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Evaluating Picturebook Complexity Through Children's Eye Movement and Miscue Analysis

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Abstract: This paper explores the potential of Eye Movement Miscue Analysis (EMMA) as a method to evaluate the complexity of picturebooks as reading material for primary school children. While EMMA has been applied to examine reading processes and strategies, this paper reports on the first study using EMMA to examine classroom picturebook complexity and its implications for developing readers. This research found EMMA method revealed specific nuances for understanding children's reading practices in response to the complexity of the text at hand. Drawing together an internationally established reading teaching resource, the text complexity guide (Pinnell & Fountas, 2007) with miscue analysis reading assessment and eye movement technology, this research sought to gain insights into potential areas of complexity or challenge in picturebooks commonly available in Australian school libraries and classrooms. The method shared here examines text complexity ratings, children's reading performance, and eye movements, as they read in natural classroom settings. Analysis of children's reading miscues revealed that readers encountered challenges not anticipated through the use of the text complexity guide. Argued in this paper is that EMMA methodologies could extend understandings about text complexity beyond established frameworks and hence guide future assessments.

Keywords: *Eye movements, miscue analysis, picturebooks, primary school.*

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Introduction

Understanding the complexities of the reading process and readers' engagement with texts has long been a formidable challenge in educational research (Duke & Cartwright, 2021; Kintsch, 1998; Moats, 2020; Pinnell & Fountas, 2007; Rumelhart, 2022). A primary obstacle lies in the unobservable nature of the mental processes of reading (Perfetti, 1999), making it difficult to observe and measure cognitive processes such as word recognition and problem solving (Perfetti & Stafura, 2014). Additional challenges are generated through individual differences such as readers' age, prior knowledge, and cognitive abilities (Daneman & Carpenter, 1980; Rosenblatt, 2018; Wittrock et al., 1975), which are further complicated as the reader interacts with the text. The dynamic nature of reading is characterised by constant and unique transactions between what the reader brings to the reading event and what is presented in the text (Pantaleo, 2015; Rosenblatt, 2018), prompting the need for sophisticated research designs that can capture readers' evolving strategies and proficiencies. These challenges necessitate interdisciplinary collaboration, advanced research methodologies, and the integration of diverse theoretical frameworks to unravel the complexities of reading and further understand readers' reading processes.

Eye Movement Miscue Analysis (EMMA) (Paulson, 2000) offers a robust methodological approach to address these challenges. EMMA integrates eye movement data with the analysis of a reader's miscues (substitutions, insertions, and omissions) during oral reading (K. S. Goodman, 1973). This integrated approach provides a real-time window into a reader's cognitive processes, reading decisions, and comprehension, enabling the examination of the interplay between

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visual and linguistic processing, reading strategies, and overall text comprehension (Just & Carpenter, 1980; Paulson, 2002).

Unlike conventional eye tracking studies, EMMA systematically links the spatiotemporal distribution of visual fixations with miscues. These observable deviations from the printed text, rather than being treated merely as errors, are considered valuable indicators of the readers' decision-making (K. S. Goodman, 1965). The concurrent examination of eye movement data and miscues allows each data stream to be interpreted in light of the other, providing a more nuanced understanding of the reading process than either method alone (Duckett, 2001; Nelson et al., 2008; Paulson, 2000). Further, the inclusion of a retelling task in EMMA provides a crucial measure of comprehension, offering further insights into the links between readers' comprehension and their control of their reading process reflected in their eye movement patterns and miscues.

While a reader's cognitive abilities are key to comprehension, the inherent complexity of the text itself also plays a critical role in determining the challenges presented to those abilities (Fisher et al., 2012). The concept of text complexity offers educators and researchers insights into the relationships between children's reading development and comprehension (Fisher et al., 2012; Pearson & Hiebert, 2014). Quantitative approaches determine complexity use mathematical formulas to assign a numerical score based on variables such as sentence length, word length, and percentage of familiar words (Cunningham & Mesmer, 2014). However, these approaches are limited because they are drawn from assessments of contrived texts that reduce the concept of 'reading' to its surface or secretarial features, which fails to take into account for nuanced meanings and coherence (McNamara et al., 2011)

Qualitative approaches use human judgement based on aspects such as genre, content, themes, text structure, language and literacy features, sentence complexity, and vocabulary (Pearson & Hiebert, 2014). These systems provide more nuanced and contextualised evaluations of text complexity and account for the interplay between text factors and reader factors. One example is Pinnell and Fountas' (2007) text complexity guide, a research-based taxonomy widely adopted in classrooms to make decisions about more authentic literary texts, including picturebooks (Pearson & Hiebert, 2014). Despite the long-standing use of quantitative and qualitative complexity scaling of books to match texts with children's reading proficiencies, many readers continue to experience difficulty (Fisher et al., 2012). One reason could be limitations in the capacity of existing guides to capture the full range of factors that influence readers' interactions and comprehension.

This paper investigates the potential of eye movement miscue analysis (EMMA) for developing deeper understandings about picturebook complexity. Reading in this research is viewed from a psycholinguistic perspective, where the act of comprehending a text is a dynamic transaction between the reader, the text, and the social context (Rosenblatt, 2018). Central to this theory is the role of authentic texts; those that are rich and nuanced, possess multiple layers of meaning, use evocative language and imagery, integrate visuals as an essential part of the narrative rather than as mere decoration, explore universal themes or dilemmas, and are capable of eliciting emotional responses (Ewing, 2020). Picturebooks, a type of authentic text, offer rich and natural interplay of visuals and textual elements, making them ideal for investigating the multifaceted nature of text complexity. Unlike decodable or levelled reading books that contrive text structures and language choices to teach specific concepts about the ways written language 'works', picturebooks present rich and authentic language structures, ideas and concepts that expose readers to diverse and natural language patterns (Al Azri & Al-Rashdi, 2014; Anstey & Bull, 2006; Berardo, 2006). In Australian classrooms, picturebooks are widely accessible and are frequently used as read-aloud texts to stimulate discussion and help students engage with social concepts and perspectives. However, they are less often used for reading teaching and assessment.

Shared in this paper is a research methodology that drew on an analysis of a series of picturebooks using Pinnell and Fountas' (2007) text complexity framework to explore readers' reading practices and comprehension of those texts using Miscue Analysis (MA) and eye movement data to identify areas of complexity and challenge. Those insights provided greater understandings about the ways readers engage with authentic texts (such as picturebooks), and hence the need for more comprehensive frameworks for understanding text complexity as educators select resources for reading teaching and assessment.

Literature Review

Miscue Analysis [MA]

Miscue analysis (MA) is an established and widely used reading assessment suitable for readers of all abilities. Its popularity lies in its capacity to reveal the strategies used and neglected by a reader, hence, informing instructional practices (Flurkey et al., 2021; K. S. Goodman, 1969; Y. M. Goodman et al., 2005; Wang et al., 2022). Traditional reading assessment focuses on accuracy and fluency. MA goes beyond these surface-level measures to explore the cognitive processes underlying comprehension as the reader actively constructs meaning. These insights are achieved through a systematic analysis of a reader's oral reading deviations from the printed text, known as "miscues" (K. S. Goodman, 1965).

Miscues manifest as substitutions, omissions, insertions, or repetitions of words, and are analysed after the reading is complete. Miscue analysis examines how readers used various information sources - graphophonic (letter-sound relationships), syntactic (grammar and sentence structure), and semantic (meaning) – to construct meaning from the

text (K. S. Goodman, 1965). A reader's process is more accurately captured through authentic reading conditions that are unconstrained by contrived, modified, or timed factors, allowing for natural engagement with the text. Moreover, the longevity of MA in classrooms lies in this focus on understanding the reader's use of a variety of information sources to construct meaning from the text (Y. M. Goodman & Goodman, 2014), grounded in the view that reading is an active and constructive process.

To illustrate, a reader may substitute the word 'home' with 'house' (Brown et al., 2012). The similarity in meaning between these words implies the accurate use of semantic and possibly grammatical (or syntactic) sources, while the only partial match between letters and sounds suggests the prioritisation of context over accuracy. Other types of substitutions where the reader replaces one word for something graphically similar but unrelated in meaning, or even a nonword – for example, substituting 'him' for 'home' - could reveal predominant reliance on phonics. Results from this analysis deepen understandings about readers' meaning-making processes by showing how the reader is working with the text, insights into the reader's understanding, strategies used, those that are neglected, and the reading activity patterns (Davenport, 2002).

In addition to examining oral miscues, the MA protocol also includes a retell task, which provides a complementary lens into comprehension. Since reading in this paradigm is understood as a construction of meaning, readers are encouraged not to parrot the original language or to mention specific events, but rather to talk about the main messages or understandings taken. Retelling is considered as a parallel story often built in forms and languages that vary from the original, allowing the readers to share their understandings as they like. However, this should not be interpreted as anything being acceptable (Y. M. Goodman et al., 2005). Unique aspects such as setting, plot, and theme should be included and examined in connection with the reader's comprehension of the story.

Building on this foundation, MA holds potential for analysing text complexity in general, and authentic texts such as picturebooks in particular. Analysing readers' oral responses to a text can shed light on the demands it poses, whether it involves decoding difficulty, new vocabulary, unfamiliar cultural reference, or areas requiring background knowledge (K. Goodman et al., 2009; Kabuto, 2017; Wang & Arslan-Ari, 2021). MA may also offer a way to explore how readers navigate the multimodal aspects of picturebooks, for example, attending to the interactions between text and image required for understanding their rich stories.

Eye Tracking Technology and its Applications in Reading Research

Complementing MA, eye tracking adds another dimension to the study of reading process. This technology tracks the movement of a person's pupils as they fixate on information in a stimulus, such as text in a book, information on a computer screen, or details in an image (Hyönä & Kaakinen, 2019; Rayner, 1997). Eye movement tools track saccades (sequence of fast eye movements over the text) and fixations (pauses during which visual information is processed) as readers interact with text, revealing how individuals allocate cognitive resources while reading (Just & Carpenter, 1980; Rayner, 1997; Reichle et al., 2009).

The Eye-Mind Theory proposes that these movements are closely reflect real-time cognitive processes, where reader fixates and for how long, reflects the mental effort required for comprehension (Just & Carpenter, 1980). Proficient readers typically tend to exhibit shorter fixations, longer saccades, and fewer regressions, indicating a more proficient reading process (Y.-S. G. Kim et al., 2019; Rayner et al., 2013). In contrast, younger and less proficient readers display longer fixation duration, shorter saccades, and increased regressions, suggesting greater effort in constructing meaning from a text (De Leeuw et al., 2016; Hyönä & Kaakinen, 2019; Korneev et al., 2018; Krstić et al., 2018) As reading proficiency develops, eye movement patterns become more streamlined, with readers extracting meaning from larger parts of text rather than letters and individual words (Blythe & Joseph, 2011; W.-J. Kim et al., 2023).

Eye movements are also sensitive to text complexity. More complex texts, with longer sentences, less common words, and more intricate syntactic structures, tend to trigger longer fixation durations, more regressions, and shorter saccades (Korneev et al., 2018; Kraal et al., 2019; Loberg et al., 2019). In contrast, simpler texts lead to shorter fixations and longer saccades, reflecting a more automatic reading process (De Leeuw et al., 2015; Joseph et al., 2013).

Beyond traditional word-based reading, eye tracking research has provided valuable insights into how readers engage with multimodal texts, such as illustrated texts, comic books, and digital texts. These texts integrate multiple modes of meaning - images, graphics, and written language - requiring readers to navigate between different sources of information (Serafini, 2010). Studies have linked fewer saccades between modes with comprehension difficulties (Hannus & Hyönä, 1999; Jian, 2017; Yusof et al., 2019). This body of research informs the present study's design by highlighting how visual attention reflects comprehension effort, especially in multimodal contexts.

Eye Movement Miscue Analysis (EMMA)

Bridging MA and eye tracking, Eye Movement Miscue Analysis (EMMA) was developed by Paulson (2000) to integrate both data streams. EMMA captures readers' eye movements during oral reading while recording and analysing their miscues. Whereas traditional miscue analysis ends with oral reading and retell, EMMA tracks the location of attention,

revealing not only readers' oral articulation but also what they see and process silently (Duckett, 2001; Nelson et al., 2008; Paulson, 2000).

Studies employing EMMA have mainly investigated readers' strategies to construct meaning, such as how individuals allocate attention and navigate text (Arya & Feathers, 2022; Liwanag et al., 2020; Mantei & Kervin, 2021). Paulson (2002) research found that even when miscues occur, readers still examine the information available. And further, that all attempts were an effort to make sense of the text rather than a result of any kind of carelessness (Mantei & Kervin, 2021; Paulson, 2002). Similarly, EMMA research has revealed that readers employ consistent reading strategies and exhibit a preference for written text over visuals in specific contexts (Arya & Feathers, 2012; Duckett, 2001). And not all text is read aloud. Liwanag et al. (2017) found that some readers' eyes fixated on headings, but the reader omitted reading them aloud, suggesting they processed the headings visually but perhaps did not feel the need to vocalise them. Importantly, EMMA studies have challenged misconceptions about readers' apparent inactivity during long pauses in oral reading, with eye movement data indicating that readers were actively searching for cues within the text (Arya & Feathers, 2012; Liwanag et al., 2017; Mantei & Kervin, 2021).

While EMMA studies have informed the field about readers' strategies and practices as they process texts. However, little is known about the nature of the text itself. The novelty of this study is the use of EMMA to investigate text complexity. This study shifts the focal point to become the text itself, as the diverse responses from readers help shed light on text complexity through what readers do (process) and understand (retell). Examining how readers are positioned by the texts they read, that is, their complexity, can offer fresh insights that could respond to some of the enduring puzzles about reading.

This shift directly informs the research question: How can EMMA provide deeper insights into the complexity of primary school students' reading materials beyond what is captured by an existing guide? To explore this, a series of picturebooks commonly held in Australian school classrooms and libraries were selected and analysed using Pinnell and Fountas' (2007) guide, a widely adopted framework for evaluating the complexity of reading materials for teaching and assessment (Pearson & Hiebert, 2014), followed by the EMMA assessment. This integrated approach combines an established complexity framework with real-time evidence of how readers interact with multimodal texts. By doing this, the study aims to broaden the horizons of research in the field, prompting new discussions about reading teaching and assessment.

Methodology

Research Design

This research used a descriptive case study, where the case under investigation is the text itself (Creswell & Poth, 2017). The study sought to explore the potential for using EMMA to evaluate text complexity. A mixed-method approach (see Figure 1) was employed to generate descriptive quantitative data (eye movement patterns) and qualitative data (miscue analysis and retell), affording a more comprehensive understanding of texts' complexity, considering real-time reading and cognitive effort indicators.

The study drew on an archive of picturebook reading captured through audio and eye-movement data obtained from primary school children ages 7-11 years old. Data were collected at a public primary school in New South Wales, Australia, where teachers used standardised reading assessments to track and group students based on their reading proficiency. Thirty students were recruited, all of whom had been identified through their teachers' classroom reading assessments as demonstrating reading proficiency below the expected levels on benchmark assessments.

The complexity of a selection of texts (picturebooks) commonly used in Australian primary school classrooms was examined using Pinnell and Fountas' (2007) text complexity guide. The complexity guide uses qualitative measures for evaluating text complexity and therefore its perceived 'difficulty' based on sentence structure, vocabulary, and content. The goal was to match a suitable picturebook with the identified reading proficiencies of the participating children (Figure 1).

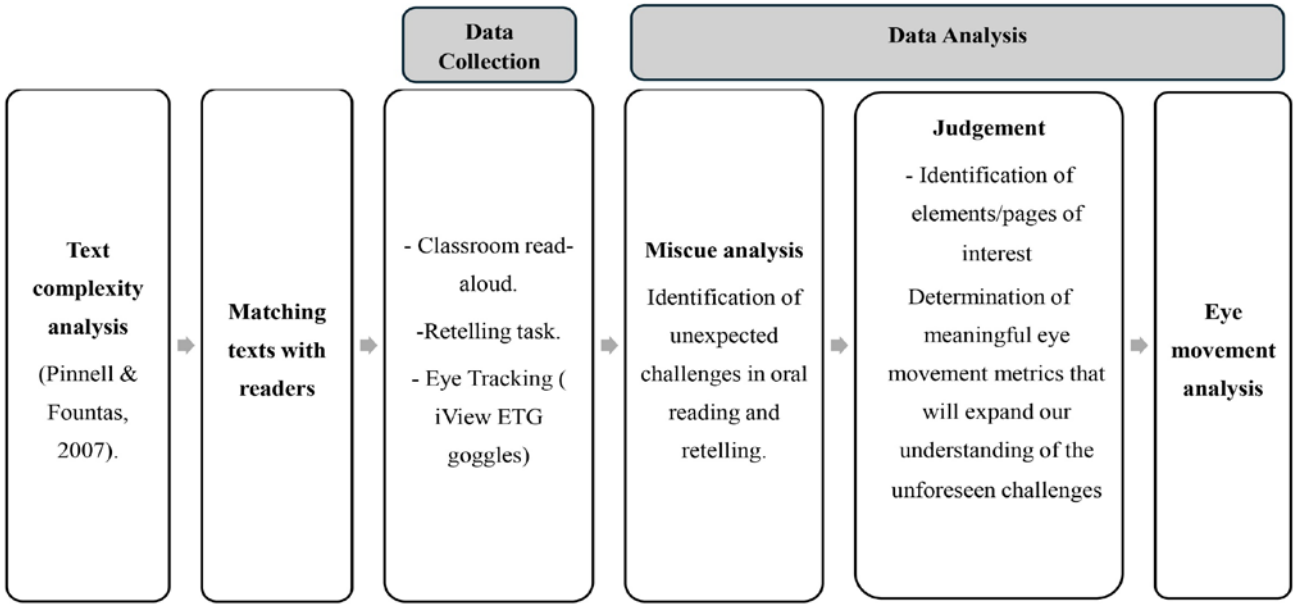

Figure 1. Research Design

Data Collection Procedures

Data were collected in the participating children's classrooms as they read selected picturebooks while wearing the iView ETG video-based eye-tracking glasses. The eye-tracking glasses were chosen over screen-based eye trackers to allow for a more natural reading experience, as they enable participants to engage with physical picturebooks in their regular classroom environment adding ecological validity to the research. Technical details about sampling rate, calibration, and software are provided in Appendix A.

The children sat in a comfortable position in or near their classroom alongside one researcher under standard classroom lighting. Using MA protocols, they were asked to: 1) read just as they would when reading independently, but out loud so the researcher could hear; 2) retell the story in their own words (unaided retell) as a demonstration of their reading comprehension; and 3) respond to prompting questions (aided retell) designed to prompt for more information about the reader's understanding. These questions and prompts relate to specific details, plots, and events, as well as interpretations and inferences about the content. The researchers used audio recordings of the reading and retelling to prepare a miscue analysis for each child's reading of each text. Each reading session lasted approximately 20 minutes, and data collection took place over a period of six weeks.

Focus Text and Participants

While the broader project involved several picturebooks, this study focuses on a single picturebook, *My Uncle's Donkey* (Riddle, 2012), to allow for an in-depth analysis of the reading process using EMMA. This approach prioritises analytical richness over breadth, aligning with the study's exploratory aims. *My Uncle's Donkey* is an award-winning picturebook written and illustrated by Australian author Tohby Riddle. An analysis of the text using Pinnell and Fountas's (2007) text complexity guide revealed that it is appropriate for readers at the end of Year 2 and the beginning of Year 3 (Ages 7-9) (see Appendix B for a summary of the complexity of *My Uncle's Donkey,* according to the guide). Of the thirty participants, ten readers (aged 7-9) were matched with and read the text.

My Uncle's Donkey is a third-person narrative about a donkey living in a house and engaging in human-like activities, creating a juxtaposition between cultural norms and unusual pet choice. Each double page presents one sentence in one to two lines. Each typically starts with the phrase 'My uncle's donkey…' and ends with an event or activity it likes to do. Examples include watching TV, talking on the phone, and juggling. The donkey and the uncle are prominently displayed in the centre of most pages, set against a white background that makes the characters and their actions stand out.

The words in *My Uncle's Donkey* are enhanced by the illustrations (Nikolajeva & Scott, 2000), that is, expanding on the story through emotional and interpretive layers not explicitly mentioned in the written text. While the writing primarily describes actions and locations, this picturebook uses images to convey emotions, power dynamics, and characters' interactions. For example, one sentence states, 'My uncle's donkey likes to hide', however an illustration of the donkey's feet, legs, and ears absurdly sticking out from the curtain shows the donkey to be poor at hiding, expanding the reader's understanding of this character (Sipe, 1998). The uncle, who is not an active character in the story, is often depicted gazing away from the donkey rather than interacting with it, suggesting he might ignore its strange behaviour or is perhaps unaware of his existence (Figure 2). The richness of this text (Ewing, 2020) is developed as ideas, emotions, and insights into the human condition are conveyed through multiple modes.

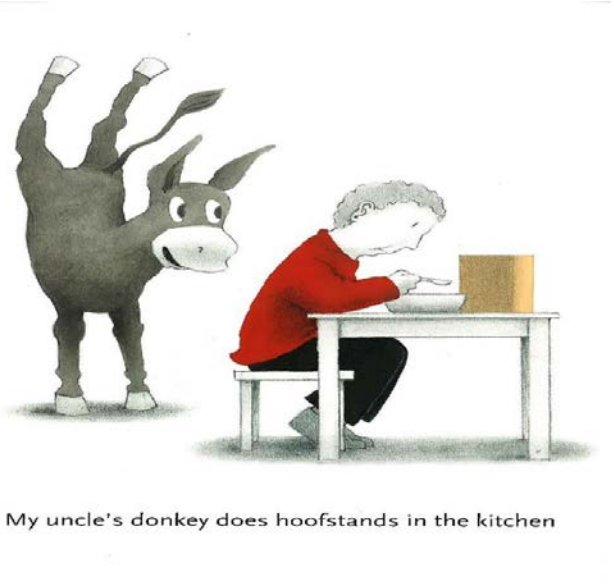

Figure 2. My Uncle's Donkey (Riddle, 214, p.6)

Data Analysis

The study employed an exploratory sequential design (Creswell, 2014), beginning with the collection of qualitative (MA) then quantitative data (EM). Qualitative data (transcripts from the read aloud and retell) were analysed to identify the nature of readers' miscues with a particular focus challenges not anticipated through the complexity analysis (Pinnell & Fountas, 2007) (Appendix B). Subsequently, a judgement was made to identify pages or elements of interest and determine the meaningful metrics that could shed light on the nature of these unanticipated challenges. Eye movement (EM) data were analysed on these identified areas of challenge to understand how readers navigate complex areas of the text. Figure 3 illustrates the study's sequential analysis approach to examining picturebook complexity.

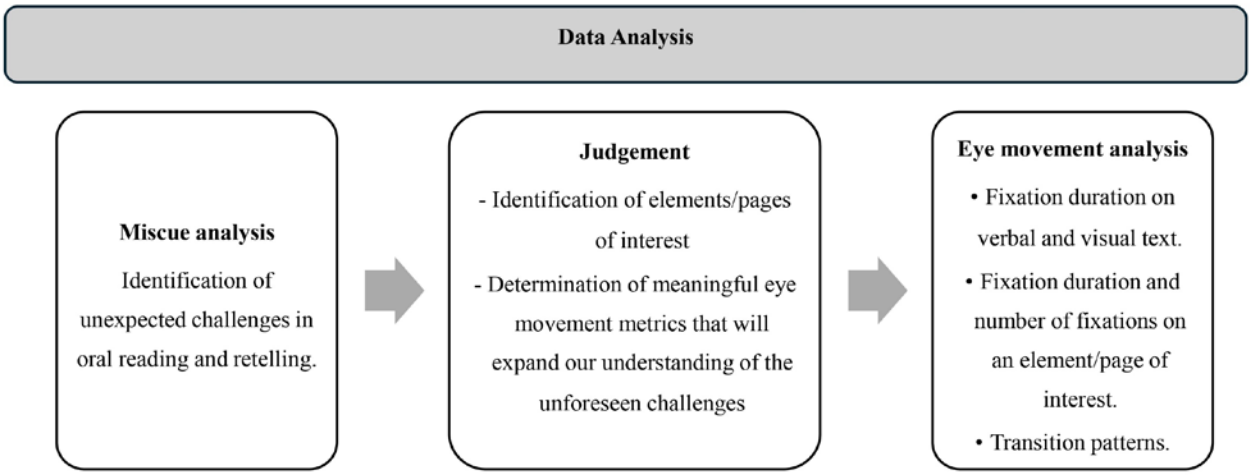

Figure 3. Data Analysis - A Sequential Approach

Miscue Analysis

The Reading Miscue Inventory (RMI) drove the Miscue Analysis assessment (Y. M. Goodman et al., 2005). To ensure reliability, the researchers listened to the recordings of both reading and retell multiple times and collaboratively constructed miscue analyses. All miscues were listed in a coding form and numbered, including substitutions, omissions, insertions, and intonations that affect the meaning, even if self-corrected (Appendix C). Following coding, a qualitative miscue analysis was conducted to rank the miscues against Y. M. Goodman et al.'s (1987) six categories: syntactic acceptability, semantic acceptability, meaning change, correction, graphic similarity, and sound similarity (Appendix C). Then, patterns of interrelationships between responses were calculated (Appendix C) along with reading grades in response to the patterns formed, providing statistical data alongside the qualitative data (Appendix D). Analysis of miscues culminated with the retell where key points in the story were identified.

Eye Movement Analysis

Results of miscue and retell analysis led to the identification of specific pages where unanticipated reading challenges warranted further investigation. While all 10 readers were initially included in this stage of analysis, data from two were excluded due to poor eye-tracking quality and one was excluded due to insufficient data (missed more than 50% of the target pages). For the specific pages, three analyses were conducted for each individual: 1) distribution of fixations on written, visuals, and other white space on the page to assess the overall attention devoted to written and visual elements, 2) frequency (total number of fixations) and duration of overall fixations on key elements/page of interests to examine the level of focus on these elements 3) origins of eye movements (fixations) that land on key elements; to determine what prompted readers to look at that element. These analyses were used to characterise readers' visual attention patterns and how they engage with specific elements of the text.

Results

Miscue Analysis

Participants' miscues were analysed and categorised, with rates calculated per hundred words (MPHW) to assess reading accuracy and are presented in Table 1. Percentages are included to highlight trends and patterns of participants' individual reading processes rather than to support generalisations across participants. Details on how these percentage were computed are provided in appendix C and appendix D.

Table 1. In-Depth Miscue Analysis Statistics Scores

Reader	Grade	Total Miscues (MPHW)	Meaning Construction	Grammatical Relations	Graphic Similarity	Sound Similarity
Hana	3	1%	100%	100%	50%	50%
Darby	3	2%	90%	100%	100%	100%
Kaidon	3	5%	81%	100%	56%	42%
Karina	3	2%	75%	100%	66%	66%
Tegan	2	2%	75%	75%	50%	50%
Joash	3	14%	32%	41%	65%	56%
Leonardo	2	14%	25%	33%	70%	70%
Vish	2	26%	15%	33%	70%	70%
Klay	2	40%	11%	66%	16%	8%
Audery	2	53%	3%	15%	75%	75%

Among the ten readers, two demonstrated accurate reading, three maintained meaning at a level of 80-75%, and the remaining five maintained meaning at a level of 32-3%. These findings broadly aligned with Pinnell and Fountas' (2007) complexity analysis, which had predicted challenges with multisyllabic words in the text, for example, 'favourite,' 'business,' 'hoofstands,' and 'cartwheels.' A notable pattern was readers pausing when encountering challenging vocabulary, often rereading the sentences, and attempting to rely on graphic cues. However, several readers abandoned correction, omitted the challenging vocabulary, and resumed reading.

Unaided and Aided Retell

While six readers produced elaborate retellings of the story, four offered briefer summaries. Common across these retellings, however, was the challenge of identifying the characters, specifically the uncle. The uncle is depicted on the cover page and ten times throughout the text in a red sweater (e.g., see Figure 2), and his relationship with feelings about his donkey are mainly conveyed through visuals. Despite this, most readers could not recognise the uncle, were confused about who was telling the story, and whether the uncle was even in the story. For example, Readers 1 and 3 were unsure who the human character was, while Reader 2 believed the uncle was not present in the story at all. Consequently, they missed some important and nuanced information about the characters and the plot. The following examples demonstrate the readers' confusion about the uncle character.

Example from reader 1: confusing the uncle in the illustrations with the story's narrator

Researcher: Who else is in the story?

Reader 1: The person

Researcher: Tell me about the person.

Reader 1: That he ummm he's talking.

Researcher: What do you mean he's talking?

Reader 1: That he's saying the ummm ummm ummm words.

Example from reader 2: Prompting did not help readers recognise the character.

Researcher: My uncle's donkey. What's an uncle?

Reader 2: He's really old.

Researcher: Is the uncle in the story?

Reader 2: No.

Researcher: You don't see the uncle?

Reader 2: Nope. And yes that guy is the uncle.

Researcher: Ohh. Could that be?

Reader 2: No.

Example from reader 3: He remembered the uncle's illustration and made inferences about his personality, but was unable to identify him from the text.

Reader 3: There was a donkey and there was a person in the background … it didn't really talk about the person. … And they talked a lot about the donkey … yeah and there were pictures and yeah.

Researcher: Tell me about the person in the background.

Reader 3: Well he didn't like the donkey

Researcher: How do you know he didn't like him?

Reader 3: About his face

Researcher: What about his face?

Reader 3: He didn't … hold on, let me look at the book. [Pointing towards the book] look at his face. It's grumpy.

Researcher: Oh, he has a grumpy face. And who do you think that is?

Reader 3: uhhh. … the uncle. No. The uncle's son … I think. [extended pause]

The miscue analysis and retellings suggest a disconnect between the challenges predicted for these readers in the text's complexity analysis (Appendix B) and the readers' actual interaction with the narrative. Despite clear illustrations, many readers struggled to recognise or understand the uncle's role in the narrative. This points to possible gaps in how visuals are interpreted and used during reading. To further explore these challenges, eye movement data were examined.

Eye Movement

The uncle appears on ten of the thirty pages, typically wearing a red sweater. Despite this visual prominence, the textual reference to the uncle is minimal. Responding to unexpected difficulties in identifying the uncle, analysis of eye movements was undertaken on the ten pages featuring the uncle's illustration. These pages take a consistent format – a large centrally positioned illustration on a white background with a sentence or sentence fragment on each, typically located at the top of the page (Figure 4).

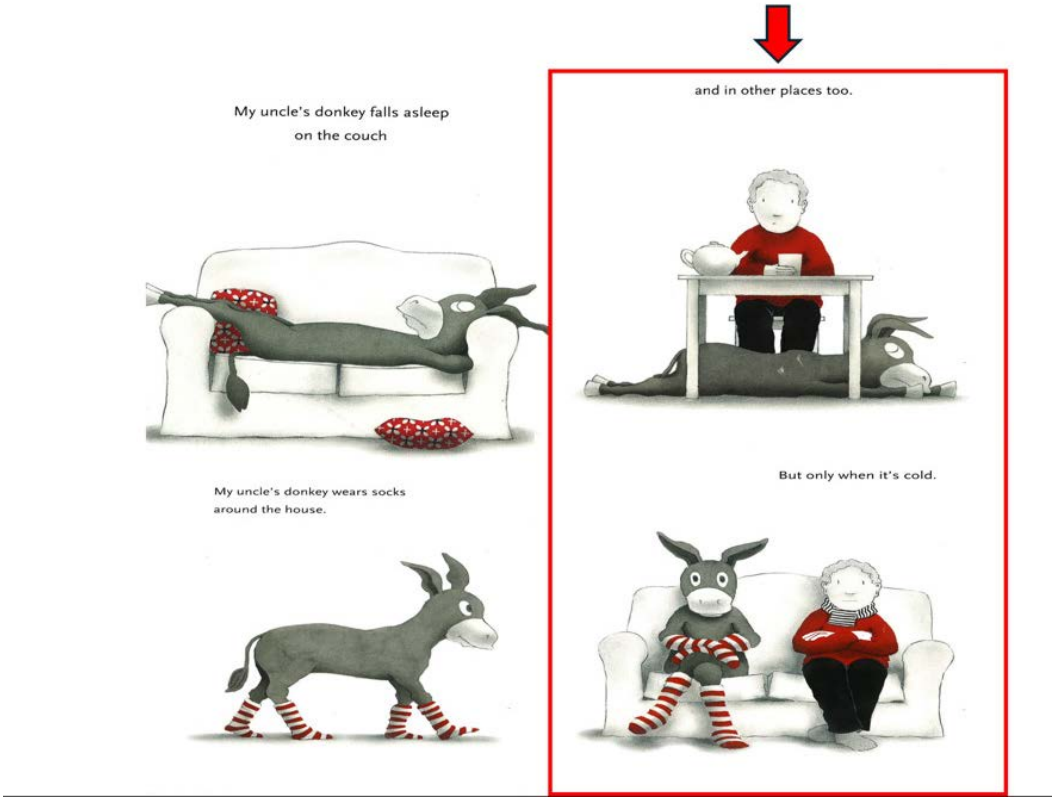

Figure 4. Uncle's Appearances in Diagram: 10 out of 30 Pages (Riddle, 2012)

Distribution of Fixation Duration Across the Pages of Interest

All seven readers showed eye movements that indicated they engaged with the visuals. Fixation durations for the pages of interest are summarised in Table 2, with durations categorised by written text, visuals, or other white space on the page. Overall, the readers devoted some (21.3%) of their visual attention to visuals (range: 9% to 34%), and most to written text (average 76.1%; range: 61% to 86%). This suggests a wide range of individual variability, with a general preference for written text over visuals, but all readers engaged with the visuals.

Table 2. Distribution of Fixations Duration (10 Target Pages)

Reader	Total Fixation Duration 10 Pages of Interest (in milliseconds)	Fixation Duration by Category (in milliseconds)		
		Written Text	Visuals	Other White Space
Hana	26398.2	18738.5	7659.7	0
Darby*	38950.5	30713.3	6889.7	1347.5
Kaidon	46917.3	36735.1	9982.4	199.8
Karina*	22413	13709	7621	1083
Joash*	38667.8	32578.5	3410.6	2678.7
Vish	219892.6	189060.1	28303.4	2529.1
Audery*	74681	55370.6	18944.5	365.9

Note. An asterisk (*) indicates that the reader skipped 1-2 pages of the targeted 10 pages during reading or that fixation data were lost due to head movements during the reading of the picturebook

Fixations and Fixation Duration on the Uncle

Fixations and overall fixation durations specifically on the uncle were further examined and are reported in Table 3. All readers fixated on the uncle's illustration at least four times. during their reading. However, individual differences were evident in the frequency and duration of fixations. Number of fixations on the uncle ranged from 4 to 30 throughout the reading, and the total fixation duration on the uncle varied from 964.7 milliseconds to 9451.2 milliseconds, highlighting individual differences in children's attention to this specific character.

Table 3. Total Number of Fixations and Fixation Duration on the Uncle Illustration (10 Target Pages)

	Visuals		Visuals – Uncle	
Reader	**Number of Fixations**	**Fixation Duration [ms]**	**Number of Fixations**	**Fixation Duration [ms]**
Hana	37	7659.7	11	2444.4
Darby	38	6889.7	15	2629.3
Kaidon	40	9982.4	8	1629.5
Karina	18	7621	10	3128.9
Joash	20	3410.6	4	964.7
Vish	119	28303.4	30	7589.3
Audery	70	18944.5	24	9451.2

Transition Patterns

To better understand the context in which the readers engaged with the uncle's illustration, the origins of transitions (fixations) to the uncle's illustration were identified. These transitions were categorised as follows: before fixating on any written text on the page; after reading written text on the page; after reading a specific word or phrase; or as a potential aid in word identification (determined by analysing eye-tracking data alongside audio recordings) (see Figure 5).

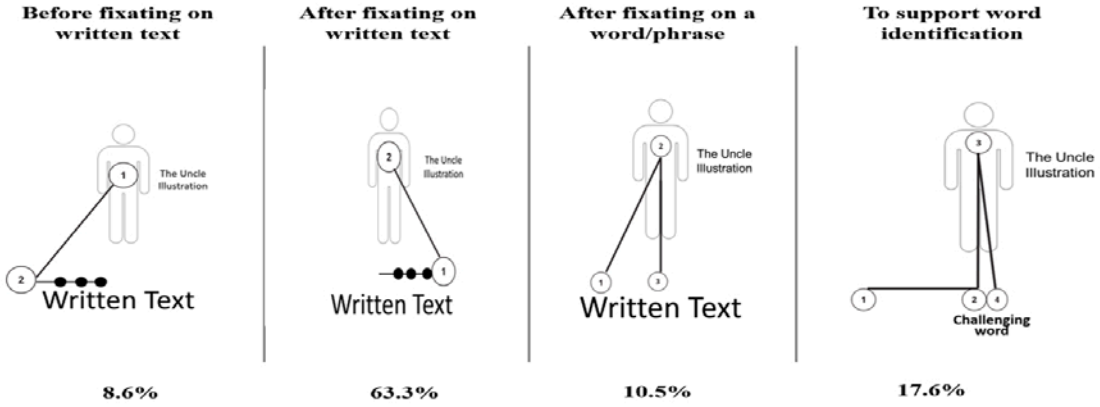

Figure 5. Transition Patterns Involving the Uncle's Illustration

Most transitions (83.22%), as detailed in Table 4, occurred before reading the corresponding text, after reading a complete page, or after reading a phrase/word. This suggests that the uncle's illustration was strategically used to support meaning construction, rather than simply as a visual aid for word decoding.

Table 4. Distribution of Transition Types Leading to Fixations on Uncle's Illustration

	Visuals – Uncle		Number of fixations based on type of transition			
Reader	**Number of Fixations**	**Fixation duration**	**Before written text**	**After written text**	**After a word/phrase**	**To support word identification**
Hana	11	2444.4		10	1	
Darby	15	2629.3	1	13		1
Kaidon	8	1629.5	2	5		1
Karina	10	3128.9		9	1	
Joash	4	964.7		3		1
Vish	30	7589.3	5	9	4	12
Audery	24	9451.2	5	5	6	8

The eye-tracking analysis reveals that while readers did fixate on the uncle, their engagement with that illustration varies significantly in terms of the number of times they visited/revisited this visual information and the duration of these fixations. However, the time spent on both the written and visuals, as well as the patterns of transitions to the uncle's illustration, suggest that readers primarily utilised this explicit illustration to supplement and reinforce textual information. Interpretive commentary on these findings is elaborated in the discussion section.

Discussion

This study introduces a novel method for assessing picturebook complexity, integrating text complexity analysis (Pinnell & Fountas, 2007), miscue analysis (Y. M. Goodman et al., 1987), and eye-tracking technology. *My Uncle's Donkey* (Riddle, 2012) was evaluated for its complexity through an established framework (Pinnell & Fountas, 2007). Careful matching of text to the reading proficiency of ten children (ages 7-9 years) afforded an examination of these readers' experiences. Utilising portable eye-tracking glasses in these readers' classroom settings allowed dynamic eye movements during oral reading to be analysed alongside miscues and comprehension. This multifaceted approach offered a more nuanced understanding of how readers engaged with seemingly simple narrative, revealing interpretive demands not visible through conventional measures alone.

'My Uncle's Donkey' (Riddle, 2012), like many children's picturebooks, exemplifies a minimalist approach in its verbal and visual elements. The apparently straightforward narrative structure appears to present challenges through the use of a third-person narrative voice, which could subtly influence meaning construction (Chen et al., 2023). While the initial complexity analysis highlighted potential difficulties, such as decoding multisyllabic words and comprehending compound sentences (Appendix B), EMMA uncovered deeper narrative and reading challenges, especially in relation to how readers comprehend implicit character cues and multimodal information.

The retellings revealed persistent confusion around a key character, the uncle, and through EMMA, we were able to trace how this confusion emerged not only in what was verbalised, but also in the visual information revealed through eye movement depicting what the readers engaged with during reading. Although the uncle appears on ten of the thirty pages and is visually prominent, the textual reference to him is minimal. Analysis showed that while participants did fixate on the illustrations of the uncle, the degree of attention varied. Further, looking at these visuals did not consistently translate into accurate or full comprehension. Eye-tracking data added a critical layer to this interpretation. Most transitions to the uncle's illustration occurred before, during, or after reading the corresponding text. This suggests readers sought to use this specific visual to construct meaning and to support their understanding of the written text. These results align with Feathers and Arya's (2015) EMMA study, which found that young readers actively use visuals to construct meaning.

The observed fixation patterns suggest that while these participants likely visited visuals to support the meaning constructed from the written text, the illustration offered new information (introducing the uncle) and expanded the story (providing another dimension to the characters' relationship). This interplay between written text and visuals forms an 'enhancing relationship' (Nikolajeva & Scott, 2000), where each mode provides additional meaning to the other. Even though visuals and written text did not contradict each other in *My Uncle's Donkey* (Nikolajeva & Scott, 2000), the implicit connection between the two modes likely posed challenges to the readers. To fully understand the uncle's role, readers needed to integrate the words and visuals to bridge the gap between what was explicitly stated and what was conveyed through visuals (Sipe, 1998). Participants' fixation patterns underscore the challenge of integrating visual information into a coherent narrative when it is not explicitly reinforced by the written text.

A key factor contributing to this difficulty may be the uncle's passive role in the story. Although he is visually present, he does not actively participate in the narrative, and his role must be inferred. The absence of explicit textual references likely required young readers to rely solely on visuals to build character comprehension, a process that may not come naturally at this developmental stage. While this finding highlights the reading challenges generated when the text relies on visual information for character identification and relationship building, pertinent to this study is that it also points to a broader limitation in existing text complexity frameworks. Two key limitations of Pinnell and Fountas (2007) text complexity framework were revealed through this method, both tied to its limited consideration of multimodal demands for reading:

(1) The guide priorities linguistic elements, such as sentence structure and vocabulary, but does not account for the interpretive effort involved required to integrate visual and textual modes.

(2) It assumes that complexity is primarily a function of written text, underestimating the demands of multimodal texts such as picturebooks. Participants' difficulty in identifying the uncle, despite his visual salience, demonstrated that meaning-making depends not only on decoding words but also on synthesizing narrative elements across modes (Walsh, 2006). The framework does not sufficiently capture how meaning is distributed across visual and written text.

The disconnect between the analysis of text complexity using Pinnell and Fountas (2007) and the actual reading challenges underscores the limitations of relying on textual aspects alone. The interplay between written text and visuals, the implicit information conveyed through illustrations, and the demands placed on readers to infer characters, relationships, and emotions are crucial aspects that must be considered when evaluating the complexity of picturebooks (Callow, 2013; Painter, 2017). The case shared here shows how texts like '*My Uncle's Donkey'* rely on visual cues for character development and narrative comprehension. While the children were able to decode the written text, their potential to fully understand the narrative was also reliant on their ability to decode visuals and make meaning across modes. The combination of miscue analysis, eye tracking and retell enable this disconnect to be identified and understood for these readers.

Conclusion

This paper demonstrates the capacity of eye movement technology alongside miscue analysis to capture the nuances of reading practices in natural settings, using authentic materials. It gives an example of the EMMA method to investigate text complexity and how it has the potential to add further depth, value, and new insights to already existing text complexity measures. Findings revealed that while students could decode written text accurately, many struggled to construct meaning when key narrative information was conveyed visually. Eye movement patterns showed a general preference for written text over visuals, yet transitions to visuals suggested a strategic effort to support comprehension.

This study addresses a significant gap in the literature by showing how EMMA can be used not only to examine reading strategies but also to reveal the demands embedded in texts, particularly multimodal texts, demands that current complexity frameworks often overlook and are difficult to examine in typical classroom reading assessment. It also highlights the significance of bringing multiple reading assessments together to inform understandings about how children make meaning with complex picturebooks, pointing to the need for more comprehensive ways to evaluate the interplay between written and visual information than is offered in existing approaches for evaluating a text's complexity. Future research could extend this method to other types of texts.

Key Considerations

The Nature of the Selected Reading Materials and Reading Settings

Methodologies that use authentic readings resources, not contrived or edited, can provide insights into the real challenges of reading. Contrived texts typically feature direct, simple vocabulary and supplementary illustrations that may not reflect the complexity and diversity of authentic texts. Authentic texts expose readers to linguistic, cultural and visual diversity that can challenge their reading comprehension and skills. Moreover, collecting data in natural settings, such as classrooms, provides a more authentic and realistic picture of how children engage with texts. Although this may introduce variability due to distractions, it offers a more ecologically valid assessment of reading.

Layered Analysis Approach

Selecting an appropriate gaze metric that is aligned with the study's purpose and offers novel insights is a crucial step in the data analysis. A layered approach can be adopted, starting with a miscue analysis, followed by an examination of gaze metrics relevant to the research. In this research, the appropriate gaze metric afforded meaningful data interpretations that led to a deeper understanding of a longstanding problem in reading research. The EMMA method here provided a view through readers' eyes and a glance into their minds.

Recommendations

This study highlights the potential of Eye Movement Miscue Analysis (EMMA) to prompt a new focus on reconsidering the demands picturebooks pose for readers, even those deemed appropriate based on known text complexity guides. Understanding those demands is crucial for supporting reading development and instruction. Future research should investigate a wider variety of multimodal texts, including digital texts and nonfiction texts, incorporating diverse narrative structures and visual representations to explore how layout and navigation influence reader comprehension. The EMMA assessment method has much to offer with these investigations. Studies could also test this approach across diverse learner profiles, such as bilingual readers or students with specific reading difficulties, to understand how different readers interact with multimodal demands.

Additionally, while existing qualitative and quantitative measures offer valuable insights into textual complexity, they often fall short in capturing the nuanced complexities of picturebooks, as illustrated by participants' engagement with *My Uncle's Donkey* (Riddle, 2012). Future work could expand understandings of text complexity to go beyond textual elements to consider visual elements within the text. By examining how visual elements interact with, or separately from, written text, researchers can gain valuable insights into layers of complexity generated by interplay between these modes.

Limitations

While this study provides valuable insights into how less proficient readers engage with picturebooks, certain limitations also offer promising directions for future inquiry. The use of a small sample size and a single picturebook allowed for an in-depth, focused analysis, but these choices may limit the generalisability of the findings. The selected text, *My Uncle's Donkey* (Riddle, 2012), provided a rich example of multimodal complexity but may not represent the full range of forms and narrative structures found in picturebook more broadly. Additionally, the participant group represents a specific reader profile, and future studies could extend this work by including readers with varied proficiency levels and backgrounds. These limitations are not only important to acknowledge but also serve to highlight areas where future research can further advance understanding in this field.

Ethics Statement

Ethical approval to conduct this research was obtained from the Human Research Ethics Committee at the University of Wollongong (Ethics code 2015/313).

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Conflict of Interest

The authors report there are no competing interests to declare.

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No generative artificial intelligence (AI) tools were used in the writing, analysis, or editing of this manuscript. All content is the original work of the authors. Where software tools were used for data management or formatting, these were standard, non-generative tools.

Authorship Contribution Statement

Alruthaya: Conceptualising, methodology, quantitative and qualitative data analysis, writing, and editing. Mantei: Supervision, conceptualising, data collection, and editing. White: Supervision, conceptualising, reviewing of quantitative analysis (eye movement), and editing. Kervin: Supervision, conceptualising, data collection, and editing.

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Appendix A

Technical Specifications of Eye-Tracking Setup

Eye-Tracking Equipment:

- Device: iView ETG video-based eye-tracking glasses
- Manufacture: SensoMotoric Instruments (SMI)
- Sampling rate: 60Hz, binocular

Calibration Procedure

- A three-point calibration was conducted prior to each session to ensure accuracy of gaze data.
- Calibration was performed in the participant's reading position, using printed calibration targets held in the participant's filed of view.

Software Used

- Eye movement data were analysed using BeGaze software (Version 3.7).
- Analyses were conducted using the average position of both eyes.
- Fixations were classified using a minimum duration threshold of 80 milliseconds.

Appendix B

Qualitative Analysis of Text Complexity in *My Uncle's Donkey* based on Pinnell and Fountas (2007)

Title: My Uncle's Donkey	
Author: Tohby Riddle (2012)	
Book and Print Features	
Length	A physical book of a story that is told in 168 words over 30 page. Each double page spread includes one sentence presented in one to two lines.
Print	Large, clear print with distinctive spaces and well-defined spaces between lines.
Layout	Each double page spread shares one event in the story. Some pages place the text on the top left, while in a few pages the sentence is placed at the bottom of the page. Few sentences begin in a page and carry over to next page. For instance, My Uncle's donkey juggles … but not very well.
Punctuation	Simple punctuation; periods, commas, and exclamation marks
Illustrations	Large drawings and watercolour paintings on each page that portray the action.
Content	A picture book about a donkey who lives in a house: he sits on a chair, talks, Juggles, takes a long bath, and wears socks.
Themes	Home, animals, imagination, and entertainment. The story playfully explores the absurd and entertaining consequences of having a donkey as a pet, challenging expectations about house rules and animals' behaviour.
Ideas	Familiar ideas about activities in the home that readers may encounter in their daily life.
Text structure	One sentence on each page.
Language and Literary features	
Perspective	Third person point of view in which the story is described from an outside observer's perspective (the uncle's nephew or niece).
Language structure	Simple sentences: e.g., 'My uncle's donkey is allowed in the house.' Repetitive sentence structures: e.g., 'My uncle's donkey has a favourite chair.' Few compound sentences: e.g., 'My uncle's donkey has a favourite chair and a favourite movie.'
Literary language/devices	Straightforward text much like oral language
Vocabulary	Words commonly used to describe items in the home; chair, movie, food, breakfast One non-standard word- Hoofstands
Words	Commonly used words that have one to three syllables and regular spelling patterns. Breakfast, bedtime, cartwheels, watermelon

Appendix C

Miscues analysis in-depth procedure coding form.

Reader Date Teacher Age/grade School Selection			1 Syntactic acceptability	2 Semantic acceptability	3 Meaning change	4 Correction	See 2,3,4 Meaning construction			See 1,2,3 Grammatical relations				5 Graphic similarity			6 Sound similarity		
Miscue No./Line	Reader	Text					No loss	Partial loss	Loos	Strength	Partial strength	Overcorrection	Weakness	H	S	N	H	S	N
a. Total Miscues: …….			Column Total																
b. Total Words: …….			Pattern Total																
a x b x 100= MPHW …….			Percentage																

Note. Adopted from Reading miscue inventory: From evaluation to instruction, by Goodman et al., 2005, Richard C. Owen Publishers.

Appendix D

Miscue analysis in-depth procedure reader profile form

Patterns	%	%	Reader		Date	
Meaning construction	Percent		Teacher	Age/grade	School	
No loss		}	Selection			
Partial loss			Repeated miscues across text			
Loss			Line	Reader	Text	Comments (place in text, correction, etc.)
Grammatical relations						
Strength		}				
Partial						
Overcorrection						
Weakness						
Word substitution in context						
Graphic similarity						
High		}				
Some						
None						
Sound similarity						
High		}				
Some						
None						
Relating						
Characteristics						
Events						
Total						
Holistic score						
MPHW ……. Time …….						
Comments						

Note. Adopted from Reading miscue inventory: From evaluation to instruction, by Goodman et al., 2005, Richard C. Owen Publishers.