

Attention Resolution and Reading Fluency in Young Children

by

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A Thesis submitted to the Faculty of Graduate and Postdoctoral Studies of

The University of Manitoba

in partial fulfilment of the requirements of the degree

MASTERS OF ARTS

Department of Psychology

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Abstract

Visual attention may support reading by helping readers select information from crowded displays, but evidence linking visual attention and reading has been inconsistent. This longitudinal study examined the development of attention resolution and attention resolution efficiency from kindergarten to Grade 1 and their relationships with reading. Attention resolution was measured using accuracy in the close–slow condition of a dot-tracking task (the “Firefly” task), whereas attention resolution efficiency was measured using accuracy in the more speed-demanding close–fast condition. The initial sample included 147 children, and longitudinal regression analyses used 96 participants. Children also completed standardized measures of phonological awareness, letter and word identification, decoding, nonverbal reasoning, and timed word-reading efficiency. Hierarchical multiple regressions tested whether kindergarten close–slow and close–fast accuracy predicted Grade 1 Total Word Reading Efficiency, Word Identification, and Word Attack after accounting for kindergarten Elision (phonological awareness). Neither attention measure accounted for additional variance in the reading outcomes, whereas Elision consistently predicted all three outcomes. Multilevel models using repeated observations indicated that close–slow and close–fast accuracy improved significantly over time. Reading efficiency was not associated with close–slow accuracy at the centred kindergarten intercept and did not explain close–slow growth. In contrast, higher reading-efficiency scores were associated with greater close–fast accuracy at the centred intercept. Reading efficiency did not explain close–fast growth. Overall, kindergarten attention resolution did not independently predict Grade 1 reading after phonological awareness was considered. However, the association between reading efficiency and close–fast accuracy suggests that reading-related differences may be more apparent when children must rapidly resolve closely spaced stimuli. The findings

demonstrate developmental improvement in both attention processes while identifying phonological awareness as a stronger longitudinal predictor of early reading. These conclusions should be interpreted cautiously because of attrition-related differences, upper-end concentration in accuracy, and the absence of equivalent reading measures across waves.

Keywords: attention resolution, visual attention, reading fluency, early literacy, longitudinal development

Acknowledgements

I would like to express my sincere gratitude to my advisor, Dr. Richard Kruk, for his guidance, patience, and encouragement throughout this project. His thoughtful feedback and expertise shaped this thesis and supported my development as a researcher. I am also grateful to my committee members, Dr. Amy Desroches and Dr. Sunmee Kim, for their time, expertise, and insightful feedback. Their perspectives strengthened this work and its interpretation.

I gratefully acknowledge the financial support provided by the Social Sciences and Humanities Research Council (SSHRC) Canadian Graduate Scholarship—Master's, Tri-Agency Top-Up Award, the University of Manitoba Tri-Agency Master's Supplement Award and the Research Manitoba Masters Studentship. This funding supported my graduate studies and contributed to the completion of this thesis.

This study would not have been possible without the children and families who participated. I also thank the schools, educators, research assistants, and others who supported recruitment and data collection.

Finally, I thank my sister, Feven, for encouraging me to return to my work when I needed it most; my partner, James, for his unwavering love, patience, and support; and all my dearly beloved friends, but especially Jenny, Jared, Aswin, Sarah, Ian, Chaz, Zal and Natalie, for being my biggest cheerleaders. I am also grateful to my classmates for helping make graduate school an unforgettable experience.

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Attention Resolution and Reading Fluency in Young Children

Reading is a skill that supports success in school and continued learning. Thus, reading is heavily emphasized throughout early years of schooling for children to ensure this skill is developed strongly. However, over one million Canadian children under the age of 15 score below-average for reading skill expected at their grade-level (Deloitte, 2020). With this in mind, it is imperative that we better understand the factors associated with reading difficulty, and identify struggling readers who may require early support to flourish within their education.

Several cognitive processes are important for the emergence of basic reading skills (e.g., decoding and fluency) during early years of education (Wolf & Pfeiffer, 2014). Phonological processing is understood within literature to have influence on reading difficulties (Deacon & Kirby, 2004). Phonological processing involves recognizing and working with the sound components of spoken language (phonemes). The ability to have phonological awareness comes from being able to identify and manipulate syllables, phonemes, and other units of speech. This includes identifying and manipulating sounds at different levels, such as syllables. Yet, it is important to note the interplay of cognitive factors that influence reading difficulties. A meta-analysis study by Kudo et al. (2015), note the wide array of academic, cognitive and behavioural factors that contribute to reading struggle.

Of these processes, visual attention has gained the interest of many researchers in recent years (Cirino et al., 2022; Perry & Long, 2022; Valdois et al., 2025). Reading requires visual attention because it makes text processing more effective (Hildebrand, 2019). Visual attention may support reading by helping readers select relevant letters and words while ignoring surrounding visual information. One aspect of visual attention that may be relevant to reading is visual-spatial attention.

Visual-Spatial Attention and Attentional Shifting

The term "visual-spatial attention" describes the capacity to concentrate on a particular spot or region inside the visual field (Gavril et al., 2021; Perry & Long, 2022). This process involves focusing attention on a specific spatial location, ignoring other areas, and enabling improved processing of stimuli in that area. For instance, you might concentrate on each section of the cluttered table independently to find your keys if you are looking for them. Gavril et al.'s (2021) meta-analysis identified an overall association between visual-spatial attention and reading performance. The analysis synthesized findings across studies involving different age groups and attention measures. These studies considered various age groups, from early childhood to adolescence, and the main result was that strong visual-spatial attention corresponds with efficiency in reading, particularly in tasks involving complex visual environments. The analysis revealed that children with well-developed visual-spatial attention skills are not only quicker at learning to read but also demonstrate greater proficiency in tasks requiring the differentiation of similar letters or words, such as distinguishing between "b" and "d" or quickly identifying words in a densely packed text. Their capacity to concentrate on a particular spot or region inside the visual field is shown to directly correlate with reading speed and accuracy, as well as overall reading fluency. Gavril et al. (2021) proposed that this phenomenon exists because visual-spatial attention aids in prompt and precise letter and word recognition, which is critical for smooth reading. Additionally, there has been neurological evidence that due to atypical distribution across the visual field, dyslexic children have been seen to have atypical functioning of their visual-spatial attention which results in impaired performance on visual search tasks (Gavril et al., 2021). It was hypothesized that this phenomenon has to do with dyslexic individuals possibly having delays in their visual attention development with worse

orientation discrimination and lower attentional selection on visual search tasks (White et al., 2019) Therefore, atypical visual-attention development may be associated with difficulty acquiring reading skills.

Additionally, Franceschini et al. (2012) experimentally examined whether visual-spatial attention training transferred to reading performance. This study did not just observe correlations, but the research team employed an experimental design. They trained children in attention tasks with visual-spatial qualities. They found that children who were in the training group showed meaningful improvements in their reading speed and accuracy in comparison to the control group which had no training. The control group did not display significant improvements in their reading scores. These findings suggest that visual-attention training may influence reading performance, although further evidence is needed to establish the reliability and scope of this transfer.

Visual-spatial attention is not the only mechanism that can influence reading efficiency. Attentional shifting, the process of switching between two or more stimuli, on reading efficiency, has also been found to play a role (Lallier et al., 2010). Lallier et al. (2010) found that young adults with dyslexia displayed slower attentional shifting during auditory and visual stream-segregation tasks. Specifically, they required longer intervals between successive tones or dots to perceive them as separate streams than controls did, indicating that they needed more time to disengage attention from one stimulus and re-engage it with the next. Later, Franceschini et al. (2022) examined associations between visual-spatial attention and reading difficulty. Visual-spatial attention was assessed using a paper-and-pencil labyrinth task of elementary school students, grades two to five. While controlling for working memory, the study discovered a weaker visual-spatial attention among children experiencing reading difficulty, which was also

associated with performance on tasks such as letter and word recognition, tracking lines of text while reading, and accurately distinguishing between similarly shaped letters like "p" and "q" or "m" and "n." These tasks are critical for fluent reading, as they require the ability to focus on and process visual details quickly and accurately. It is possible that orthographic (visual word) processing of letter strings¹ involves visuo-spatial attention mechanisms. Franceschini et al. (2022) proposed that difficulties with attention cause reading speeds to slow down and frequent errors to occur. The children who struggled with visual selective attention found it difficult to process visual information in written text efficiently.

Franceschini et al. (2017) examined whether action-video-game training influenced attentional shifting and reading among children with dyslexia. They were particularly interested in observing children with dyslexia. The study looked specifically at a form of cross-modal attention shifting from visual to auditory. This kind of task required the children to make accurate and quick shifts of focus. Critically, children needed to move from visual information to auditory inputs. Children with dyslexia often wrestle with this ability to mix visual and auditory information which is crucial for efficient reading skills (Franceschini et al., 2017). Franceschini et al. discovered that dyslexic children who played action video games exhibited a crucial difference from participants who did not. Children's ability to shift attention between different senses significantly improved. Training with video games effectively improved selective phonological decoding and increased attentional control, which is thought to be caused by plasticity induced in the fronto-parietal attentional control (Franceschini et al., 2017). They also observed improvements in reading efficiency after the action video game training, which was measured by increased reading speed without decreases in accuracy. These studies not only

¹ Letter strings are words that contain the same grouping of letters (e.g. -ight, right, fight, light) Franceschini et al. (2022).

support the connection between attention resolution and reading efficiency, but it also once again suggests attention-based interventions that can target specific cognitive deficits which impede reading skills development.

Visual Selective Attention and Reading Acquisition

Visual selective attention involves prioritizing relevant visual information while limiting interference from competing stimuli (Casco et al., 1998; Perry & Long, 2022). This process involves the capacity to weed out unimportant stimuli and focus on the most crucial or pertinent visual objects to achieve a goal. When reading a book in a noisy café, for instance, you focus just on the words on the page and tune out other distractions. While visual selective attention manages items within a given space, visual spatial attention focuses on space itself. Indeed, research by Casco et al. (1998) was some of the first to show a direct connection between children's visual selective attention and reading performance. The study measured accuracy, which was assessed as a function of set size for visual selective task. The visual selective attention task involved having children identify a specific letter within a crowded visual field, with varying degrees of difficulty depending on how many distractor letters were present. They found that children with refined visual attention skills could perform better on reading tasks. More specifically, as the number of distractor letters increased, children with higher visual selective attention skills maintained high accuracy in identifying the target letter, whereas children with lower attention skills showed a significant drop in accuracy (Casco et al., 1998). These findings were significant because they demonstrated that children with better developed visual attention could read quicker and with higher accuracy than their peers with lower visual selective attention skills. This study was a landmark in noting that reading is not just a skill in

language but also heavily depends on cognitive processes such as visual attention, which permits the effective analysis of text.

While there have been connections established between visual attention and reading acquisition, exactly how it affects reading is still controversial and has varied with the type of attentional skills tested, the nature of stimuli and tasks used, and whether other phonological and language skills were taken into account (e.g., Cirino et al., 2022; Gavril et al., 2021; Perry & Long, 2022). What is not clear is the nature of this relationship: it is possible that differences in visual-attentional skills can cause differences in reading, but that reading instruction itself reorganizes visual cortical systems involved in word recognition (Feng et al., 2022). Therefore, attentional differences may contribute to reading difficulties, emerge alongside reading instruction, or reflect a reciprocal relationship between visual attention and reading development.

Visual Crowding

Visual crowding occurs when nearby elements interfere with identification of a target, and research has shown it may significantly impact reading decoding and fluency. Pelli and Tillman (2008) support this relationship, demonstrating that inter-letter spacing affects performance across visual attention tasks, including the visual attention span. Visual attention span describes the amount of letter information that can be processed simultaneously. Pelli and Tillman (2008) argue that letter spacing, not letter size, determines reading speed. Visual crowding limits the number of letters we can process during fixations, thereby affecting reading rates.

Legge et al. (2007) estimated that reading speed increased by approximately 39% for every additional letter encompassed by the visual span. He and Legge (2017) further linked visual attention span to reading speed, showing that a larger visual span correlated with faster

reading speeds. This reinforces the idea that proficient reading requires a high degree of attentional focus. An extended visual span may support faster reading, whereas a restricted visual span may contribute to slower reading performance (Hawelka & Wimmer, 2005; He & Legge, 2017; Legge et al., 2007). Hawelka and Wimmer (2005) found that readers with dyslexia required progressively more time and eye movements as word length increased. This word-length effect suggests that these readers processed fewer letters during each fixation than typical readers.

Martelli et al. (2009) indicated that visual crowding affects peripheral vision more than central vision. Due to visual crowding, children who struggle with reading may have a reduced visual attention span, making it harder to decode text and leading to less fluent, slower reading. Joo et al. (2018) explored individual differences in children's visual systems, suggesting that predispositions to crowding may influence reading challenges. Their findings indicated that poor readers were more susceptible to crowding effects, particularly in the peripheral visual field, than typical readers. This heightened susceptibility suggests that poor readers may have coarser attention resolution, making it harder for them to identify individual letters when they were surrounded by competing visual information. Such coarser resolution may underline their difficulties in efficient decoding and fluent reading.

Chiu and Drieghe (2023) focused on text spacing, examining how increasing space between words and letters could minimize visual crowding. Their research found that increasing spacing reduces crowding strain and facilitates text processing, especially for children struggling with reading. Children with coarser attention resolution limits may have difficulty distinguishing individual letters due to visual clutter. These children's diminished clarity in letter recognition stems from their poor capacity to focus on and discern between closely spaced letters. By

increasing text spacing, the overlap and distraction from nearby characters are lessened, making it easier for these children to process and interpret written information.

Recent studies further elaborate on the effects of spacing on reading performance. Łuniewska et al. (2022) investigated the impact of inter-letter spacing on reading performance and eye movements in typically reading and dyslexic children, supporting the notion that increased spacing can aid those with reading difficulties. Conversely, Korinth et al. (2020) observed that while wider letter-spacing facilitates word processing, it may impair reading rates for fast readers who are not dyslexic. These findings suggest that individual differences in visual processing must be considered when designing interventions to mitigate visual crowding and enhance reading skills.

Overall, substantial evidence supports the idea that visual crowding and reading efficiency are related. A coarse attention resolution can exacerbate a predisposition to crowding effects, making it harder to isolate and focus on individual letters, especially when they are closely surrounded by others (Joo et al., 2018). This increased susceptibility can lead to a reduced visual attention span, limiting the number of letters processed in a single glance (Pelli & Tillman, 2008), and a narrower visual span, or the amount of visual information processed at one time (Legge et al., 2007). Both visual attention span and visual span contribute to fluent decoding by supporting the rapid recognition of letter patterns and words. A coarse attention resolution reduces this capacity, leading to slower, less accurate decoding, which can impair reading comprehension by hindering smooth translation of text into meaningful language (Hawelka & Wimmer, 2005; He & Legge, 2017). These findings suggest that visual span and attention resolution warrant further investigation as possible targets for supporting children with reading difficulties.

The Development of Attention Resolution

Wolf and Pfeiffer (2014) offer a detailed overview on the development of attentional resolution. They point out that this skill is not fully developed right away. Rather, it progresses gradually through early childhood and continues to develop into adolescence. The goal of Wolf and Pfeiffer's study (2014) was to chart the developmental trajectory of attentional resolution from middle childhood to adulthood. They used an object tracking task with variations in the minimum distances between objects to be tracked and distractors. The task required mere individuation instead of identification, specifically exploring the lower bound of attentional selection. Individuation involved distinguishing and tracking objects as separate entities without recognizing or labelling them, while identification requires recognizing and categorizing the objects. In Wolf and Pfeiffer's (2014) study, focusing on individuation meant tracking objects based on their movement or position without needing to identify them, exploring how well participants could maintain attention amidst distractors. Their findings reveal a significant improvement in attentional resolution between 7 years of age and adulthood, with notable advancements occurring between 7 and 9 years, and another substantial change between 13 years and adulthood. The study suggests a plateau in development between 11 and 13 years, indicating a deceleration in the rate of improvement during early adolescence. Improvements are noted to be possibly due to neurological maturation. However, they also result from the increasing complexity of environmental demands. Moreover, the study's implications extend to understanding the acquisition of reading abilities and potential implications for dyslexia treatment. It suggests that adjustments in letter size and spacing in reading material could facilitate successful reading acquisition, while interventions targeting attentional resolution may benefit individuals with dyslexia.

Wolf et al. (2018) used functional magnetic resonance imaging (fMRI) and a dot-tracking task to investigate the neurocognitive mechanisms underlying the resolution of visuospatial attention. Their findings showed that the development of attentional resolution is linked to strengthened activation and enhanced connectivity in the fronto-parietal network when comparing groups of 7- and 11-year-old children. The fronto-parietal network is crucial for attention control. The study showed that as children grow older there is a significant increase in the efficiency and overall effectiveness of this network. This facilitates performance in tasks that are attention demanding. Regions like the posterior parietal cortex, which engages in spatial attention and visual processing, and the dorsolateral prefrontal cortex, which is involved in executive function and attentional regulation, are part of the fronto-parietal network. Wolf et al. (2018) discovered an increase in these brain regions' efficacy and efficiency as children get older. Children perform better on activities demanding high degrees of attentional focus, such as those requiring the precise isolation and identification of visual stimuli, due to the improved connection between the frontal and parietal regions. Furthermore, the research showed a clear correlation between enhancements in cognitive control and attention regulation and fronto-parietal network growth. Younger children frequently struggle with tasks requiring selective attention because they show less developed connectivity within this network. On the other hand, older children with better fronto-parietal connections demonstrate noticeably finer attentional resolution, making it easier for them to individuate closely spaced objects, block out distractions and concentrate on important stimuli.

Individual Differences in Attention Resolution Development

Individual differences are important to consider when discussing attentional resolution. Wolf and Pfeiffer (2014) found that attention resolution improved substantially across childhood,

although its development was not uniform across all ages. Neuroimaging evidence further indicates that these behavioural improvements are accompanied by developmental changes in the frontoparietal networks involved in controlling visual-spatial attention (Wolf et al., 2018). Together, these findings suggest that individual differences in attention resolution may partly reflect variation in the timing and progression of broader cognitive and neural development.

Hildebrand (2019) examined attention resolution and attention resolution efficiency in Grade 2 and Grade 6 children who differed in reading ability. The study used a dot-tracking task in which children had to identify a target dot while ignoring surrounding distractor dots. The task varied both the distance between the target and distractors and the speed at which the dots moved. These manipulations allowed the study to assess how accurately children could process visual information when it was presented under relatively easy or demanding conditions. Within each grade, children with stronger reading abilities generally performed more accurately than children with weaker reading abilities. The difference was especially apparent when the target and distractor dots were close together or when the dots moved quickly, because these conditions required more precise and efficient visual attention. However, the age-related findings complicated a simple reading-experience explanation. Grade 6 children with weaker reading abilities performed better than Grade 2 children who had been matched to them on reading age. In other words, the older struggling readers showed stronger attention-resolution performance even though their reading performance was similar to that of the younger children. This pattern suggests that chronological age and broader developmental maturation may contribute to attention-resolution performance beyond the effects of reading experience alone. At the same time, because the study compared different age and reading groups at one point in time, it could not determine whether maturation caused the observed differences or whether stronger attention

resolution led to better reading. Overall, Hildebrand's findings indicate that attention resolution is associated with both age and reading ability, particularly under demanding visual conditions, but they do not establish a causal relationship between reading development and improvements in attention resolution.

Attention Resolution and Reading Acquisition

Attention resolution is explained as the smallest spatial distance allowing the ability to focus selectively on pertinent stimuli and ignore irrelevant ones and has been found consistently related with reading development. Reading efficiency, defined as how well text can be read and understood, also appears to be associated with reading development in parallel to attention resolution (Franceschini et al., 2022). Reading fluency is an aspect of reading efficiency that observes the ability to accurately read text at an appropriate rate (Peters et al., 2019). Some visuo-attentional interventions have produced improvements in reading outcomes, although the evidence and proposed mechanisms remain mixed (Peters et al., 2019). There seems to be an apparent relationship between attention and reading, yet observations of attention resolution and reading fluency need further investigation.

As stated earlier, attention resolution refers to the smallest distance permitting ability to precisely isolate and localize visual areas within conscious attention. This skill is crucial for visual analysis, as it enables individuals to distinguish and identify specific objects within a densely packed array (He et al., 1997). Attentional resolution is often measured by tasks that require individuals to discriminate between closely spaced stimuli or to track moving objects with high spatial accuracy (He et al., 1997). Attention resolution continues to develop during childhood (Wolf & Pfeiffer, 2014). Previous studies have also identified associations between attention-resolution performance and reading ability, with stronger readers generally

demonstrating greater accuracy than struggling readers within the same age group (Hildebrand, 2019). However, these findings do not establish that attention resolution directly causes stronger reading performance. For instance, those experiencing difficulties in visual-spatial attention are likely not to grasp information clearly because they may find it hard processing such details (Franceschini et al., 2022).

Attention resolution efficiency refers to the ability to adjust the spatial precision of attention as processing demands change (Hildebrand, 2019). In the Firefly task, it was represented by children's accuracy when the targets were closely spaced and moving quickly. This condition required children to resolve spatially crowded information while responding to increased movement-speed demands. Attention resolution efficiency may be relevant to reading because fluent reading requires the rapid selection and identification of closely spaced visual information; however, its independent contribution to reading remains uncertain. One example of the visual demands involved in learning to read is distinguishing between mirror-image letters such as "b" and "d." This discrimination requires the developing reading system to overcome mirror invariance which is the visual system's natural tendency to treat an object and its left-right mirror image as equivalent. Although mirror invariance supports object recognition, it can initially produce letter-reversal errors; with reading experience, the visual word form area becomes sensitive to the orientation of individual letters (Pegado et al., 2011). Attention resolution efficiency may similarly help children identify closely spaced letters accurately and rapidly. However, this proposed relationship remains theoretical, and the available evidence does not establish that attention resolution efficiency directly causes faster, more accurate, or more fluent reading.

The possible effect of attention resolution and attention resolution efficiency on reading accuracy and fluency can be vital to understanding the underlying mechanisms of reading acquisition and reading difficulty.

Current Study

This study aimed to expand upon existing literature on individual differences in attention resolution and reading development. We examined the connection between attention resolution and achievement in basic reading abilities such as word decoding and reading fluency. Despite findings relating to visual selective attention and reading development, gaps within the research remain. We do not fully understand the predictive relation between attention resolution and attention resolution efficiency and reading acquisition. Although previous research shows that aspects of visual attention, such as visual selective attention and visual attention span, can play roles in uniquely predicting overall reading skills, the current study is focused on how attention resolution specifically predicts reading acquisition through a longitudinal design, tracking the development of reading abilities from kindergarten to Grade 1. By tracking these changes over time, we can better understand the impact of attention resolution on reading development.

Hildebrand (2019) used a similar dot-tracking task to compare attention-resolution performance among Grade 2 and Grade 6 children with different levels of reading ability. Because that study was cross-sectional, it provided evidence of age- and reading-group differences but could not directly measure within-child development. Furthermore, comparatively little research has followed attention resolution longitudinally during kindergarten and Grade 1, when foundational reading skills are emerging. The present study addressed this gap by examining changes in attention resolution and attention resolution efficiency from kindergarten to Grade 1 and their associations with reading performance.

The main goal of our study was to determine if attention resolution and attention resolution efficiency could be useful in predicting reading skills in young children. Our attention resolution measure is conducted through a computerized dot-tracking task called the Firefly task. The Firefly task consists of the participant following one specific firefly dot amongst a crowd of other firefly dots on the computer screen. A firefly-catching narrative was used to produce an interesting task narrative to enhance children's engagement during the task. The goal is for participants to remember the starting "firefly" and track it during its motion and motion of distractor dots, involving modulation of dot motion speed (slow and fast) and minimum distance separating dots (close and far). Attention resolution and attention resolution efficiency were assessed using participants' accuracy in identifying the target firefly under different distance and speed conditions. Attention resolution was qualified as accuracy in the close-slow condition, which assessed participants' ability to distinguish the target when the fireflies were closely spaced while minimizing demands associated with movement speed. Attention resolution efficiency was qualified as accuracy in the close-fast condition, which assessed participants' ability to maintain fine-grained attentional resolution when the fireflies moved quickly. Thus, the two conditions had equivalent spatial demands but differed in their temporal demands. Our study also included specific standardized reading measures.

Hypotheses

Two primary hypotheses guided the study. First, attention resolution and attention resolution efficiency measured in kindergarten would predict reading efficiency (decoding and fluency) in Grade 1 children when controlling for kindergarten phonological processing. Previous research has identified associations between attention-resolution performance and reading ability, particularly under demanding spatial and speed conditions (Hildebrand, 2019;

Wolf & Pfeiffer, 2014). Accordingly, kindergarten attention resolution and attention resolution efficiency were expected to be positively associated with Grade 1 decoding and word-reading efficiency.

Attention resolution may support reading by helping children select individual letters or letter sequences from surrounding visual information. Greater spatial precision could facilitate the identification of closely spaced visual elements, although reading also depends on phonological decoding, lexical knowledge, and language comprehension. Previous research has identified associations between visual-spatial attention and reading performance, but the independence and direction of this relationship remain uncertain (Gavril et al., 2021; Hildebrand, 2019).

Attention resolution efficiency may support word recognition and decoding by facilitating the rapid selection of relevant visual information (Franceschini et al., 2017; Peters et al., 2019). Efficient attentional processing allows for quicker recognition of letter patterns, reducing the time needed to decode words. Speed and flexibility in attention help children process text more fluidly, contributing to smoother reading and comprehension. Studies like those by Franceschini et al. (2017) and Wolf & Pfeiffer (2014) suggest that efficient visual attention and rapid attentional shifting are key components in developing fluent reading skills, supporting smoother decoding and word reading efficiency. Attention resolution and attention resolution efficiency develop throughout childhood, although the respective contributions of neurological maturation and reading experience remain uncertain (Hildebrand, 2019; Wolf & Pfeiffer, 2014; Wolf et al., 2018). Younger children are still refining these skills, while older children benefit from more developed neural connectivity in regions responsible for visual processing and attention control (Gavril et al., 2021). Hildebrand (2019) identified age-related

differences in attention-resolution performance, allowing older children to resolve visual information more efficiently, which supports fluent reading. These developmental improvements are observed across age groups and among children with different levels of reading performance, highlighting the role of attention resolution in reading proficiency.

Secondly, it was hypothesized that Grade 1 reading ability would be associated with children's attention resolution performance and its development over time. Close-slow accuracy was selected as the measure of attention resolution because it represented performance under close spatial conditions. Close-fast accuracy was selected as the measure of attention resolution efficiency because it combined close spacing with increased speed demands. Reading ability was represented continuously by Grade 1 TOWRE-2 Total Word Reading Efficiency (TWRE) scores. Higher TWRE scores were expected to be associated with greater close-slow and close-fast accuracy at the kindergarten-centred intercept and with rates of change in accuracy over time. These associations were expected to be stronger for close-fast accuracy because this condition combined spatial and speed demands. TWRE was measured in Grade 1, thus, these effects were interpreted as associations with model-estimated attention performance and growth.

Phonological processing, our ability to process sounds in language plays an established role in children's reading development (Deacon & Kirby, 2004). To increase the validity of the conclusions of this research and avoid phonological processing becoming a confounding variable, several standardized reading measures were administered. The Elision subtest from CTOPP-2 (Comprehensive Test of Phonological Processing-Second Edition) measures phonological processing. Including performance on this test in our statistical analyses should allow us to isolate phonological processing and observe if there are significant unique effects

involving attention resolution and attention resolution efficiency and reading, independent of phonological processing.

This study was specifically designed to extend our knowledge of the roles that attention resolution and attention resolution efficiency play in very young children's reading skill development in a number of ways. First, to expand our knowledge beyond the age ranges previously investigated by offering in-depth insights into how attention resolution and attention resolution efficiency affect early reading acquisition. The study examined whether early differences in attention resolution and attention resolution efficiency impact the development of fundamental reading abilities like decoding and fluency by concentrating on younger children. In order to provide insight on developmental trajectories and how these cognitive processes change as children progress from kindergarten to Grade 1, the study illuminated the features of attention resolution and attention resolution efficiency at earlier ages than has been done in previous research. More broadly, the study aimed to address gaps in literature by examining attention resolution and attention resolution efficiency in early readers.

Methods

Participants

The present data were collected as part of a broader longitudinal project that started in spring 2023. Participants were recruited from six public schools in Winnipeg, Manitoba. Participant data was collected in kindergarten and reassessed in Grade 1 allowing for repeated measures study design. Ethical approval from the University of Manitoba was obtained; parents/guardians of participating children provided signed written consent (see Appendix A). Children provided verbal assent before testing and were informed that they could discontinue participation at any point.

In spring of 2023, Cohort A (wave 1; $n = 79$) was tested. In the spring of 2024, Cohort B (wave 1; $n = 68$) was tested. Simultaneously, Cohort A participants were tested again as first grade students (wave 2; $n = 70$). In spring 2025, Cohort B was tested for their Grade 1 scores (wave 2; $n = 46$). There was a total of 147 participants ($N = 147$) who were involved in wave 1 data collection. Due to attrition, there was a total of 116 participants ($N = 116$) who participated in wave 2 data collection.

The participants included in the study met the inclusion criteria: were between the ages of four to seven years old at the time of testing; had normal-corrected visual acuity and if not, they were required to use their usual corrective lenses when the testing occurred; and capable of using and understanding the English language.

Participants were included in each analysis when they provided valid data for the variables required by that analysis. For the first hypothesis, participants were required to have valid scores for the outcome, predictors, and covariates included in the regression model. For Hypothesis 2, the unconditional models included participants with at least one valid observation for the relevant attention outcome. The conditional models additionally required a valid Grade 1 TWRE score. Maximum-likelihood estimation allowed participants with partially missing repeated attention observations to contribute their available data. Participants were excluded only when they did not meet the study eligibility criteria or when their task data were insufficient to produce a valid score. Consequently, sample sizes varied across analyses.

Procedure

Before going to the schools to collect in-person data, all lab research assistants had two training sessions, and practiced both the computer- and reading-based tasks and how to standardize delivery of the task.

Research assistants sat with each participant throughout the testing procedure in an unused room that was free from distractions as much as possible. The test sessions consisted of two consecutive days with the total time for testing being 45 minutes on each day. Children were administered a combination of reading-based and computer-based measures and testing sessions were counter-balanced among participants. The computer-based portion involved playing a series of computer tasks, including the Firefly task, and the reading-based portion involved administering a number of reading tests.

Measures

Firefly Task

The present study used the Firefly task previously administered by Hildebrand (2019), which was adapted from Wolf and Pfeiffer's (2014) dot-tracking procedure. The task provided measures of attention resolution and attention resolution efficiency. A firefly-catching narrative was incorporated to maintain children's interest and engagement. Children were instructed to follow the "special" firefly, which represented the target. Their cumulative number of correct responses was displayed using an animated jar accompanied by the message, "You caught # fireflies!"

The task involves two target-distractor minimum distances (close: 3.5 arcmin, 0.224 cm; far: 8 arcmin, 0.512 cm) and two speeds (slow: 0.645 cm/s; fast: 2.2575 cm/s), yielding 48 trials (12 per condition). These visual angle measurements were converted to linear distances based on a screen distance of 100 cm. Additionally, the minimum center-to-center spacing between distractor dots was set at 6 arcmin (0.384 cm), consistent across all trials. The practice procedure followed Hildebrand (2019).

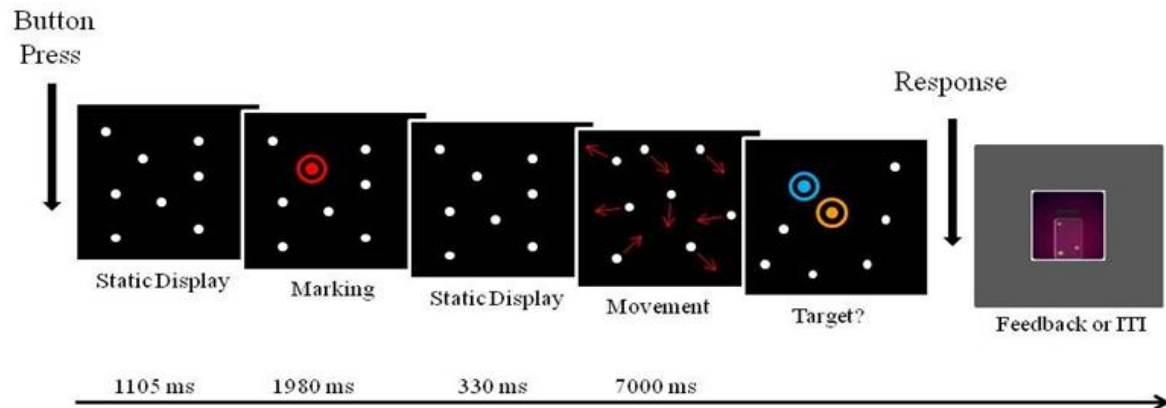
The chosen distance and speed parameters align with prior research demonstrating that children could track dots at 8 arcmin with 75% accuracy, whereas only adults achieved comparable performance at closer distances (e.g., 3.3 arcmin; Wolf & Pfeiffer, 2014). The speed of all dots was consistent within each trial. These adjustments ensure the task is sensitive to differences in attention resolution across age and reading abilities.

Task Sequence. A Dell Precision M7600 laptop computer featuring a 15.6-inch ultra-high-resolution LCD was used to perform the task. At the start of the experiment, the child was seated 100 cm away from the computer screen. The research assistant provided instructions to the child participants and ensured that the child understood. Before beginning the experimental trials, children completed practice trials to confirm that they understood the task. Advancement to the experimental phase required four consecutive correct responses within a maximum of 16 practice trials. If this criterion was not met, the practice sequence was administered again. Practice difficulty was reduced by presenting four rather than seven distractors and by setting the minimum target–distractor passing distance to 10 rather than 6 arcmin. Children received feedback following each practice response.

Each trial opened with a small black fixation square presented against a dark-grey background. The square subtended approximately 0.81° of visual angle and had a luminance of 27.4 cd/m^2 (RGB [0, 0, 0]); the background had a luminance of 51.8 cd/m^2 (RGB [30, 30, 30]). The display remained in place until the research assistant initiated the trial by pressing the space bar. Eight white dots were then presented in randomly selected locations for 1,105 ms. Each dot measured 0.0112° of visual angle, or 0.675 arcmin, and had a luminance of 159 cd/m^2 (RGB [200, 200, 200]). A flashing red circle identified one of the dots as the target for 1,980 ms. Following an additional stationary interval of 330 ms, all dots began moving.

Dot trajectories were generated according to several spatial constraints. During every trial, the target passed a distractor at the designated minimum centre-to-centre distance on six occasions. Its path also traversed at least 10 cells within an invisible 6×6 grid dividing the display into 36 equal, nonoverlapping regions. All dots travelled along linear paths and changed direction when they reached a boundary. To make the trajectories less predictable, there was a 10% chance of a directional change after every five frames. The complete stimulus set contained 92 trials generated from 23 movement sequences for each speed–distance combination. Following a visual-comparability review, 12 trials were retained for each of the four conditions, producing 48 experimental trials.

After 7,000 ms of movement, all dots became stationary. Two dots were then marked with coloured rings: one ring identified the target, and the other marked the distractor located nearest to it. Across trials, the target was marked equally often in orange and blue, with colour assignment randomized. Children identified the target by saying “orange” or “blue” or, if they did not know the colour names, by pointing to their selection. The research assistant recorded the response using mouse buttons labelled with corresponding orange and blue stickers. Corrective feedback was not given during the experimental trials. Instead, children received general encouragement unrelated to response accuracy and were asked to guess when uncertain. They could revise an answer before it was entered, with the final response recorded by the program. After every six trials, the Firefly display showed the child’s cumulative number of correct responses. The trial sequence and display specifications were adapted from Hildebrand (2019). Figure 1 illustrates the complete trial sequence.

Figure 1*Attention Resolution Dot-Tracking Task*

The 48 experimental trials were administered in two 24-trial blocks. Each block contained the same number of trials from every combination of distance, speed, and target colour. Trial order was randomized within the blocks, and block order was counterbalanced across participants. Children could take breaks when needed. Including instructions, practice, experimental trials, and optional breaks, administration generally required between 15 and 20 minutes. Across the 48 trials, Hildebrand (2019) reported Cronbach's alpha of .83. Reliability was comparable in the present sample, $\alpha = .82$.

CTOPP-2: Comprehensive Test of Phonological Processing - Second Edition

The CTOPP-2 Elision subtest was utilized to measure phonological awareness, the ability to manipulate spoken language sounds. The task involved children removing phonological segments from spoken words to create new words/nonwords. There were up to 34 words presented within the elision task where participants were asked to correctly state what each word is with an absent phonological segment; the task stopped when three consecutive errors were made or when the list of words was completed. Elision performance was represented by the age-

normed scaled score (norm population $M = 10.00$, $SD = 3.00$), calculated based on the total number of correct responses. According to Wagner et al. (2013), the average internal consistency coefficient for the subtest is .80 which shows good reliability.

WRMT-III: Woodcock Reading Mastery Tests - Third Edition

The WRMT-III Letter Identification subtest measured the ability to recognize letters presented in uppercase and lowercase forms. Participants said the names of letters and words aloud. Kindergarten participants were given the Letter Identification subtest, while Grade 1 participants were additionally given the Word Identification and Word Attack subtests. These additional subtests examined the decoding abilities of participants through reading words and nonsense words of increasing difficulty. The Word Identification task had participants reading and pronounce words in isolation as they increased in difficulty. Despite some of the words presented being unfamiliar, participants used their decoding skills to articulate the presented words properly to be counted as correct (De Rose, 1999). The Word Attack subtest similarly evaluated participants' phonetic decoding skills through the ability to read pronounceable nonsense words in isolation that increased in difficulty as the test continued. Nonsense words are utilized to account for the fact that some words in Word Identification may just be known from pronouncing them from memory (De Rose, 1999). These subtests were not presented to kindergarten participants due to reading skills not being present in the majority of the sample. Letter knowledge is fundamental for early word reading as children need to know what letters are and match them to sounds in spoken language to decode words. A growing body of longitudinal work supports this claim by explaining that knowledge of individual letter-sound correspondences in kindergarten predicted both beginning word-reading skills and development of word-reading skills in Grade 1 (Clayton et al., 2020). Kindergarten Letter Identification was

therefore used as a measure of initial print knowledge, and Grade 1 Word Identification and Word Attack were intended as measures of more developed application of the alphabet to decode words. Standard scores were used. The total reading cluster's average reliability is .97 and the Letter Identification subtest demonstrated a split-half reliability coefficient of .91 for kindergarten students on Form A (Woodcock, 2011).

WASI-II: Wechsler Abbreviated Scale of Intelligence - Second Edition

The WASI-II Matrix Reasoning subtest provided an estimate of nonverbal reasoning ability. For each item, children selected which of five alternatives correctly completed an incomplete visual pattern. Performance was converted to age-normed T-scores, which have a normative mean of 50 and a standard deviation of 10. A score at least two standard deviations below the normative mean was established as the exclusion threshold. No participant obtained a T-score of 30 or lower; therefore, no participants were excluded on this basis. Interrater agreement for the Matrix Reasoning subtest was reported to range from .98 to .99 (Irby & Floyd, 2013).

TOWRE-2: Test of Word Reading Efficiency - Second Edition

Grade 1 participants completed the Sight Word Efficiency (SWE) and Phonemic Decoding Efficiency (PDE) subtests of the TOWRE-2. The SWE subtest assessed the number of printed real words read accurately within 45 seconds. The PDE subtest measured the number of phonemically regular non-words that participants are able to decode accurately within the same time period. These measures capture the accuracy and efficiency of both real word and phonological decoding. The raw score was measured by the total number of words or non-words read accurately. Additionally, age-normalized Total Word Reading Efficiency (TWRE) Index standard score (sum of SWE and PDE standardized scores to obtain a composite measure of

overall word-reading efficiency) was generated for these subtests. The subtests' average alternate form's reliability coefficients (content sampling) are greater than .90, and there are minimal reported measurement errors (Torgesen et al., 2012).

In summary, the WRMT-III Word Identification subtest represented word decoding, and Word Attack pseudoword decoding. The TOWRE-2 SWE measured word reading efficiency, and PDE measured pseudoword reading efficiency. The TOWRE-2 TWRE (Total Word Reading Efficiency) standard scores, which was the sum of SWE and PDE standard scores to measure overall word-reading efficiency, were analyzed as a continuous measure of reading ability. The CTOPP-2 Elision subtest for phonological awareness was included in the analyses to control for potential phonological awareness confounding for the influences of attention resolution and attention resolution efficiency.

Assumptions for the hierarchical multiple regression analyses were evaluated before the models were interpreted. Linearity and homoscedasticity were examined using residual and partial-regression plots. Residual normality was evaluated using histograms, normal probability plots, and Shapiro–Wilk tests of the model residuals. Variance inflation factors were examined to assess multicollinearity, while standardized residuals and Cook's distances were used to identify potentially influential observations. Because the Total Word Reading Efficiency model demonstrated non-normal residuals, bootstrapped 95% confidence intervals based on 10,000 resamples were examined as a sensitivity analysis.

Results

Sample Characteristics

Statistical analyses were conducted using IBM SPSS Statistics (Version 30) for demographic and descriptive analyses and for testing the first hypothesis. The initial

kindergarten sample consisted of 147 participants. Of these, 96 participants ($N=96$; 65.3%) had complete data on the variables required for the first hypothesis. This analytic sample included 52 boys (54.2%) and 44 girls (45.8%). At the kindergarten assessment, these participants had a mean age of 70.46 months ($SD = 3.94$), or approximately 5.9 years. At the Grade 1 assessment, their mean age was 80.88 months ($SD = 3.44$), or approximately 6.7 years.

The remaining 51 participants (34.7%) were not included in the analysis of the first hypothesis because of attrition or missing reading or computerized-task data required for that analysis. For Hypothesis 2, the unconditional models included participants with at least one valid observation for the relevant attention outcome. The conditional models additionally required a valid Grade 1 TWRE score. Consequently, the analytic sample size differed across hypotheses according to the availability of the variables and observations required for each analysis.

Baseline Analysis

Baseline comparisons were conducted between participants included in the final longitudinal sample ($N=96$) and participants excluded because of attrition or incomplete task data. Sample sizes varied across comparisons because participants were required to have a valid baseline score on the measure being compared. Welch's independent samples t-test was used as this test does not assume equality of variance between groups. The retained and attrition groups did not differ significantly in kindergarten accuracy for the close-slow, $t(68.41) = 1.78, p = .080$; close-fast, $t(67.53) = 1.94, p = .057$; far-slow, $t(57.34) = 1.71, p = .092$; or far-fast conditions, $t(56.76) = 1.92, p = .059$. Thus, attrition was not significantly associated with baseline attention resolution performance. Retained participants were significantly older at the kindergarten assessment, $t(94.75) = 2.19, p = .031$, and obtained significantly higher Elision, $t(106.22) = 3.70, p < .001$, and Letter Identification scores, $t(62.89) = 2.46, p = .017$. The groups did not differ

significantly in Matrix Reasoning T-scores, $t(93.55) = 0.10, p = .918$. Sex was also not significantly associated with attrition status, $\chi^2(1, N = 147) = 0.18, p = .674$.

Importantly, because attention resolution was the primary focus of the study, the absence of statistically significant baseline differences across all four attention conditions reduces concern that the retained sample was selectively composed based on initial attention resolution ability. Nevertheless, retained participants were older and demonstrated stronger initial phonological awareness and letter-identification skills. Therefore, systematic differences in broader reading-related characteristics cannot be ruled out, and the retained sample may have somewhat underrepresented younger children and those with weaker initial literacy skills.

Preliminary Analyses

Attention Resolution Descriptive Statistics

Participants generally demonstrated high accuracy across conditions, with mean accuracy ranging from .76 to .86 in kindergarten and from .87 to .92 in Grade 1. Accuracy was descriptively higher in Grade 1 than in kindergarten. Scores were negatively skewed across all conditions, indicating that observations clustered toward the upper end of the accuracy scale. Skewness ranged from -1.61 to -0.74 in kindergarten and from -2.06 to -1.10 in Grade 1. Kurtosis ranged from 0.32 to 3.00 in kindergarten and from 0.41 to 5.00 in Grade 1. Shapiro–Wilk tests were significant for all conditions (all $ps < .001$), indicating that the raw accuracy distributions departed significantly from normality. Nevertheless, one-sample t tests demonstrated that mean accuracy was significantly below perfect performance of 1.00 in every condition, all $|ts|(95) \geq 5.99$, all $ps < .001$. Thus, participants continued to demonstrate measurable errors and variability despite the upper-end concentration of scores. The departures from normality were considered in the subsequent analyses through model-specific diagnostic

checks and, where necessary, bootstrapped confidence intervals. Descriptive statistics for the attention resolution task are presented in Table 1.

Table 1*Descriptive Statistics for Attention Resolution Task Accuracy by Condition and Grade*

Kindergarten				
Condition	Accuracy (<i>M, SD</i>)	Skewness	Kurtosis	Shapiro-Wilk <i>W</i>
Close and Slow	.85 (0.20)	−1.61	3.00	.76***
Close and Fast	.76 (0.21)	−0.74	0.33	.89***
Far and Slow	.84 (0.19)	−1.20	1.09	.80***
Far and Fast	.86 (0.18)	−1.47	2.07	.76***
Grade 1				
Condition	Accuracy (<i>M, SD</i>)	Skewness	Kurtosis	Shapiro-Wilk <i>W</i>
Close and Slow	.91 (0.13)	−2.06	5.00	.65***
Close and Fast	.87 (0.16)	−1.10	0.41	.77***
Far and Slow	.92 (0.12)	−1.55	1.82	.67***
Far and Fast	.91 (0.16)	−1.90	3.39	.66***

Note. Scores represent the proportion of correct responses ($N = 96$). Close and far refer to the distance between stimuli, whereas slow and fast refer to stimulus movement speed. For all Shapiro–Wilk tests, $p < .001$.

Predictive Relationship - Regression (Hypothesis 1)***Primary Data Analysis***

Hypothesis 1 examined whether kindergarten attention resolution and attention resolution efficiency predicted Grade 1 reading performance after accounting for kindergarten phonological awareness. The eligible sample consisted of 96 participants, although the model-specific sample sizes ranged from 94 to 95 because of missing Elision or reading-outcome scores. Kindergarten Elision was entered in the first step of each hierarchical multiple regression. Kindergarten close-slow and close-fast accuracy were entered simultaneously in the second step as measures of attention resolution and attention resolution efficiency, respectively. Separate regression models were conducted for Grade 1 Total Word Reading Efficiency, Word Identification, and Word Attack. Kindergarten Letter Identification and performance in the far-slow and far-fast conditions were included in the preliminary correlational analyses but were not entered into the confirmatory regression models.

Bivariate Correlations. Pearson correlations were first calculated to examine the bivariate relationships among the variables. Kindergarten Elision was significantly and positively associated with Grade 1 Total Word Reading Efficiency, $r = .438, p < .001$; Word Identification, $r = .395, p < .001$; and Word Attack, $r = .502, p < .001$. Kindergarten Letter Identification was also significantly associated with Total Word Reading Efficiency, $r = .460, p < .001$; Word Identification, $r = .484, p < .001$; and Word Attack, $r = .413, p < .001$. Thus, stronger kindergarten phonological-awareness and letter-identification abilities were associated with stronger Grade 1 reading performance. In contrast, none of the four kindergarten attention conditions were significantly associated with any of the Grade 1 reading outcomes (all $ps > .30$). However, accuracy scores across the four kindergarten attention conditions were moderately to

strongly intercorrelated, with correlations ranging from $r = .440$ to $.691$ (all $ps < .001$). Close–slow and close–fast accuracy were moderately associated, $r(95) = .542$, $p < .001$. Correlations can be found in Table 2.

Table 2

Correlations Between Kindergarten Predictor Variables and Grade 1 Reading Outcomes

Kindergarten variable	Total Word Reading Efficiency	Word Identification	Word Attack
Elision	.438***	.395***	.502***
Letter Identification	.460***	.484***	.413***
Close and Slow Accuracy	.078	.069	.067
Close and Fast Accuracy	.101	.085	.105
Far and Slow Accuracy	-.036	-.064	.031
Far and Fast Accuracy	.046	.048	.059

Note. *** $p < .001$.

Regression Assumption Checks. Regression diagnostics indicated no problematic multicollinearity, with variance inflation factors ranging from 1.03 to 1.44. No standardized residual exceeded an absolute value of 3, and no Cook’s distance exceeded 1, indicating that no observations were highly influential according to these criteria. Residuals were approximately normally distributed for the Word Identification model, $W = .975$, $p = .067$, and the Word Attack model, $W = .974$, $p = .057$. However, residuals for the Total Word Reading Efficiency model departed significantly from normality, $W = .946$, $p < .001$. No substantial heteroscedasticity was detected. Because residual normality was not supported for Total Word Reading Efficiency, bootstrapped confidence intervals based on 10,000 resamples were examined. The 95% bootstrap confidence intervals included zero for both close–slow accuracy, $B = 1.23$, 95% CI $[-21.83, 26.13]$, and close–fast accuracy, $B = 1.12$, 95% CI $[-19.26, 21.20]$. Thus, the bootstrapped results supported the original conclusion that neither attention variable significantly predicted Total Word Reading Efficiency.

Hierarchical Multiple Regression Analyses. For Total Word Reading Efficiency, kindergarten Elision explained 19.2% of the variance at Step 1, $F(1, 92) = 21.80, p < .001$. The addition of close–slow and close–fast accuracy at Step 2 did not explain significant additional variance, $\Delta R^2 = .001, \Delta F(2, 90) = 0.03, p = .973$. Although the final model was statistically significant, $F(3, 90) = 7.13, p < .001, R^2 = .192$, adjusted $R^2 = .165$, this result was attributable to Elision. In the final model, Elision was a significant predictor, $\beta = .434, p < .001$, whereas close–slow accuracy, $\beta = .013, p = .906$, and close–fast accuracy, $\beta = .013, p = .912$, were not significant. This conclusion was unchanged when bootstrapped confidence intervals were examined to address the non-normal residual distribution.

For Word Identification, kindergarten Elision explained 15.6% of the variance at Step 1, $F(1, 93) = 17.20, p < .001$. Adding the two attention measures did not significantly increase the explained variance, $\Delta R^2 < .001, \Delta F(2, 91) = 0.02, p = .983$. The final model was significant, $F(3, 91) = 5.62, p = .001, R^2 = .156$, adjusted $R^2 = .129$. Elision remained a significant predictor, $\beta = .392, p < .001$, whereas close–slow accuracy, $\beta = .014, p = .904$, and close–fast accuracy, $\beta = .006, p = .958$, were not significant.

A similar pattern emerged for Word Attack. Kindergarten Elision explained 25.2% of the variance at Step 1, $F(1, 92) = 31.05, p < .001$. Close–slow and close–fast accuracy did not explain significant additional variance, $\Delta R^2 < .001, \Delta F(2, 90) = 0.02, p = .985$. The final model was significant, $F(3, 90) = 10.14, p < .001, R^2 = .253$, adjusted $R^2 = .228$. Elision was a significant predictor, $\beta = .500, p < .001$, whereas close–slow accuracy, $\beta = -.011, p = .922$, and close–fast accuracy, $\beta = .019, p = .863$, were not significant. The hierarchical regression results are summarized in Table 3.

Table 3*Hierarchical Regression Models Predicting Grade 1 Reading Outcomes*

Outcome and step	Predictor	<i>B</i>	<i>SE B</i>	β	<i>t</i>	<i>p</i>	<i>R</i> ²	Adjusted <i>R</i> ²	ΔR^2	ΔF	<i>p</i> for ΔF
Total Word Reading Efficiency (<i>N</i> = 94)											
Step 1	Elision	3.77	0.81	.438	4.67	< .001	.192	.183	—	—	—
Step 2	Elision	3.74	0.83	.434	4.50	< .001	.192	.165	.001	0.03	.973
	Close–slow accuracy	1.23	10.45	.013	0.12	.906					
	Close–fast accuracy	1.12	10.11	.013	0.11	.912					
Word Identification (<i>N</i> = 95)											
Step 1	Elision	3.73	0.90	.395	4.15	< .001	.156	.147	—	—	—
Step 2	Elision	3.70	0.92	.392	4.01	< .001	.156	.129	< .001	0.02	.983
	Close–slow accuracy	1.41	11.64	.014	0.12	.904					
	Close–fast accuracy	0.59	11.21	.006	0.05	.958					
Word Attack (<i>N</i> = 94)											
Step 1	Elision	3.56	0.64	.502	5.57	< .001	.252	.244	—	—	—
Step 2	Elision	3.55	0.66	.500	5.40	< .001	.253	.228	< .001	0.02	.985
	Close–slow accuracy	−0.82	8.28	−.011	−0.10	.922					
	Close–fast accuracy	1.39	8.01	.019	0.17	.863					

Note. Kindergarten Elision was entered at Step 1. Kindergarten close–slow and close–fast accuracy were entered simultaneously at Step 2.

Secondary Data Analysis

As a secondary exploratory analysis, backward multiple regression was used to identify the combination of kindergarten variables that best predicted each Grade 1 reading outcome. All four attention conditions, Elision, age, and sex were entered into the initial models. Predictors were sequentially removed when $p \geq .10$. Because automated selection can be sensitive to sampling variability, the predictive performance of the resulting models was evaluated using 100 repetitions of 10-fold cross-validation. Model selection was repeated within each training fold to reduce optimistic bias.

Total Word Reading Efficiency. The backward-elimination procedure retained only kindergarten Elision as a predictor of Grade 1 Total Word Reading Efficiency. The selected model was significant, $F(1, 92) = 21.80, p < .001$, and explained 19.2% of the variance, $R^2 = .192$, adjusted $R^2 = .183$. Higher kindergarten Elision scores predicted higher Total Word Reading Efficiency scores, $\beta = .438, p < .001$. Repeated cross-validation produced a mean cross-validated R^2 of .088 ($SD = .028$) and a mean root-mean-square error of 17.66 ($SD = 0.27$). By comparison, consistently fitting an Elision-only model produced a higher mean cross-validated R^2 of .156. Thus, allowing additional variables to enter during the resampling process did not improve prediction and introduced some instability.

Word Identification. For Word Identification, the backward-elimination procedure retained kindergarten Elision and age. The selected model was significant, $F(2, 92) = 13.42, p < .001$, and explained 22.6% of the variance, $R^2 = .226$, adjusted $R^2 = .209$. Elision was a significant positive predictor, $\beta = .392, p < .001$. Age was a significant negative predictor, $\beta = -.264, p = .005$. The selected model produced a mean cross-validated R^2 of .123 ($SD = .034$) and a mean root-mean-square error of 18.88 ($SD = 0.36$). The Elision-only model produced a similar mean cross-

validated R^2 of .115. Therefore, including age resulted in only a modest improvement in out-of-sample prediction.

Word Attack. The backward-elimination procedure also retained Elision and age as predictors of Word Attack. The selected model was significant, $F(2, 91) = 18.59, p < .001$, and explained 29.0% of the variance, $R^2 = .290$, adjusted $R^2 = .274$. Elision was a significant positive predictor, $\beta = .501, p < .001$, while age was a significant negative predictor, $\beta = -.194, p = .030$. The selected model produced a mean cross-validated R^2 of .228 ($SD = .025$) and a mean root-mean-square error of 13.38 ($SD = 0.22$). This was similar to the Elision-only model, which produced a mean cross-validated R^2 of .221. Therefore, adding age provided little improvement in out-of-sample prediction.

Kindergarten Elision was selected in 100% of the cross-validation training models for all three reading outcomes. Age was also selected consistently for Word Identification and Word Attack. In contrast, none of the four attention conditions demonstrated stable predictive value. The exploratory findings therefore supported the primary regression results: phonological awareness predicted Grade 1 reading, whereas attention resolution did not provide consistent additional predictive information.

Reader Ability and Attention Resolution Ability (Hypothesis 2)

Data Analysis

SAS 9.4 Maintenance Release 9 was used to examine changes in attention resolution and attention resolution efficiency over time. Multilevel modelling was selected because individual Firefly trials were nested within participants and assessment timing differed across participants. The Level 1 unit was the individual Firefly trial. Each trial was coded 1 for a correct response and 0 for an incorrect response. Participants could contribute up to 12 trials per condition at each

assessment, and all available valid trials were retained. Close–slow trials were analyzed as observations of attention resolution, whereas close–fast trials were analyzed as observations of attention resolution efficiency. The close–slow unconditional model included 138 participants and 1,415 trial-level observations, whereas the close–slow conditional model included 109 participants and 1,220 observations. The close–fast unconditional model included 138 participants and 1,412 trial-level observations, whereas the close–fast conditional model included 109 participants and 1,216 observations. Conditional-model sample sizes were smaller because participants were required to have a valid Grade 1 TWRE score. For Hypothesis 2, individual correct or incorrect trial responses were retained as Level 1 observations to model performance over time while accounting for the nesting of trials within participants. Trial accuracy was analyzed in its original binary form using linear mixed-effects models. Consequently, the fixed-effect estimates represented differences in the probability of a correct response. This approach also maintained comparability with the proportion-correct outcomes reported in the descriptive and regression analyses. The models used all available observations under the assumption that incomplete outcome data were missing at random conditional on the variables included in the models. The more restrictive assumption that data was missing completely at random was not made because retention was associated with some observed baseline characteristics.

Close–slow accuracy was used as the measure of attention resolution, whereas close–fast accuracy was used as the measure of attention resolution efficiency. Time was measured continuously in months and centred at April 1 of kindergarten, approximately the median date over which the kindergarten data were collected in each cohort. Consequently, the intercept represented predicted accuracy at the beginning of April in kindergarten. TOWRE-2 Total Word

Reading Efficiency scores were centred at the normative mean of 100; therefore, a centred TOWRE-2 score of zero represented population-average reading performance.

Time was modelled as a Level 1 predictor, whereas centred TWRE scores were included as a Level 2 participant-level predictor. Unconditional models were first estimated to examine change in accuracy over time without including reading ability. Conditional models were then estimated to determine whether TWRE performance accounted for individual differences in accuracy or growth. In the conditional models, the fixed effect of centred TWRE represented the association between Grade 1 reading ability and model-estimated attention accuracy at the kindergarten-centred intercept. The Time $\times$ TWRE interaction represented the association between Grade 1 reading ability and the monthly rate of change in attention accuracy over time. These results were interpreted as associations, not predictions, because TWRE was measured in Grade 1 and could not show that reading ability caused earlier attention performance.

The fixed effects in both conditional models included time, centred TWRE scores, and the Time $\times$ TWRE interaction. Random intercepts and slopes allowed participants to vary in their initial accuracy and rates of change. The interaction was retained in both models because Hypothesis 2 directly examined whether reading ability was associated with the rate of growth, although the random slope variance was not statistically significant for attention resolution efficiency.

Missing Data and Model Assumptions

The initial sample consisted of 147 participants. Multilevel modelling with maximum-likelihood estimation permitted participants with partially incomplete repeated-outcome data to contribute their available observations. However, participants were required to have a valid

TWRE score and at least one valid observation for the attention outcome to be included in the relevant conditional model.

Missing-data patterns were examined using Little's MCAR test (Little, 1988). The test was nonsignificant for the complete set of attention-resolution, reading, Elision, and age variables, $\chi^2(103) = 121.58, p = .102$. A focused test of the variables used for Hypothesis 1 was also nonsignificant, $\chi^2(26) = 34.72, p = .118$. Therefore, the null hypothesis that the data were missing completely at random was not rejected. However, nonsignificant Little's tests do not establish that the data were definitively MCAR.

Comparisons between retained and excluded participants indicated significant differences in baseline age, Elision, and Letter Identification, although no significant differences were found in baseline attention resolution, nonverbal intelligence, or sex. Thus, evidence concerning the missing-data mechanism was mixed. Missing at random was retained as a plausible working assumption for the likelihood-based multilevel models.

The multilevel models used all available outcome observations from participants with the predictor information required for the relevant model. Likelihood-based estimation can provide valid estimates under MCAR and under MAR when the missingness mechanism is adequately accounted for by observed information included in the analysis (Schafer & Graham, 2002). Participants missing the required TOWRE-2 predictor could not contribute to conditional models containing TWRE.

Unconditional and Conditional Models

In each model, a positive time coefficient indicated that accuracy improved over time. In the conditional models, the TWRE coefficient represented the expected difference in accuracy associated with a one-point difference from the normative mean of 100 at the April intercept.

The Time $\times$ TWRE interaction tested whether reading ability was associated with the linear rate of growth. The unconditional and conditional model results are presented in Tables 4 and 5.

Table 4

Unconditional Model for Close-Slow Attention Resolution

Parameter	Unconditional estimate (<i>SE</i>)	Conditional estimate (<i>SE</i>)
Fixed effects		
Intercept	.8233*** (.01735)	.8561*** (.02219)
Time in months	.00761*** (.00176)	.00611** (.00216)
Centred TWRE	-	.00109 (.00107)
Time $\times$ centred TWRE	-	.00004 (.00011)
Covariance parameters		
Intercept variance	.02108*** (.00514)	.02155*** (.00558)
Intercept-slope covariance	-.00129** (.00045)	-.00141** (.00048)
Slope variance	.000082* (.000050)	.000099* (.000051)
Residual variance	.10250*** (.00424)	.09291*** (.00412)
Goodness of fit		
-2 log likelihood	902.5	658.8
AIC	914.5	674.8
AICC	914.6	674.9
BIC	932.4	696.5

Note. The intercept represents predicted accuracy at the beginning of April for a participant with a TWRE score of 100. Positive time coefficients indicate increasing accuracy. AIC = Akaike information criterion; AICC = corrected Akaike information criterion; BIC = Bayesian information criterion.

$p < .05$. * $p < .01$. ** $p < .001$.

Table 5*Conditional Model for Close-Fast Attention Resolution Efficiency*

Parameter	Unconditional estimate (<i>SE</i>)	Conditional estimate (<i>SE</i>)
Fixed effects		
Intercept	.7173*** (.010805)	.7248*** (.02218)
Time in months	.01332*** (.00190)	.01202*** (.00214)
Centred TWRE	-	.00145* (.00073)
Time × centred TWRE	-	-.00011 (.00012)
Covariance parameters		
Intercept variance	.01584**	.01815** (.00626)
Intercept-slope covariance	-.00078	-.00105† (.00058)
Slope variance	.000012 (.000061)	.000055 (.000070)
Residual variance	.15170***	.14460*** (.00641)
Goodness of fit		
-2 log likelihood	1400.6	1156.7
AIC	1412.6	1170.7
AICC	-	1170.8
BIC	1430.5	1189.7

Note. The conditional intercept represents predicted accuracy at the beginning of April for a participant with a TWRE score of 100. Positive time coefficients indicate increasing accuracy.

AIC = Akaike information criterion; AICC = corrected Akaike information criterion; BIC = Bayesian information criterion.

† $p < .10$. $p < .05$. * $p < .01$. ** $p < .001$.

Attention Resolution

The unconditional model indicated that close–slow attention resolution accuracy improved significantly over time, $b = .00761$, $SE = .00176$, $t(1276) = 4.33$, $p < .001$. On average, accuracy increased by approximately .008, or 0.76 percentage points, per month. The intercept was .823, indicating average predicted accuracy of approximately 82.3% at the beginning of April in kindergarten. Significant variability was observed in both the intercept, variance = .02108, $SE = .00514$, $p < .001$, and slope, variance = .000082, $SE = .000050$, $p = .049$. Participants therefore differed in their initial close–slow accuracy and rates of change. The intercept–slope covariance was significant and negative, covariance = $-.00129$, $SE = .00045$, p

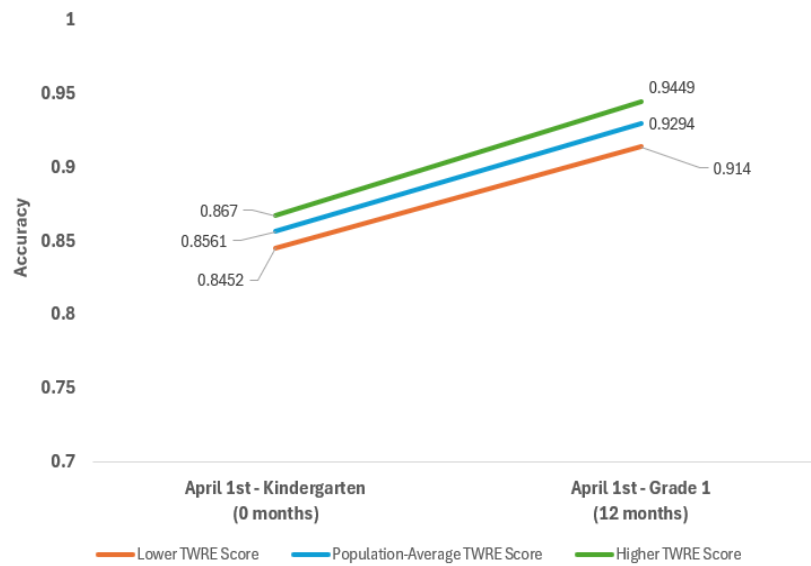
= .004, indicating that participants with higher initial accuracy tended to demonstrate smaller increases over time.

In the conditional model, the positive time coefficient remained significant, $b = .00611$, $SE = .00216$, $t(1109) = 2.84$, $p = .005$. On average, close–slow accuracy increased by approximately .006, or 0.61 percentage points, per month. The intercept was .856, indicating that a participant with population-average TWRE performance was predicted to achieve approximately 85.6% accuracy at the beginning of April. Centred TWRE scores did not significantly predict accuracy at the intercept, $b = .00109$, $SE = .00107$, $t(107) = 1.02$, $p = .312$. Thus, participants with higher and lower reading scores did not differ significantly in their predicted close–slow accuracy at the centred intercept. The Time $\times$ TWRE interaction was also nonsignificant, $b = .00004$, $SE = .00011$, $t(1109) = 0.36$, $p = .717$. Therefore, TWRE performance did not significantly explain individual differences in the rate of growth in close–slow attention resolution accuracy. Significant variability remained in both the intercept, variance = .02155, $SE = .00558$, $p < .001$, and slope, variance = .000099, $SE = .000051$, $p = .027$. The intercept–slope covariance also remained significant and negative, covariance = $-.00141$, $SE = .00048$, $p = .004$. Participants therefore differed in their initial attention resolution accuracy and rates of change, but TWRE performance did not explain these differences.

As illustrated in Figure 2, predicted close–slow attention resolution accuracy increased from kindergarten to Grade 1 across TWRE scores of 90, 100, and 110. Although the three lines appear distinct, the distance between them remained essentially unchanged over time, consistent with the nonsignificant Time $\times$ TWRE interaction. Thus, TWRE performance was not significantly associated with either accuracy at the centred intercept or its rate of growth.

Figure 2

Predicted Close–Slow Attention Resolution Accuracy by TWRE Score and Assessment Time



Note. Predictions were calculated for TWRE scores of 90, 100, and 110. Time was centred at April 1 of kindergarten, with Grade 1 represented as 12 months. TWRE scores were centred at the normative mean of 100.

Attention Resolution Efficiency

The unconditional model indicated that close–fast attention resolution efficiency improved significantly over time, $b = .01332$, $SE = .00190$, $t(1273) = 7.02$, $p < .001$. On average, accuracy increased by approximately .013, or 1.33 percentage points, per month. The intercept was .717, indicating average predicted accuracy of approximately 71.7% at the beginning of April in kindergarten. Significant variability was observed in the intercept, variance = .01584, $p = .002$, indicating that participants differed in their initial close–fast accuracy. However, the slope variance was not significant, variance = .000012, $SE = .000061$, $p = .420$. The intercept–slope covariance was also nonsignificant, covariance = $-.00078$, $p = .122$. Thus, there was insufficient evidence that participants differed in their rates of close–fast growth.

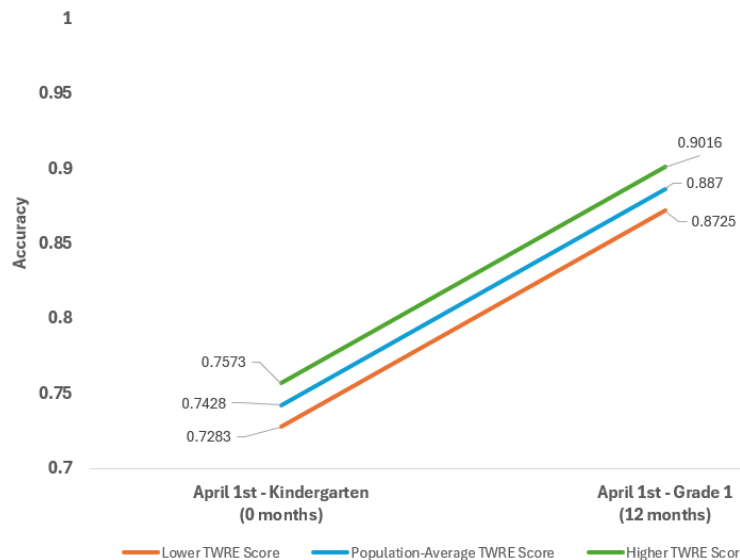
In the conditional model, the positive time coefficient remained significant, $b = .01202$, $SE = .00214$, $t(1105) = 5.61$, $p < .001$. Accuracy increased by approximately .012, or 1.20 percentage points, per month. The intercept was .743, indicating predicted accuracy of approximately 74.3% at the beginning of April for a participant with a TWRE score of 100. Centred TWRE scores significantly predicted accuracy at the intercept, $b = .00145$, $SE = .00073$, $t(107) = 1.98$, $p = .050$. Participants with stronger reading performance therefore demonstrated higher predicted accuracy in the close-fast condition at the centred intercept. Each one-point increase in TWRE performance was associated with an increase of approximately .00145, or 0.15 percentage points, in predicted accuracy.

There was significant variability in the intercept, variance = .01815, $SE = .00626$, $p = .002$, indicating that participants differed in their close-fast accuracy at the centred intercept. The slope variance was not significant, variance = .000055, $SE = .000070$, $p = .216$, indicating insufficient evidence of between-participant variability in growth. The intercept-slope covariance was also not statistically significant, covariance = $-.00105$, $SE = .00058$, $p = .073$. The Time $\times$ TWRE interaction was not statistically significant, $b = -.00011$, $SE = .00012$, $t(1105) = -0.95$, $p = .344$. Therefore, although TWRE performance was significantly associated with close-fast attention resolution efficiency at the centred intercept, it did not significantly explain differences in the rate of growth over time.

As illustrated in Figure 3, predicted close-fast attention resolution efficiency increased from kindergarten to Grade 1. Participants with higher TWRE scores demonstrated higher predicted accuracy at the centred intercept.

Figure 3

Predicted Close–Fast Attention Resolution Efficiency Accuracy by TWRE Score and Assessment Time



Note. Predictions were calculated for TWRE scores of 90, 100, and 110. Time was centred at April 1 of kindergarten, with Grade 1 represented as 12 months. TWRE scores were centred at the normative mean of 100.

Discussion

Attention Resolution Hypotheses

The present study examined the longitudinal relationship between attention resolution and early reading development. Two complementary questions were investigated: whether kindergarten attention resolution predicted Grade 1 reading performance and whether reading ability was associated with attention resolution performance and its development over time. Overall, the findings provided little evidence that kindergarten attention resolution independently predicted subsequent reading performance. However, reading ability was associated with

attention resolution efficiency under the more demanding close–fast condition at the centred kindergarten intercept.

Predictive Relationship Between Attention Resolution and Reading

Hypothesis 1 proposed that kindergarten attention resolution and attention resolution efficiency would predict Grade 1 reading performance. This hypothesis was not supported. Neither close–slow nor close–fast accuracy was significantly correlated with Grade 1 Total Word Reading Efficiency, Word Identification, or Word Attack. The less demanding far–slow and far–fast conditions were also not significantly correlated with the Grade 1 reading outcomes. Furthermore, close–slow and close–fast accuracy did not explain additional variance in any reading outcome after kindergarten Elision was included as a covariate. Kindergarten Elision consistently predicted all three Grade 1 reading outcomes. Children with stronger kindergarten phonological-awareness skills subsequently demonstrated stronger word-reading efficiency, word identification, and phonetic-decoding performance. Kindergarten Letter Identification was also significantly correlated with all three Grade 1 reading outcomes. These findings reinforce the importance of foundational phonological awareness and letter knowledge skills in early reading development. Within the present sample, these established reading-related abilities provided more information about subsequent reading performance than attention resolution accuracy.

Several factors may help explain the absence of significant predictive effects for attention resolution. Accuracy was generally high and negatively skewed, particularly in Grade 1, with observations concentrated toward the upper end of the scale. Although mean accuracy remained significantly below perfect performance in every condition, the concentration of scores may have restricted the amount of between-participant variability available to predict reading. Close–slow

and close–fast accuracy may also measure attentional processes relevant to concurrent task performance without independently predicting later reading once phonological awareness is considered.

The regression results do not appear to be explained solely by violations of residual normality. Residuals were approximately normally distributed in the Word Identification and Word Attack models. Although the residuals for Total Word Reading Efficiency departed significantly from normality, bootstrapped confidence intervals led to the same substantive conclusion as the conventional regression analysis: neither close–slow nor close–fast accuracy significantly predicted Total Word Reading Efficiency. Thus, the evidence consistently failed to support the proposed longitudinal predictive relationship.

Reading Ability and Growth in Attention Resolution

Hypothesis 2 examined whether reading ability was associated with attention resolution performance at the centred kindergarten intercept and with changes in accuracy over time. Close–slow attention resolution and close–fast attention resolution efficiency both improved significantly over time. These findings indicate developmental improvement in children’s ability to identify targets under both spatial and speed demands.

For close–slow attention resolution, TWRE performance was not significantly associated with accuracy at the centred kindergarten intercept. The Time $\times$ TWRE interaction was also nonsignificant, indicating that reading ability did not explain differences in the rate of close–slow growth. Participants nevertheless demonstrated significant variability in both their intercepts and slopes. Children therefore differed in their predicted accuracy and rates of change, but these differences were not explained by TWRE performance. Other developmental, cognitive, or task-related characteristics may account for this remaining variability.

For close–fast attention resolution efficiency, higher TWRE scores were significantly associated with greater accuracy at the centred kindergarten intercept. This finding suggests that reading ability differentiated children’s performance when the target stimuli were both closely spaced and moving quickly. This combination may place greater demands on the rapid selection and resolution of visual information than the close–slow condition. The association was modest, however, and should not be interpreted as evidence that stronger reading ability caused better attention resolution efficiency.

The Time $\times$ TWRE interaction was not significant for close–fast attention resolution efficiency. Thus, although children with higher TWRE scores demonstrated higher predicted accuracy at the centred intercept, TWRE performance did not explain differences in the rate of growth. The random slope variance was also nonsignificant, providing insufficient evidence that children differed substantially in their close–fast growth rates. The differences among the slopes were not statistically significant.

These findings provide partial support for Hypothesis 2. Reading ability was associated with close–fast attention resolution efficiency at the centred intercept, but it was not associated with close–slow attention resolution or growth in either condition. The results therefore suggest that reading-related differences were most apparent in accuracy under the more demanding close–fast condition, rather than in the rate at which attention performance developed.

The findings for the two hypotheses are not necessarily contradictory. Hypothesis 1 tested whether kindergarten attention performance predicted Grade 1 reading after accounting for phonological awareness. Hypothesis 2 examined whether Grade 1 TWRE performance was associated with estimated attention performance and growth across the assessment period. Close–fast attention resolution efficiency may distinguish children with different levels of

reading performance without functioning as an independent longitudinal predictor of later reading. The temporal interpretation of the second analysis also requires caution. TWRE was measured in Grade 1 but was used as a participant-level predictor of the modelled attention trajectory, including accuracy at the kindergarten-centred intercept. Consequently, the significant TWRE coefficient identifies an association between Grade 1 reading performance and estimated attention resolution efficiency at the centred intercept; it does not demonstrate that Grade 1 reading ability prospectively caused earlier attention performance. The direction of this relationship cannot be determined from the present analysis.

Developmental Change in Attention Resolution

Attention resolution and attention resolution efficiency improved significantly from kindergarten to Grade 1, indicating developmental change in children's ability to identify targets under varying spatial and speed demands. This finding is consistent with Wolf and Pfeiffer's (2014) evidence that attention resolution continues to develop throughout childhood between approximately 7 and 13 years of age. Attention resolution may therefore represent a developing cognitive mechanism whose maturation overlaps with the acquisition of increasingly fluent reading skills. However, the present findings do not establish that improvement in attention resolution was caused by reading experience.

Developmental maturation and reading experience may make distinct contributions to visual processing. Hildebrand (2019) found that struggling readers in Grade 6 outperformed reading-age-matched children in Grade 2 on attention resolution despite the groups having comparable reading abilities. This finding suggests that chronological age and general maturation may contribute to attention resolution more strongly than reading experience alone. Consistent

with this interpretation, attention resolution and attention resolution efficiency improved over time in the present study, whereas reading ability did not explain growth in either condition.

The significant negative intercept–slope relationship for close–slow attention resolution indicated that participants with higher predicted accuracy at the centred intercept tended to demonstrate smaller subsequent increases. Children who initially performed less accurately may have had more opportunity to improve, whereas children with stronger performance had less available room for change. This pattern could reflect developmental convergence, restrictions imposed by the bounded accuracy scale, or regression toward the mean. It should therefore be interpreted cautiously.

Accuracy was generally high, particularly in Grade 1, with condition means ranging from approximately .87 to .92. Scores were negatively skewed and concentrated toward the upper end of the accuracy scale. Nevertheless, one-sample t-tests indicated that mean performance remained significantly below perfect accuracy in every condition. The distributions therefore do not demonstrate that all participants performed perfectly, but the concentration of scores may have limited the task’s sensitivity to individual differences. It is also possible that the relationship between attention resolution and reading changes across development. Grade 1 may be too early to observe a stable association with reading efficiency because many children are still developing basic decoding and word-recognition skills. Relationships with reading fluency could become more apparent in grade 2 or later, when reading performance is more automatic and individual differences in efficiency are more established. Nevertheless, this explanation remains speculative. Later assessments may produce further concentration of scores toward the upper end of the scale unless task difficulty is adjusted. Future longitudinal research should

therefore follow children beyond Grade 1 and include more demanding or adaptive task conditions capable of capturing variability across developmental stages.

Interpreting the Relationship Between Attention Resolution and Reading

The processes underlying the relationship between visual attention and reading remain uncertain. Although visual-attention theories propose that attentional selection supports the identification and processing of letters and words, empirical findings have not demonstrated a uniformly strong or direct relationship. In their critical review, Perry and Long (2022) found that visual attention span tasks were generally small but significant predictors of reading after phonological abilities were controlled. However, findings from other visual-attention tasks were weaker and often nonsignificant when phonological awareness or rapid naming was considered. They also emphasized that visual-attention tasks may measure different underlying processes, making results difficult to compare across studies. The specific task used in the present study may help explain why attention resolution accuracy did not predict Grade 1 reading after Elision was included in the analyses. The dot-tracking task requires participants to resolve and identify moving visual targets, whereas reading additionally requires learned letter representations, phonological decoding, lexical access, and linguistic comprehension. Performance on the attention task may therefore reflect only one component of the broader collection of processes supporting reading.

Neuroimaging research nevertheless demonstrates that learning to read reorganizes aspects of the visual system. Feng et al. (2022) found that word-specific neural responses were absent in prereaders but emerged in beginning readers of approximately the same age, suggesting that the development of word-selective responses was associated with reading acquisition rather than age alone. In contrast, the continued development of face-selective responses was primarily

associated with age. These findings indicate that maturation and reading experience can influence different visual processes in distinct ways.

Taken together, this evidence raises the possibility that developing reading skills may contribute to changes in visual attention rather than visual attention functioning only as a precursor to reading. Repeated experience identifying closely spaced letters and words may strengthen aspects of visual selection and processing, potentially contributing to performance under demanding conditions such as close–fast attention resolution efficiency. However, the present findings cannot establish this direction of influence, and it is also possible that reading and attention develop reciprocally or reflect shared developmental processes.

The present findings therefore do not suggest that visual attention is unrelated to reading. Instead, the relationship may depend on the visual-attention process being measured, the difficulty of the task, the child’s developmental stage, and whether phonological skills are considered. Although attention resolution did not independently predict later reading, higher TWRE performance was associated with greater close–fast attention resolution efficiency at the centred intercept. This association suggests that reading-related differences may be most apparent under conditions requiring children to resolve closely spaced, rapidly moving stimuli. However, because attention resolution did not independently predict subsequent reading and TWRE did not explain growth in either condition, the findings do not establish attention resolution as a primary causal mechanism of early reading development.

Attrition and Generalizability

The findings should be interpreted in light of differences between retained and excluded participants. Participants retained for the Hypothesis 1 analyses were older and demonstrated stronger baseline phonological-awareness and letter-identification abilities. Although the groups

did not differ significantly in baseline attention resolution, nonverbal intelligence, or sex, the retained sample may have overrepresented children with stronger initial reading-related abilities.

Consequently, results based on the retained Hypothesis 1 sample may generalize less well to younger children and children with weaker initial reading skills. This restriction may also have reduced variability in reading and attention performance, making predictive relationships more difficult to detect. The absence of significant differences in baseline attention resolution is reassuring for the study's primary construct, but it does not eliminate the possibility of systematic attrition.

The multilevel models reduced the loss of outcome information by allowing participants with incomplete repeated attention observations to contribute available data. However, participants without the TWRE predictor could not contribute to conditional models containing TWRE. Little's MCAR tests were nonsignificant but retained and excluded participants differed on some observed baseline characteristics. Evidence regarding the missing-data mechanism was therefore mixed, and the possibility of residual bias under the missing-at-random assumption cannot be ruled out.

Limitations and Future Directions

Several limitations should be considered when interpreting the findings. First, the design of the attention resolution task prevented the use of the threshold-estimation procedure described by Wolf and Pfeiffer (2014). Their procedure estimated the stimulus separation associated with a particular level of accuracy, such as 75%, across six distance points. The present task included only two distance levels, providing insufficient information to estimate individual accuracy thresholds reliably. Applying a 75% exclusion criterion to the most difficult condition would also risk excluding children with genuinely weaker attention resolution rather than only participants

who were disengaged or guessing. Such an exclusion could artificially reduce variability and remove the participants most relevant to the research question. Future studies should incorporate additional distance levels or an adaptive staircase procedure to estimate individual attention-resolution thresholds more precisely.

Second, Word Identification was not administered during kindergarten. As a result, the analyses could determine whether kindergarten attention resolution predicted Grade 1 reading achievement, but they could not determine whether it predicted growth in word-reading ability after controlling for kindergarten Word Identification. Kindergarten Letter Identification provided an indicator of emergent literacy, and letter knowledge is an established precursor of later word-reading development. Nevertheless, letter identification and word identification are not equivalent measures. The lack of the same reading measure at both waves limits conclusions about improvement and change. Future studies should administer developmentally appropriate word-reading measures at every assessment or use an item set with sufficient range to measure both beginning and more advanced readers.

Third, the developmental period examined may have been too early or too brief to detect stable longitudinal associations between attention resolution and reading efficiency. Kindergarten and Grade 1 children are still acquiring basic decoding and word-recognition skills, and individual differences in fluent reading may not yet be fully established. Following participants into grade 2 and later would make it possible to determine whether attention resolution becomes more strongly associated with reading once decoding is more automatic. However, later assessments should use more difficult or adaptive attention conditions because the current Grade 1 scores were highly accurate, negatively skewed, and concentrated toward the

upper end of the scale. Without increasing task difficulty, continued improvement could further restrict variability and reduce the ability to detect associations with reading.

Finally, the significant association between Grade 1 TWRE and model-estimated close-fast performance at the kindergarten-centred intercept should not be interpreted as establishing temporal precedence. Future studies should obtain equivalent reading-efficiency measures at multiple waves and examine reciprocal longitudinal relationships. Such a design could test whether earlier attention resolution predicts later reading, whether earlier reading predicts later attention resolution, or whether both develop together because of shared underlying processes.

Overall, future research would benefit from additional stimulus-distance levels, adaptive threshold estimation, equivalent reading measures across waves, and a longer follow-up period. These changes would permit more precise measurement of individual differences and clearer conclusions about whether attention resolution predicts reading development rather than reading achievement alone.

Conclusion

The present study examined the development of attention resolution and its relationship with early reading from kindergarten to Grade 1. Close-slow attention resolution and close-fast attention resolution efficiency improved over time, suggesting continued development in children's ability to identify visual targets under varying spatial and speed demands. The close-fast condition produced the lowest mean accuracy in kindergarten, suggesting that the combination of close spacing and faster movement was descriptively more demanding at that developmental stage.

Kindergarten close-slow and close-fast accuracy did not predict Grade 1 TWRE, Word Identification, or Word Attack after accounting for kindergarten Elision. In contrast,

phonological awareness consistently predicted all three reading outcomes. Thus, Hypothesis 1 was not supported, and the findings indicate that phonological awareness was a more robust longitudinal predictor of early reading than attention resolution.

Hypothesis 2 received partial support. Higher TWRE scores were associated with greater close–fast attention resolution efficiency at the centred kindergarten intercept but were not associated with close–slow attention resolution. TWRE performance also did not explain the rate of growth in either condition. Thus, reading ability differentiated attention performance under the more demanding close–fast condition at the centred intercept but did not account for developmental change.

Collectively, the findings suggest that attention resolution efficiency under demanding visual conditions may be associated with Grade 1 reading performance, but kindergarten attention resolution did not independently predict subsequent reading after phonological awareness was considered. This distinction contributes to a more specific theoretical understanding of the relationship between visual attention and early literacy. Given the upper-end concentration of the accuracy scores, attrition-related differences, limited number of stimulus distances, and absence of equivalent reading measures across waves, these conclusions should be interpreted cautiously. Future research using adaptive attention tasks, equivalent longitudinal reading measures, and assessments extending into Grade 2 and later may clarify whether attention resolution becomes more strongly associated with reading as fluency develops.

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Appendix A

Parent Consent Form

Research Project Title: **Visual Attention and Reading Study**

Principal Investigator and contact information: **Richard Kruk**

Sponsor: **University of Manitoba**

Dear Parents or Guardians:

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

An important part of every child's early educational experience is learning to read. As a researcher in the Department of Psychology at the University of Manitoba, I am conducting a study to help us understand more about how children become mature readers. In particular I am studying how children's developing skills in visual attention and spoken language have an impact on learning to recognize printed letters and words. These are important dimensions of learning to read.

Children often acquire their reading abilities at different rates, and occasionally certain youngsters develop difficulties learning to read and write. Although the reasons for their problems are not always clearly understood, with a better understanding of how underlying skills develop in the first school years, and how they are related to learning to read, more effective methods of instruction can be developed for children, particularly those with reading difficulties.

The participation of your child is requested for a study that will examine the relationship between visual attention and reading skills. The study will take place at your child's school and will involve two 40-minute sessions in a quiet room at the school. Your child's teacher will be asked to indicate the best days and times for your child to be involved in the sessions. During those sessions, each child will participate in several brief paper-and-pencil school-like tasks that involve language, vision, memory and reading. In addition, each child will participate in several computer-based visual games and reading-like tasks. The computer presentation will be both motivating and fun, as it is designed to be game-like. Our past experience with these tasks indicates that children very much enjoy playing with these computer "games" and experiencing the paper-and-pencil tasks. A researcher and a psychology student from the University who are carefully trained in working with children will conduct the study at the school.

All results will be kept in strict confidence to protect your child's anonymity; only researchers involved in the study will have access to results, organized using code numbers

rather than children's names, and stored in a locked room at the University. Involvement in this research will not affect your child's work or progress at school. Any results that could be useful in developing effective reading instruction for individual children will be shared with you. At the end of the study, children will be given a short explanation of the study and offered stickers and a chapter book as tokens of our appreciation.

With your support I hope that this research will bring us closer to a better understanding of reading in children. This is critical to a literate society like ours. When the study is complete, anticipated at about the summer of 2026, a report of the overall findings will be available at the school to interested teachers and parents, and on a website dedicated to this project (www.earlyreadingproject.ca). Reading researchers will learn about the results in professional journals and conferences. A copy of the report of overall findings will be sent to you; please include your mail or email address on the attached form.

If you will allow your child to be included in this study, please detach and complete the form and return it to your child's teacher in the envelope provided within the next several days. Participation in this study is completely voluntary, and you and your child have the right to withdraw from the research at any time. I sincerely appreciate your cooperation. If you would like more information about the study please contact me at the Department of Psychology, University of Manitoba.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. The University of Manitoba may look at the research records to see that the research is being done in a safe and proper way.

This research has been approved by the Psychology/Sociology Research Ethics Board, and by the school division. If you have any concerns or complaints about this project, you may contact me, or the Human Ethics Coordinator (HEC) at (204) 474-7122 or the Human Ethics Coordinator (HEC) at 474-7122. A copy of this consent form has been given to you to keep for your records and reference.

Sincerely,
Richard Kruk, Ph.D.,
Associate Professor

Visual Attention and Reading Study
Parent/Guardian Consent Form
Richard Kruk, Dept. of Psychology
University of Manitoba

Name of Child (please print): _____

Child's Date of Birth: Month _____ Day _____ Year _____

CHECK HERE

_____ I give permission for my child to participate in the study conducted by Richard Kruk.

_____ I do NOT give permission for my child to participate in the study conducted by Richard Kruk.

If you are giving permission, please provide us with additional information in the attached questionnaire.

Signature of Parent/Guardian: _____ Date: _____

Researcher's Signature: _____ Date: _____

If you are interested in receiving a copy of a report of the final results, please write your mailing or email address below:

We are planning to conduct a **follow-up** study involving a small number of children at the University. If you are willing to have your child considered for this follow-up study, please indicate:

_____ YES, I am willing to have my child considered for a follow-up study

_____ NO, I am NOT willing to have my child considered for a follow-up study

If you indicated YES, please provide the best way to contact you for the follow-up:

Telephone: _____ Email: _____