in a larger study, to ensure sound psychometric properties. In terms of study design, the two-group study compared Write Start-K with standard teaching. Write Start-K was not tested against other handwriting fluency intervention methods, and the addition of alternate intervention approaches in future study designs would allow for further contrast and comparison. Evidence was found for impacts of both perceptual motor and fluency features of handwriting on literacy in Kindergarten (Chapter 2). Studies comparing intervention approaches may help to refine the weighting afforded to different elements in the Kindergarten year and determine more clearly how to support handwriting fluency acquisition. Finally, future study of Write Start-K should ensure an even match of teaching time allocated to handwriting and related activities between groups. Our study did not record individually logged teaching activities and therefore we cannot be certain that equivalent focus was spent on instructional activities across classrooms. Future study should ensure that time spent on teaching and/or intervention tasks is carefully logged.

8.8 Concluding Remarks and Recommendations for Further Research

The body of work in this thesis has explored the role of handwriting in reading and writing for Kindergarten children. The combined findings of this thesis are supportive of a significant role for handwriting fluency in Kindergarten literacy. A systematic literature review found that both letter writing fluency (comprising cognitive and perceptual motor skills) and perceptual motor skills independently were significantly associated with literacy outcomes. Both skill areas, combined in whole-class, co-taught interventions, impacted reading and writing outcomes. A pilot intervention, modified Write Start, had a significant impact on handwriting fluency, measured with a newly designed tool, the LFA. However, children with higher early literacy generally responded better. Strengthening aspects of intervention related to cognitive processes (for example, grapheme phoneme correspondence) was indicated. A proposed model, the 4*Rs*, integrated literature and pilot study evidence by identifying essential skills and processes for handwriting fluency acquisition. The 4*Rs* identify four elements including cognitive processing (*recall* and *retrieval*), perceptual motor abilities (*reproduce*) and integration of all processes together (*repetition*). The 4*Rs* model was the basis for a revised and updated intervention, Write Start-K. Write Start-K was tested in a two-group pre-post-test study and significant gains in handwriting fluency, writing composition and reading were observed. The revised and updated LFA-2 was an effective measure of handwriting fluency for beginning writers. Overall, the work in this thesis has contributed to the present reconsideration of the role of handwriting in early literacy. Further, a framework for revising interventions has been proposed, and tested by revising and updating an intervention with established efficacy. The positive outcomes associated with Write Start-K provide preliminary validation of use of the 4*Rs* model to revise handwriting intervention approaches. Application to more general teaching instruction may be indicated and needs further investigation. Further study of Write Start-K is indicated for whole-class, co-taught instructional approaches. Co-teaching may present challenges in terms of effective collaboration and access to resources to support the program, however strong benefits are evident including transfer of skills between professionals, and enabling access to therapeutic approaches within the naturalistic classroom environment. Replication of effects in a randomised study would enable generalisation of findings and provide a tested, efficacious intervention approach where co-taught approaches are indicated.

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APPENDICES

Appendix 1—Risk of Bias Assessment for Systematic Review – Johns Hopkins Evidence-Based Practice

Risk of bias rating – Johns Hopkins Evidence-Based Practice

Author, year	Level of evidence		
	Manipulation of independent variable	Control group?	Participants randomly assigned to intervention or control
Bazyc, 2009	Y	N	NA
Dolin, 2016	Y	Y	N
Dunsmuir 2004	N	N	NA
Eidlitz-Neufeld, 2003 (Study 1)	N	N	N
Eidlitz-Neufeld, 2003 (Study 2)	Y	Y	N
Frolek Clark 2014	N	N	NA
Jones, 2012	Y	Y	N
Karlsdottir, 2003	N	N	NA
Kent, 2014	N	N	NA
Kim, 2014	N	N	NA
Kim, 2011	Y	N	NA
Kim, 2015	Y?	N	NA
Malpique, 2017	N	N	NA
Puranik 2012	N	N	NA
Puranik, 2017	N	N	NA
Reutzal, 2019	N	N	N
Zylstra 2016	Y	Y	N

Author, year	Quality review											
	Identific-ation of problem and gaps in knowledge	Study purpose clear	Current literature review (>50% sources <5 years old or seminal)	Sufficient sample size	Similar control and intervention demographics and settings	Clearly described data collection methods	Instruments reliable	Validity discussed	Results clearly presented	Limitations addressed	Conclusions based on results	Level of evidence and quality rating *
Bazyc, 2009	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Dolin, 2016	Y	Y	N	Y	Y	Y	P	Y	Y	Y	Y	IIB
Dunsmuir 2004	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Eidlitz-Neufeld, 2003 (Study 1)	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Eidlitz-Neufeld, 2003 (Study 2)	Y	Y	N	Y	Y	Y	P	N	Y	Y	Y	IIB
Frolek Clark 2014	Y	Y	N	Y	NA	Y	P	Y	Y	Y	Y	IIIB
Jones, 2012	Y	Y	N	Y	Y	Y	NR	N	Y	N	Y	IIB
Karlsdottir, 2003	Y	Y	N	Y	NA	Y	NR	N	Y	Y	Y	IIIB

Author, year	Quality review											
	Identification of problem and gaps in knowledge	Study purpose clear	Current literature review (>50% sources <5 years old or seminal)	Sufficient sample size	Similar control and intervention demographics and settings	Clearly described data collection methods	Instruments reliable	Validity discussed	Results clearly presented	Limitations addressed	Conclusions based on results	Level of evidence and quality rating *
Kent, 2014	Y	Y	Y	Y	NA	Y	Y	N	Y	Y	Y	IIIB
Kim, 2014	Y	Y	N	Y	NA	Y	P	N	Y	Y	Y	IIIB
Kim, 2011	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Kim, 2015	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Malpique, 2017	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Puranik 2012	Y	Y	Y	Y	NA	Y	P	N	Y	Y	Y	IIIB
Puranik, 2017	Y	Y	Y	Y	NA	Y	Y	P	Y	Y	Y	IIIB
Reutzal, 2019	Y	Y	N	Y	NA	Y	Y	N	Y	Y	Y	IIIB
Zylstra 2016	Y	Y	Y	Y	Y	Y	P	N	Y	Y	Y	IIB

Appendix 2—Ethical Approval and Safety Clearance for Pilot Study Retrospective Analysis

HUMAN RESEARCH ETHICS COMMITTEE

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Notification of Expedited Approval

To Chief Investigator or Project Supervisor:	**Associate Professor Alison Lane**
Cc Co-investigators / Research Students:	**Doctor Kerry Dally** **Mrs Karen Ray**
Re Protocol:	**Evaluation of an embedded occupational therapy program to improve handwriting in kindergarten aged children.**
Date:	**13-Feb-2018**
Reference No:	**H-2017-0415**
Date of Initial Approval:	**13-Feb-2018**

Thank you for your **Response to Conditional Approval** submission to the Human Research Ethics Committee (HREC) seeking approval in relation to the above protocol.

Your submission was considered under **Expedited** review by the Ethics Administrator.

I am pleased to advise that the decision on your submission is **Approved** effective **13-Feb-2018**.

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research, 2007, and the requirements within this University relating to human research.

Approval will remain valid subject to the submission, and satisfactory assessment, of annual progress reports. *If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.*

The full Committee will be asked to ratify this decision at its next scheduled meeting. A formal *Certificate of Approval* will be available upon request. Your approval number is **H-2017-0415**.

If the research requires the use of an Information Statement, ensure this number is inserted at the relevant point in the Complaints paragraph prior to distribution to potential participants You may then proceed with the research.

Conditions of Approval

This approval has been granted subject to you complying with the requirements for *Monitoring of Progress*, *Reporting of Adverse Events*, and *Variations to the Approved Protocol* as detailed below.

PLEASE NOTE:
In the case where the HREC has "noted" the approval of an External HREC, progress reports and reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, or a Renewal of approval, you will apply to the External HREC for approval in the first instance and then Register that approval with the University's HREC.

- ***Monitoring of Progress***

Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. A progress report is required on an annual basis. Continuation of your HREC approval for this project is conditional upon receipt, and satisfactory assessment, of annual progress reports. You will be advised when a report is due.

- ***Reporting of Adverse Events***

1. It is the responsibility of the person **first named on this Approval Advice** to report adverse events.
2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
3. Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Approval Advice to the (HREC) by way of the Adverse Event Report form (via RIMS at https://rims.newcastle.edu.au/login.asp) within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
4. Serious adverse events are defined as:
   - Causing death, life threatening or serious disability.
   - Causing or prolonging hospitalisation.
   - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
   - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
   - Any other event which might affect the continued ethical acceptability of the project.

5. Reports of adverse events must include:
   - Participant's study identification number;
   - date of birth;
   - date of entry into the study;
   - treatment arm (if applicable);
   - date of event;
   - details of event;
   - the investigator's opinion as to whether the event is related to the research procedures; and
   - action taken in response to the event.

6. Adverse events which do not fall within the definition of serious or unexpected, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.

- ***Variations to approved protocol***

If you wish to change, or deviate from, the approved protocol, you will need to submit an *Application for Variation to Approved Human Research* (via RIMS at https://rims.newcastle.edu.au/login.asp). Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. **Variations must be approved by the (HREC) before they are implemented** except when Registering an approval of a variation from an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

Linkage of ethics approval to a new Grant

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.

Best wishes for a successful project.

Associate Professor Helen Warren-Forward
Chair, Human Research Ethics Committee

For communications and enquiries:
Human Research Ethics Administration

Research & Innovation Services
Research Integrity Unit
The University of Newcastle
Callaghan NSW 2308
T +61 2 492 17894
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RIMS website - https://RIMS.newcastle.edu.au/login.asp

Linked University of Newcastle administered funding:

Funding body	Funding project title	First named investigator	Grant Ref

Appendix 3 – Ethical Approval and Safety Clearance for Two-Group Study

HUMAN RESEARCH ETHICS COMMITTEE

Notification of Expedited Approval

To Chief Investigator or Project Supervisor:	**Associate Professor Alison Lane**
Cc Co-investigators / Research Students:	**Doctor Kerry Dally** **Mrs Karen Ray** **Ms Robyn Evans**
Re Protocol:	**Effectiveness of Write Start-K on handwriting ability and literacy skills in Australian Kindergarten children.**
Date:	**20-May-2019**
Reference No:	**H-2019-0049**
Date of Initial Approval:	**20-May-2019**

Thank you for your **Response to Conditional Approval (minor amendments)** submission to the Human Research Ethics Committee (HREC) seeking approval in relation to the above protocol.

Your submission was considered under **Expedited** review by the Ethics Administrator.

We are pleased to advise that the decision on your submission is **Approved** effective **20-May-2019**.

In approving this protocol, the Human Research Ethics Committee (HREC) is of the opinion that the project complies with the provisions contained in the National Statement on Ethical Conduct in Human Research, 2007, and the requirements within this University relating to human research.

Approval will remain valid subject to the submission, and satisfactory assessment, of annual progress reports. *If the approval of an External HREC has been "noted" the approval period is as determined by that HREC.*

The full Committee will be asked to ratify this decision at its next scheduled meeting. A formal *Certificate of Approval* will be available upon request. Your approval number is **H-2019-0049**.

If the research requires the use of an Information Statement, ensure this number is inserted at the relevant point in the Complaints paragraph prior to distribution to potential participants You may then proceed with the research.

Conditions of Approval

This approval has been granted subject to you complying with the requirements for *Monitoring of Progress*, *Reporting of Adverse Events*, and *Variations to the Approved Protocol* as detailed below.

PLEASE NOTE:
In the case where the HREC has "noted" the approval of an External HREC, progress reports and reports of adverse events are to be submitted to the External HREC only. In the case of Variations to the approved protocol, or a Renewal of approval, you will apply to the External HREC for approval in the first instance and then Register that approval with the University's HREC.

- ***Monitoring of Progress***

Other than above, the University is obliged to monitor the progress of research projects involving human participants to ensure that they are conducted according to the protocol as approved by the HREC. A progress report is required on an annual basis. Continuation of your HREC approval for this project is conditional upon receipt, and satisfactory assessment, of annual progress reports. You will be advised when a report is due.

- ***Reporting of Adverse Events***

1. It is the responsibility of the person **first named on this Approval Advice** to report adverse events.
2. Adverse events, however minor, must be recorded by the investigator as observed by the investigator or as volunteered by a participant in the research. Full details are to be documented, whether or not the investigator, or his/her deputies, consider the event to be related to the research substance or procedure.
3. Serious or unforeseen adverse events that occur during the research or within six (6) months of completion of the research, must be reported by the person first named on the Approval Advice to the (HREC) by way of the Adverse Event Report form (via RIMS at https://rims.newcastle.edu.au/login.asp) within 72 hours of the occurrence of the event or the investigator receiving advice of the event.
4. Serious adverse events are defined as:
    - Causing death, life threatening or serious disability.
    - Causing or prolonging hospitalisation.
    - Overdoses, cancers, congenital abnormalities, tissue damage, whether or not they are judged to be caused by the investigational agent or procedure.
    - Causing psycho-social and/or financial harm. This covers everything from perceived invasion of privacy, breach of confidentiality, or the diminution of social reputation, to the creation of psychological fears and trauma.
    - Any other event which might affect the continued ethical acceptability of the project.
5. Reports of adverse events must include:
    - Participant's study identification number;
    - date of birth;
    - date of entry into the study;
    - treatment arm (if applicable);
    - date of event;
    - details of event;
    - the investigator's opinion as to whether the event is related to the research procedures; and
    - action taken in response to the event.
6. Adverse events which do not fall within the definition of serious or unexpected, including those reported from other sites involved in the research, are to be reported in detail at the time of the annual progress report to the HREC.

- ***Variations to approved protocol***

If you wish to change, or deviate from, the approved protocol, you will need to submit an *Application for Variation to Approved Human Research* (via RIMS at https://rims.newcastle.edu.au/login.asp). Variations may include, but are not limited to, changes or additions to investigators, study design, study population, number of participants, methods of recruitment, or participant information/consent documentation. **Variations must be approved by the (HREC) before they are implemented** except when Registering an approval of a variation from an external HREC which has been designated the lead HREC, in which case you may proceed as soon as you receive an acknowledgement of your Registration.

Linkage of ethics approval to a new Grant

HREC approvals cannot be assigned to a new grant or award (ie those that were not identified on the application for ethics approval) without confirmation of the approval from the Human Research Ethics Officer on behalf of the HREC.

Best wishes for a successful project.

Human Research Ethics Committee

For communications and enquiries:
Human Research Ethics Administration

Research & Innovation Services
Research Integrity Unit
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RIMS website - https://RIMS.newcastle.edu.au/login.asp

Linked University of Newcastle administered funding:

Funding body	Funding project title	First named investigator	Grant Ref

Appendix 4 – Participant Information Statement for Principal of Intervention School

Associate Professor Alison Lane
School of Health Sciences
Faculty of Health & Medicine
University of Newcastle
University Drive
Callaghan NSW 2308
Ph: 02 4921 5004
alison.lane@newcastle.edu.au

THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Information Statement for Principal - Intervention Site
Effectiveness of Write Start-K on handwriting ability and literacy skills in Australian Kindergarten children

Document Version 3: 24th May, 2019

Your school is invited to participate in the research project identified above which is being conducted by Karen Ray, as part of her Higher Degree Research studies under the supervision of Associate Professor Alison Lane and Dr Kerry Dally from the University of Newcastle. Karen Ray is a registered occupational therapist with over twenty years of experience, and six years of recent experience working directly in a school setting. Karen is experienced in assessment and intervention with children to support developmental and learning goals. An Honours Occupational Therapy Student Researcher, Robyn Evans, will also be a member of the research team. Robyn is supervised by Alison Lane and Karen Ray.

Why is the research being done?

The purpose of the research is to investigate the effectiveness of the program, Write Start-K, which was found to have positive effects on handwriting skills for Kindergarten students in a previous pilot study. The current research aims to test a revised and updated version of Write Start-K, and assess any associations between handwriting fluency and early literacy skills. All Kindergarten students are eligible for the study except for those who may not be able to complete the assessments due to English language fluency or significant developmental concerns. There will be no immediate or ongoing costs to your school for participation in this research, and your school will be provided with skills and knowledge to enable ongoing use of the intervention program if desired.

Who can participate in the research?

Two schools matched for socioeconomic and demographic backgrounds are being invited to participate in the research. Your school was chosen to participate in this research as it is representative of schools in the region, and because the school's socioeconomic and demographic profile may indicate a greater proportion of children potentially at risk for challenges related to handwriting acquisition. After consideration by the researchers of the logistic and practical factors impacting the study, your school is invited to participate as the intervention site. Children at both schools will be asked to complete assessments of handwriting, fine motor and literacy skills at three time points throughout the year. Children at the intervention school will receive the Write Start-K program in Term Three. All Kindergarten students receiving the Write Start-K program will be invited to participate in the research and informed consent will be sought from the Kindergarten teacher and students' parents/guardians.

What choice do you have?

Your school's participation in this research is your choice and also depends on the choice of the Kindergarten teacher/s. Whether or not you allow the school to participate in the research will not disadvantage you, your staff or your students. Whether or not the Kindergarten teacher/s decide to participate will not disadvantage them, or their students.

The Kindergarten teacher/s and the students' parents/guardians will be given information about the project and are able to choose whether or not they want to participate. If you and the Kindergarten teacher/s consent to participate, all Kindergarten children will participate in the Write Start-K program, however assessment data will only be collected on children whose parents/guardians provide consent.

You will have two weeks from receipt of this information statement to decide whether you wish to participate. You will be able to withdraw your school at any time without giving a reason and you also have the option of withdrawing any data you have provided up until the time of publication.

What would you be asked to do?

Participant information, consent and initial data collection

If you agree for your school to participate, you will be asked to:

- Disseminate the Information Statements and Consent Forms to the Kindergarten teacher/s and the parents/guardians of the Kindergarten children in each Kindergarten class
- Assist the researchers to identify the children who may be ineligible for the study.

If you and the Kindergarten teacher/s agree to participate, you will be asked to allow time for the teacher/s to:

- Provide data on the consenting Kindergarten student's age and gender
- Provide Best Start data collected by the school on the Kindergarten children for whom parents/guardians have provided consent.

Participant assessment

You will be asked to allow time for consenting participants to complete age appropriate, game-like assessments at three time points. The types of activities include writing and identifying letters, copying shapes, matching shapes, manipulating small items such as coins and tracing lines. It is expected that the assessment activities will take one hour per student at each assessment time point, with breaks included after each activity. The assessments will be carried out by trained and supervised research assistants in a quiet location near the classroom, under the supervision of Karen Ray. The research assistants will be undergraduate occupational therapy students, including the Honours student, Robyn Evans, all with current Working With Children Checks and who have received specific training on both the developmental needs of children, and the methods for carrying out the assessments with Kindergarten children.

Intervention program

The intervention program, Write Start-K, consists of two 45 minute session per week for eight weeks, conducted in class, in collaboration with the classroom teacher and a trained and supervised research assistant. The research assistant for the intervention phase can be either a school staff member, or a trained occupational therapy undergraduate student with a current Working With Children Check, and this decision will be made in consultation with you and the Kindergarten teacher/s. Children will participate in fun, engaging activities designed to develop their handwriting skills using a range of materials and activities. During the intervention program, child attendance data will be collected. A sample of one session from the intervention program showing the types of activities the students will participate in is attached.

For the intervention phase of the program, you will be asked to:

- Allow the researcher, Karen Ray, to provide a half day planning and training workshop at the end of Term Two for the Kindergarten teacher/s who will be involved in the delivery of the co-taught Write Start-K program
- Provide release from regular duties for the Kindergarten teacher/s and any other school staff identified to participate in the Write Start-K program to attend this planning and training workshop.

In regards to teacher time, the teacher/s will be asked to:

- Co-teach the intervention in two 45 minute sessions per week for eight weeks
- Have regular review meetings with Karen of approximately 30 minutes per week to review program delivery progress and provide further training as required
- Carry out one component of the pre, post and follow up assessment through a whole class written composition task designed for Kindergarten aged students.

How much time will it take?
The time commitment for data collection and assessment, as described above, is summarised in the table below.

Data collection and assessment time commitment

What	Who	When	Time commitment estimate
Compile age, gender and Best Start data for consenting participants	Kindergarten teacher or identified delegate	Term 3	Two hours
Collect writing samples	Kindergarten teacher/s	Term 2, 3 and 4	30 minutes of in class time per term
Participant assessments	Consenting Kindergarten participants	Term 2, 3 and 4	One hour per term per child.

The time commitments during the implementation of Write Start-K, as described above, are summarised in the table below.

Intervention program time commitment

What	Who	When	Time commitment estimate
Training for Write Start-K co-teachers	Kindergarten teachers/s and others as identified by school	Term 2	Half day
Co-teach Write Start-K	Kindergarten teacher/s	Term 3	2 x 45 minute sessions per week for 8 weeks
Review Write Start-K sessions with Karen Ray	Kindergarten teacher/s	Term 3	30 minutes per week for 8 weeks

***What are the risks and benefits of participating*?**

It is anticipated that this research will provide minimal risks to your school or the staff who participate. Minimal risk of fatigue from assessments may occur for students, and this risk will be carefully managed by providing sufficient breaks and monitoring response to assessments. Further, the assessment activities chosen have been selected for their suitability for children in this age group, and their emphasis on game-like, fun activities. Varying levels of ability are also accommodated by the assessment activities chosen for this study, with each task only requiring consenting participants to perform to their own level. Consenting participants who have an identified disability or for whom English is not their first language will be identified in consultation with the school and if it is deemed the assessments are not suitable for them, they will not be included in the assessment aspects of the study. The intervention however, is suitable for all children, and will be provided with adjustments made for students with identified disability or language barriers as required.

The anticipated benefits of the research are that it will provide the school with a previously tested and subsequently updated Write Start-K program, which has been shown to improve handwriting accuracy. Some associated benefits for literacy may also occur as a result of the handwriting intervention.

In addition, the Kindergarten teacher will receive a summary of the initial assessments specific to each child. Parents/guardians will also receive their child’s assessment summary. Recommendations for support and intervention will be provided if required.

How will your privacy be protected?

Any information collected by the researchers which might identify your school, staff or students will be stored securely and only accessed by the researchers unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as research data/records may be subpoenaed by law.

Data will be retained for at least 15 years and will be held at the University of Newcastle.

Student data will only be accessible by University of Newcastle Human Research Ethics Committee approved members of the research team. Study data will be stored electronically in password-protected files and secure University servers. Hard copies of assessment forms will be stored in the University office of Karen Ray in a locked filing cabinet. Individual results will be de-identified and coded for data analysis by Karen Ray, so that individuals will not be identifiable in analysis, reports or presentations from this study.

How will the information collected be used?

The data collected will consist of each child's Best Start data and a set of scores for each child on the assessments carried out as part of the research program. To analyse this data, we will compare the scores on the writing, literacy and fine motor tasks for the intervention and control schools. You will be offered a summary of the results at the conclusion of the research project.

The results of analysis of the data will be used in a thesis by Karen Ray as a requirement of a Doctorate of Philosophy and in a paper by Robyn Evans as a requirement for an Honours degree in Occupational Therapy. The de-identified data will also be used in conference presentations and journal papers by the research team.

***What do you need to do to participate*?**

Please read this Information Statement and discuss the project with the Kindergarten teacher before you consent to your school's participation. If there is anything you do not understand, or you have questions, please contact the researcher.

If you would like your school to participate, please complete and return the attached Consent Form to karen.ray@uon.edu.au. Karen will then provide you with the teacher and parent/guardian Information Statements and Consent Forms to distribute.

Further information

If you would like further information please contact Karen Ray using the email or telephone contacts provided below. Thank you for considering this invitation.

Associate Professor Alison Lane Signature:
Phone: (02) 4921 5004
Email: Alison.lane@newcastle.edu.au

Dr Kerry Dally Signature:
Phone: (02) 4921 6281
Email: kerry.dally@newcastle.edu.au

Mrs Karen Ray Signature:
Phone: 0425 223 073
Email: karen.ray@uon.edu.au

Complaints about this research

This project has been approved by the University's Human Research Ethics Committee, Approval No. H-2019-0049.

Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Services, NIER Precinct, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone (02) 4921 6333, email Human-Ethics@newcastle.edu.au.

Appendix 5—Participant Information Statement for Teachers at Intervention School

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THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Information Statement for Kindergarten Teacher - Intervention Site

Effectiveness of Write Start-K on handwriting ability and literacy skills in Australian Kindergarten children

Document Version 3: 24th May, 2019

You are invited to participate in the research project identified above which is being conducted by Karen Ray, as part of her Higher Degree Research studies under the supervision of Associate Professor Alison Lane and Dr Kerry Dally from the University of Newcastle. Karen Ray is a registered occupational therapist with over twenty years of experience, and six years of recent experience working directly in a school setting. Karen is experienced in assessment and intervention with children to support developmental and learning goals. An Honours Occupational Therapy Student Researcher, Robyn Evans, will also be a member of the research team. Robyn is supervised by Alison Lane and Karen Ray.

Why is the research being done?

The purpose of the research is to investigate the effectiveness of the program, Write Start-K, which was found to have positive effects on handwriting skills for Kindergarten students in a previous pilot study. The current research aims to test a revised and updated version of Write Start-K, and assess any associations between handwriting fluency and early literacy skills. All Kindergarten students are eligible for the study except for those who may not be able to complete the assessments due to English language fluency or significant developmental concerns. There will be no immediate or ongoing costs to your school for participation in this research, and your school will be provided with skills and knowledge to enable ongoing use of the intervention program if desired.

Who can participate in the research?

Two schools matched for socioeconomic and demographic backgrounds are being invited to participate in the research. Your school was chosen to participate in this research as it is representative of schools in the region, and because the school's socioeconomic and demographic profile may indicate a greater proportion of children potentially at risk for challenges related to handwriting acquisition. After consideration by the researchers of the logistic and practical factors impacting the study, your school is invited to participate as the intervention site. Children at both schools will be asked to complete assessments of handwriting, fine motor and literacy skills at three time points throughout the year. Children at the intervention school will receive the Write Start-K program in Term Three. All Kindergarten students receiving the Write Start-K program will be invited to participate in the research and informed consent will be sought from the students' parents/guardians.

What choice do you have?

Your participation in this research is entirely your choice. The school principal and the students' parents/guardians will be given information about the project and are able to choose whether or not they want to participate. Whether or not you decide to participate, your decision will not disadvantage you or your students.

If you and the school principal consent to participate, all Kindergarten children will participate in the Write Start-K program, however assessment data will only be collected on children whose parents/guardians provide consent.

You will have two weeks from receipt of this information statement to decide whether you wish to participate. You will be able to withdraw at any time without giving a reason and you also have the option of withdrawing any data you have provided up until the time of publication.

What would you be asked to do?

<u>Initial data collection</u>

If you agree to participate, you will be asked to:

- Assist the researchers to identify participating children who may be ineligible for the study
- Provide data on the participating Kindergarten students' age and gender
- Provide Best Start data collected by the school on the Kindergarten children for whom parents/guardians have provided consent.

<u>Participant assessment</u>

You will be asked to allow time for consenting participants to complete age appropriate, game-like assessments at three time points. The types of activities include writing and identifying letters, copying shapes, matching shapes, manipulating small items such as coins and tracing lines. It is expected that the assessment activities will take one hour per student at each assessment time point, with breaks included after each activity. The assessments will be carried out by trained and supervised research assistants in a quiet location near the classroom, under the supervision of Karen Ray. The research assistants will be undergraduate occupational therapy students, including the Honours student, Robyn Evans, all with current Working With Children Checks and who have received specific training on both the developmental needs of children, and the methods for carrying out the assessments with Kindergarten children.

<u>Intervention program</u>

The intervention program, Write Start-K, consists of two 45 minute sessions per week for eight weeks, conducted in class, in collaboration with you and a trained and supervised research assistant. The research assistant for the intervention phase can be either a school staff member, or a trained occupational therapy undergraduate student with a current Working With Children Check, and this decision will be made in consultation with you and the principal. Children will participate in fun, engaging activities designed to develop their handwriting skills using a range of materials and activities. During the intervention program, child attendance data will be collected. A sample of one session from the intervention program showing the types of activities the students will participate in is attached.

For the intervention phase of the program, you will be asked to:

- Participate in a half day planning and training workshop at the end of Term Two on the delivery of the co-taught Write Start-K program.
- Co-teach the intervention in two 45 minute sessions per week for eight weeks

- Have regular review meetings with Karen of approximately 30 minutes per week to review program delivery progress and provide further training as required
- Carry out one component of the pre, post and follow up assessment through a whole class written composition task designed for Kindergarten aged students.

How much time will it take?
The time commitment for data collection and assessment, as described above, is summarised in the table below.

Data collection and assessment time commitment

What	Who	When	Time commitment estimate
Compile age, gender and Best Start data for participating students	Kindergarten teacher or identified delegate	Term 2	Two hours
Collect writing samples	Kindergarten teacher/s	Term 2, 3 and 4	30 minutes of in class time per term
Participant assessments	Participating Kindergarten children	Term 2, 3 and 4	One hour per term per child

The time commitments during the implementation of Write Start-K, as described above, are summarised in the table below.

Intervention program time commitment

What	Who	When	Time commitment estimate
Training for Write Start-K co-teachers	Kindergarten teachers/s and others as identified by school	Term 2	Half day
Co-teach Write Start-K	Kindergarten teacher/s	Term 3	2 x 45 minute sessions per week for 8 weeks
Review Write Start-K sessions with Karen Ray	Kindergarten teacher/s	Term 3	30 minutes per week for 8 weeks

***What are the risks and benefits of participating*?**
It is anticipated that this research will provide minimal risks to your school or the staff who participate. Minimal risk of fatigue from assessments may occur for students, and this risk will be carefully managed by providing sufficient breaks and monitoring response to assessments. Further, the assessment activities chosen have been selected for their suitability for children in this age group, and their emphasis on game-like, fun activities. Varying levels of ability are also accommodated by the assessment activities chosen for this study, with each task only requiring participating children to

perform to their own level. Participating students who have an identified disability or for whom English is not their first language will be identified in consultation with the school and if it is deemed the assessments are not suitable for them, they will not be included in the assessment aspects of the study. The intervention however, is suitable for all children, and will be provided with adjustments made for students with identified disability or language barriers as required.

The anticipated benefits of the research are that it will provide your class with a previously tested and subsequently updated Write Start-K program, which has been shown to improve handwriting accuracy. Some associated benefits for literacy may also occur as a result of the handwriting intervention. In addition, you and parents/guardians will receive a summary of the initial assessments specific to each child. Recommendations for support and intervention will be provided if required.

How will your privacy be protected?

Any information collected by the researchers which might identify your school, staff or students will be stored securely and only accessed by the researchers unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as research data/records may be subpoenaed by law. Data will be retained for at least 15 years and will be held at the University of Newcastle.

Student data will only be accessible by University of Newcastle Human Research Ethics Committee approved members of the research team. Study data will be stored electronically in password-protected files and secure University servers. Hard copies of assessment forms will be stored in the University office of Karen Ray in a locked filing cabinet. Individual results will be de-identified and coded for data analysis by Karen Ray, so that individuals will not be identifiable in analysis, reports or presentations from this study.

How will the information collected be used?

The data collected will consist of each child's Best Start data and a set of scores for each child on the assessments carried out as part of the research program. To analyse this data, we will compare the scores on the writing, literacy and fine motor tasks for the intervention and control schools. You will be offered a summary of the results at the conclusion of the research project. The results of analysis of the data will be used in a thesis by Karen Ray as a requirement of a Doctorate of Philosophy and in a paper by Robyn Evans as a requirement for an Honours degree in Occupational Therapy. The de-identified data will also be used in conference presentations and journal papers by the research team.

***What do you need to do to participate*?**

Please read this Information Statement and be sure you understand its contents before you consent to your participation. If there is anything you do not understand, or you have questions, please contact the researcher. If you would like to participate, please complete and return the attached Consent Form to karen.ray@uon.edu.au

Further information

If you would like further information please contact Karen Ray using the email or telephone contacts provided below. Thank you for considering this invitation.

Associate Professor Alison Lane
Phone: (02) 4921 5004
Email: Alison.lane@newcastle.edu.au

Signature:

Dr Kerry Dally
Phone: (02) 4921 6281
Email: kerry.dally@newcastle.edu.au

Signature:

Mrs Karen Ray
Phone: 0425 223 073
Email: karen.ray@uon.edu.au

Signature:

Complaints about this research

This project has been approved by the University's Human Research Ethics Committee, Approval No. H-2019-0049. Should you have concerns about your rights as a participant in this research, or you have a complaint about the manner in which the research is conducted, it may be given to the researcher, or, if an independent person is preferred, to the Human Research Ethics Officer, Research Services, NIER Precinct, The University of Newcastle, University Drive, Callaghan NSW 2308, Australia, telephone (02) 4921 6333, email Human-Ethics@newcastle.edu.au

Appendix 6—Participant Information Statement for Parents and Guardians of Kindergarten Children at Intervention School

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THE UNIVERSITY OF NEWCASTLE AUSTRALIA

Information Statement for Parents/Guardians – Intervention Site

Effectiveness of Write Start-K on handwriting ability and literacy skills in Australian Kindergarten children

Document Version 3: 24th May, 2019

Your child is invited to participate in the research project identified above which is being conducted by Karen Ray, as part of her Higher Degree Research studies under the supervision of Professor Alison Lane and Dr Kerry Dally from the University of Newcastle. Karen Ray is a registered occupational therapist with over twenty years of experience, and six years of recent experience working directly in a school setting. Karen is experienced in assessment and intervention with children to support developmental and learning goals. An Honours Occupational Therapy Student Researcher, Robyn Evans, will also be a member of the research team. Robyn is supervised by Alison Lane and Karen Ray.

Why is the research being done?

The purpose of the research is to investigate the effectiveness of the classroom based program, Write Start-K, which was found to have positive effects on handwriting skills for Kindergarten students in a previous pilot study. The current research aims to test a revised and updated version of Write Start-K, and assess any associations between handwriting fluency and early literacy skills. The study is open to all Kindergarten students except those who may not be able to complete the assessment activities due to English language fluency or significant developmental concerns. If you have any concerns about your child's eligibility you are welcome to discuss this with the researchers and/or the school.

Who can participate in the research?

Kindergarten children at two similar schools are being invited to participate in the research. Children at both schools will be asked to complete assessments of handwriting, fine motor and literacy skills at three time points throughout the year. One school will be a control site, which means that children will receive normal classroom teaching, and one school will be an intervention site, meaning that children will receive the Write Start-K program in class as part of normal literacy activity time. After consideration by the researchers of the logistic and practical factors impacting the study, your school is being invited to participate as the intervention site. Children at the intervention school will receive the Write Start-K program in class, in two 45-minute session per week over eight weeks in Term Three. Children will participate in fun, engaging activities designed to develop their handwriting skills using a range of materials and activities. The class teacher, Karen Ray and a trained and supervised research assistant will carry out the program together. During the intervention program, child attendance data will be collected. All Kindergarten students receiving the Write Start-K program will be invited to participate in the research and informed consent will be sought from the school as well as from individual parents/guardians for each child.

What choice do you have?

Your child's participation in this research is entirely your choice. Whether or not you decide to allow your child to participate, your decision will not disadvantage you or your child. If you agree for your child to participate by completing the Consent Form, your child will be included in the research project. You will have two weeks from receipt of this information statement to decide whether you wish to allow your child to participate. You will be able to withdraw your child at any time without giving a reason and you also have the option of withdrawing any data you have provided up until the time of publication.

What would you be asked to do?

If you agree for your child to participate in the research study, you will be asked to allow access to:

- Information on your child's age and gender
- Scores from the Best Start assessment which are collected by your child's teacher at the beginning of the Kindergarten year.

If you agree for your child to participate in the study, they will complete age appropriate game-like assessment activities at three time points. The types of activities include writing and identifying letters, copying shapes, matching shapes, manipulating small items such as coins and tracing lines. It is expected that the assessment activities will take one hour at each assessment time point, with breaks included after each activity. The assessments will be carried out by trained and supervised research assistants in a quiet location near the classroom, under the supervision of Karen Ray. The research assistants will be undergraduate occupational therapy students, including the Honours student, Robyn Evans, all with current Working With Children Checks and who have received specific training on both the developmental needs of children, and the methods for carrying out the assessments with Kindergarten children. If you do not agree for your child to participate, your child will not be included in any data collection and will not participate in any assessment activities.

How much time will it take?

The assessment activities will be carried out once per term in Terms Two, Three and Four of 2019. As described above, one hour per child at these three time points will be required for carrying out the assessment activities, with regular breaks included in this time.

***What are the risks and benefits of participating*?**

It is anticipated that this research will provide minimal risks to you or your child's teacher and school. Minimal risk of fatigue from assessments may occur for your child, and this risk will be carefully managed by providing sufficient breaks and monitoring response to assessments. Further, the assessment activities chosen have been selected for their suitability for children in this age group, and their emphasis on game-like, fun activities. The assessment activities are also suitable for children of varying levels of ability, with each task only requiring consenting participating children to perform to their own level. If you have any concerns about your child's ability to carry out the types of assessment activities described you are encouraged to discuss this with your child's teacher and/or the researchers.

You and your child's teacher will receive a written summary of the initial assessments specific to your child. The written summary will be returned to you in a sealed envelope and sent home with your child. This summary will be a report with a meaningful explanation of your child's results on the assessment activities. The report may assist you in seeking further support if this is identified, or making daily adjustments that may assist your child. Your child will also receive the intervention program, Write Start-K, which has been shown to assist students of varying ability levels in Kindergarten with handwriting development.

How will your privacy be protected?

Any information collected by the researchers which might identify your child will be stored securely and only accessed by the researchers unless you consent otherwise, except as required by law. There are limits on assurances of confidentiality as research data/records may be subpoenaed by law.

Data will be retained for at least 15 years and will be held at the University of Newcastle.

Your child's data will only be accessible by University of Newcastle Human Research Ethics Committee approved members of the research team. Study data will be stored electronically in password-protected files and secure University servers. Hard copies of assessment forms will be stored in the University office of Karen Ray in a locked filing cabinet. Individual results will be de-identified and coded for data analysis by Karen Ray, so that individual children will not be identifiable in analysis, reports or presentations from this study.

How will the information collected be used?

The data collected will consist of a set of scores for each child on the assessments carried out as part of the research program. To analyse this data, we will compare the scores on the writing, literacy and fine motor tasks for the intervention and control schools. You will be offered a summary of the results at the conclusion of the research project. The results of analysis of the data will be used in a thesis by Karen Ray as a requirement of a Doctorate of Philosophy and in a paper by Robyn Evans as a requirement for an Honours degree in Occupational Therapy. The de-identified data will also be used in conference presentations and journal papers by the research team.

***What do you need to do to participate*?**

Please read this Information Statement and discuss the project with your child before you consent to your child's participation. If there is anything you do not understand, or you have questions, please contact the researcher.

If you would like your child to participate, please complete and return the attached Consent Form to karen.ray@uon.edu.au

Further information

If you would like further information please contact Karen Ray using the email or telephone contacts provided below. Thank you for considering this invitation.

Associate Professor Alison Lane Signature:
Phone: (02) 4921 5004
Email: alison.lane@newcastle.edu.au

Dr Kerry Dally Signature:
Phone: (02) 4921 6281

Email: kerry.dally@newcastle.edu.au

Mrs Karen Ray Signature:
Phone: 0425 223 073
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Appendix 7—Letter Form Assessment (LFA)-2

Examiner script:

1. Could you please write your name next to the star?
2. I am going to ask you to write some letters. I want you to write them the way you have been learning in class. I will show you a picture and tell you what letter the picture starts with and the sound it makes. Then I want you to write the letter in lower case. Sometimes I might ask you to write the letter again.
3. The first picture is an apple. Apple starts with the letter 'a'. The sound is /a/. Write a lower case letter 'a' on the line next to the picture *(point).*

If formation error noted:

1. I am going to show you the letter for you to copy.
2. *(Show the prompt letter)* – This is the letter 'a'. Can you copy the letter a just like this one? *NB* – if student first attempt is recognisable but formed incorrectly (e.g. wrong start point, use of extra strokes to form letter), say 'that looks just the same – now I'm going to show it to you – can you write it again?'

If formation error noted in copying:

1. Now I am going to write the letter 'a'. Watch me write the letter (write in pen on test sheet). Can you write the letter just the way I did?

If formation error imitating move onto next letter.

Scoring:

4 – Correct formation from memory

3 – Correct formation from copying

2 – Correct formation from imitation

1 – Incorrect formation but recognisable letter

0 – non recognisable letter

Letter Form Assessment Administration Rules

2. Follow the script to introduce the test, noting the instruction to write in lower case, using the way being taught in class.
3. If the first letter (a) is written in uppercase, remind the participant to write in lower case and allow a second attempt. Do not score the uppercase letter A as incorrect, base scoring on the second attempt and follow procedures as per usual. If the participant writes the letter in uppercase on the second attempt, score as incorrect formation (but recognisable) and proceed with prompts as usual.

4. For all subsequent letters, if the first attempt is uppercase, score this as incorrect formation.
5. Only the first attempt at a letter is used to make a decision about recognisability of the letter.
6. Uppercase letters are scored as recognisable letters.
7. Reversed letters are scored as unrecognisable.
8. For f and t, any direction of crossing the letter is acceptable.
9. For x any direction of making the strokes is acceptable e.g. two top to bottom strokes, a top to bottom stroke then a bottom to top stroke.
10. For letters b, d, and h use the 'more than half' rule – if the beginning of the 'ball' or the 'bump' comes up more than half the length of the stick, mark as unrecognisable and incorrect formation.
11. For v and w, a pointy bottom rather than curved is recognisable but incorrect formation (as a pointy shape is for the capital).

Letter Form Assessment-2 Score Sheet and Participant Response Forms

Name:______________________________Date___________

DOB:______________Chronage:______________________

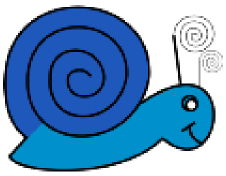
Grade:_____________Teacher:_________________________

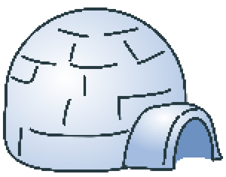
Time to complete:______________min________________sec

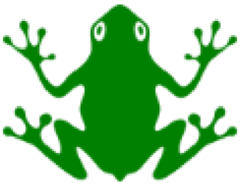
Score (a –z): __________/104

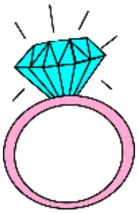
Letter/sound correspondence________________/26

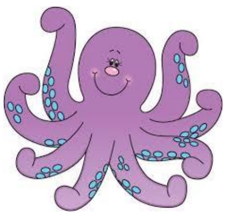
	Recognisable letter (Y or N)	Correct formation from memory (4)	Correct copy from model (3)	Correct imitation (2)	Recognisable letter, incorrect formation (1)	Unrecognisable letter (0)
a						
m						
t						
s						
i						
f						
d						
r						
o						
g						
l						
h						
u						
c						
b						
n						
k						
v						
e						
w						
j						
p						
y						
x						
q						
z						

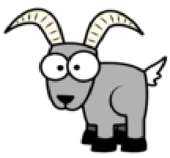


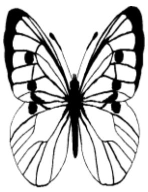


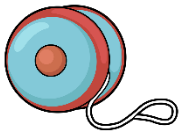












Appendix 8—Letter Name and Sound Knowledge Assessment Sheet

Cc	Hh	Mm	Bb	Xx
Ll	Ss	Dd	Ii	Ff
Rr	Aa	Kk	Zz	Uu
Ee	Jj	Qq	Oo	Ww
Gg	Pp	Tt	Vv	Yy
Nn				

Letter Identification Assessment Test Items

Appendix 9—Procedure and Scoring for Alphabet Test Administered by Teachers

Alphabet Task

On a separate lined page (see template) ask children to write the lowercase alphabet in order when you say go, as quickly and as clearly as they can. Time for 60 seconds. At 60 seconds say 'pencils down' – mark on each page with a red line, showing the last letter written at 60 seconds. Then allow children to complete writing alphabet until they are finished or cannot write any more letters.

Scoring

Each letter receives a score of 0 points, 0.5 points or 1 point

Score given based on four possible errors:

- Letter form/control
- Reversal/inversion
- Uppercase
- Unrecognisable

None of four errors = 1 point

Only one error from form, reversal or uppercase = 0.5 points

Multiple errors or unrecognisable = 0 points

Omitted letters = 0

Repeated letters do not get scored more than once

Letters in random order (ie not in alphabetical sequence of at least two letters) do not receive a score.

Clarifications

- **Letter form** refers to the appearance of the letter on the page. An acceptable letter form is a recognisable representation of the letter.
- Use NSW Foundation font as reference for form, e.g. V and W (pointed base) would be counted as uppercase.
- Use the 'more than half' rule to make decisions on form for letters such as h – if the 'bump' part of the letter starts more than half way up the stick, this would be a form error as the letter may look like an 'n'. Similarly, if the bump part of 'n' starts more than half way down the stick, this would be a form error as the letter may look like 'h'.

Appendix 10—Writing Composition Task Procedure and Scoring

Composition task procedure

Children are given the A4 template attached (please use the lined or blank template according to what the children are used to using for writing) and asked to write a story about things they like. Ask students to write their name at the top of the page. Have a brief discussion about ideas for the story (see script below) and then allow children 6 minutes to draw a picture of something they like. After 6 minutes ask them to stop drawing their picture and write their story. Allow 10 minutes for story writing.

Script

Today you are going to write a story about things you like. You might like to write about things you like to eat, or things you like to do, or things you like to play. Who can tell me about something you like to eat?

Ask a few children to answer and ask them why they like eating… or what they like about…

Now who can tell me about something you like to do?

Ask a few children what they like to do and follow up with asking them why or where or who they do that with.

Now who can tell me about something you like to play or something you like to play with?

Repeat as above- e.g. *where or how do you play that? What do you like about playing with …*

Ok- now think about something you like and draw a picture at the top of your page.

Walk around the room to check that children have written their name at the top of the page and that they can think of something they like. If they are not able to write their name the teacher can write it for them. If they are not drawing a picture ask some questions to help them think of something (or a few things) they like.

After 4 minutes say- *You have a few minutes to finish off your picture because soon you are going to start writing your story.*

After 6 minutes say- *Now it is time to stop drawing your picture. Put your pencils down and listen. You are now going to write your story. Remember you are going to write about things you like. I will write the first two words on the board for you to copy.*

Teacher writes 'I like' on the board.

This says "I like" (pointing to each word). *Copy these words and then you can finish the sentence to say what you like. Then write some more about what you like. You can write about one thing you like or lots of things.*

After 10 minutes ask children to stop writing. Please check writing and write under any words that are illegible to assist in clarifying meaning of writing.

Writing Sample Scoring (Total = 26)

<u>Quality of ideas/expression (rating scale 0 -4)</u>

0 – no message

1 – one idea (answers - what) (e.g. I like apples.)

2 – more than 1 idea, ideas may be unrelated or listed (answers – who and what) (I like apples. I like bananas.

3 – one or more ideas elaborated (answers – who, did what, where or when) e.g. I like playing with my friends. We play on the swings.

4 – coherent story connecting ideas (answers – how, when or why)

Spelling (point for each item, mark out of 5)

- Correct spelling of most decodable one-syllable words with short vowel sounds (e.g. hot, pet)
- Correct spelling of most common one-syllable sight words (e.g. the, was, to)
- Mostly uses correct initial and final sounds, using knowledge of letters and sounds to write words e.g. hid for heard, or san for sound
- Correctly spells one or more irregular words containing more complex medial vowels (e.g. ocean, surf)
- Attempts one or greater sound blends such as consonant digraphs, (e.g. sh, ck) consonant blends (e.g. bl, tr) or double final consonants (e.g. nt, lp)

Punctuation (point for each item, mark out of 4)

- Consistently uses capitals at the beginning of a sentence
- Consistently uses a full stop at the end of sentence
- Consistently uses capital for pronoun 'I' and/or their own name within a sentence (0.5 for each)
- Uses capitals for a range of proper nouns (but may not be consistent) and/or experiments with further punctuation e.g. (0.5 for each)

Sentence structure (point for each item, mark out of 4)

- Uses sentence starters such as… I like, I can, I am…to create simple sentences
- Uses compound sentences with simple conjunctions e.g. and, but (for example listing)
- Varies sentence beginnings
- Uses appropriate conjunctions to add ideas or give additional information

Vocabulary (rating scale 0 – 4)

0 – no words , single letters only

1 – Uses mostly simple words such as nouns, no colourful or describing words used.

2 – Uses nouns, and some verbs or describing words.

3 – Uses nouns, verbs and some precise or subject specific describing words.

4 – Choice of words paints a picture, has nouns, verbs and describing words - may show feelings

Handwriting (rating scale 0 – 5)

0 – Appears to be 'scribble' - not recognisable as letters

1 - Letter like forms with some recognisable letters

2 – Mix of upper and lowercase letters and/or some reversals/distortions

3 – Mostly correct letter forms yet may contain poor spacing, positioning or messy corrections

4 – Correct letter forms, mostly well positioned and spaced

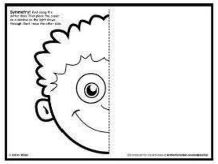
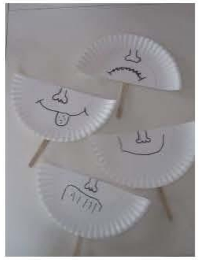
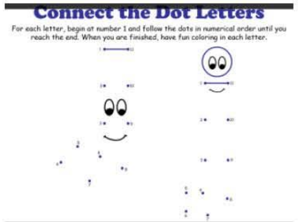
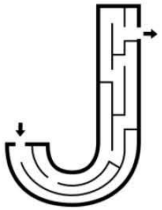
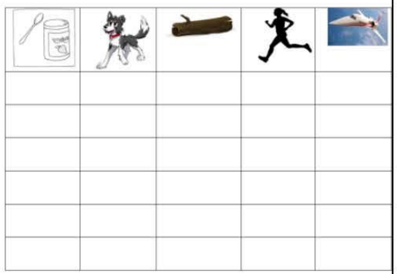
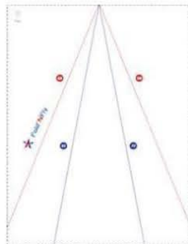
5 – Regularity of letter forms and letter size, words well placed, oriented and spaced

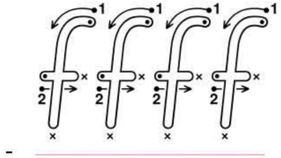
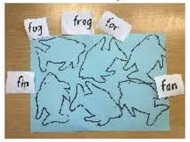
Total number of words written (do NOT include this score in total above)

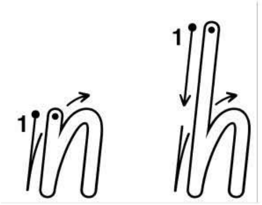
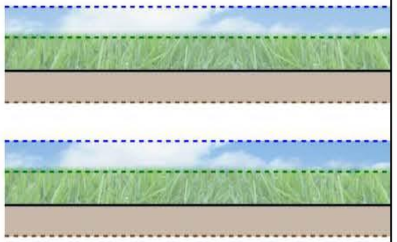
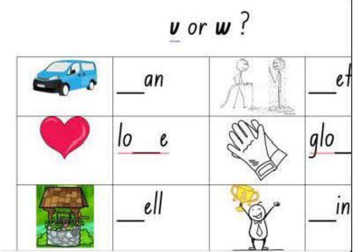
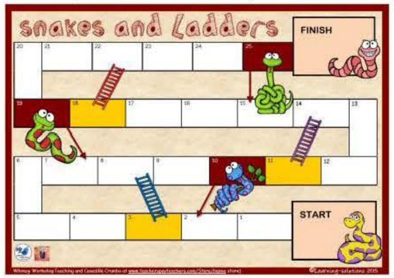
Count of number of words written. Spelling does not have to be correct, but must be recognisable as a word rather than a string of disconnected letters.

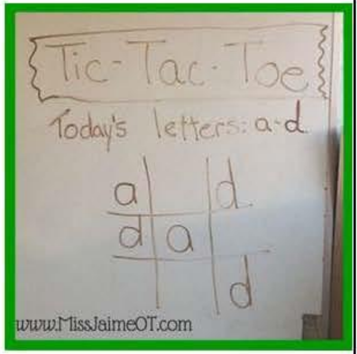
Appendix 11—Write Start-K Session Summary

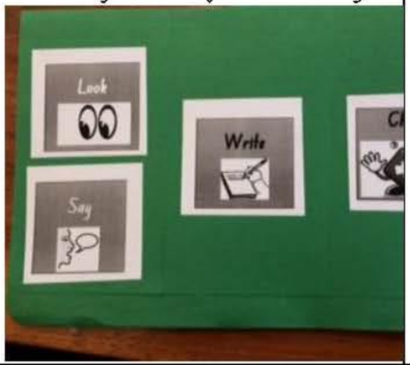
Write Start-K Session Summary Weeks 1 – 8

Week	Session 1			Session 2 – Writing and Craft	
Letters	**Visual Motor**	**Fine Motor**	**Cognitive**	**Craft**	**Writing**
Week 1 cadg	Mirror face drawing and writing – sad and glad 	Playdough magic c letters, press in beads then scrunch and find 	Writing on goo bags with large dice words: at, glad, dad, add, did, gag 	Face mask – sad and glad 	Write words on whiteboards: changing first letter: dad, sad, glad, lad changing medial and end letter: lid, did, dad, gag. Sentence writing in book: The dad is sad and glad.
Week 2 revision: cadg new: o i l t j	Connect dots and maze  	Playdough letters i,l,t,j – drive toy cars firmly along each letter 	Roll, remember and write – which word will win? dog, dig, jet, jog, log, jam (picture cues on large dice) 	Paper jet folding along dotted lines – skills: visual motor coordination, fine motor precision. following instructions 	Write words on whiteboards: Medial letter change: jag, jog, jig, Initial, medial and end letter change – dig, dog, dot, jot, jet Focus word – jet Sentence writing: The dog jogs to the jet.

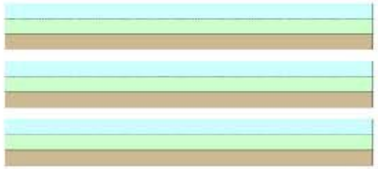
Week	Session 1			Session 2 – Writing and Craft	
Letters	Visual Motor	Fine Motor	Cognitive	Craft	Writing
Week 3 Revision: Tricky letters New: fes	Mystery squares game – 9 square grid for each student in plastic sleeve (or chalk boards if available). Students copy modelled pattern of letters from teacher 9 square from memory (with help as required).	Magnet and paper clip letter writing with large number cued letters e, f and s. Extension – write own letters on sheet and trace with magnet 	Students take turns to fish for words with paperclip on each word and magnet 'fishing rod' and write from memory (read then turn word over) on fish sheet, with help as required. Extension – children can work independently to fish for letters and write from memory. 	Handprint frog 	Write words on whiteboards: fat, fell, off, the, log, logs, frog, frogs Sentence in workbook: The fat frogs fell off the logs. Word list – fad, fat, of, off, fill, fig, fit, fed, fell, fog, egg, sad, sag, sat, set, see, is, fish
Week 4 New: pbk Focus skills – visual sequential memory, hand strength	Guided panda and pig drawing behind windows, draw then write the word. 	Feeding tennis balls – Children write large letter in crayon on large butchers paper 'table cloth' with crayon, trace out the letter in beads. Tennis ball monster eats the beads. Repeat with additional letters. 	Working memory chalkboard challenge – instructor writes letter, sequence of letters or short word on small board, show then hide. Students write from memory using chalk. Use a small damp sponge to 'rub out' by wiping over each letter following the letter formation pattern. 	Nest for bird 	Word list letter formation practice from memory on paper: pick, pack, back, bad, bat, pat, bird, pet Sentence on paper Put the pet bird back in the nest.

Week	Session 1			Session 2 – Writing and Craft	
Letters	Visual Motor	Fine Motor	Cognitive	Craft	Writing
Week 5 Revision: p b k New: r n m h	Large letter tissue paper scrunching and outline 	Playdough letter making, outline in toothpicks 	Sky and grass letter writing r, n, m, h 	Paper plate hat 	Words: Butterfly words – the, and, for, on, am, went, this, can, are , in Sentence: I can run and put on my hat.
Week 6 Revision n, h New: vwuy Focus: v and y	Magic sticks – letters u y and v w on front and back of paddlepop sticks, match to word beginnings and endings and write missing letter on double sided sheet eg: 	"Wet, dry, try" lucky dip – take turns to pick a word with letter sequences and words written on paddlepop sticks. Encourage writing from memory using accurate letter formation.  	v, w, u and y letter and word snakes and ladders. Can be played as group or individually (or both to differentiate within each group). Two levels – one easy (letters only), one harder (words). Roll the dice, read and cover the letters or word with the counter, write the letters or word on worksheet from memory and move on e.g:  Encourage writing from memory with correct letter formation.	Whale 	Words: van, vet, wave, was, way, yum, yummy, you, love, wet Sentence: The whale can wave and wet you. (Extension: I love the big blue whale!)

<table>
<tr><td>Week</td><td colspan="3">Session 1</td><td colspan="2">Session 2 – Writing and Craft</td></tr>
<tr><td>Letters</td><td>Visual Motor</td><td>Fine Motor</td><td>Cognitive</td><td>Craft</td><td>Writing</td></tr>
<tr>
<td>Week 7
Revise:
d
New:
q</td>
<td>Chalk board letter q and d tic tac toe in pairs. For first game, identify each student as being either letter d or q and play in pairs 'as a group', providing step by step instructions, to ensure students understand the game. Once completed one game, students can swap letters and repeat the game independently.

</td>
<td>Writing in playdough – Students press out a firm playdough surface, Instructor models letters/word, reveal and then have students say the letters/word. Hide the modelled letters/word and then students write in playdough using toothpick from memory. Add shapes/other marks for fun and to develop visual memory.

</td>
<td>Look say cover write check
Using folders with three flip covers cut out and a worksheet inside. Look at first letter sequence/word under first cover. Say letter names or word. Close flap and write letters or word from memory under next flap. Check and then write a third time under last flap, making any corrections if needed. Repeat with next letter sequence/word in list.
Goal – accurate letter formation when using visual sequential memory.

</td>
<td>Duck – paper scrunching for body, folding for legs
</td>
<td>Digraphs and words: qu, ck, duck, quack, quit, quiz, quill, quid, did, dad.

Sentence:
The duck can quack.</td>
</tr>
</table>

Week	Session 1			Session 2 — Writing and Craft	
Letters	Visual Motor	Fine Motor	Cognitive	Craft	Writing
Week 8 **New** **x and z** **Focus — letter formation revision and practice**	Chalkboard o's and x's with spinner for letter combinations:  	X —ray hand make and write (add name and words to sheet) 	Laser pointer letter and word finding and writing. Model on sky grass dirt paper, students copy or write from memory with correct letter formation.  Letters to focus on: : xz; mnv ; fdhbk; jyg	Shaving cream letter name and writing game — copy the pattern on the whiteboard in a grid using letter combinations:  xz; hn; db; kf; jg; yq; yv; mh; xv	Words: Look, say, cover, write  Sentence: The fox and the kids eat the big ham pizza.

Appendix 12—Fidelity Measures

Write Start Fidelity Checklist: Session One

Date ___21/8/2019______________________ Week ________5_________

Letters taught ____r, n, m, h_____________ Letters reviewed _____p, b, k______________

Small Group Activities: __playdoh + marble, crepe paper + glue, sky grass dirt paper + repetition____

Criteria	Complete Correct	Partially Complete/ Correct	Not Complete/ Correct	Comments
1. All Children and All teachers are present.		x		
INSTRUCTION				
2. Instructor models the letter 2 to 3 times	x			
3. The instructor and model appear visible to all students.	x			
4. At least 90% of children write letter on dry erase boards.	x			
5. Specific visual cues are given.	x			
6. All instructors provide modelling	x			
7. Instructor teaches a continuous, vertical stroke letter style is used.	x			
8. The instructors provide age appropriate verbal cueing	x			
9. Verbal cueing uses consistent words to guide letter formation.	x			
PRACTICE				
10. All students practice writing letter multiple times (>2).	x			
11. During practice, the majority of students receive some feedback about letter formation.	x			
12. During practice, feedback is positive.	x			

Criteria	Complete Correct	Partially Complete/ Correct	Not Complete/ Correct	Comments
13. During practice, feedback is specific.	x			
14. During practice, both verbal and visual cues are provided.	x			
15. Feedback is faded during the practice.		x		Not by all instructors
16. The majority of students (with or without prompt) check their letters.	x			
SMALL GROUP ACTIVITY				
17. Materials are well organized.		x		
18. Specific instructions about the activity are provided.		x		
19. The activity provides for multisensory learning.	x			
20. 90% of students appear engaged and fully participate.	x			
21. Individualized guidance is provided.	x			
22. Cueing is faded.		x		
23. Relationship of activity to writing letters is clear.	x			
24. Majority of students complete activity in time allotted.	x			

Write Start Fidelity Checklist: Session 1

Date ___21/8/2019______________________ Week ___5______________

Letters taught ____r, n, m, h_____________ Letters reviewed ____p, b, k_______________

Small Group Activities: __playdoh + marble, crepe paper + glue, sky grass dirt paper + repetition____

Criteria	**Complete Correct**	**Partially Complete/ Correct**	**Not Complete/ Correct**	**Comments**
1. All Children and All teachers are present.		x		
INSTRUCTION				
2. Instructor models the letter 2 to 3 times	x			
3. The instructor and model appear visible to all students.	x			
4. At least 90% of children write letter on dry erase boards.	x			
5. Specific visual cues are given.	x			
6. All instructors provide modelling		x		
7. Instructor teaches a continuous, vertical stroke letter style is used.	x			
8. The instructors provide age appropriate verbal cueing	x			
9. Verbal cueing uses consistent words to guide letter formation.	x			Consistent among all instructions
PRACTICE				
10. All students practice writing letter multiple times (>2).	x			>6 repetitions
11. During practice, the majority of students receive some feedback about letter formation.	x			
12. During practice, feedback is positive.	x			
13. During practice, feedback is specific.	x			
14. During practice, both verbal and visual cues are provided.	x			

Criteria	**Complete Correct**	**Partially Complete/ Correct**	**Not Complete/ Correct**	**Comments**
15. Feedback is faded during the practice.		x		
16. The majority of students (with or without prompt) check their letters.	x			
SMALL GROUP ACTIVITY				
17. Materials are well organized.	x			
18. Specific instructions about the activity are provided.		x		Improved as session progressed
19. The activity provides for multisensory learning.	x			
20. 90% of students appear engaged and fully participate.	x			
21. Individualized guidance is provided.	x			
22. Cueing is faded.		x		
23. Relationship of activity to writing letters is clear.	x			
24. Majority of students complete activity in time allotted.		x		

Write Start Fidelity Checklist: Session 2 (Weeks 7-12)

Date _____23/8/2019____________________ Week ____5_______________

Letters taught ___nil- functional application of "letters of the week"______________ Letters reviewed ___r, n, m, h________________

Writing Activity: ___butterfly words and sentence____

Criteria	Complete Correct	Partially Complete/ Correct	Not Complete/ Correct	Comments
1. All Children and All teachers are present. Groups combine high and low achieving students		x		
INSTRUCTION/ PRACTICE				
2. Instructor asks students to recall letter		x		
3. Cues are provided to students who need them.	x			
4. Children write letter on dry erase boards.	x			
5. Instructors monitor correct formation and provide cues.	x			
6. All instructors provide modelling		x		
7. Students discuss the letter and its specific features.		x		
8. Students practice writing letter at least 3 times.	x			
9. During practice, feedback is positive.	x			
10. During practice, feedback is specific.	x			
11. During practice, both verbal and visual cues are provided.	x			Hand over hand as required
12. Students (with or without prompt) check their letters.	x			
WRITING SAMPLE				
13. Students make writing sample	x			
14. Writing sample is timed.			x	
WRITING APPLICATION				
15. Instructors provide writing application that requires recall of letters and words previously learned	x			

Criteria	**Complete Correct**	**Partially Complete/ Correct**	**Not Complete/ Correct**	**Comments**
16. Writing application clearly relates to other parts of the curriculum or current projects.	x			
17. Students (>90%) begin writing a story within the first 5 minutes of the workshop		x		
18. Students are instructed to write so others can read their words.	x			Group reflection and review
19. Individualized feedback and guidance is provided during writing.		x		Mostly verbal, from front of group
20. Students appear engaged.	x			
21. Majority of time is spent in students writing.	x			
22. Instructors encourage students to share their writing with at least 1 other peer.			x	
23. Peers interact, about writing, provide peer support			x	
24. Specific students who were identified during Weeks 1-6 receive individualized support (e.g., modelling, the choice to dictate or copy instead of composing independently)		x		

Write Start Fidelity Checklist: Session 2 (Weeks 7-12)

Date ____23/8/2019______________________ Week ____5________________

Letters taught __nil- functional writing application of “letters of the week”_____ Letters reviewed _____r, n, m, h_______________

Writing Activity: ___butterfly words and sentence____

Criteria	**Complete Correct**	**Partially Complete/ Correct**	**Not Complete/ Correct**	**Comments**
1. All Children and All teachers are present. Groups combine high and low achieving students		x		
INSTRUCTION/ PRACTICE				
2. Instructor asks students to recall letter		x		
3. Cues are provided to students who need them.	x			
4. Children write letter on dry erase boards.	x			
5. Instructors monitor correct formation and provide cues.	x			
6. All instructors provide modelling	x			
7. Students discuss the letter and its specific features.		x		
8. Students practice writing letter at least 3 times.	x			
9. During practice, feedback is positive.	x			
10. During practice, feedback is specific.	x			
11. During practice, both verbal and visual cues are provided.	x			
12. Students (with or without prompt) check their letters.	x			
WRITING SAMPLE				
13. Students make writing sample	x			
14. Writing sample is timed.			x	
WRITING APPLICATION				

Criteria	**Complete Correct**	**Partially Complete/ Correct**	**Not Complete/ Correct**	**Comments**
15. Instructors provide writing application that requires recall of letters and words previously learned	x			
16. Writing application clearly relates to other parts of the curriculum or current projects.		x		
17. Students (>90%) begin writing a story within the first 5 minutes of the workshop		x		
18. Students are instructed to write so others can read their words.		x		
19. Individualized feedback and guidance is provided during writing.		x		
20. Students appear engaged.	x			
21. Majority of time is spent in students writing.	x			
22. Instructors encourage students to share their writing with at least 1 other peer.			x	
23. Peers interact, about writing, provide peer support			x	
24. Specific students who were identified during Weeks 1-6 receive individualized support (e.g., modelling, the choice to dictate or copy instead of composing independently)		x		

Appendix 13—Published Article, Reprinted with Permission

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Please feel free to include the final, published version of your article as an appendix to your dissertation. Just include the appropriate acknowledgement, noted below:

> Ray, K., Dally, K., Colyvas, K., & Lane, A.E., The Effects of a Whole-Class Kindergarten Handwriting Intervention on Early Reading Skills, *Reading Research Quarterly*, Wiley, © 2021 International Literacy Association

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Best,

Jackie

Jacquelyn Kelley

(she/her/hers)

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The citation for this paper has been updated since receiving this correspondence, and is:

Ray, K., Dally, K., Colyvas, K., and Lane, A.E., The effects of a whole-class kindergarten handwriting intervention on early reading skills, *Reading Research Quarterly*, *56* (S1), 193-207. https://doi.org/10.1002/rrq.395

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The Effects of a Whole-Class Kindergarten Handwriting Intervention on Early Reading Skills

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The University of Newcastle, New South Wales, Australia; and La Trobe University, Melbourne, Victoria, Australia

ABSTRACT

The ultimate goal of reading is to comprehend written text, and this goal can only be attained if the reader can decode written words and understand their meanings. The science of reading has provided compelling evidence for the subskills that form the foundation of decoding. Decoding words requires understanding of the alphabetic principle and letter-sound, or grapheme-phoneme, correspondence. In the first year of formal schooling (kindergarten), this same understanding is also required for young learners who are learning to write the letters of the alphabet. In this article, we examine the effectiveness of a handwriting intervention, Write Start-K, that emphasizes the recall, retrieval, reproduction, and repetition (the 4*R*s model) of grapheme-phoneme relations. We conducted a two-group, pre/posttest study at two Australian schools across four kindergarten classes (n = 77 students). One school received the intervention, and the other continued with standard teaching. Participants (mean age = 5 years 8.45 months, standard deviation = 4.18 months) at both schools were assessed at baseline, immediately after the eight-week intervention period, and at 12 weeks following the end of the intervention (follow-up). We used linear mixed models to determine the statistical significance of effects over three time intervals. We identified statistically significant Group × Time effects for letter name knowledge and word reading, whereas changes in letter sound knowledge and nonsense word-reading fluency approached statistical significance. These results indicate that a handwriting intervention, incorporating repeated practice in recalling and reproducing letter forms, had a statistically significant impact on early reading skills.

The science of reading has provided clear evidence that knowledge of letter names and sounds is one of the most important foundational skills when learning to read (Hulme & Snowling, 2013). Learning how sounds (phonemes) are associated with or attached to letter shapes (graphemes) leads to understanding of the alphabetic principle (Apel, 2009; Castles, Rastle, & Nation, 2018). Mastery of the alphabetic principle enables young learners to begin to decode written language by using phonemic knowledge and phonics skills to sound out words (Castles et al., 2018). In order for alphabet knowledge to support decoding and word reading, the names and sounds of all 26 letters need to be memorized and then retrieved not only accurately but also fluently (Clemens, Lai, Burke, & Wu, 2017). Ample research from the science of reading has shown that many beginning readers face challenges in learning the arbitrary connections between letter forms and their names and sounds (Castles et al., 2018), and Roberts, Vadasy, and

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pp. 1–15 | doi:10.1002/rrq.395

Sanders (2019) described this process as a form of paired-associate learning.

Paired-associate learning serves to secure in long-term memory the link between orthographic information (the letter form) and its corresponding sound or name (Ehri, 2005). Mastery of alphabet knowledge is typically not acquired naturally, or by exposure only (Castles et al., 2018), and for 30% of kindergartners, difficulties in establishing these links have been resistant to targeted reading instruction (Paige, Rupley, Smith, Olinger, & Leslie, 2018). Studies in early literacy instruction have shown that the motor-perceptual links and sensory integration involved in writing letters enhance spelling (Cunningham & Stanovich, 1990) and support letter recognition through repeated exposure to letter variants (Li & James, 2016). Despite the fact that the beginning stages of both reading and writing require this same kind of alphabet knowledge, the sciences of reading and writing have typically been conducted separately, and there is a need for integrated research investigating how reading and writing can support each other (Graham, 2020).

Studies of the relation between reading and writing have reported both uni- and bidirectional effects. For students in the second year of formal schooling or higher, writing can influence reading (Graham & Hebert, 2011); however, other studies have suggested that reading may have a stronger impact on writing (Berninger, Abbott, Abbott, Graham, & Richards, 2002; Kim, Petscher, Wanzek, & Al Otaiba, 2018). During kindergarten, the phonological aspects of reading (through understanding the alphabet), and writing (handwriting letters using grapheme–phoneme correspondences [GPCs]) are taught concurrently (Moats, 2020; Ritchey, 2008). A small body of evidence points to an association between handwriting fluency and reading building blocks (letter-naming fluency, initial sound fluency, nonsense word reading, and word reading) in kindergarten (Frolek Clark & Luze, 2014; Malpique, Pino-Pasternak, & Valcan, 2017). A number of studies involving preschoolers have found modest effects on alphabet knowledge from interventions that emphasize the pairing of printed letters with their corresponding names and sounds (Castles, Wilson, & Coltheart, 2011; Roberts et al., 2019). In these studies, the students were shown a visual representation of the letter form while the teacher provided the verbal label. It was hypothesized that the orthographic information provided by repeated exposure to a grapheme (printed letter) aided the storage and retrieval of both the visual form of the letter and its verbal labels (Castles et al., 2011). Given that, in preliterate learners, brain regions associated with reading are activated by writing letters as opposed to merely viewing them (James, 2010), it is timely to investigate whether handwriting instruction in kindergarten can impact the phonological skills required for reading acquisition.

Handwriting as an Aid to GPCs in Kindergarten

Handwriting is an aural, cognitive, and motor skill, combining phonetic knowledge, retrievable orthographic representations for letter forms, and the creation and execution of associated motor patterns (Alstad et al., 2015; Berninger, 1999; Berninger et al., 1997). Many of these skills are emerging in kindergartners (Berninger & Rutberg, 1992; Graham & Weintraub, 1996; Weintraub & Graham, 2000). Based on the literature, four features of handwriting fluency development have been identified. First, fluent handwriting requires recall of the orthographic code or mental representation for a letter or word (Abbott & Berninger, 1993; Berninger et al., 1997). Second, retrieval entails accessing the system of movements, or motor plan, associated with the recalled letter form (Graham, Struck, Santoro, & Berninger, 2006; Tseng & Murray, 1994; van Galen, 1991). Third, reproduction factors may impede or enhance fluent handwriting and include fine-motor, visuomotor, visuoperceptual, and kinesthetic abilities (Cornhill & Case-Smith, 1996; Graham et al., 2006; Kushki, Schwellnus, Ilyas, & Chau, 2011). Finally, repetition or sufficient practice is crucial to developing handwriting fluency (Hoy, Egan, & Feder, 2011).

These four factors—recall, retrieval, reproduction, and repetition—are conceived as a handwriting fluency development model (the 4*R*s model; Ray, Dally, Colyvas, & Lane, 2021) and may provide an explanation for the potential role of handwriting as a mediator of GPC knowledge and acquisition of the alphabetic principle, which in turn leads to improved word-reading accuracy and fluency. Recall of letter forms is potentially facilitated by and demonstrated through writing from memory. Memory recall as part of handwriting instruction has been shown to increase fluent alphabet writing and contextual word and sentence writing, indicating enhanced access to mental representations of letters and words (Berninger et al., 1997; Wolf, Abbott, & Berninger, 2017). Recursively, writing (or written fast-mapping) has been used to indicate the development of mental orthographic representations of novel, nonsense words in kindergartners (Apel, 2009). Mental processes may be more efficient when motor programs for letter writing are easily retrievable. For example, when learning a new letter symbol and reproducing it, learners with good handwriting are found to activate fewer brain regions than those with poor handwriting do (Palmis, Danna, Velay, & Longcamp, 2017). Importantly, reproduction of the recalled and retrieved letter form pattern may aid visual letter recognition and categorization (James, 2010; Li & James, 2016). Finally, sufficient repetition underpins the circular relation between identified handwriting fluency factors and may contribute to the creation of stable mental images of letters (James, 2010; Palmis et al., 2017). Sufficient, developmentally suitable repetition within an intervention that promotes handwriting fluency may therefore be indicated in both phoneme–grapheme mapping and automatic letter identification.

Handwriting Intervention in Kindergarten

Handwriting instruction generally follows a prescribed path of demonstrating the method used to form a particular letter (the letter formation pattern) followed by student practice. Explicit, direct instruction of a new motor pattern has been found to be more effective than following a prompt line on an electronic application, or tracing the pattern (Overvelde & Hulstijn, 2011). An effective handwriting intervention approach based on the 4*R*s model of handwriting fluency development (Ray et al., 2021) should also ensure that all aspects of the handwriting system are activated and supported to work in synchrony. For kindergarten-age students, this may include a focus on factors such as fine-motor and visuomotor skills that impact letter reproduction.

Write Start–K is a whole-class, cotaught (teaching and occupational therapy) handwriting intervention devised for kindergarten based on Write Start for grade 1 students (Case-Smith, Holland, Lane, & White, 2012; Case-Smith, Weaver, & Holland, 2014). Write Start–K includes explicit instruction and practice of letter formation both in isolation and in words and sentences, through a combination of whole-class instruction and themed, station-based activities. Using the 4*R*s model to guide intervention, each instructional activity encourages students to recall mental or orthographic images and retrieve and reproduce related motor patterns while utilizing different task elements that support emerging writing, such as fine-motor, visuomotor, and cognitive skills. In addition to supporting factors that contribute to fluency, engagement in a variety of themed, station-based authentic writing and crafts activities ensures sufficient repetition, with the aim of students automatically associating the orthographic representation of a letter with its verbal label and then retrieving and executing the correct motor pattern for its formation. Because of the repeated practice in recalling, retrieving, and reproducing letters, we hypothesized that participation in Write Start–K would promote stronger GPCs and greater letter recognition, thereby facilitating greater gains in reading than would be made from standard instruction alone.

Research Question

In the current study, we examined whether participation in Write Start–K alongside standard literacy instruction would improve early reading skills in kindergartners when compared with participation in standard teaching of handwriting and literacy. We drew the data for this study from a larger study examining the impact of Write Start–K on the handwriting fluency and writing abilities of kindergartners. One research question guided the current study: Does the addition of a handwriting fluency intervention, Write Start–K, to standard teaching of reading and writing impact early reading skills as compared with standard teaching of reading and writing alone?

Method

We used a two-group, nonrandomized, prospective comparison study design. Students from two schools participated; one school received the intervention, and the second school continued with standard teaching and served as the control. Ethics approval was obtained from the relevant bodies.

Participants

The two schools included in the study are in suburbs of a large regional city in New South Wales, Australia. Both schools had similar numbers of enrollments in the kindergarten year and were selected because of their location in community areas of lower socioeconomic status. In New South Wales public schools, a school socioeconomic index, the Family Occupation and Employment Index (FOEI), is calculated at the beginning of each year based on data provided by parents of all enrolled children on level of parental education, nonschool qualifications, and occupational status. The FOEI weights and combines parent information into an index that allows comparison among all public schools in New South Wales (NSW Government, 2020). The FOEI for the control and intervention schools identified both schools as having a similarly low level of socioeconomic status. The schools were also matched overall for racial and linguistic diversity, with both schools having approximately equivalent numbers of indigenous students (control 12%, intervention 16%) and students with a language background other than English (control 2%, intervention 3%; Australian Curriculum Assessment and Reporting Authority, 2020). No students from either school had a diagnosis of dyslexia or learning difficulty.

Informed consent was received from all parties approached for inclusion in the study, including principals, teachers of the kindergarten classes, and parents of the children in each class. At the intervention school, parental consent was received for all 39 enrolled kindergartners and for all 41 enrolled kindergartners at the control school. Included participants at the intervention school (n = 38) had a mean age of 5 years 8.7 months (range = 57–77 months). Included participants at the control school (n = 39) had a mean age of 5 years 8.2 months (range = 62–77 months). There was no statistically significant difference between the schools in participant ages.

All kindergartners at the intervention school received the Write Start–K program, as it allowed for individual adjustments and used a range of strategies for providing instructions for activities such as visual modeling, demonstration, and specific feedback where needed. Pre- and post-assessments on some students (n = 1 at the intervention school, n = 2 at the control school), however, were not able to be completed due to a significant disability that impacted the ability of the students to understand and/or carry out assessment activities. The first author, a registered occupational therapist, assisted the research assistants (RAs) conducting the assessments to make judgments about whether assessments could be completed in a valid way. Where partial assessment data were collected, this was provided to class and specialist learning support teachers for the purposes of educational program and support planning; however, we did not use the data in the study analyses. No students were excluded from the study because of English-language difficulties.

Procedures

All participants in both schools were assessed at baseline, immediately after the intervention phase (eight weeks), and at 12 weeks following the end of the intervention (follow-up). Participants were assessed individually, and each assessment session, including breaks, took approximately 45 minutes per participant. After baseline data collection, Write Start–K was administered to all kindergartners at the intervention school in two 45-minute sessions per week for eight weeks. Kindergartners at the intervention school were distributed evenly across two classes. During the intervention phase, the control school continued with standard teaching according to the curriculum, including introduction to the alphabetic principle, handwriting, phonics instruction, and reading. This regular instruction also continued at the intervention school, with the exception that handwriting lessons and some aspects of the curriculum, such as crafts, were replaced by Write Start–K. Assessments were conducted by a team of 12 trained, supervised, and blinded RAs, who were selected from a pool of undergraduate occupational therapy students. RAs were randomly allocated to schools and participants, with all RAs working across both schools at each data collection point. Training for the RAs was conducted by the first and second authors and included face-to-face instruction, written procedures for nonstandardized tools, developmentally appropriate use of language, and on-site supervision by the first, second, or last author. Scripts and procedures of standardized and published tools were followed as published by the test developers. Integrity of the RA blinding was maintained, as only the supervising research team member interacted with school teaching staff involved in the study.

Measures

Measures collected and relevant to the current study are summarized in Table 1. The Dynamic Indicators of Basic Early Literacy Skills (DIBELS) is a frequently used test of literacy skills (Goffreda & DiPerna, 2010). For this study, three subtests were administered: Letter Naming Fluency, Nonsense Word Fluency, and Word Reading Fluency (Good & Kaminski, 2002). Each subtest was administered for one minute. An intraclass coefficient of .99, 95% confidence interval (CI) [0.982, 0.996], has been reported for inter-rater reliability for kindergarten DIBELS subtests (University of Oregon, 2020). Concurrent validity ranges of the kindergarten subtests with measures of reading have been reported: for letter-naming fluency, r = .27–.60; for nonsense word–reading fluency, r = .27–.65; and for word-reading fluency, r = .26–.73 (University of Oregon, 2020).

TABLE 1
Assessment Measures Description and Scoring

Assessment	Description	Scoring
DIBELS Letter Naming Fluency subtest	The student is shown a sheet of randomized upper- and lowercase letters and asked to name as many as possible.	The total number of letters named correctly in one minute
DIBELS Nonsense Word Fluency subtest	A list of simple nonsense words is presented, and the student can pronounce either the whole word or individual sounds.	The number of correct letter sounds identified in one minute
DIBELS Word Reading Fluency subtest	The student reads words from a page of decodable and irregular words of increasing complexity.	The number of words read correctly in one minute
Letter name and letter sound knowledge	A sheet of randomized, matched upper- and lowercase letters is shown one row at a time, and the student is asked the letter name and sound.	A point is awarded for each correct name and correct sound, totaling 26 for each category.

Note. DIBELS = Dynamic Indicators of Basic Early Literacy Skills.

In addition to the DIBELS, a researcher-designed test of letter name and sound knowledge was administered to obtain a baseline of skill ability in an untimed condition. Because we anticipated that accurate retrieval of letter names and sounds would be a likely key outcome of the writing intervention, it was important to gain a measure of letter name and sound knowledge for all 26 letters of the alphabet, and the timed DIBELS Letter Naming Fluency subtest did not provide this score. Both letter names and sound were included in this task because each type of knowledge makes a unique contribution to reading (Clemens et al., 2017). This untimed test mirrored tests used in studies with kindergartners (Karlsdottir & Stefansson, 2003; Zylstra & Pfeiffer, 2016), in which participants are presented with a page of randomly sequenced upper- and lowercase letter pairs and asked to name the letter and sound of the matched upper- and lowercase letter pair. Clay (2002) reported a split-half reliability of .97 for a similar Letter Identification task that is part of the Observation Survey of Early Literacy Achievement. Names and sounds were given by RAs for any letters not known, and participants were invited to move on to the next letter.

Intervention

This study was conducted during the second half of the kindergarten school year. At the commencement of the intervention phase, all participants at both schools had received preliminary instruction in the alphabetic principle and had been introduced to all letters as part of standard teaching. Write Start–K was delivered in the classrooms by the first author, the classroom teacher, and one of two additional RAs who were undergraduate occupational therapy students and had experience in and received additional training in Write Start–K. Write Start–K was conducted in two 45-minute sessions per week for eight weeks. The structure of each session was explicit, whole-class instruction in the formation of a group of letters, followed by station-based activities, which were based on use of the letters, and related words and sentences.

Mnemonics to describe the formation patterns of each letter were introduced during the initial whole-class instruction and then used consistently and repetitively during session activities; for example, the mnemonic for the letter *a* was "around, up, and down." All alphabet letters were revised over the course of the eight-week intervention by grouping letters with similar patterns of formation and using the groupings to establish fluency in writing for letters, words, and sentences. The focus of activity stations varied between session 1 and 2. Each activity station was led by one member of the intervention team and was themed through activity design based on the 4*R*s model. For session 1, activities focused on fine-motor, visuomotor, and cognitive aspects of the handwriting task, and for session 2, the stations used crafts and writing tasks to create an authentic writing task. In each session, high levels of support and feedback were provided by station leaders, with the aim of consolidating the letter-forming patterns taught. In effect, each activity station engaged all four elements of the 4*R*s model while also emphasizing foundational skill development.

In the first weekly session, the focus was on letter forming using a range of sensory and motor mediums, with a strong focus on the recall of letter formation patterns. The activity stations in session 1 emphasized repeated practice of letter forms using recall, retrieval, and reproduction routines through the medium of fine-motor, visuomotor, and cognitive station-based activities. Intervention activities were designed to be engaging to kindergartners and to include authentic writing tasks wherever possible. Fine-motor-themed activities emphasized finger and hand skills that support writing, such as pressing Play-Doh flat to make a page and writing letters in the Play-Doh with a pencil tip. Visuomotor-themed activities emphasized the coordination of eye and hand skills, such as drawing a mirror image of half a face and writing the theme words *sad* or *glad* to represent the facial expression in the picture. Cognitive activities emphasized the use of memory recall in games and tasks, such as a "look, say, cover, write" activity in which flaps on folders were lifted one at a time to first reveal and then cover a letter or word, write the word, and then check and correct as needed. This meant that important foundation skill development for writing, such as fine-motor and visuomotor skill, and memory recall skill could develop at the same time as consolidation of letter name, sound, and form relations, as well as writing being embedded in authentic and relevant tasks.

In the second session of the week, letter formation practice was repeated through whole-class instruction and then facilitated through two activity stations: an authentic writing activity and a crafts activity. This approach approximated a writer's workshop model often used with older students. For example, at the crafts station for making a paper plate hat, using cutting, paper-tearing, and pasting skills was the basis for the related writing task. At the writing station, a guided and prompted sentence, "I can run and put on my hat," was used to apply the newly learned letter-forming knowledge and consolidate foundation skills indicated in handwriting fluency. In many cases, students were encouraged to extend their writing following the guided sentence and were encouraged to use their developing handwriting skills.

In the control school, the standard teaching approach included typical handwriting and literacy teaching. Literacy methods included teachers demonstrating a letter or letters; for example, the letters *u* and *e* together make the /u/ sound. Small-group rotations or individual activities followed the demonstration, such as pasting colored squares onto printed bubble letters, copying words, tracing letters on a worksheet, cutting and sorting words that fit under headings (e.g., words with and without a silent *e*), and use of an iPad for literacy activities. Handwriting lessons at the control school used standard procedures, such as modeling of letter formation and provision of worksheets for practice. A key difference in the approach at the intervention school was the focus on handwriting fluency and consolidation of letter-forming patterns for each letter through visuomotor, fine-motor, and cognitive-themed activities. This was a distinct difference, as usually at this stage of the curriculum, after all letters have been introduced, attention would turn to reading and spelling in literacy lessons, rather than reemphasizing letter forming of all letters through handwriting.

It is important to note that the teachers at both the control and intervention schools had comparable levels of qualifications (a bachelor's degree in education) and that at each school, there was one teacher with more than 15 years of experience in teaching kindergarten and one teacher with three to five years of experience. Classroom observations at each school indicated that the regular literacy activities were similar at both schools. All kindergarten classes in Australia follow the same Early Stage 1 curricular objectives. Literacy instruction in kindergarten follows a balanced approach by which students develop reading and comprehension skills through exposure to written, visual, and digital texts from a variety of cultures. By the end of kindergarten, students are expected to have developed sound and letter knowledge, be able to identify letter patterns and sounds in words, and be able to read short, predictable printed texts on familiar topics with some fluency and accuracy (Australian Curriculum Assessment and Reporting Authority, 2014). Observations of literacy lessons at the control and intervention schools revealed that teachers at both locations adopted a similar blend of direct teaching of GPC and phonics strategies with story reading and class discussions. Write Start–K was timetabled into the usual time allotted for handwriting and crafts activities and did not replace standard literacy and reading groups.

Data Analysis

We used linear mixed models (LMMs) to assess all outcomes for the impact of group, time, and the Group × Time interaction, with these three terms forming the base model. LMMs are useful for analyzing nonindependent data, such as those collected with repeated measures within a subject. The aim of the analysis was to determine the amount of growth for each measure as compared with each individual's own baseline score, and whether there was a difference between the groups in this growth. These changes from baseline score (i.e., growth) provided a way to adjust for potential nonequivalence of the groups due to the nonrandomized study design so only the growth differences between the groups were being compared. This type of analysis ensured that group differences at baseline would have minimal impact in assessing the size of the growth in the intervention relative to the control. We assessed potential differences in variances and correlations between timepoints using residual covariance structures for each outcome measure. Three structures were tried, beginning with the simplest, compound symmetry, but to check for variability and/or correlation differences between time periods, we generally chose either heterogeneous compound symmetry or, the most general, unstructured.

We decided on the best structure based on the structure with the lowest Akaike information criterion. We chose a lower Akaike information criterion of 10 or more before we considered a structure better (Burnham & Anderson, 2004). We calculated nonstandardized effect sizes and 95% CIs for each measure for growth over time for each group and also for comparing the size of the difference in growth between the treatment and control groups. These were based on the fitted values from the LMMs. We set statistical significance at the .05 level.

Results

A general observation across all variables was that the modeling assumption of constant variance was broken, with variability in scores differing over time. In some cases, the variability decreased in the later time periods due to scores approaching the ceiling for each scale as students improved their skill levels. In other cases, the variability increased in the later time periods as some participants approached the ceiling for a measure while others stayed relatively stable. We overcame this nonconstant variance problem by using appropriate residual covariance structures in the modeling.

Baseline Comparison

We determined differences between baseline measures using LMMs (see Table 2). Statistically significant baseline differences were detected for letter-naming fluency (mean [M] = −9.6, 95% CI [−17.6, −1.5]), letter name knowledge (M = −9.0, 95% CI [−12.2, −5.6]), and letter sound knowledge (M = −2.5, 95% CI [−4.7, −0.2]), with the intervention group identifying fewer letters and sounds. The baseline differences for word-reading fluency and nonsense word–reading fluency were not statistically significant.

Reading Measures

Visual inspection of means with 95% CIs for each data collection point indicated the pattern of change in the means within and between groups across the three timepoints—baseline, post-intervention, and follow-up—for all variables in the study (see Figure 1). We conducted statistical analysis using LMMs to determine the statistical

TABLE 2
Baseline Characteristics by Group (Intervention and Control) and Baseline Differences

	Intervention (n = 38)		Control (n = 39)		Baseline difference	
Variable	Mean (*SD*)	Median (min, max)	Mean (*SD*)	Median (min, max)	Mean	95% confidence interval[a]
Letter-naming fluency	16.6 (20.0)	7.0 (0, 64)	26.2 (15.5)	26.0 (0, 59)	−9.6	[−17.6, −1.5]
Nonsense word–reading fluency	30.2 (16.1)	32.5 (0, 63)	24.9 (13.5)	25.0 (0, 57)	5.3	[−1.3, 12.0]
Word-reading fluency	7.2 (7.7)	6.0 (0, 43)	8.6 (4.9)	8.0 (0, 18)	−1.3	[−4.2, 1.6]
Letter name knowledge	13.71 (9.24)	13.0 (1, 26)	22.7 (4.8)	25.0 (9, 26)	−9.0	[−12.2, −5.6]
Letter sound knowledge	21.6 (6.6)	25.0 (2, 26)	24.1 (2.6)	25.0 (15, 26)	−2.5	[−4.7, −0.2]

Note. *SD* = standard deviation.
[a]If the 95% confidence interval does not cross 0, the difference between mean scores is significant at $p < .05$.

significance of effects. Estimated marginal means from the models were used to assess the difference between groups in the differences between means across the three time intervals (baseline to post-intervention, post-intervention to follow-up, and baseline to follow-up) and the overall study effect sizes (see Table 3). For each measure and each group, a subtraction of means (e.g., mean at post-intervention minus mean at baseline) yielded a difference in means (e.g., for word-reading fluency for the period from baseline to post-intervention, the mean difference for the intervention group was 4.2 more words read, 95% CI [3.0, 5.5], whereas the mean difference for the control group was 2.9 more words read, 95% CI [1.6, 4.1]). For all variables and both groups, the difference in means for each time interval were positive, indicating improvement over time regardless of group. This could be expected because the intervention and control groups received the intervention program and standard teaching, or standard teaching alone, respectively, and were therefore likely to gain in reading skills.

We then determined the overall study effect size for each variable by subtracting the control group difference in means from the intervention difference in means at each of the time intervals. For example, for word-reading fluency (follow up minus baseline), the difference in intervention minus control was 12.4 − 6.6 = 5.8, 95% CI [1.1, 10.5], in this case a statistically significant effect because the CI did not contain zero. All effect sizes were positive, indicating greater improvement for the intervention group relative to the control group for each variable across each time interval. Although not all of these effects were statistically significant as judged by their 95% CIs, it points to a general pattern in which the intervention group tended to outperform the control group. This indicated that the intervention was effective in impacting early markers of reading and word-reading fluency, over and above effects of standard teaching. We conducted statistical analysis to determine the statistical significance of these greater mean differences for the intervention group. Unstandardized effect sizes have been reported because they provide a more meaningful metric (i.e., number of letters or words) by which to judge the effects of the intervention and are recommended for primary research reporting (Pek & Flora, 2018).

LMM analysis showed a statistically significant Group × Time interaction for the variables word-reading fluency (p = .05) and letter name knowledge ($p < .001$), indicating that there was sufficient difference between groups across varying intervals to establish statistically significant effects. For word-reading fluency, greater change occurred for the intervention group relative to the control group in the period from baseline to follow-up, with an estimated mean difference in effect of 5.8 words, 95% CI [1.1, 10.5]. A statistically significant difference was also seen for word-reading fluency for the time interval from immediate post-intervention to follow-up, with an effect size of 4.5 words, 95% CI [0.4, 8.5]. Given that both schools continued with standard curriculum instruction in reading, this effect on word-reading fluency suggests a benefit to word-reading fluency for the intervention group as a result of the intervention. For letter name knowledge, there were two time intervals in which the intervention group statistically significantly outperformed the control group. From baseline to post-intervention, the effect size was 5.2 letters, 95% CI [2.6, 7.9], and from baseline to follow-up, the effect size was 6.3 letters, 95% CI [3.6, 9.0]. Because instruction in the alphabetic principle continued at both schools during the intervention phase, these results suggest an enhanced effect of the intervention on letter-naming ability.

For comparison purposes, Hedges' g is reported for the two measures where the Group × Time interaction was significant: letter name knowledge and word-reading fluency. We calculated Hedges' g by subtracting the mean of the change score for the control group from the mean of the change score for the intervention group and dividing by the pooled standard deviation. As a small sample

FIGURE 1
95% Confidence Interval (CI) for Reading Markers and Word-Reading Fluency for the Intervention and Control Groups at Time 1 (Baseline), Time 2 (Immediate Post-Intervention), and Time 3 (Follow-Up)

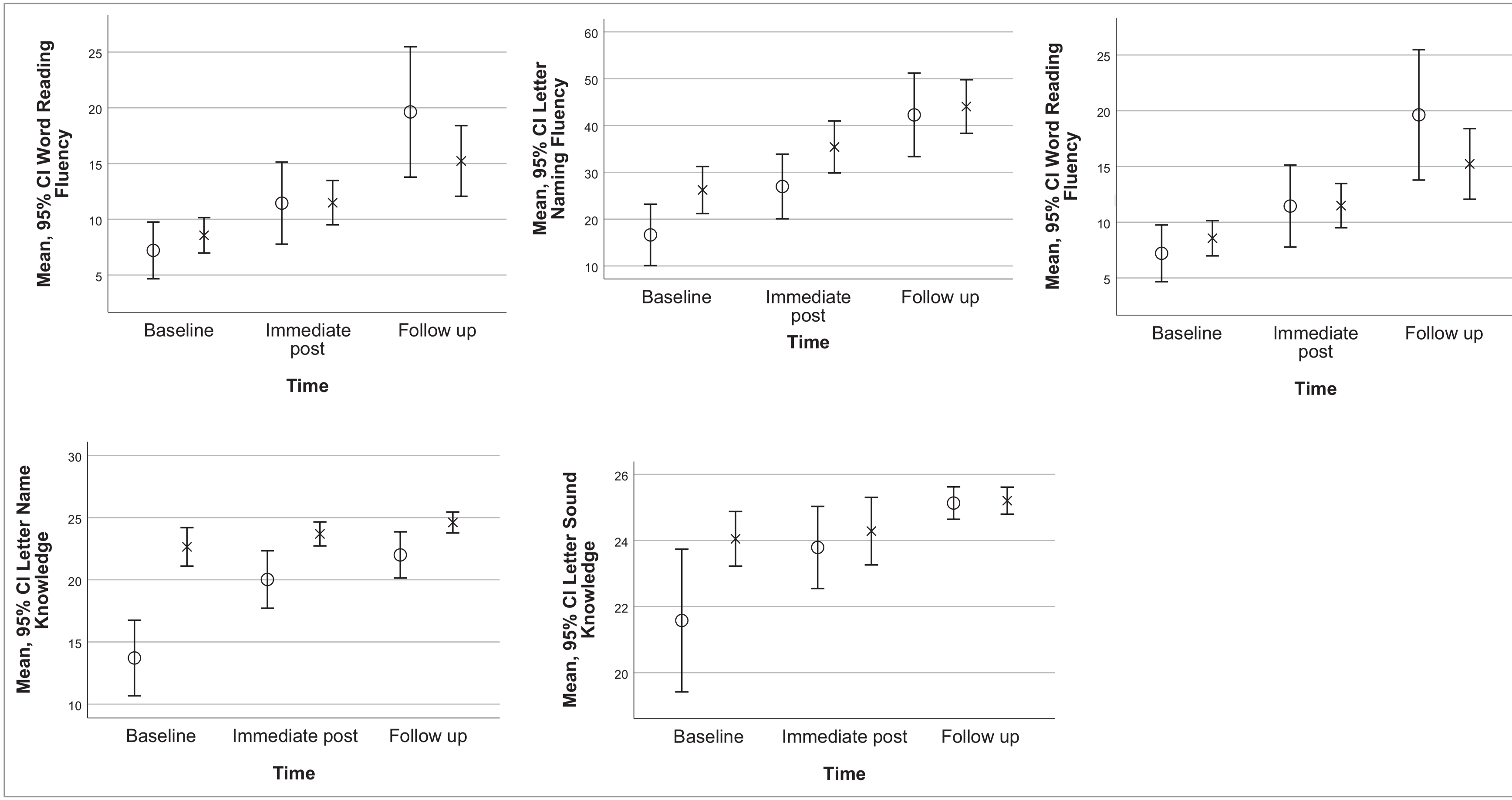

TABLE 3
Effect Sizes for Changes in Means of Outcome Scores Over the Three Time Intervals by Group

		Intervention difference in means [95% CI] (n = 38)			Control difference in means [95% CI] (n = 39)			Effect size for intervention minus control [95% CI][a]		
Variable	Group × Time interaction (p)	Baseline to post-intervention	Post-intervention to follow-up	Baseline to follow-up	Baseline to post-intervention	Post-intervention to follow-up	Baseline to follow-up	Baseline to post-intervention	Post-intervention to follow-up	Baseline to follow-up
Letter-naming fluency	.15	10.3 [6.4, 14.2]	15.3 [9.9, 20.7]	25.6 [20.0, 31.3]	9.4 [5.5, 13.3]	8.6 [3.3, 14.0]	18.0 [12.4, 23.6]	0.9 [−4.6, 6.5]	6.6 [−0.9, 14.2]	7.6 [−0.4, 15.5]
Nonsense word–reading fluency	.09	9.0 [4.0, 14.0]	11.9 [5.2, 18.5]	20.8 [14.3, 27.4]	6.3 [1.4, 11.3]	4.2 [−2.4, 10.7]	10.5 [4.0, 17.0]	2.6 [−4.4, 9.7]	7.7 [−1.7, 17.1]	10.3 [1.1, 19.6]
Word-reading fluency	.05	4.2 [3.0, 5.5]	8.2 [5.3, 11.1]	12.4 [9.1, 15.8]	2.9 [1.6, 4.1]	3.7 [0.8, 6.6]	6.6 [3.3, 9.9]	1.3 [−0.4, 3.1]	4.5 [0.4, 8.5]	5.8 [1.1, 10.5]
Letter name knowledge	<.001	6.3 [4.4, 8.2]	2.0 [1.0, 3.0]	8.3 [6.4, 10.2]	1.1 [−0.8, 3.0]	0.9 [−0.05, 1.9]	2.0 [0.1, 3.8]	5.2 [2.6, 7.9]	1.1 [−0.3, 2.4]	6.3 [3.6, 9.0]
Letter sound knowledge	.07	2.2 [0.5, 4.0]	1.3 [0.2, 2.5]	3.6 [2.1, 5.0]	0.2 [−1.5, 2.0]	0.9 [−0.2, 2.0]	1.2 [−0.3, 2.6]	2.0 [−0.5, 4.4]	0.4 [−1.2, 2.0]	2.4 [0.4, 4.4]

Note. CI = confidence interval.
[a]This notation is only applied to the study effect sizes (i.e., intervention minus control). If the 95% CI does not cross 0, the difference between means for the overall study effect size is significant. The overall study effect size was calculated by subtracting the control difference in means for each time interval from the intervention difference in means for each time interval.

correction, we applied Hedges' (1981) formula (multiplying the Hedges' g by a factor of $\omega = [1 - 3/(4N - 9)]$, with N being the total sample size) to produce an unbiased effect size estimate (What Works Clearinghouse, 2020). Use of change scores (see Table 3) allowed adjustment for differences in the baseline performance of each group. For letter name knowledge, baseline to post-intervention, the Hedges' g corrected for small-sample bias was 0.88, and for this same measure, the baseline to follow-up corrected Hedges' g was 1.05, indicating a large standardized effect size across both time periods. For word-reading fluency, the corrected Hedges' g from post-intervention to follow-up and from baseline to follow-up was 0.54 and 0.49, respectively. These standardized effect sizes suggest that the medium improvement in word-reading fluency that was evident at the end of the intervention was maintained over time.

Other measures that approached statistical significance for Group × Time interaction were letter sound knowledge ($p = .07$) and nonsense word–reading fluency ($p = .09$). For both of these measures, a statistically significant effect was detected favoring the intervention group for the period from baseline to follow-up; however, this was not sufficient for a statistically significant Group × Time interaction. For the period from baseline to follow-up, unstandardized effect sizes were 10.3 words (95% CI [1.1, 19.6]) for nonsense word–reading fluency and 2.4 letter sounds (95% CI [0.4, 4.4]) for letter sound knowledge. One measure, letter-naming fluency, did not demonstrate a statistically significant Group × Time interaction or a statistically significant effect size at any of the three timepoints. However, as shown in Table 3, all effect sizes were greater for the intervention group across each time interval for all measures, including letter-naming fluency.

Discussion

In this study, we sought to determine whether the introduction of Write Start–K, a handwriting fluency development program, into a kindergarten curriculum would result in growth of measures of reading greater than the growth that could be expected from standard teaching. To answer this question, we used two groups: one that received Write Start–K and regular literacy instruction and one that received regular teaching of handwriting and literacy. The key difference between the groups was the methodology used in the intervention group for handwriting fluency development, which was grounded in theory of how handwriting fluency develops in kindergarten. We hypothesized reading gains because of the development of GPCs facilitated through handwriting fluency processes. The method for analysis we used was to determine the growth (change over time) for each group and to compare differences in the growth between groups at varying time intervals with the aim of determining whether the growth in the intervention group exceeded that of the control group. Our purpose in using this approach was to determine how effective the intervention was in facilitating change and eliciting growth in commonly used markers of early reading. The benefit of analyzing differences in amount of change contributes to the science of reading by clearly showing whether intervention can impact emerging literacy by enhancing growth. Also, this method adjusts for any differences between groups at baseline.

The intervention had a statistically significant impact on two of the literacy measures, word reading and letter name knowledge, and the effect on two other measures, letter sound knowledge and nonsense word reading, approached statistical significance. Simply stated, the group that received the intervention, irrespective of baseline similarities or differences, made greater gains, or showed greater growth, than the gains made by the control group. We expected the control group to make some gains because they were receiving continued handwriting and literacy instruction, using standard and commonly used teaching methods. The intervention group also continued with similar literacy instruction but received a carefully designed handwriting intervention, designed to facilitate fluency in letter writing. We were interested in whether Write Start–K would have an impact on reading by strengthening GPCs. The statistically significant effects for letter naming and word reading and the finding that the effects for letter sound naming and nonsense word reading approached statistical significance suggest that this may have been the case.

A range of literacy markers, including letter naming and word reading, have a demonstrated relation with early reading development (Schilling, Carlisle, Scott, & Zeng, 2007). We detected statistically significant intervention effects for the intervention group in letter-naming and word-reading skills. The greatest gains in knowledge of letter names occurred both immediately (from baseline to post-intervention) and overall (from baseline to follow-up). This suggests a rapid and immediate gain in letter-naming ability for the intervention group. Greater gains in word reading occurred in the period from post-intervention to follow-up and overall from baseline to follow-up. This suggests that most of the change in word reading occurred in the period from the end of intervention to the follow-up point. Word reading in grade 1 has been found to be predicted by letter naming (Stage, Sheppard, Davidson, & Browning, 2001) and letter–sound correspondence (Speece & Ritchey, 2005). The growth in letter naming immediately after intervention and in word reading over time points to a cumulative effect of enhanced letter recognition on word-reading fluency.

In this study, improvement in fluency in reading nonsense words, a predictor of reading (Fien et al., 2008), and knowledge of letter sounds, the basis of decoding (Earle

& Sayeski, 2017; Treiman, Stothard, & Snowling, 2019), both approached statistical significance. A timed measure of letter identification, used to measure fluency and accuracy, also followed the trend of greater gains across each time period made by the intervention group, but did not reach statistical significance. It is important to note that for the intervention group, these combined results indicate that all mean differences for all measures across all time periods were greater than the mean differences for the control group. This result is important in terms of the efficacy and potential benefit of the intervention, as growth effects were not limited to one or two measures.

We suggest that the overall positive trend for all literacy measures and specific statistically significant effects indicate that the handwriting fluency intervention, Write Start–K, impacted letter identification and GPCs and contributed to greater growth in word reading for the intervention group over the control group. Ehri (2014) explained that the process of learning to read is aided by both forming connections between graphemes and phonemes and understanding the alphabetic principle. When combined with phonemic skills, alphabetic and grapheme–phoneme knowledge enable bonding of spellings of words in memory and, ultimately, the ability to read words by sight. Decoding is another means used to read unfamiliar words, and this skill is in frequent use for students learning to read and also requires alphabetic and GPC knowledge (Castles et al., 2018; Rastle, 2019). Both sight word reading and decoding are therefore dependent on the establishment of alphabetic knowledge and GPCs. Further, rapid automatic naming, a measure of letter-naming fluency, has been found to predict spelling and word reading for kindergartners and first graders (Bar-Kochva & Nevo, 2019). The growth shown in this study may point to a stronger base in GPCs and more efficient retrieval of letter names and sounds, which may have contributed to the intervention group's statistically significant gain scores for reading, and gains in nonsense word reading that were close to statistical significance.

Why might an intervention for handwriting have impacted reading? We suggest that the handwriting intervention focus in this study impacted the mechanisms that underlie GPCs and alphabetic knowledge. For preschoolers, neuroimaging studies have demonstrated enhanced activation in visual processing of letters and brain areas associated with reading after letter printing (James, 2010; James & Engelhardt, 2012). Further, in experimental studies with preschoolers, letter writing has been found to facilitate letter recognition (Kiefer et al., 2015; Longcamp, Zerbato-Poudou, & Velay, 2005). It is possible that the Write Start–K methodology activated reading circuits by associating a letter name, sound, and form. Similar to Roberts et al.'s (2019) paired-associate learning intervention for preschoolers, Write Start–K uses station-based small-group handwriting activities to reinforce and repeatedly expose students to the relation among letter names, sounds, and forms. This consolidates the circular relation among cognitive representations of letters, motor patterns for letter formation, and reproduction of the cognitive representation using the correct motor pattern.

Reproduction factors that may limit handwriting ability, such as fine-motor and visuomotor skills, are also specifically targeted through Write Start–K, thereby enhancing effective practice. As previously noted, researchers have found a facilitating relation between letter writing and letter recognition (James, 2010; James & Engelhardt, 2012; Kersey & James, 2013). Participation in Write Start–K resulted in greater letter knowledge and word recognition automaticity. Also, enhanced visuomotor and fine-motor practice of letter writing is a feature of Write Start–K. Li and James (2016) found that both writing practice and visual studying of novel letter forms contributed to increased form recognition in kindergartners. Li and James therefore advocated increased handwriting practice as one means of promoting letter recognition. The practice element in Write Start–K, combining visuomotor, cognitive, and fine-motor skills in a fluency development model, may therefore underpin the enhanced reading gains made by students participating in the handwriting intervention. The coteaching features of Write Start–K may also be instrumental in the results, as the combination of teaching and occupational therapy specialties supports the use of specific, direct feedback and adjustment of intervention activities to ensure accessibility for all students based on developmental and cognitive needs.

In summary, these results demonstrate a key difference between the groups across a range of reading markers, despite both groups receiving ongoing literacy instruction, and we suggest that the repeated practice of retrieving letter forms from memory and writing the letters during the intervention was the contributing factor. We propose repeated practice through developmentally tailored handwriting fluency activities in kindergarten as the means by which a greater connection was established among the letter names, sounds, and forms, resulting in stronger letter identification and GPCs. Further, we see the use of the 4*R*s model of handwriting fluency (Ray et al., 2021) as a basis for designing the intervention activities as key to the gains made in reading for the intervention group. This literature-informed model emphasizes four aspects of fluency: recall of the letter form, retrieval of the motor pattern, reproduction of the retrieved form through handwriting, and sufficient repetition. Each factor was considered within the instructional model of Write Start–K. Activities based on the 4*R*s model may be able to stand alone; however, the coteaching framework of Write Start–K ensured sufficient feedback, monitoring, and practice time and allowed for both educational and developmental knowledge to inform the intervention.

Limitations

This translational research was conducted rigorously in an authentic classroom and, as such, was impacted by the natural variations that occur when working in the field. Randomization of participants into intervention and control groups was not possible because the intervention was intended to trial an approach that could be potentially adopted by whole classes, using the Write Start–K coteaching approach. Although the findings in the present study are supportive of the use of handwriting interventions as a means to promote reading acquisition in kindergarten, the results need to be confirmed through a larger, randomized study with more evenly matched control and intervention groups.

It is inevitable in small-scale studies with limited randomization that baseline differences will occur. In this study, we sought to minimize the effects of no randomization between groups by using a control group to provide partial matching on factors such as socioeconomic status. The control group nevertheless enabled the measurement of growth of key markers of reading when using regular teaching. Comparing the groups using differences in amount of growth from baseline controlled for the group differences at baseline.

In terms of effects, the Write Start–K intervention may have provided additional handwriting instruction over that allocated in standard teaching, and there is a possibility that the study effect was partly or wholly due to the extra guidance provided by two additional adults leading the small-group handwriting activities rather than the nature of the handwriting approach. Future study designs will need to address this possible mismatch in intensity of teaching between groups. Similarly, the program effects may have been impacted by differences between teachers and teaching practices at the intervention and control schools that we were unable to measure or discern. Although the teachers followed the same curriculum and had similar years of experience in teaching kindergarten, given the small number of students and teachers, pedagogical differences between the intervention and control teachers could have either inflated or reduced the program's effects.

Due to the low numbers of enrolled students at the participating schools with English as a second language, we were unable to assess the effectiveness of this approach with a more linguistically diverse student group. The use of multisensory activities in Write Start–K within a model that promotes fluency through use of memory, developmental skills support, letter formation, and practice, however, is expected to be an accessible methodology for emerging bi/multilingual learners. Further, the principles of the 4*R*s framework could be incorporated into both regular and tailored activities to support multilingual or emergent bilingual learners. For example, an application of this research into more diverse practice could include adaptation of learning activities to incorporate the 4*R*s framework with individuals or small groups with specific needs.

Implications for Policy and Practice

The findings from this study indicate that a classroom-based kindergarten handwriting intervention had a positive impact on reading outcomes. We hypothesize that this might occur through consolidation of the foundational phonological knowledge of GPCs, which in turn support automatic word recognition (Moats, 2020). As noted by Moats (2020), most young readers require explicit instruction and sufficient practice to gain this knowledge. She recommended that beginning reading instruction should "focus on teaching students how to read and write words, following a systematic and logical sequence" (p. 7). Similarly, Rastle (2019) called for an integrated approach to the teaching of reading and writing, arguing that the nature of the reading system is a reflection of the writing system and that understanding how information is transmitted through written language facilitates skilled reading. The Write Start–K coteaching methodological approach tested in the current study provides one possible pathway to achieve integration between early writing and reading. Based on our results, we hypothesize that with repeated practice, beginning writers establish an efficient, accurate cognitive representation of a letter that contributes to the consolidation of the grapheme–phoneme relation, which in turn supports word-reading fluency. Replication of these results is needed, however, before practice guidelines can be amended.

The findings of our study also support the further consideration of methods used to integrate specialty services in education, with indications that collaborative, interdisciplinary, whole-class models may be a means to address a wide range of developmental and instructional needs. The feasibility of one such model was tested in our study. The school and teachers involved found that the collaborative model worked effectively, strengthened and consolidated relationships, and allowed for early identification of issues as the intervention was progressing.

Contribution to the Science of Reading

This study contributes to the science of reading and the science of reading instruction (Shanahan, 2020) by providing empirical evidence that the repeated practice of recalling, retrieving, and reproducing letters through the act of writing serves to establish strong GPC knowledge, which leads to more efficient word-reading skills in beginning readers. Castles et al. (2018) proposed that instruction in GPCs and alphabetic decoding will have maximum benefit for higher order reading and text comprehension if this instruction is situated in the early stages of learning to read. These findings have implications for policymakers and practitioners in terms of teacher professional development in understanding how reading and writing processes can be integrated as part of effective early reading instruction. The current study meets recent calls for translational research that advances the science of reading through the implementation of instructional practices in classroom settings (Solari et al., 2020). The results will help equip kindergarten teachers with the knowledge and skills they need to support students' early reading and writing.

To read effectively and with comprehension, young learners first need a basis in the subskills that form the foundation of decoding. The science of reading has established the importance of phonological skills and alphabet knowledge in the early stages of learning to read. In this study, we found that a cotaught handwriting intervention, Write Start–K, led to statistically significant gains in these components. We speculate that the tailored handwriting intervention, emphasizing the 4*R*s (recall, retrieval, reproduction, and repetition of letter forms) model, facilitated stronger GPCs, resulting in enhanced letter and word recognition. This research contributes to the emerging evidence for the role of handwriting fluency in reading acquisition. Future research with larger samples is needed to further substantiate these results and guide practice.

NOTE

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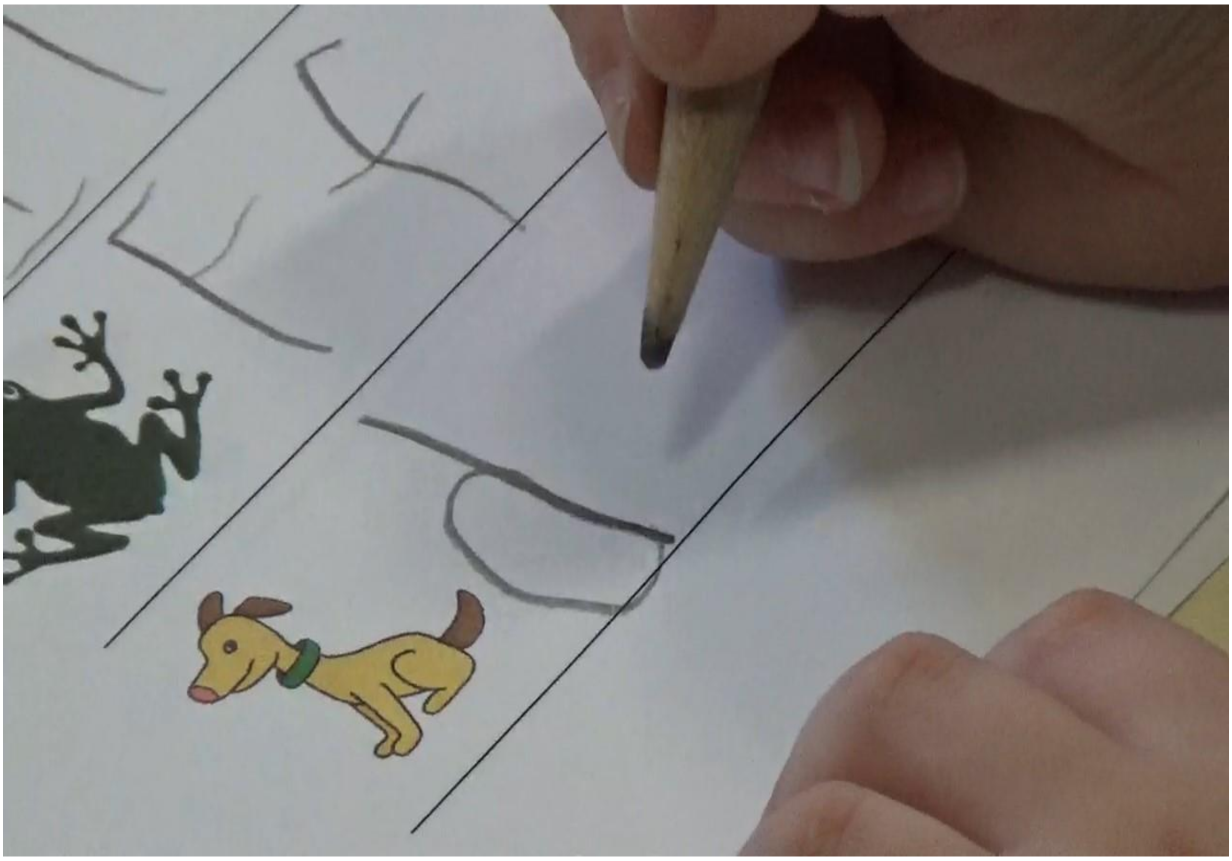
Appendix 14—Policy Brief in Development—Learning to Read the Write Way—A Policy Brief



Learning to Read the *Write* Way

A policy brief

Authored by

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The cover image is a still from a video of handwriting assessment conducted as part of the study, with consent for use of the still obtained from study participants.

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The challenge

Children who struggle with literacy from the outset of their schooling are at risk of long-term difficulties in education, with potentially pervasive effects across their lifetime. In 2020, a new report "Nurturing Wonder and Igniting Passion" was published by the NSW Education Standards Authority,[1] after a major NSW education review which commenced in 2018, in response to community and professional concerns about curriculum overcrowding and a loss of focus on foundation skills. Crucially, the report recognises Kindergarten as a critical time for building strong foundation skills for literacy, including reading and writing.

Handwriting has been identified as a core Kindergarten foundation skill requiring renewed focus because of its central role in creating written texts.[2] Recently, it has been reported that handwriting fluency, which entails the ability to write legible letters from memory, may also impact the equally foundational and vital phonic knowledge that contributes to reading.[3] However, children entering Kindergarten may be at a new level of disadvantage for acquiring handwriting skills, impacted by a profile of increasing developmental risk, particularly children in areas of socio-economic disdavantge.[4] Decreases in manual play stemming from increasingly early use of digital devices may contribute to developmental risk factors for handwriting acquisition.[5, 6] There is a paucity of evidence for curriculum-based ways to support Kindergarten students to develop handwriting skills, and wide variation in instructional practices.[7, 8] The NSW Government has committed to a new K-2 curriculum by 2022[9] based on the recommendations of the "Nurturing Wonder and Igniting Passion" report, which include a renewed focus on foundation skills in the early years and the need for capacity building for teachers to ensure they can implement the new curriculum. In this context, it is timely and essential to consider effective methods for supporting the foundation skill of handwriting. Focussing on effective instruction and intervention for handwriting may be a means to address pervasive developmental risk, support curriculum implementation through teacher capacity building, and facilitate transfer effects of fluent handwriting to literacy.

Problems

Risk for difficulty with handwriting is increasing and writing readiness is reducing

Kindergarten is a critical time for handwriting development, which requires the integration of cognitive and motor processes. However, a decline in handwriting-related motor skills in "digital natives" has recently been reported.[5] Other reports speculate that increasing use of digital technologies is the cause of teacher observations of declining student ability to concentrate and focus on learning, suggesting a possible pervasive impact of early childhood experiences on learning across all foundation skills, including handwriting.[6] These problems may be compounded in areas of high socio-economic risk, with a widening gap in developmental vulnerabilities reported between children in advantaged and disadvantaged areas[4]. The confluence of these factors may explain the concerning numbers of Kindergarten children who have low abilities in handwriting fluency at the end of their first year of school. For example, an Australian study found that nearly a quarter of Kindergarten children (42 out of n=177) were only able to write five or fewer alphabet letters in a minute.[8]

High expectations for output without a solid base

According to the Australian curriculum, by the end of the school year, Kindergarten students should be able to correctly form known upper and lower case letters, use familiar words and phrases in writing and demonstrate letter and sound knowledge.[10] However, as observed in the recent NSW Education review, time spent on foundation skill development may be compromised by overall curriculum pressure.[1] Further, explicit skills for handwriting, such as accurate letter formation, have historically been de-emphasised in favour of process writing and whole language approaches.[11-13] This shift in pedagogy may have compounded the impact of curriculum pressure.

Handwriting instruction may be a lost art

Teachers report varying levels of undergraduate training and preparedness in handwriting instruction[14-16] and there is a wide variation in both time spent on specific instruction, and instruction methods used by teachers.[8, 17, 18] Further, evidence for effective curriculum-based handwriting intervention or early intervention programs is clustered in the pre-school years, or from Year 1 on, crucially lacking in the Kindergarten year.[7] Within this context, it appears that handwriting may indeed be "a forgotten language skill" [13, p34].

Impacts on handwriting acquisition

The three proposed factors impacting handwriting acquisition, handwriting readiness, curriculum pressure and insufficient knowledge on effective instruction may converge and lead to poor handwriting acquisition (Figure 1). This is of major concern as lack of development of handwriting fluency may contribute to an insufficient solid base for literacy tasks.

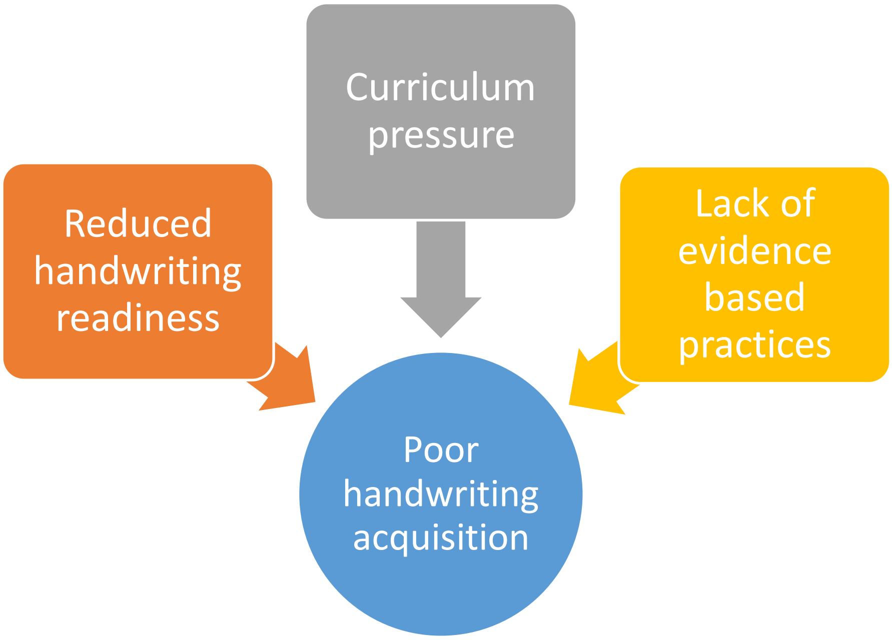

Figure 1 Factors impacting on handwriting acquisition

Addressing the current problems requires an approach that acknowledges the complexities of the issues for teachers and students, including:

- Many students in Kindergarten are impacted by developmental risk factors that may impede the acquisition of vital foundations for learning, including handwriting.
- Children with increased developmental risk factors may not necessarily respond to standard teaching of handwriting, contributing to general concern about literacy development and progress.
- Wide variation exists in time and focus spent on Kindergarten writing, suggesting a lack of clarity on the nature of effective instruction.
- There is a need for evidence on handwriting fluency acquisition and effective instructional and intervention methods to support both typically developing children, and children with increased developmental risk factors.

"…kindergarten presents a window of opportunity for preventing future reading and writing difficulties through early intervention" [19, p.29]

Potential gains - handwriting fluency impacts on literacy

Handwriting develops gradually, combining emerging knowledge of letter names, sounds and forms with developing fine and visuomotor skills. This skill is a recognised basis for writing texts.[2] Handwriting fluency refers to the ability to form upper and lowercase letters automatically from memory, and is implicit in many typical school tasks. There are also downstream impacts of handwriting fluency on writing quantity, writing quality, and reading.

Handwriting fluency releases working memory from mechanical task demands during writing composition.

Being able to recall the image of a letter and reproduce it in writing enables legible handwriting, and with practice, leads to *automaticity*, or fluency in the act of writing a letter or word. When children are able to form letters correctly and quickly, vital memory resources are directed away from mechanical handwriting processes, and are available for spelling, generating ideas and using writing structures.[20-23] Strong evidence exists for impacts of handwriting fluency in Kindergarten on writing composition, specifically:

- Number of recognisable words, sentences or ideas.[3, 23-28]
- Writing quality such as use of structure for text and complexity of word choice.[19, 25-27, 29]
- Spelling from dictation.[19, 23, 26-31]

Handwriting enhances grapheme– phoneme correspondences (GPC)

Understanding the alphabetic principle, the relationship between letter names, sounds and forms, is crucial in reading acquisition.[32] Handwriting interventions that focus on development of fluency have reported downstream benefits for early reading skills known to support the acquisition of the alphabetic principle.[3, 33] These effects are explained by the role of handwriting in creating strong grapheme-phoneme correspondences. Specifically, handwriting aids visual letter recognition and categorization.[34, 35] Further, sufficient repetition of letter writing contributes to the creation of stable mental images of letters.[34, 36]

Impacts of handwriting fluency on reading, include:

- Letter name and sound knowledge.[3, 29, 31, 33, 37, 38]
- Text reading.[30]
- Real word reading.[3, 8, 19, 23, 26, 27, 29, 31]
- Nonsense word reading.[19, 27, 29, 38]

The impact of perceptual motor skills on literacy

Perceptual motor skills such as fine and visual motor skills have traditionally been associated with handwriting abilities[39] and are associated with improved spelling[40], letter knowledge[40], letter naming fluency[37, 38] and nonsense word reading[38]. The development of these skills provides a crucial underpinning to handwriting fluency.

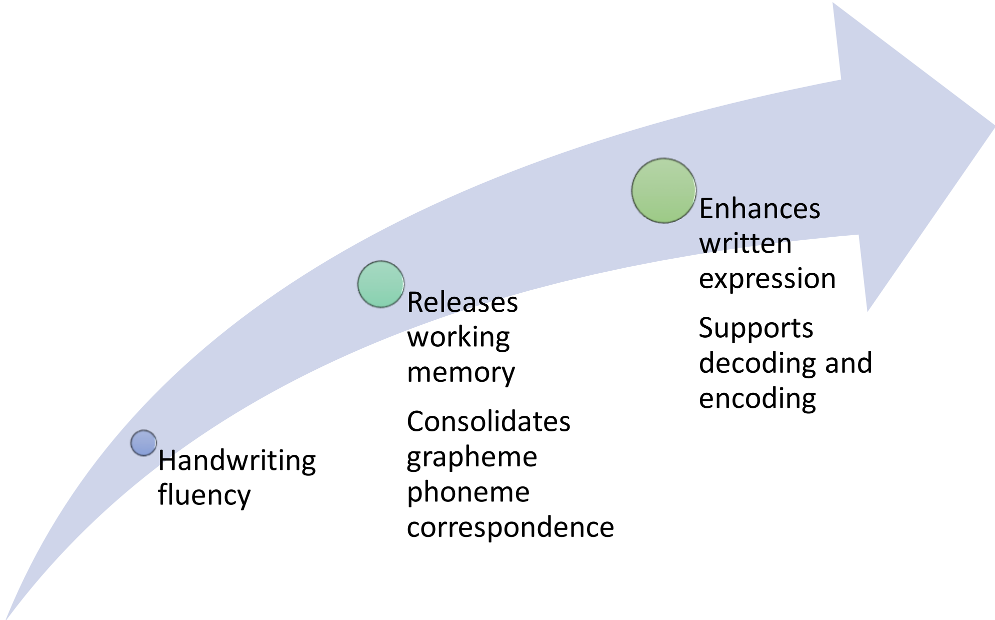

Figure 2 The downstream impacts of handwriting fluency on literacy

The 4*Rs* – A handwriting fluency acquisition model

Relationships between literacy, perceptual motor skills and handwriting fluency, which entails key cognitive skills such as memory, are evident. Handwriting intervention approaches for Kindergarten that include both perceptual motor and cognitive factors, impact literacy.[24, 25, 40] The 4*Rs* model (*Recall, Retrieve, Reproduce, Repeat)*[41]for handwriting fluency acquisition incorporates both cognitive and perceptual motor processes for beginning writers. Fluent handwriting requires: *Recall* of the orthographic code or mental representation for a letter or word[42, 43], *Retrieval* of the system of movements, or motor plan, associated with the recalled letter form[44-46], efficient letter *Reproduction* using adequate perceptual motor abilities such as fine and visual motor skills[44, 47, 48] and sufficient *Repetition*[49]. These four factors are suggested as the key elements needed to work together to create handwriting fluency. Importantly, this model integrates the evidence for impacts of memory, motor plans and perceptual motor skills in emerging handwriting. The 4*Rs* model is proposed as a practice model to enable evidence-based classroom instruction. The 4*Rs* model is also a basis for revising and updating handwriting intervention approaches.

Write start-K: A test case

The authors of this brief, through the University of Newcastle, partnered with teachers at two New South Wales regional schools to test the effectiveness of Write Start-K. The schools were identified as being from lower socio-economic areas. Write Start-K is a whole-class, co-taught Kindergarten handwriting intervention, revised using the 4*Rs* model, and adapted from Write Start, a Year 1 intervention program (Figure 3).[50-52] Co-teaching, was used as a key strategy in this intervention approach to address the potential impacts of developmental risk on handwriting fluency acquisition, by embedding occupational therapy services into the handwriting instructional sessions. The co-teaching team consisted of the class teacher, an occupational therapist and a trained assistant. Key benefits of co-teaching include the blend of skills that each partner brings to the intervention approach, information exchange and capacity building that results from working in collaboration.[52] Occupational therapy focusses on use of meaningful, age appropriate activities to support participation in tasks, in this case, handwriting fluency acquisition.

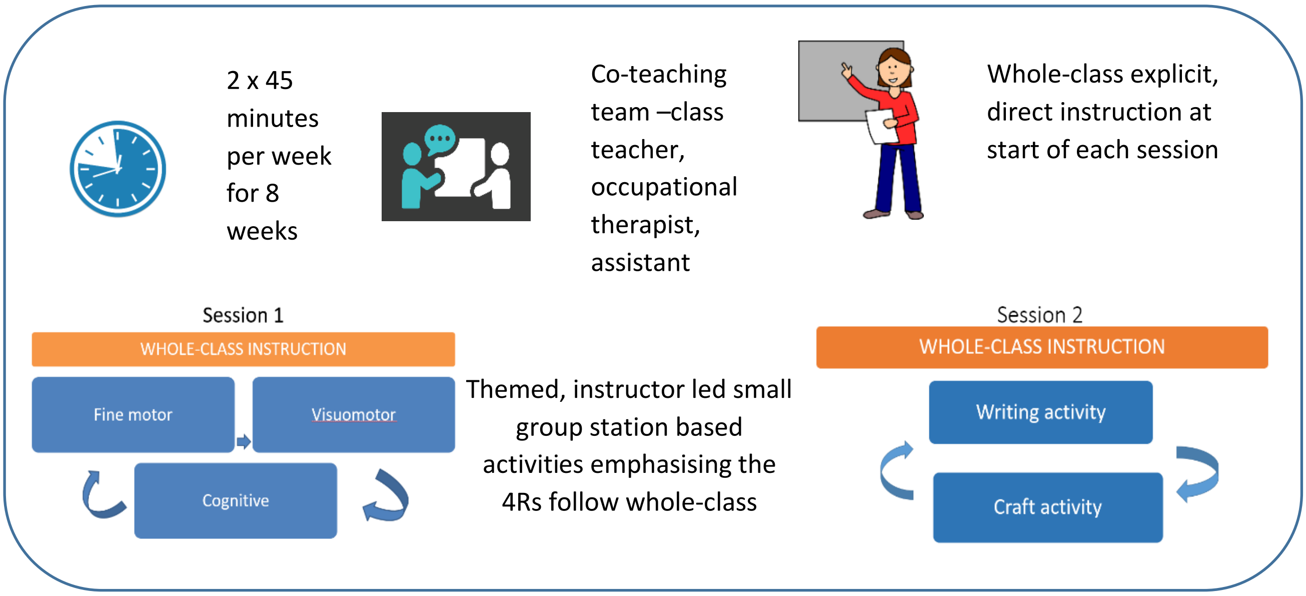

Figure 3 Write Start-K eight week intervention program

The intervention consists of two 45-minute weekly sessions for eight weeks, introducing and/or revising letter formation for small groups of letters. Whole-class instruction is followed by small group, station-based activities. Session one stations emphasise foundation fine motor, visual motor and cognitive skills during letter writing activities that activate *Recall*, *Retrieval*, *Reproduction* and *Repetition* of letter formation. Session two includes craft and writing activity stations, adapting a writing workshop approach used for Year 1. Write Start-K is informed by extensive evidence for:

- Multisensory instruction and practice to facilitate handwriting fluency (for example, mnemonics, air writing, use of a range of mediums for writing).[24, 25]
- Embedding letter name, sound and form relationships through sensory motor processes in handwriting.[53]
- Interaction of both cognitive and perceptual motor processes in handwriting fluency.[42-44, 46, 47, 49, 54]
- Enhancing mental representations of letters and letter recognition by handwriting.[34, 35, 55, 56]
- Role of novel, varied and graded tasks direct, and dynamic and explicit feedback to support skill development.[51]
- Sufficient amount of intervention to ensure an effect.[7, 49]

In our study, we administered Write Start-K to two Kindergarten classes (n=38) and compared outcomes with Kindergarten students (n= 39) in another school who received usual handwriting instruction. Both the intervention and control classes continued with similar literacy instruction. We measured the differences between groups in amount of change in handwriting fluency and literacy. We found:

Handwriting fluency gains: The intervention group made greater gains in handwriting fluency and letter sound correspondence. The intervention group made greater gains in writing recognisable letters from memory using correct letter formation and with less reliance on visual, verbal or demonstration prompts. Both of these skills were influential in the gains seen in writing composition and reading.

Writing composition gains: The intervention group made greater gains in the number of words they could write in a story. This significant growth can be explained by increased handwriting fluency, which released working memory, and allowed more attention to be given to generating ideas, spelling and writing [57].

Reading gains: After the 8 week program, the gains in key reading skills of letter name knowledge and word reading fluency were significantly greater for the intervention group than the control. This effect is a downstream impact of handwriting fluency on reading, and supports the evidence for the broader impacts of handwriting fluency on literacy in Kindergarten.

Implications

Our study tested a whole-class, co-taught intervention for Kindergarten, which was revised and updated using the 4*Rs* model of handwriting fluency acquisition. Our results, indicate that Write Start-K shows promise as method to impact handwriting fluency acquisition in Kindergarten classrooms, and may be particularly relevant in schools where socio-economic disadvantage is high. Further, Write Start-K is a promising approach to facilitating capacity building in teachers through skills exchange. More broadly, the 4*Rs* model is a potential framework to:

- Integrate handwriting instruction with reading and writing outcomes.
- Devise activities that promote letter name, sound and form relationships through handwriting.
- Strengthen the relationships between letter names, sounds and forms to support writing, spelling and reading.
- Underpin teacher practice guidelines to support curriculum goals and outcomes for Kindergarten.

Key policy options

On the basis of the existing literature and new data from the study described in this brief, we recommend a range of policy options for a broad range of stakeholders including education standards authorities, government departments, professional bodies and tertiary institutions. Specific policy options are detailed for each.

Policy options for **education standards authorities** at a state and national level include:

- Ensure evidence informed practices are included in teacher practice guidelines for handwriting instruction, specifically:
    1. Outline factors that contribute to handwriting fluency acquisition, including memory of letters and associated correct formation patterns, skills that impact letter writing such as hand and eye-hand skills, and the need for sufficient repetition to develop these skills and embed letter form relationships.
    2. Differentiate between handwriting legibility and fluency, by explaining the role of memory in handwriting fluency, in contrast to copying or tracing tasks.
    3. Report evidence for relationships between handwriting fluency and literacy, both reading and writing.
    4. Emphasise evidence from frameworks that integrate knowledge of both cognitive and motor processes that underpin handwriting fluency acquisition such as the 4*Rs.*
- Seek out and approve professional development opportunities for teachers that provide evidence-based instructional methods for handwriting fluency acquisition.
- Identify effective handwriting instruction as an important inclusion in priority professional development areas.

Policy options for **departments of education** responsible for funding and resourcing of schools include:

- Address potential for large proportions of children in lower socioeconomic schools to be impacted by issues of developmental risk, with potential for flow on difficulties with handwriting acquisition through:
    1. Upscaling access for schools in high areas of need to co-teaching partnerships, such as with occupational therapy, to support handwriting fluency acquisition in Kindergarten.

2. Increase access to professional development for teachers to upskill and capacity build in the area of handwriting fluency acquisition, such as through the identification of and training in courses that target handwriting fluency acquisition.
3. Consider research partnerships with tertiary institutions to build the knowledge base for effective handwriting fluency intervention approaches that can be delivered to whole classes in areas of need.

Policy options for **tertiary institutions** include:

- Increase inter-disciplinary training at undergraduate level to upskill teachers in mechanisms for promoting handwriting fluency.
- Embed instruction on handwriting fluency acquisition into undergraduate teaching programs.
- Increase inter-disciplinary practice experiences as part of educational training, such as collaboration between student occupational therapists and student teachers.
- Collaborate with education departments in researching handwriting instruction, intervention and benefits of different methodologies for both.

Policy options for **professional organisations** include:

- Generate a practice guideline for occupational therapists for working in schools collaboratively with teachers to support handwriting fluency acquisition.
- Ensure accessible resources on effective handwriting fluency acquisition instruction and intervention, relevant to professional disciplines.

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