An Investigation of the Role of Gaze and Attention on Learning

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Abstract

Individuals with Autism Spectrum Disorders (ASD) have been observed to have deficits in attending to the "global whole", which is the ability to integrate piecemeal information into a coherent whole. Instead, they often attend to local, specific features of a visual scene leading in many cases to an inappropriate focus on irrelevant detail. Interest in this type of deficit stimulated research in determining if eye gaze patterns were linked to their difficulties attending to global information. When eye-tracking has been used to record eye gaze patterns, however, the results have been mixed, with some studies citing atypical gaze patterns and others demonstrating eye gaze patterns similar to typically developing individuals. In many of these studies, however, participants were passively rather than actively engaged with visual stimuli, the latter of which has been shown to assist individuals with ASD to overcome their processing bias for local rather than global features. Accordingly, a systematic review was conducted to compare the eye gaze patterns of those individuals with ASD to typically developing (TD) individuals during active task engagement (e.g. reading). Overall, about half of the studies demonstrated that eye gaze patterns of individuals with ASD were atypical when actively engaged with visual stimuli. Importantly, however, while there was a difference in eye gaze patterns, performance was not impaired, suggesting that a difference in eye gaze patterns did not necessarily lead to a deficit in attending to the global whole. Only TD participants and those with ASD who were capable readers were included in the studies, which, in turn, highlighted a gap in the literature concerning the gaze patterns of poor readers, both with and without ASD. An empirical study, therefore, utilising eye-tracking was conducted to investigate the eye-gaze patterns of individuals with ASD and TD controls, as well as high skilled and low skilled readers during text reading and when required to answer text related questions. Readers with ASD, regardless of reading skill level, displayed longer fixations than TD readers. This finding could lead to the conclusion that these students employed a more "cautious and careful" reading style, which should be considered in the context of time limits imposed on these students in educational assessment. During question-answering, high skilled readers tended to re-read the answer, their gaze-patterns demonstrating that they looked at information immediately adjacent to the answer more than low skilled readers, and looked to pictures and supplementary information less. High skilled readers also used a linear, sequential search strategy (with a high success rate) to locate answers to questions. In contrast, low skilled readers used a haphazard and random search strategy, with a low success rate at locating the answer. A careful examination of the results led to the conclusion that low skilled readers select the haphazard strategy over the linear strategy as an effect of response efficiency. Implications for improving selection of the more successful linear strategy for low skilled readers is discussed.

Publications during enrolment

Peer Reviewed Articles

Drysdale, B. M., Moore, D. W., Furlonger, B. E., & Anderson, A. (2017). Gaze patterns of individuals with ASD during active task engagement: a systematic literature review. *Review Journal of Autism and Developmental Disorders*, *5*(1), 1 – 14. doi: 10.1007/s40489-017-0119-z

Peer Reviewed Conference Presentations

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Submitted Articles

Ginsberg, E. S., **Drysdale, B. M.**, Furlonger, B. E., Anderson, A., & Moore. D. W. (2019). Deixis and Reading in Autism Spectrum Disorder: A Pilot Study. *Journal of Autism and Developmental* Disorders. (In press).

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Abbreviations List (in alphabetical order)

ANOVA	Analysis of Variance
AOI	Area of interest
ASD	Autism Spectrum Disorder
DSM-5	Diagnostic and Statistical Manual – Fifth Edition
ERP	Event-Related Potential
HFA	High functioning autism
HMD	Head-mounted displays
ORF	Oral Reading Fluency
PCCR	Pupil Centre/Corneal Reflection
RE	Response Efficiency
SI	Supplementary Information
SO	Stimulus Overselectivity
TD	Typically Developing
ToM	Theory of Mind
WCC	Weak Central Coherence
WIAT-II	Wechsler Individual Achievement Tests – Second Edition
WRMT-III	Woodcock Reading Mastery Tests – Third Edition

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Chapter 1: Introduction

In this chapter, the thesis topic is introduced, a brief background of the research area is provided, the rationale for conducting the study is articulated, the aim highlighted and finally the chapter concludes with the thesis framework and structure.

1.1 Background Information & Thesis Aims

While many deficits are associated with a diagnosis of Autism Spectrum Disorder (ASD), selective attention is one of the more noticeable deficits in younger children and infants – thus it is used in diagnostic assessments such as the Autism Diagnostic Interview – Revised (ADI-R) and Autism Diagnostic Observation Schedule (ADOS) to indicate presence of this disorder. For example, clinicians are trained to ask questions and make observations around making eye contact and preoccupation with objects (see Table 1).

Table 1. Examples of Questions from Autism Diagnostic Interview - Revised (ADI-R) about Selective Attention.

Interview Section	Question
Social Development and Play	50. Direct Gaze. Does [subject] look you directly in the face when doing things with you or talking with you?
Social Development and Play	52. Showing and Direction Attention. Does s/he ever show you things that interest her/him?
Social Development and Play	62. Interest in Children. What does [subject] think about other children of approximately the same age who s/he does not know? Is s/he interested in them?
Interests and Behaviour	60. Repetitive Use of Objects or Interest in Parts of Objects. Will s/he play with the whole toy or does s/he seem to be more interested in a certain part of the toy (e.g. spinning the wheels of a car or opening and shutting its door)…

The development of selective attention is thought to be a pre-requisite skill for the development of social skills, which are important for building and maintaining fulfilling relationships, essential for a positive quality of life. Abnormal selective attention in ASD has been researched in depth in the form of unusual gaze behaviour displayed by such individuals. Theories such as Weak Central Coherence (WCC; Happé & Frith, 2006) have emerged to explain the phenomena behind abnormal selective attention. WCC proposes that people with ASD have a preference for local detail over a more global level of interpretation. In terms of gaze towards social stimuli (other people), individuals with ASD demonstrate WCC through a preference for featural processing (recognising facial features in piecemeal fashion) over configural processing (combining these facial features into in a meaningful whole; Happé & Frith, 2006). In other words, they will gaze at facial features such as the mouth, in a singular way, but will not combine information from each facial feature to gain the "gist" of the social situation. For example, they will fail to follow gaze to understand what another person is looking at or thinking about, or fail to look at the mouth and eyes together to identify how others might be feeling. These particular gaze patterns in individuals with ASD are also associated with difficulties in learning and mastery of social skills.

The majority of studies investigating gaze in people with ASD support the finding that this population tend to select non-social (e.g. objects) stimuli over social stimuli in naturalistic viewing tasks (see Chita-Tegmark, 2016; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002). More recently, interest in this area of study has led to the quest for a more accurate measurement system as opposed to the use of the naked eye, identified as being unreliable. In contrast, eye-tracking has emerged as a viable and increasingly popular procedure to measure gaze, even for special populations such as those with ASD. Eye movement data is collected via an eye tracker, a device that shines infrared light on the cornea and pupil of the eyes, and estimates the point-of-gaze toward a visual stimulus. Significantly, eye-tracking provides moment-to-moment information on the movement of gaze. Moment-to-moment data is valuable in that it provides continuous information on the process of eye movements and can highlight strengths and weaknesses on specific tasks.

Since the emergence of eye-tracking technology, researchers have focused on the investigation of selective attention to visual stimuli in individuals with ASD. Interestingly, although this technology provided more accurate gaze data than captured in earlier studies, the literature remains divided on a crucial issue. While well-known studies have reported unusual gaze patterns to faces demonstrated by people with ASD (e.g. Klin et al., 2002; Pelphrey et al., 2002), other studies have contended that those with ASD exhibit similar gaze to typically developing (TD) individuals (see Speer, Cook, McMahon, & Clark, 2007; van der Geest, Kemner, Camfferman, Verbaten, & van Engeland, 2002) when viewing social stimuli. In order to investigate this further, a systematic literature review was conducted as part of the present study to identify and summarise eye-tracking studies where participants with ASD and TD participants were actively engaged with visual stimuli. Passive engagement is in contrast to active engagement, where participants are instructed to view stimuli and perform an additional behaviour while doing so. An example of active engagement is a reading task, where participants are required to gaze at the passage, read it aloud or answer questions relating to the text.

The findings of the literature review raised the following research questions: First, would those with ASD consistently exhibit atypical eye gaze patterns while actively engaged in tasks? Second, were the same individuals' eye gaze patterns intimately connected to their task performance?

Following the systematic literature review, reading behaviour emerged as a behaviour of interest and is the major focus of the second half of this thesis. During my work placements as a trainee psychologist I frequently encountered students with reading difficulties, who were also diagnosed with ASD. During shared reading activities it appeared that while these students were competent and fluent in their decoding skills, they demonstrated problems with capturing the “bigger picture” or gist of the plot. Anecdotally, I also started to notice a pattern whereby children with ASD, who were confident readers in their early primary school years, appeared to fall further behind in their comprehension abilities. Once precocious and engaged students were beginning to show frustration resulting in the avoidance of reading tasks in their middle primary school years. Reading comprehension difficulties in ASD are frequently cited in the literature. Nation, Clarke, Wright, and Williams (2006), for example, reported that 65% of their sample of children with ASD scored poorly on comprehension tasks (at least one standard deviation below the mean), despite average or above average decoding abilities. For young students diagnosed with ASD, who may also experience co-morbid anxiety disorders, social challenges, and sensory issues (Simonoff et al., 2008), the school experience can be a stressful time even without additional challenges in reading text. Therefore, a between-groups observational approach utilising eye-tracking was taken to investigate *why* a large proportion of children with ASD experience reading comprehension difficulties.

The aim of this comparative study, therefore was to identify the gaze behaviours demonstrated by students with, and without ASD, and with varying reading competence levels, during question answering following passage reading. It has been suggested that reading comprehension is the “most important academic skill learned in school” (Mastropieri & Scruggs, 1997, p.1) – being able to read and understand written text broadens learning opportunities and communication (Nation & Norbury, 2005), which are important for independent functioning and future vocation. Indeed, reading skills are vital for participation in society, whether it be filling out forms, following traffic and safety instructions, reading labels on food, banking, signing any kind of contract, or deciding what to order from a menu. While reading is a requisite skill for entry into university, and traditional white-collar vocations, possessing these skills is also imperative for learning and upskilling in manual and technical labouring jobs, e.g. growing plants, farming animals. Conversely, the failure to develop reading comprehension skills can have a widespread impact on an individual’s ability to function independently. Identifying, therefore, whether the gaze patterns of students with ASD impact on their reading abilities may lead to an understanding about how to better address their reading difficulties.

The broad approach of this thesis, therefore, was to investigate the topic of selective attention in ASD, particularly the effect on task and skill performance when actively engaged with visual stimuli, and to identify the gaze behaviours that facilitate the understanding of written text by students with and without ASD.

1.2 Thesis Structure and Chapter Organisation

The thesis is organised into seven chapters, which encompass two broad sections: the narrative/literature review, and the empirical study. These two sections are preceded by the introduction chapter (see Figure 1 below).

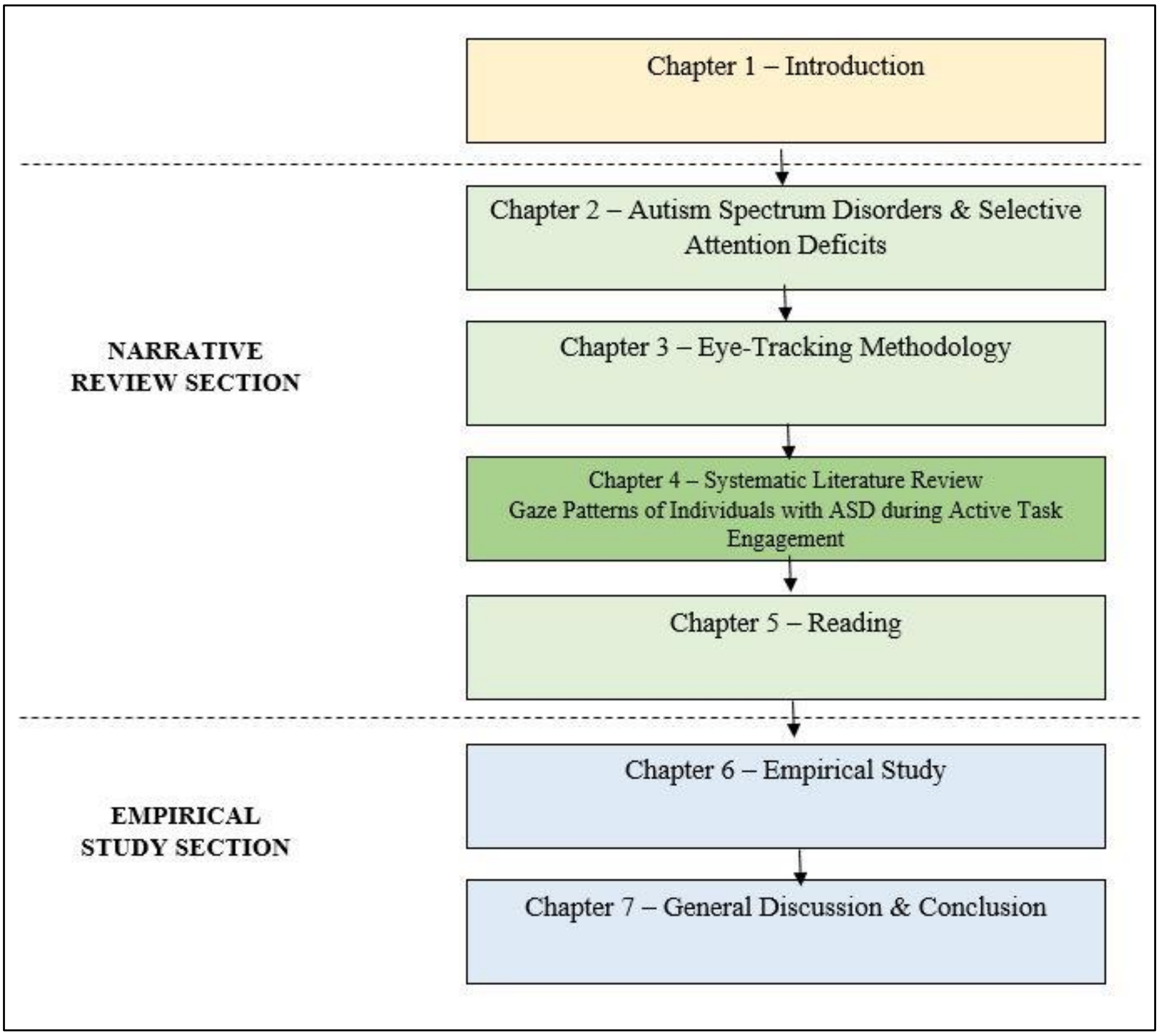

Figure 1. Advance Organiser for Thesis

In Chapter 1 the thesis topic is introduced, a brief background of the research area provided, the rationale for conducting the study discussed, the aim described, and it concludes with a description of the framework and structure of the thesis. Next literature relevant to the topic is explored in the following areas: Individuals with ASD and their selective attention/eye movements (Chapter 2), eye-tracking methodology (Chapter 3), and reading development (Chapter 5). Within the overall narrative/literature review section, a systematic literature review is included that compares eye gaze patterns of people with ASD and neuro-typical individuals during active task engagement (Chapter 4).

This review summarises the eye-tracking research studies to date in this area, and discusses their findings and limitations.

The systematic literature review is presented before the chapter on reading (Chapter 5) as it informed the need and planning for an empirical study. The empirical study, presented in Chapter 6, compares eye gaze patterns of primary school students during reading tasks. The student participants were divided into those with ASD, and those that were typically developing. These two groups were further divided into those with high, and low reading competence. The empirical study is split into two parts: analysis of global eye movements, and analysis of local eye movements. Global eye movements refer to eye gaze patterns generally across reading tasks e.g. number and length of fixations. Local eye movements refer to eye gaze patterns at a micro level e.g. gaze location during a particular question. Finally, the results are discussed in Chapter 7, including a consideration of some implications of the findings of this study for future practice and research.

Chapter 2: Autism Spectrum Disorders and Selective Attention Deficits

The purpose of this chapter is to provide an introduction to the selective attention deficits commonly attributed to Autism Spectrum Disorders (ASD). The chapter begins with outlining the importance of selective attention as a pre-requisite skill for development of further, related, social skills. Next, selective attention deficits are considered through the lens of attentional theories, and their disruptive effect on future learning and functioning. Selective attention deficits are then explored through the measurement of eye movements and gaze, and a summary of studies investigating gaze in this population is provided. The chapter ends with a discussion of recent advances in eye-tracking technology as a method to reliably and accurately capture gaze behaviour.

2.1 Overview of the Problem

Autism Spectrum Disorders (ASD) are characterised by deficits in communication and social interaction as well as the presence of unusually strong preferences and interests, which lead to rigid behaviours and adherence to routines and rituals (American Psychiatric Association, 2013). While it is evident that for children with ASD, the skill of sustaining attention for extended periods of time is intact, substantial research conducted into the way in which stimuli is attended to and processed by this population has revealed difficulties with arousal and selective attention (Orekhova & Stroganova, 2014). While attentional impairment specifically is not a clinical symptom of ASD in the Diagnostic and Statistical Manual – Fifth Edition (DSM-5), it has been proposed by some to contribute to the core impairments of this disorder (Keehn, Müller, & Townsend, 2013). Functional selective attention acts as a pre-requisite skill for further acquisition of skills in related domains, including generalised imitation, joint attention, observational learning, emotion recognition, and social skills broadly. Therefore, deficits in selective attention may have widespread effects on development of skills which are crucial to independent functioning making this area worthy of investigation.

2.2 Theories of Selective Attention Deficits

Selective attention allows people to filter relevant from irrelevant sensory information in their environment, a skill essential to competent and adaptive functioning (Downing, 2000). Impaired selective attention leads to increased distraction and diminished cognitive functioning, as responses to irrelevant stimuli interfere with the processing of targeted information (Burack, 1994). An example of an attentional deficit commonly found in people with ASD is what Lovaas, Koegel, and Schreibman (1979) originally described as *Stimulus Overselectivity* (SO). This type of deficit is characterised by the excessive allocation of attention on specific parts of an object or scene. This can result in the processing of obscure or apparently meaningless stimuli while ignoring critical stimuli in the environment; thus, people with ASD may fail to capture the gist or comprehend the meaning of a situation due to over-attending to irrelevant information (Schwartzberg & Silverman, 2013). Belmonte and Yurgelun-Todd (2003) suggested that an over-stimulated sensory system would naturally lead to the development of a cognitive style that emphasises local features at the expense of global forms, as a way for individuals with ASD to regulate such a system. For a long time SO was viewed as a bona fide attention deficit displayed by the population of those with ASD (Ploog, 2010).

Despite the longstanding perception of this feature as a deficit, based on more recent findings researchers have suggested that reduced attentional filtering could be associated with (or even lead to) enhanced visual search in individuals with ASD (Milne, Dunn, Freeth, & Rosas-Martinez, 2013). For example, Milne et al. (2013) found that during a visual search task, the occipital lobe of individuals with ASD was not over-aroused, meaning search tasks may require less effort, resulting in more efficient searching of visual information. In reality, the phenomenon of SO is found on a continuum in all human beings, with strong local processing at one end of the continuum and strong global processing at the other. Individuals with ASD tend to have strong local or detail-focused processing, and appear to share this cognitive profile with other clinical groups, such as people with Schizophrenia, William's syndrome, Major Depressive Disorder and right hemispheric damage (Happé & Frith, 2006). On the other end of the continuum, a person with strong global processing gives up attention and memory for detail and surface form, and may struggle with tasks requiring attention to fine detail such as proof reading.

Over time, the idea of SO as a core deficit was refined into a more comprehensive theory that has become known as *Weak Central Coherence* (WCC; Happé & Frith, 2006). WCC describes a cognitive style, or processing bias for local, or specific features of a visual scene, coupled with a failure to attend globally to that scene (Schwartzberg & Silverman, 2013). WCC implies that these individuals display different attention allocation, which may be viewed as a relative-strength in detail-focused tasks (Van Bourgondien & Coonrod, 2013), rather than being detrimental to functioning, as was previously believed.

This processing bias has been likened to a narrow beam of spotlight, which can attend to small, circumscribed aspects of the environment one at a time, and, although multiple pieces of information can be observed, the individual has difficulty summarising the information to form a whole (Van Bourgondien & Coonrod, 2013). For example, an individual with this processing bias identifies a crying child, and a spilt ice-cream on the floor, without making an association between the two events. An interpretation of the evidence has led to the conclusion that people with ASD may display this bias when they are not directed to attend to global information. Lopez, Donnelly, Hadwin, and Leekam (2004) demonstrated that participants with ASD showed configural processing of faces in attentionally-cued conditions, but not in non-cued conditions. In other words, they were able to process and recognise faces as a whole when directed to do so. People with WCC can overcome this bias for local detail; for example, extract the gist of a long speech, when explicit instructions are given to process information globally (Happé & Frith, 2006), however, in naturalistic settings these overt cues are rarely available for individuals with ASD which impacts the manner in which they allocate attention within their visual environments.

2.3 Difficulties in Learning and Functioning associated with WCC

A local processing bias can lead to difficulties in learning and skill generalisation. As people with such biases code experiences in terms of details, they remember specific examples rather than extract prototypes. Therefore, only highly similar exemplars to those used in learning trials would evoke skill generalisation (Plaisted, 2001). Attending to irrelevant details can also hinder learning. Consider the child with ASD learning a new classroom routine, who may attend to extraneous visual or auditory events which coincide with the routine e.g. unrelated hand gestures from the teacher (Carnahan, Williamson, & Christman, 2011). That child then may become prompt dependent on the gesture, resulting in an error in learning as the gesture is not a reliable cue to begin the routine. Similarly, the inability to filter out distractors can impact upon cognitive processing in individuals with ASD. O'Riordan (2000) conducted a negative priming task to compare spatial inhibition in university students with ASD relative to typically developing (TD) controls. O'Riordan found that individuals with autism could inhibit irrelevant and distracting information about objects based on identity (colour, form, and shape) as well as the controls could. However, participants with ASD could not inhibit distractors as well as controls when objects appeared in the same location as the target, although this result was still within normal limits (O'Riordan, 2000). Broadbent (1991) demonstrated similar findings, with participants' performance on visual search only impaired when distractor objects appeared in relatively close spatial proximity to the target stimuli. When stimuli appeared outside or in the periphery of this area, they were easily filtered out. Similarly, Burack (1994) found that for participants with ASD, the spatial proximity of distractors to the target increased visual search reaction time more than did the number of distractors present. The evidence from multiple studies suggests that people with autism have an attentional lens which is inefficient in contracting its focus to a more optimal visual field (Broadbent, 1991; Burack, 1994; O'Riordan, 2000). The inability to filter out extraneous information coupled with over-processing of this information potentially results in a failure to perceive the overall scene, or complete the goal associated with the task.

Although the effectiveness of the attentional spotlight can be enhanced through environmental changes (such as removing distractors, providing a smaller field of view), real environments do not provide such facilitation as they are typically large and inundated with information (Burack, 1994). Therefore, people with autism need assistance in attending to relevant stimuli in their environment

(Van Bourgondien & Coonrod, 2013). To understand atypical attention allocation displayed by those with ASD, researchers measure this behaviour by observing eye gaze movements.

2.4 Behavioural Manifestations of Selective Attention Abnormalities

Selective attention abnormalities are reflected in atypical eye gaze behaviours. Gaze behaviours frequently observed in ASD include limited gaze to social stimuli in general, specifically eyes, which is thought to detrimentally impact skills acquisition in emotion recognition and social skills. Rather than selecting eyes and social stimuli as information sources, people with autism demonstrate greater interest in distractor objects and object movement.

2.4.1 Attention to Social Stimuli

Faces have a special status in attention for neuro-typical adults and are processed in an automatic and mandatory fashion even when neuro-typical adults try to ignore them (Remington, Campbell, & Swettenham, 2012). Remington et al. (2012) imposed high distractor load conditions in a visual search task. Under these conditions irrelevant stimuli are not usually processed, however typical adults continued to process distractor faces, whereas adults with ASD were able to ignore them, suggesting that, for people with ASD, faces do not hold the same status. Arguably, faces hold a special status for neuro-typical people because eyes and eye movement convey key social information such as personal interest, and engagement: relevant information in the environment is accessed through gaze to eyes (Ristic et al., 2005). This status holds true for neuro-typical children also. Ristic et al. (2005) found that TD children paid attention to eyes in order to extract socially relevant information, whereas children with High Functioning Autism (HFA) did not. In Ristic's study, participants were required to rapidly locate objects and were cued by a human face gazing at the locations where the objects were to appear. Participants were randomly assigned to non-predictive (target appears at the gazed-at location 50% of the time) or predictive conditions (target appears at gazed-at location 80% of the time). Both groups were faster to detect targets occurring at the gazed-at location, and when gaze was a reliable aid to the task at hand, both groups could perceive and use gaze direction as an attentional cue. In the non-predictive condition, TD participants continued to rely on eye gaze even when it was spatially non-predictive at chance levels, whereas ASD participants stopped using eye gaze as a cue when it became unreliable, and actually took longer to respond in this condition. These findings provided support for the idea that social stimuli are highly salient to neuro-typical people, and much less so for people with ASD.

2.4.2 Effects of Atypical Eye Gaze on Development

Development of selective attention skills, which includes preferential attending to social stimuli, is a "gateway" to accessing new opportunities and reinforcers, as well as a pre-requisite to other related skills, such as generalised imitation, joint attention, observational learning, emotion recognition, and social skills. Selective attention is therefore considered a behavioural cusp. Cooper, Heron, and Heward (2007) define a behavioural cusp as a "behaviour that has sudden and dramatic consequences that extend well beyond the idiosyncratic change itself because it exposes the person to new environments, reinforcers, contingencies, responses, and stimulus controls" (p. 691). The effect of atypical eye gaze towards other people has the potential to disrupt development of social skills, which will be discussed in the next section.

Emotion recognition is an important life skill used for establishing relationships and developing emotional reciprocity, a skill which children with ASD take longer to develop, in particular, in recognising dynamic emotions in human faces (Bal et al., 2010). When people with autism gaze to faces, a bias to the mouth region is evident (Klin et al., 2002). Since emotions are expressed both on the upper (eyes) and lower (mouth) parts of the face (Dimberg & Petterson, 2000), people with ASD may fail to interpret negative or hostile reactions because they have missed relevant information conveyed by the eye region. Several studies involving individuals with ASD have found increased gaze to bodies and objects instead of eyes when watching videos of emotional interaction (e.g. Bal et al., 2010; Dalton et al., 2005). Abnormal eye gaze to faces by people with autism is associated with difficulties in engaging with peers during common social activities, such as completing a joint activity during play, which requires requesting, responding to the peer, and most importantly, attending to them (Madzharova & Sturmey, 2015). Bal et al. (2010) found that children with less severe ASD symptoms and increased gaze to the eye region were more accurate in emotion recognition, suggesting that failing to attend to eyes can lead to failure in recognising emotions. A valid question therefore is: what do people with ASD preferentially attend to?

2.4.3 Preferential Attention to Objects

Individuals with autism appear to learn to orient their attention to stimulus motion and objects in visual scenes, which serve as competing stimuli to social stimuli (Ristic et al., 2005). Rombough and Iarocci (2013) compared the ability of children with ASD to follow cues from gaze and arrows. Whilst not statistically significant, these researchers found that children with ASD did not follow gaze at short or long interval durations, but did follow gaze at medium interval durations. This suggests that for persons with autism, eyes only have orientation saliency (or attention-grabbing power) for a small window of time, compared with neuro-typical people, who responded to eyes at all intervals (Rombough & Iarocci, 2013). However, as Birmingham and Kingstone (2009) argued, the spatial-cueing paradigm employed in this study preselected gaze-cues for viewers and thus such a paradigm measures orienting, rather than selective social attention (Rombough & Iarocci, 2013). Ultimately, because participants were directed or instructed to the model's gaze in this study, these results tell us how well people with ASD can follow gaze or use it as a cue, without any information regarding whether they would attend to this cue in the first place. There is a fundamental difference in the way people with ASD select social stimuli. Evidence also suggests that this population are slower to disengage, or shift gaze away from dynamic abstract objects compared to social stimuli, suggesting that difficulties with disengaging are stimulus-specific in people with ASD (Leekam, Lopez, & Moore, 2000).

However, there are contrasting findings in the literature. Chawarska, Klin, and Volkmar (2003) found that neuro-typical children and children with ASD demonstrated similar disengagement times from human faces. A reason for this difference appeared to be linked not only with the stimulus type, but also the activity level of that stimulus. Naturalistic and complex stimuli such as social scenes, which include dynamic stimuli seem to provoke differences in viewing behaviour (between TD and ASD populations) more effectively than non-naturalistic or relatively simple stimuli, such as isolated faces (Hanley et al., 2015; Speer et al., 2007). Most studies employing dynamic stimuli, as opposed to static pictures, report group differences (Drysdale, Moore, Furlonger, & Anderson, 2017). In real-world settings faces never appear in isolation and usually accompany distractor objects and movement, and thus the evidence suggesting group differences between ASD and TD may be more ecologically valid.

Over time, as abnormal eye gaze is continually exhibited, the areas of the brain responsible for selective attention become more hardwired and set to function in this way, which makes behaviour difficult to change (Wass, Scerif, & Johnson, 2012). Therefore, early intervention designed to teach this population to attend to relevant stimuli in their environment is crucial and beneficial to future learning (Wass et al., 2012). Importantly, such intervention must continue to be informed by observation and assessment of gaze behaviour, and advances in this methodology will continue to enhance our understanding of eye movements in special populations.

2.5 Advances in Technology Measuring Eye Movements

Interest in the observation of gaze has led to the desire for more precise and accurate measurement of eye movements. In some cases, the reliance on the "naked eye" can compromise the validity of the results. For example, researchers employing video-based instruction techniques such as Video Modelling would use a camera to record and analyse participant gaze (see Sancho, Sidener, Reever, & Sidener, 2010; Smith, 2010). Participants were said to be "attending" if they appeared to be gazing toward the screen. However, this definition of "attention" is loose and fails to address several limitations. Firstly, participants could be oriented towards the screen but gazing off-screen. Secondly, it does not provide moment-to-moment information about gaze as substantial periods of time are left unmeasured due to researcher observational limitations. Thirdly, it provides no information about gaze location. Participants could be gazing at the screen but attending to stimuli irrelevant to the task, which fails to provide information about the stimuli that facilitate the task when they are attended to.

A solution to capturing more reliable and precise moment-to-moment data on visual attention is to utilise eye-tracking technology. Eye-tracking techniques have become increasingly popular and affordable to researchers over the last decade. This technology has assisted researchers to understand and quantify where visual attention is allocated. For people with ASD, this includes measurement of gaze towards people and faces, as well as the problems they face with disengagement and attention (Falck-Ytter, Bölte, & Gredebäck, 2013). Other uses include predicting future risk of ASD diagnosis in infants and young children by tracking gaze behaviour, in an attempt to characterise this disorder at a unique level of behaviour. Eye tracking is advantageous over other methods in complex environments, where it is better able to capture the dynamics of gaze behaviours (Hosozawa, Tanaka, Shimizu, Nakano, & Kitazawa, 2012).

2.6 Summary

The development of selective attention is essential to independent functioning. Conversely, deficits in selective attention may have a disruptive knock-on effect for the development of other skills necessary for this level of functioning. Difficulties with selective attention have been proposed to contribute to the core impairments of Autism Spectrum Disorder (Keehn et al., 2013). Over time, the view of such a bona-fide attention deficit in the form of Stimulus Overselectivity, has moved to the more strengths-based view of Weak Central Coherence, which depicts the unusual attention allocation displayed by those with ASD as a cognitive style. Nevertheless, strong interest in this area has led to a desire for more precise measurement of attention, via eye movements, to which the technique of eye-tracking shows promising utility.

Chapter 3: Eye-Tracking Methodology

Eye-tracking is a viable and reliable method to capture gaze mechanics, even in special populations (excluding cortical blindness) for whom there is a high demand and interest in studying eye movements. This chapter provides a broad overview of eye-tracking techniques for readers who are unfamiliar with the methodology. First, Pupil Centre/Corneal Reflection (PCCR), the technique utilised by contemporary eye-trackers is explored, as well as the different system types available today. The advantages and weaknesses of each system are discussed. Next, relevant eye movements, such as fixations, saccades, smooth pursuits, regressions, and pupil dilation, which can be tracked by these systems are defined. The concept of Areas of Interest (AOIs) is introduced; the researcher can use the software to create these areas within the video or live scene, and eye movements can be analysed. Then, existing issues and limitations of eye-tracking techniques are discussed, followed by recommended fidelity procedures to ensure best practice in eye-tracking, and considerations for researchers when analysing gaze of people with ASD. A summary of eye-tracking literature in ASD is then presented, with focus on two primary areas: early identification of ASD diagnosis through eye movements; and, selective attention to visual stimuli. The chapter closes with a question relating to the nature of eye-tracking task stimuli and gaze behaviour in individuals with ASD, which informs the design of the systematic literature review which follows.

3.1 Overview

Eye-tracking technologies automatically track the point of an individual's gaze while that person views or interacts with a visual image (Wilkinson & Mitchell, 2014). The technology records a running sample of the orientation of the viewer's eyes, which is then translated into a series of x-y coordinates, representing the location of gaze at each time point sample (Wilkinson & Mitchell, 2014). This detailed recording of the path of visual attention is a non-invasive method of revealing mechanisms of attention or visual processes, which are difficult to detect with less advanced methods e.g. coding from video, behaviour paradigms (Falck-Ytter et al., 2013; Karetekin, 2007; Wilkinson & Mitchell, 2014).

Eye-tracking also allows the direct, objective, and quantitative observation of gaze behaviour, and while attention is a multifaceted construct that is difficult to observe, it is generally accepted that eye-tracking tasks capture specific aspects of visual attention, and can indicate which information from a scene is available to the brain (Boraston & Blakemore, 2007; Falck-Ytter et al., 2013). Exploring gaze behaviour not only reveals components of the attentional system (Henderson, 2003), but also reveals social interests, and can provide insights into the difficulties shown in everyday social interactions by special needs populations such as those with ASD (Boraston & Blakemore, 2007; Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003). In behavioural studies that do not utilise eye-tracking, conclusions about the allocation of attention can only be indirectly inferred through variations in performance. Furthermore, eye-tracking technologies have been used frequently with those with ASD, as a way of closing the gap between performance on cognitive assessments and everyday social abilities, as studies of cognitive function in ASD have rarely been able to demonstrate this link (Boraston & Blakemore, 2007). Utilising eye-tracking technologies may assist in understanding abnormal cognitive processes in this population (Boraston & Blakemore, 2007; Dalton et al., 2005) and reduced task performance (Corden, Chilvers, & Skuse, 2007).

3.2 Techniques & Systems

Currently, most eye-tracking systems are remote video-based or desktop systems utilising the Pupil Centre/Corneal Reflection technique (PCCR; Guillon, Hadjikhani, Baduel, & Rogé, 2014). This involves a self-contained desktop system composed of a viewing monitor and data-recording computer. The eye-tracker can either be attached to the viewing monitor or is built-in. Remote systems are non-invasive: they involve no physical contact between the technology and the participant. PCCR estimates location of gaze with high accuracy, hence it is a common method used to study gaze performance in infants and young children. Using this method, invisible infrared light is projected by the eye-tracker onto the eye, illuminating the eye through highly visible reflections. A high-resolution camera then captures the image of the eye showing these reflections, which are then used to identify the reflection of the light source on the cornea (glint) and in the pupil (Guillon et al., 2014). A vector is then calculated through the angle formed between the cornea and pupil reflections and used to calculate gaze direction. Using this method, both bright and dark-coloured pupils can be captured by an eye tracker (Guillon et al., 2014). The viewing monitor presents the participant with the stimulus image or task, and the data-recording computer controls presentation and data acquisition.

Alternatives to remote-desktop systems include head-mounted displays (HMDs) e.g. Eyelink II and mobile eye-tracking systems e.g. Tobii Pro Glasses 2. As the name suggests, HMDs involve an eye-tracker embedded into a visor or cap that the participant wears while viewing a stimulus. HMDs were the first form of automated eye-tracking systems and are invasive to the participant (Wilkinson & Mitchell, 2012), hence the increasing popularity of the remote-desktop systems. HMDs account for head motion, which if uncorrected can compromise the integrity of acquired gaze data. While many older systems ensured accurate tracking through head stabilisation via HMD (or use of a chin-rest for remote-desktop systems), these options are not ideal solutions for young children who may resist efforts to restrict head movements or have equipment placed on them (Sasson & Elison, 2012). The development of remote-desktop systems have addressed this limitation by the creation of software programs that can return highly accurate eye-tracking results from freely-moving participants. Despite these advances, accommodation of head movements is often better for lateral movements than closer or farther from the monitor, and these gross head movements may result in reductions in calibration accuracy over time (Nystrom, Andersson, Holmqvist, & van de Weijer, 2012; Wilkinson & Mitchell, 2014).

Recently, some manufacturers have developed goggles or glasses which independently function as eye-trackers without additional equipment such as monitors or computers. These mobile eye-tracking systems are advantageous in that they record gaze patterns during day-to-day activities of mobile participants, and therefore not solely contained to video content and laboratory-bound stimuli. However, there are practical and analytic demands of recording gaze patterns during such complex interactions, and remote-desktop systems remain the most widely used of the eye-trackers.

3.3 Measures

3.3.1 Areas of Interest

Studies can be broken up into the key outcome variables the researcher is interested in: a) properties of gaze shift, and b) aggregated looking time in various areas of interest (AOIs; Falck-Ytter, Bölte, & Gredebäck, 2013). Most software programs accompanying eye-tracking systems allow these different outcome variables to be created (Falck-Ytter et al., 2013). AOIs are pre-defined regions created within the video or live scene where multiple clusters of fixations are predicted to occur. Researchers can quantify the stream of gaze data by using a drawing tool within the eye tracking software to divide each stimulus image into regions or areas (Wilkinson & Mitchell, 2014). AOIs are typical outcome measures in eye-tracking studies, and this approach is used to quantify the spatial distribution of visual attention across the scene and therefore, determine which AOIs attract and hold the participant’s visual attention (Klin et al., 2002). Common AOIs found in the literature are face, eye, or mouth regions, gazed or acted-upon objects, distractor objects, and different regions of text. Researchers usually compute the cumulative time spent looking within each AOI of the visual scene to counterbalance the loss of raw gaze data (Guillon et al., 2014) through blinking, for example. Loss of gaze data occurs more frequently in infants, toddlers, and pre-schoolers due to frequent head movements and less exhaustive calibration of the eye tracker (Klin et al., 2002).

3.3.2 Eye Movements

Eye movements that can be captured are fixations, saccades, smooth pursuits, regressions, and in some cases pupil dilation. Fixations are defined as the maintenance of gaze at a single location, and have been of interest to eye-tracking researchers. Saccades are rapid movements of the eyes between fixations, and smooth pursuits are slower eye movements which allow the eye to follow a moving object. Regressions are a class of eye movements specific to reading text, and refer to backwards eye movements against the normal reading order to a previously read word.

3.3.2.1 Fixations

Fixations were traditionally defined as gaze remaining stationary for 200ms, which was derived from the literature on reading (Wilkinson & Mitchell, 2014). However, visual search studies using other stimuli suggest that fixations as short as 80 – 100ms reveal significant information without contamination from blinks, saccades, and other non-fixation behaviours (Wilkinson & Mitchell, 2014). To be considered a fixation, the point of gaze must also remain within a strict spatial area which can be defined in terms of pixels (e.g. within a 35-pixel area) or degree of visual angle (e.g. a 1 degree radius). Dube and Wilkinson (2014) reviewed studies on Stimulus Overselectivity (SO), which relates to the overly-narrow focus on specific details of an image. By studying fixations these researchers illustrated how eye-tracking can enrich the understanding of the mechanism underlying SO as well as methods for intervening to broaden the attentional spotlight (Wilkinson & Mitchell, 2014).

3.3.2.2 Pupil diameter

Pupil dilation refers to the dilation (widening) or constriction of the pupil and is measured through pupil diameter. Pupil dilation is commonly measured using HMDs, which use a second camera (attached to the cap or visor) to record the participant's eye. Pupil dilation is related to the brain's locus coeruleus-norepinephrine (LC-NE) system, activation of which is a marker of the amount of task-relevant cognitive processing (Wong & Moss, 2016). Measuring pupil dilation could be a method to unobtrusively measure a reader's engagement with the task, as past neuroimaging studies targeting reading suggest that the level of cognitive control and pupil dilation tend to vary depending on the activity of the reading strategy used (Moss, Schunn, Schneider, & McNamara, 2013; Wong & Moss, 2016). Passive reading strategies which required less engagement of the participant with the stimuli e.g. re-reading, resulted in less changes to pupil dilation than active reading strategies e.g. summarising. However, increases in slow-twitch muscle contractions of pupils have been found to be associated with a lack of phasic (fast-twitch muscle) responses and periods of mind wandering (Smallwood et al., 2011), and thus act as a confound.

3.4 Issues and Limitations

Despite the technological advances and the benefits of measuring visual attention, eye-tracking methods are not without limitations. One of the significant challenges to research of this nature is the maintenance of ecological validity (Wilkinson & Mitchell, 2014), particularly with the ability to generalise findings from video clips to applied, real-life scenarios. This is not a reason to abandon this form of data collection, rather it is one consideration of several that researchers must use to weigh up the significance of their findings.

3.4.1 Are Fixations Necessary for Visual Processing?

While fixations are generally considered a measure of attention, some argue that attention is *inferred* through the presence of a fixation. For example, this argument assumes that we infer that the latency to fixate reflects a measure of initial selective attention, or that the number and/or duration of fixations may be used to infer maintenance of attention over the viewing period (see, e.g. Gliga et al., 2009). However, there is evidence which suggests that fixations are necessary for perception of visual information.

Memmert (2006) recorded fixations during an *inattentional blindness* task, where participants watched a well-known clip of basketball players passing the ball to one another while moving around the court (from Simons & Chabris, 1999). A person in a gorilla suit walks onto the court and stands amongst the players while the participant is instructed to count the number of times the basketball was passed between players. Although participants demonstrated a fixation to the gorilla, not all participants recalled "seeing" it when asked afterwards. This simple experiment indicates that the presence of fixation is not, by itself, sufficient to guarantee processing (Wilkinson & Mitchell, 2014). Indeed, Rayner (2009) argues that while it is possible to allocate attention elsewhere in the visual field during simple tasks, during complex tasks (e.g. reading, visual search, scene perception) eye location and covert attention are overlapping and at the same location. In summary, presence of fixation is *necessary,* but not sufficient to ensure processing of a visual stimulus. Nevertheless, researchers across a range of disciplines agree that fixation patterns are fairly robust indicators of attention in more naturalistic tasks. The limitation of studying fixation patterns is that they cannot indicate how the brain uses the visual information it receives, for example, where gaze towards eyes is typical, though the individual may not make use of this information.

3.4.2 Calibration

Calibration is an important process that must be performed with each participant prior to data collection to ensure the accuracy and precision of gaze data collected (Wilkinson & Mitchell, 2014). Accuracy refers to the closeness between the actual gaze location and x-y coordinate measured by the eye-tracker i.e. high accuracy indicates less error between estimate of and actual gaze. Precision refers to the closeness of two or more measurements to each other. For example, if five fixations are made to a target, and the gaze estimate is located on the target each time, then the measurement is very precise. Accuracy and precision are independent of each other. Nystrom et al. (2012) found that while accuracy mostly remains unaffected, precision can be impacted by a number of factors including "bluish" eye colour, glasses, eye contacts, and mascara, which researchers must account for and consider when running calibrations. Greater precision is reflected in less dispersion around the target, while lower precision is reflected in greater dispersion (Wilkinson & Mitchell, 2014).

Most systems allow for a different number of calibration points to be presented. In many technologies, these range from two points (often used with infants) to nine points (used with adolescents or adults), with five points as an intermediate level (Sasson & Elison, 2012). The argument follows that the greater number of well-calibrated points, the greater the precision. However, when working with individuals with disabilities, or younger children, a practical reality is that calibration involving nine points requires effortful sustained attention which these participants may struggle with. It is possible that five accurately calibrated points can result in greater data fidelity than nine poorly calibrated points, yet this requires further investigation (Wilkinson & Mitchell, 2014).

3.5 Considerations for participants with ASD

Although eye-tracking has been used extensively to research visual attention behaviours in individuals with ASD, when testing young children on the autism spectrum, researchers need to consider making accommodations to ensure reliable and valid collection of data. Sasson and Elison (2012) have suggested that the equipment most conducive to testing young children is that which accounts for head motion, yet is non-invasive, such as remote-desktop displays, which are currently widely available to consumers. Short data collection sessions seem likely to minimise possibility for "drift" in calibration accuracy. As van der Geest et al. (2002) stated: "high stability in the output of the video recording system [is] over a time course of several minutes", implying that monitoring session length is important. Hornof and Halverson (2002) suggested building in a required fixation location re-test to help prevent drift. This involves an accurate behavioural response (e.g. mouse click) only after the user has fixated on the target, and would help to redirect attention to the display for children whose attention has lapsed. Redirection of attention can also be achieved through use of an inter-stimulus animation with accompanying sound effect (Sasson & Elison, 2012). Finally, it is crucial for researchers to select an eye-tracking system with a sampling rate that is appropriate in addressing their research questions. Most corneal reflection systems have a minimum sampling rate of 50Hz i.e. 50 data points per second, which is suitable for examining young children's gaze patterns during visual scanning of both images and videos (Sasson & Elison, 2012). Researchers who are interested in more subtle oculomotor behaviour, e.g. smooth pursuit, express saccades, will require a higher sampling rate i.e. 250Hz.

Eye-tracking is considered "ASD-friendly" as it can alleviate social demands by providing a direct and quantifiable measure of visual preferences and gaze behaviour while participants watch video clips (Sasson & Elison, 2012). Given the social and communicative impairments that exist in this population, eye-tracking has emerged as a particularly promising application to capture early-emerging developmental mechanisms of the disorder. Before eye-tracking was available, researchers obtained gaze data using naked-eye observation by researchers who employed traditional behavioural tasks, resulting in less accurate data collection. While illuminating the early course and characteristics of ASD remains a primary outcome of eye-tracking studies, the use of this technology in researching this population has many untapped applications.

3.6 Findings from Eye-Tracking Studies of ASD

The types of tasks most commonly used in eye-tracking research fall into one of two broad categories: free viewing and task-based (Wilkinson & Mitchell, 2014). As discussed in section 2.5, the application of eye-tracking research in ASD has two primary areas of focus: longitudinal studies which focus on the early identification of symptoms and diagnosis, and studies of attention allocation to social stimuli, particularly faces and interpretation of gaze cues and emotions. Major findings in each area will be examined below.

3.6.1 Early Identification Studies

Many eye-tracking studies focus on infants' gaze to eyes as an indicator of ASD symptom severity, as well as prediction of ASD diagnosis. Longitudinal studies, which followed infant siblings of children with ASD, have led to the substantially increased knowledge of developmental trajectories in children at risk for ASD in the first years of life (see Rogers, 2009; Yirmiya & Charman, 2010; Zwaigenbaum, 2010). Gliga et al. (2015) longitudinally tracked eye gaze of siblings of children with ASD, from infancy through childhood. Infant siblings completed a visual search task by fixating on a target letter amongst a display in a ring of highly similar distractor letters. Gliga et al. analysed the first saccade made in each trial, and found that at 9 months old, enhanced visual search performance (i.e. able to rapidly find the odd letter out in the ring) predicted higher level of ASD symptoms at 15 months and 2 years, supporting evidence of a local processing bias in this population. It appears that infant perceptual atypicalities are thus intrinsically linked to the emerging autism phenotype, and are more important than previously believed in the developmental pathway to this disorder. Interestingly, this relationship between enhanced visual search and level of ASD symptoms disappeared after 15 months, suggesting that this relationship exists within a finite window. This outcome of enhanced visual search and increased attention to non-social objects may be a consequence of low preference for social information, even in older children with ASD (Falck-Ytter et al., 2013); accordingly studying visual gaze patterns of people with ASD toward social stimuli is another major focus in this area.

3.6.2 Gaze Patterns to Social Stimuli

Many eye-tracking studies which investigated the gaze patterns of individuals with autism have focused on how these people gaze at faces and process emotions. One of the first studies which utilised eye-tracking techniques to study eye movements in those with ASD was Pelphrey et al.

(2002), who monitored gaze of five adult males with ASD and five controls while performing tests of emotion recognition from static photographs of facial expressions. Participants with ASD spent a smaller proportion of time examining core facial feature such as eyes, nose, and mouth.

Klin et al. (2002) extended this work and is perhaps the most well-known study investigating eye gaze in those with autism. Klin et al. studied spontaneous viewing patterns of people with ASD while viewing digitised clips of the movie *Who's Afraid of Virginia Woolf?* This movie was chosen as it involved characters who displayed exuberant rather than subtle emotions, and contained many content-rich social scenes, and measuring gaze toward dynamic stimuli, rather than static pictures, is thought to hold more ecological validity. Klin et al. demonstrated that TD individuals and those with ASD reacted differently to different cues: TD participants reacted more quickly and accurately to social cues such as a glance, and participants with ASD responded more quickly to physical cues e.g. panning of the camera. More importantly, this study and others largely support findings of a mouth bias in people with ASD (Guillon et al., 2014; Holmqvist et al., 2011; Klin et al., 2002), and established the central role that attending to social stimuli plays in the process of socialisation. Klin et al. (2002) argued that Weak Central Coherence displayed by these individuals leads to a tendency to neglect contextual and overall meaning of the environment. Given this attentional style, a lack of repeated exposure to social stimuli early in these individuals' lives may lead to a lack of expertise with facial stimuli. These researchers notably posited that while eye-tracking methods allow better capture, characterisation, and measurement of the profound social dysfunction evidenced in the naturalistic interactions of people with ASD, they also allow researchers to see the world through the eyes of these individuals. Eye-tracking therefore affords a unique perspective-taking opportunity for neuro-typical people to better understand and empathise with the behaviour of this population. The publication of Klin et al.'s seminal paper in 2002 paved the way for a new wave of researchers to investigate and further understanding of ASD traits and behaviour using eye-technology.

Evidence of people with ASD demonstrating difficulties in interpreting gaze cues has been corroborated by more recent studies. Riby and Hancock (2009) showed social scenes involving cartoon and human characters to participants with ASD, Williams syndrome, and neuro-typical controls. Participants with Williams syndrome demonstrated increased interest to social information compared with participants with ASD, who preferentially attended less to both cartoon and human faces. Thus, participants with ASD had less opportunity to perceive and interpret social cues (whether gaze or emotion expression) conveyed by the characters (Riby & Hancock, 2009). This study, along with others, supports a general consensus of decreased eye region fixations, evidenced by abnormal viewing of faces and people within social scenes by people with ASD (see Dalton et al., 2005, Pelphrey et al., 2002).

However, conflicting findings of this population's gaze patterns exist within the literature (e.g. Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2008; cf. Riby & Hancock, 2009). A critical difference could lie in the nature of stimuli used. As mentioned earlier (see section 2.4.3), gaze differences displayed by people with ASD mostly exist in response to dynamic stimuli, due to impaired dorsal stream function (Drysdale et al., 2017; Kemner & van Engeland, 2003). For example, Speer et al. (2007) showed both static pictures and movie extracts from Klin et al. (2002) to 12 individuals with High Functioning Autism (HFA), who only exhibited atypicalities when viewing moving and not static images. Furthermore, atypicalities were only found for movies involving more than one character. The reduced attention captured during movies reveals that participants with ASD may be less engaged by moving and complex information with sound and language (Riby & Hancock, 2009). Such a finding has important implications for the design of teaching materials and implies that children with autism may be more engaged by pictures than dynamic or complex information (Riby & Hancock, 2009).

Differential gaze patterns appear to emerge across the lifespan for people with ASD. For example, the majority of studies involving adult participants report group differences in gaze, between TD participants and those with ASD (Boraston & Blakemore, 2007). Van der Geest et al. (2002), on the other hand, found no group gaze differences towards social stimuli when TD children and children with ASD were viewing cartoons. Although cartoon extracts may not represent the most natural stimuli, there are other sources of evidence across stimuli types reporting similar gaze behaviour between ASD and TD groups (e.g. Fletcher-Watson et al., 2008). Confusion remains about the extent of atypical gaze by people with ASD towards social stimuli, leading to Chita-Tegmark's (2016) meta-analytic review, which attempted to summarise the eye-tracking literature in order to definitively answer this question.

3.6.3 Passive Viewing vs Active Engagement

Chita-Tegmark (2016) conducted a meta-analytic review which investigated whether individuals with ASD demonstrated overall atypical attention to social stimuli. Chita-Tegmark aggregated data from 68 studies investigating gaze pattern differences between individuals with ASD and TD individuals when viewing social and non-social stimuli. Across studies tracking gaze in both ASD and neuro-typical populations, people with ASD were found to spend more time looking at human bodies, and non-social stimuli (e.g. objects in a scene), and spent less time looking at face, eye, and mouth regions, and less time looking to the viewing screen (where stimuli was shown), compared to their neuro-typical counterparts.

However, when compared individually, the findings from these studies were quite mixed, suggesting that people with autism were not consistently displaying unusual eye gaze, and under certain conditions, appear to exhibit typical gaze. I put forward two theories as to why these inconsistencies appear: firstly, a large proportion of reviewed studies involved free viewing, in other words, participants passively viewed rather than actively engaged with stimuli. Given that in some samples, normal attention preferences appear intact in those with ASD (e.g. Fletcher-Watson et al., 2008), it is possible that when participants are actively engaged with visual stimuli, these individuals are being cued to attend to the global whole and consequently able to overcome WCC bias.

Secondly, evidence from Theory of Mind (ToM) tasks has shown that individuals with HFA can often pass these formal tests, yet have real difficulties generalising these skills to everyday social situations (Boraston & Blakemore, 2007). I suggest that individuals with ASD are not performing these tasks in the same way as do other people, but adopt some kind of unusual strategy to complete the task. It is possible that these individuals also use unusual gaze strategies to complete tasks involving visual stimuli, but is this behaviour merely *different* or does it truly represent a deficit of this population?

3.7 Summary

In this chapter a discussion on the advantages of eye-tracking techniques in measuring eye gaze patterns is presented. This technique allows for a direct, objective, and quantitative data collection method over previously used, less reliable techniques and has started to gain popularity in measuring eye gaze patterns in populations where atypical gaze is displayed, such as those with ASD. While it has been used extensively with this population to study eye gaze patterns toward social stimuli, the majority of these studies have involved passive viewing of visual stimuli. There is evidence to suggest that during active task engagement, that is, when simultaneously viewing stimuli and performing a task, individuals with ASD have demonstrated the ability to overcome their processing bias for local, detail-focused information and attend to the global information, instead gathering contextual and overall meaning of their environment or the task. The following chapter presents a published systematic literature review (Drysdale et al., 2017) examining published studies comparing the performance of ASD and TD individuals while actively engaged in tasks while their eye movements were tracked. We sought to better understand the relationship between atypical gaze patterns and skill performance.

Chapter 4: Gaze Patterns of Individuals with ASD during Active Task Engagement: a Systematic Literature Review

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REVIEW PAPER

Gaze Patterns of Individuals with ASD During Active Task Engagement: a Systematic Literature Review

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Abstract Despite the increasing number of studies investigating eye gaze patterns in individuals with autism spectrum disorder (ASD) during passive viewing of stimuli, few studies have focused on gaze behaviour of people with ASD during active task engagement. Active engagement may cue these individuals to allocate gaze to task-related information and display typical eye gaze patterns, whereas in the absence of cues, they demonstrate *weak central coherence* and tend to allocate attention to specific, yet irrelevant, visual detail in the environment. If individuals with ASD are exhibiting typical eye gaze patterns when engaged in everyday tasks, then interventions targeting gaze remediation may be misguided. The present review, therefore, aimed to investigate whether (1) individuals with ASD consistently exhibited atypical eye gaze patterns when actively engaged in tasks and (2) atypical eye gaze was associated with skill deficits in regard to task performance. Typical gaze patterns were found during reading, following instructions, and memory tasks, while atypical gaze patterns were evident in driving, word learning, and imitation tasks. Atypical gaze patterns were only associated with impairments in imitation performance, whereas individuals with ASD and typically developing controls performed equally on word learning and driving tasks, suggesting that atypical gaze patterns were not associated with a general performance deficit.

Keywords Eye-tracking · Visual attention · Autism spectrum disorder · Active engagement · Systematic review

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The emergence of eye-tracking technology has allowed researchers to reliably and precisely measure eye gaze patterns in people with autism spectrum disorder (ASD; Hosozawa et al. 2012; Wilkinson and Mitchell 2014).

This is partly due to the non-invasive, remote table-mounted video-based eye-tracking systems which are less intrusive in recording gaze behaviours (Guillon et al. 2014). These systems use pupil centre/corneal reflection technique to estimate point of gaze, which relies on optical sensors to capture reflection patterns of infrared light off the eyes. Researchers can quantify gaze behaviours by using a drawing program within the eye-tracking software to divide each stimulus image into areas of interest (AOIs; Wilkinson and Mitchell 2014). AOIs are pre-defined regions created within the video or live scene where multiple clusters of fixations are predicted to occur.

People diagnosed with ASD are commonly attributed with a preference for processing specific visual detail over the greater whole, also known as weak central coherence (WCC) (Happé and Frith 2006). Possibly, in consequence of this, many eye-tracking researchers have investigated whether individuals with ASD demonstrate unusual eye gaze patterns toward people (Keehn et al. 2013). To date, the evidence is divided.

Three studies who have reported evidence for atypical eye gaze patterns among individuals with ASD when compared to typically developing (TD) individuals. Klin et al. (2002) compared gaze patterns between these two groups while participants watched clips from the movie *Who's Afraid of Virginia Wolf?* Their results showed that individuals with ASD spent less time attending to eye AOIs, but more time attending to mouths, bodies, and objects compared to the TD group. Similarly, Riby and Hancock (2009) found that their 13-year-old participants with ASD spent less time looking at faces of human actors and cartoons when watching movies depicting social interactions than did two control groups matched on chronological age and non-verbal ability. Hanley et al. (2013) reported that 20-year-old individuals with ASD spent less time looking at face AOIs than did TD individuals when viewing pictures of scenes depicting natural interactions.

Conversely, several researchers have reported similar gaze behaviours with ASD and TD populations. Fletcher-Watson et al. (2009) compared gaze patterns of individuals with ASD and TD individuals when viewing a split screen. One side of the screen displayed a person-present; the other, a person-absent scene. Both groups spent more time looking at the person-present scene relative to the person-absent scene; hence, both groups preferentially attended to the person. Grossman et al. (2015) also found typical eye gaze behaviour by both adolescents with ASD and TD controls toward an eye AOI when watching videos of a female speaker. Norbury et al. (2009) found no group differences between ASD and TD groups in duration of time spent viewing mouth AOIs when watching social scene clips, which contrasts with the findings of Klin et al. (2002).

Such mixed findings from the last decade have yet to establish whether eye gaze patterns of those with ASD are atypical. In a recent meta-analysis of eye-tracking studies, Chita-Tegmark (2016) attempted to identify whether overall attention allocation in ASD was atypical. In her meta-analysis, data was aggregated from 68 studies comparing eye gaze patterns of individuals with ASD and TD individuals. Mean effect sizes for gaze duration to six AOIs were computed: eyes, mouth, face, body, non-social elements, and the viewing screen. Chita-Tegmark found that compared to TD controls, people with ASD spent more time gazing at bodies and non-social stimuli; spent less time gazing at faces, eyes, and mouths; and gazed less at the viewing screen. Since individuals with ASD focused less on areas high in social information, Chita-Tegmark suggested that overall, they engaged in less social information processing and as a result, had fewer opportunities for social learning. Overall, the studies reviewed by Chita-Tegmark (2016) shared a common feature: participants passively viewed, rather than actively engaged with stimuli.

Interestingly, individuals typically attend to, recognise, analyse, and store important detail when actively engaged (Quill 2000) and then construct meaning by integrating this detail into a greater whole (Carnahan et al. 2009). Active engagement is one of the strongest predictors of learning for students with ASD (Iovannone et al. 2003). Actively engaging with visual stimuli may assist individuals with ASD to learn skills despite reduced attention to social information. Alternatively, it might help direct students with ASD to social information. Individuals with ASD have been shown to overcome the WCC bias when cued to attend to the greater whole (Happé and Frith 2006; López et al. 2004). Similarly, being actively engaged in a task may produce different eye gaze patterns in this population. For example, when driving a car, individuals with ASD may attend to the road scene overall (global information) rather than focussing exclusively on irrelevant elements within it (local information). If this is the case, the prevalence of atypical eye gaze patterns in ASD may be overestimated, calling into question the necessity for interventions targeting gaze remediation, a recent focus of considerable researcher attention (Whalen and Schreibman 2003). Therefore, research designed to improve our understanding of eye gaze patterns of people with ASD during active task engagement is warranted. Indeed, no research to date has explored these differences across task types. Comparing gaze and task performance of TD persons and those with ASD during active task engagement is necessary to evaluate prevalence of atypical gaze patterns in ASD and, importantly, whether these patterns are associated with a decline in task performance.

The current review, therefore, aimed to systematically review studies comparing eye gaze patterns of people with ASD and TD controls when actively engaged in tasks. Quality indicators for group experimental research in special education, derived from Gersten et al. (2005), were used to evaluate study quality. Two research questions were posed: first, do individuals with ASD consistently display atypical eye gaze patterns while actively engaged in tasks? Second, is atypical eye gaze associated with a skill deficit or is atypical eye gaze irrelevant to task performance? By addressing these research questions, this review attempts to shift the focus of eye-tracking research in ASD from eye gaze during passive viewing of stimuli to active engagement.

Method

Initial Literature Search

The terms *eye-tracking* and *autism spectrums disorders* were entered separately into a PsycINFO thesauri and keyword search to generate a list of synonyms that mapped each term to subject heading: (1) *eye-tracking* terms (i.e. visual tracking, eye movements, eye fixation, and visual attention), and (2) *autism spectrum disorder* terms (i.e. Asperger's syndrome, autism, autistic children, autistic psychopathy, early infantile autism, and pervasive developmental disorder). All search terms under the two main headings (*eye-tracking* and *autism spectrum disorders*) were combined for literature searches from four databases: PsycINFO, ERIC, PubMed, and Web of Science, up to the end of August 2017. Filters were applied to include only peer-reviewed journal articles written in English and the date of publication was not restricted. This resulted in an initial collection of 3372 articles. Duplicates and any remaining book chapters, dissertations, or other non-peer-reviewed articles were removed, leaving 2065 papers.

Inclusion Criteria

To-be-included studies were required to use eye-tracking technology to measure eye gaze in ASD and TD participants while actively engaged in tasks. For the purposes of this review, passive engagement was defined as "participants given instruction to only view stimuli". Active engagement was defined as "participants given instruction to view stimuli, and to engage in an observable and measurable behaviour" (e.g. recall digits, answer comprehension questions, imitate). Eye gaze was described in terms of saccades, fixations, or smooth pursuit movements. Fixations are defined as the maintenance of gaze at a single location, and saccades are rapid movements of the eyes between fixations. Smooth pursuits are slower eye movements which allow the eye to track a moving object.

To qualify for the review, studies had to include at least one TD participant, and at least one participant diagnosed with ASD (or previously recognised subtypes).

Participants with ASD and co-morbid conditions (e.g. intellectual disability, attention hyperactivity-deficit disorder, language disorder) were also included. A large proportion of the studies were able to match ASD participants to TD controls on measures of language and cognition, thereby excluding participants with additional language disorders or intellectual disability.

Eye gaze data must have been collected by eye trackers utilising the pupil centre/corneal reflection technique. Studies measuring pupil dilation were excluded (e.g. Aldaqre et al. 2016), as this measurement provides information on arousal level and emotion, rather than location of visual attention. Studies which measured vestibule-ocular reflexes (e.g. Carson et al. 2017), rapid eye movement, or vertical or horizontal eye movements (without any information about gaze) were also excluded.

In addition to eye gaze, study outcomes needed to include other behaviours that could be reliably observed and measured. This included behaviours related to learning or academic outcomes (e.g. reading), functional skills (e.g. driving), or language skills. Studies where the behaviours were private events that could not be reliably observed or measured by researchers, including prototype formation (e.g. Gastgeb et al. 2012), prediction (e.g. Pillai et al. 2014), and face or emotion processing (e.g. Wieckowski and White 2017), were excluded.

Procedure

Application of Inclusion Criteria A title and abstract analysis of 2065 papers was conducted, reviewing titles and abstracts against the inclusion criteria. If it was evident that a paper did not meet all inclusion criteria, it was removed. This resulted in the exclusion of 1855 studies. Electronic versions of the full articles for the 210 remaining papers were obtained. Full article analysis was conducted by examining the methods and results sections of each paper to determine which articles fulfilled all inclusion criteria, resulting in the exclusion of a further 195 studies and retention of 15. Ancestral searches of the 15 articles were undertaken by searching through the reference lists to identify additional, relevant papers which had not been located during the initial search. Thirteen studies were identified through this process and the full article obtained for each. Of these, only one met inclusion criteria, bringing the total number of studies to be reviewed to 16.

Design Standards All included studies employed group designs which compared ASD and TD groups. The protocols used to evaluate methodological acceptability were drawn from quality indicators developed by Gersten et al. (2005). These protocols ensured that key features of the study (e.g. participants, eye tracker used), outcomes, and interventions were described.

To pass design standards, a study had to meet *Acceptable* or *High* standards after applying the protocols (see Gersten et al. 2005). For a study to be considered *Acceptable*, it had to contain at least 9 of 10 *Essential Quality Indicators*, and at least one of the *Desirable Quality Indicators*. For a study to be considered *High*, it had to contain at least nine of the *Essential Quality Indicators*, and at least four of the *Desirable Quality Indicators*. Papers which were not rated at least as *Acceptable* were discarded from further analysis. The entire procedure for the systematic review is outlined in Fig. 1.

Inter-rater Agreement

Inter-rater agreement data was collected on three occasions: for the title and abstract analysis, full article analysis, and application of design standards.

Title and Abstract Analysis A subset of 620 papers was created (30% of the articles found in the initial search) in Endnote X.7 by assigning record numbers to each paper. The subset was created by randomly allocating numbers to all the studies in the sample and using those studies numbered from 1 to 620. The subset was then given to a second researcher, independent of this review. The second researcher read each paper's title and abstract to determine whether the paper met the inclusion criteria. Inter-rater agreement was calculated as the number of agreements between researchers, divided by the total number of agreements and disagreements. This number was then converted to a percentage. Inter-rater reliability was 98% for this step.

Full Article Analysis A subset of 63 articles was created (30% of the articles after title and abstract analysis by the first author) using the same method. The second researcher read each paper's methods and results section to determine whether

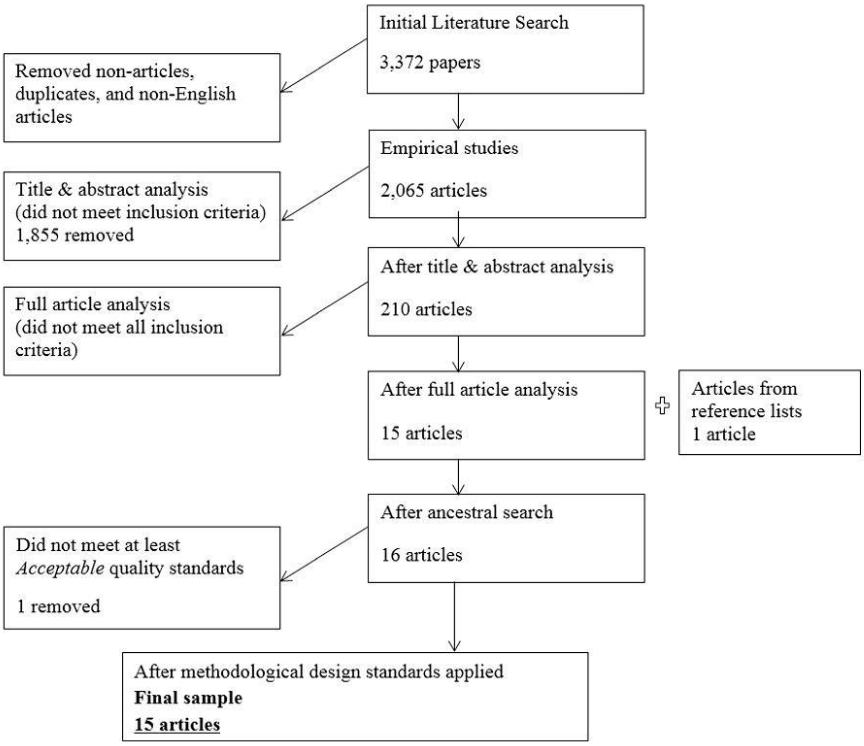

Fig. 1 Flow diagram of the systematic review process

the paper met inclusion criteria. Inter-rater agreement was 100% for this step.

Design Standards The second researcher applied the design standards to the final sample of studies and determined the standard for each. For this process, inter-rater agreement was calculated as the number of agreements on inclusion in the review (either *Acceptable* or *High* standard) between researchers, divided by the total number of agreements and disagreements on inclusion. Inter-rater reliability was 94% for this step.

Results

Of the 16 studies (date range 2008–2017) included in the present review, 14 met *High* standards, one met *Acceptable* standards, and one was excluded as it failed to meet design standards, as determined by Gersten et al. (2005), leaving 15 studies for final analysis. Table 1 provides an overview of participant descriptive features, assessments used, eye tracker details, eye movements measured, and independent variables in the included studies. Table 2 lists the quality descriptor for each study, as well as eye gaze findings and performance outcomes for each of the 15 studies.

Descriptive Statistics of Participants

Overall, 593 individuals participated in the 15 studies: 141 were female (24%) and 426 were male (72%); one study (Norbury et al. 2010) did not provide information on participant gender (4%). Participants ranged from 3.5 to 36.9 years of age (mean = 12.3). Of the 593 participants, 272 were diagnosed with autism spectrum disorder (45.9%), 279 were typically developing (TD; 47.0%), and 42 were diagnosed with global developmental delay (GDD; 7.1%). All 15 studies compared gaze behaviour between ASD and TD groups. Two studies additionally compared GDD participants to TD and ASD groups (Trembath et al. 2015; Vivanti and Dissanayake 2014), while one study compared an ASD group to a combined TD + GDD group, which served as a control for language and imitation abilities (see Vivanti and Dissanayake

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Table 1 Overview and features of included studies

Study	Independent Variable	Eye tracker Frequency (Hz) Type	Eye movementsrecorded	Participants				Assessments
				Group	*n*	Gender	Age (years)	
Aldaqre et al. (2015)	Gaze cues from model Distractor "jiggling"	Tobii T60 60 Hz Remote	Fixation—count AOIs—target object, distractor object, face	ASD TD	15 15	F = 6 M = 9 F = 9 M = 6	36.9 32.5	Autism-Spectrum Quotient (AQ-k) [German] Culture Fair Test 20-R (CFT 20-R) German Vocabulary Test (MWT-B)
Au-Yeung et al. (2015)	Presence/absence of irony in reading passages	Eyelink 1000 1000 Hz Remote	Fixation—duration AOIs—context, critical, spill-over, context restatement (text)	ASD TD	18 19	F = 2 M = 16 F = 6 M = 13	32.4 23.8	Wechsler Abbreviated Scale of Intelligence (WASI) Autism-Spectrum Quotient (AQ)
Falck-Ytter et al. (2015)	Direct vs averted gaze Digit-span test	Tobii TX300 60 Hz Remote	Fixation—duration AOIs—eyes, mouth	ASD TD	10 25	F = 1 M = 9 F = 8 M = 17	6.7 6.9	Wechsler Intelligence Scales Social Responsiveness Scale (SRS) In-house socioeconomic status form
Gillespie-Lynch et al. (2013)	Animated vs real model Eye gaze and labelling	Tobii 1750 60 Hz Remote	Fixation—duration Saccade—latency	ASD TD	21 42	F = 2 M = 19 F = 6 M = 36	4.7 4.2	Childhood Autism Rating Scale (CARS) Differential Ability Scales II (DAS) Mullen Scales of Early Learning (MSEL) Social Responsiveness Scale (SRS)
Loth et al. (2011)	Context (burglar vs party story) Scene viewing	Tobii x50 50 Hz Remote	Fixation—count, duration AOIs—context relevant, content irrelevant, neutral items	ASD TD	13 14	F = 2 M = 11 F = 3 M = 11	25.5 23.3	Wechsler Abbreviated Scales of Intelligence (WASI) Autism Diagnostic Observation Schedule (ADOS) False Belief Task + Strange Stories (ToM)
Lucas and Norbury (2014)	Presentation of spoken word and picture	Tobii T120 60 Hz Remote	Fixations—count, duration AOIs—picture, word	ASD TD	20 21	F = 5 M = 15 F = 9 M = 12	10.6 10.5	Wechsler Abbreviated Scales of Intelligence (WASI) Test of Word Reading Efficiency (TOWRE) Expressive One-Word Picture Vocabulary Test Receptive One-Word Picture Vocabulary Test
Micai et al. (2017)	Reading paragraphs which did not (literal condition) and did (inferential condition) require an inference to be made to demonstrate understanding	EyeLink 1000 1000 Hz Remote	Fixations—count, duration Saccades—count, duration	ASD TD	22 22	F = 3 M = 19 F = 7 M = 15	12.6 13.0	Autism Diagnostic Observation Schedule (ADOS) Wechsler Intelligence Scale for Children-Fourth Edition (WISC-IV) Wechsler Adult Intelligence Scale-Fourth Edition (WISC-IV) Peabody Picture Vocabulary Test-Third Edition (PPVT-III) Grammatical Structures Comprehension Test (CEG) Magellan Scales of Reading and Writing (EMLE TALE—2000)
Norbury et al. (2010).	Gaze toward object (in a field of 3 objects) and spoken word	ASL 504 50 Hz Remote	Fixation—count, duration AOIs—face, target object	ASD TD	13 13	n/a n/a	7.2 7.1	British Picture Vocabulary Scales (BPVS) Social Communication Questionnaire (SCQ) Autism Diagnostic Observation Schedule (ADOS)
Reimer et al. (2013)	Driving simulation Phone task Auditory continuous performance task	FaceLAB 5.0 60 Hz Remote	Fixation—vertical + horizontal position	ASD TD	10 10	M = 10 M = 10	20.2 20.7	Wechsler Scales Psychiatric interview Kennedy Simulator Sickness Questionnaire (SSQ)

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Table 1 (continued)

Study	Independent Variable	Eye tracker Frequency (Hz) Type	Eye movementsrecorded	Participants Group	*n*	Gender	Age (years)	Assessments
Sansosti et al. (2013)	Two-sentence passages Primed vs unprimed inference to answer general knowledge question	Tobii T120 120 Hz Remote	Fixation—count, duration, regressions (looking back through the text)	ASD	18	F = 1 M = 17	15.5	Grey Oral Reading Test-Fourth Edition (GORT-4)
				TD	16	F = 7 M = 9	15.0	Peabody Picture Vocabulary Test-Fourth Edition (PPVT-4)
Trembath et al. (2015)	Presence/absence of pictures while giving instruction	Tobii T120 120 Hz Remote	Fixations—count, duration AOIS—actor's face, picture of target object, picture of target container	ASD	25	F = 3 M = 22	4.0	Social Communication Questionnaire (SCQ)
				TD	19	F = 6 M = 13	4.2	Autism Diagnostic Observation Schedule (ADOS)
				GDD	17	F = 9 M = 8	3.7	Mullen Scales of Early Learning (MSEL)
Vivanti et al. (2014)	Video demonstrations of actions on objects Functional Tool Use task	Tobii 1750 60 Hz Remote	Fixations—duration Saccades AOIs—actor's head, congruent object, incongruent object	ASD	28	F = 3 M = 25	4.0	Social Communication Questionnaire (SCQ)
				TD	17	F = 6 M = 11	4.3	Autism Diagnostic Observation Schedule (ADOS)
				GDD	17	F = 8 M = 9	3.7	Mullen Scales of Early Learning (MSEL)
Vivanti et al. (2008)	Video demonstrations of actions on objects and non-meaningful gestures	Model H6 (ASL) 60 Hz Head-mounted	Fixations—duration AOIs—face, action regions	ASD	18	F = 2 M = 16	11.3	Clinical Evaluation of Language Fundamentals-Fourth Edition (CELF-4) Wechsler Abbreviated Scale of Intelligence (WASI) Vineland Adaptive Behaviour Scales-Second Edition (VABS-II) Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2) Social Communication Questionnaire (SCQ) Autism Diagnostic Observation Scale (ADOS)
				TD	13	F = 2 M = 11	11.1	
Vivanti and Dissanayake (2014)	Videos demonstrating actions Direct gaze vs averted gaze	Tobii 1750 60 Hz Remote	Fixations – durations AOIs- face, action regions	ASD	25	F = 3 M = 22	4.0	Mullen Scales of Early Leaning (MSEL)
				TD + G-DD	178	F = 12 M = 13	3.5	Social Communication Questionnaire (SCQ) Autism Diagnostic Observation Schedule (ADOS)
Wild et al. (2012)	Video demonstrating hand movements Goal-less vs goal-directed imitation clips	Eyelink II 250 Hz Head-mounted	Fixations—count, duration AOIs—targets 2 + 4 Saccades—count, amplitude Smooth pursuits—duration	ASD	16	F = 5 M = 11	30.6	Autism Diagnostic Observation Schedule (ADOS)
				TD	16	F = 5 M = 11	29.3	Wechsler Abbreviated Scale of Intelligence (WASI)

n/a not available

2014). Thirteen of the 15 studies (87%) used an assessment to screen for or measure the severity of autism symptoms in order to confirm a diagnosis.

Eye Movements and Other Dependent Variables Measured

Videos, pictures, animations, or text was displayed to the participants on a computer screen, while gaze data toward these visual stimuli was recorded. One hundred percent of studies measured fixation number or duration as the dependent variable, with operational definitions of *fixation* consistent across the literature. Seventy-three percent of studies created AOIs in the visual scenes viewed by participants. Commonly found AOIs in reviewed studies were face, eye, or mouth regions; objects that were gazed or actioned upon; distractor objects; and—in reading studies—regions of text.

Eye gaze and skill performance served as study outcomes. Six separate skills sets were identified in these studies: (1) word learning, (2) memory, (3) imitation, (4) following

Table 2 Findings and design standards status of included studies

Study	Target behaviour	Design quality	Findings—eye gaze	Findings—target behaviour
Aldaqre et al. (2015)	Word learning	High	-ASD: less time looking at the target compared to TD group. In "mismatch condition" spent considerably more time looking at distractor than TD group. -No group difference between looking time to face. -All participants looked at target longer in the response segment compared to familiarisation trials (they were not already looking at targets preferentially).	-Looking longer at target during the response segment made word learning more likely. -ASD: identified the correct word 80% of the time in the "static condition" and ~ 50% of the time in the "mismatch condition" → distractor affected learning.
Au-Yeung et al. (2015)	Reading	High	-Ironic statements required more effortful processing (TD and ASD) compared with literal, non-ironic statements. -ASD group spent more time overall than TD group rereading the passages, suggesting that they take longer to construct a coherent representation of the text or to make a decision.	-ASD group performed as well as TD group in their comprehension accuracy in both ironic and non-ironic conditions. -ASD individuals able to use contextual information to infer a non-literal interpretation of ironic text.
Falck-Ytter et al. (2015)	Memory—recall	High	-Children looked more at experimenter's face during encoding phase than answering phase. -Children looked less at the experimenter in the averted gaze condition compared to the direct gaze condition. -Children looked higher at the face of experimenter (more time at eyes, rather than mouth). -No group differences for where attention was allocated.	-TD: performed worse in the averted gaze condition than the direct gaze condition. -ASD: performed equally well in the two conditions (actually slightly better in the averted gaze condition).
Gillespie-Lynch et al. (2013)	Word learning	High	-Gaze following occurred less frequently in the eye tracker assessment than the in-person. -ASD group followed gaze less frequently overall than TD group. -ASDs exhibited impaired reflexive gaze following.	-No relation between gaze following and referent selection were observed. -Gaze following was associated with referent (target) preference, which was related to cognitive level. -Word learning from gaze cues better explained by developmental level (i.e. non-verbal matching ability) than autism.
Loth et al. (2011)	Memory—immediate + delayed recall	High	-TD group spent first 10 fixations looking longer at relevant items than the ASD group. -ASD group made more fixations to the neutral items than the TD group. -Both groups looked on average significantly longer at relevant and irrelevant items than neutral ones. -No significant group differences in overall gaze time, number of fixations, or fixation duration.	-During immediate and delayed recall, only the TD group selectively recalled context-relevant objects, and significantly more context-relevant objects than the ASD group. -ASD group recalled more neutral items (effect size was large but did not survive Bonferroni corrections).
Lucas and Norbury (2014)	Word learning	High	-No group differences during learning phase for time spent fixating the written form. -ASD group spent less time looking at picture region, and slightly more time looking at word region (differences were marginal and not statistically significant).	-Vocabulary learning of both groups facilitated by the presence of orthography. Both groups retained or increased new knowledge after 24 h (re-testing). -Groups did not differ in comprehension of new words or recognition of new orthographic forms. -Children with ASD demonstrated superior phonological learning (measured through picture naming task) relative to TD peers.
Micai et al. (2017)	Reading	High	-No group difference in global paragraph reading time.	-Both groups were significantly less accurate on questions in inferential condition than literal condition.

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Table 2 (continued)

Study	Target behaviour	Design quality	Findings—eye gaze	Findings—target behaviour
			-ASD group displayed longer gaze latencies on word necessary to produce an inference. -ASD group made more regressions than TD group to target word that supported inferences after reading question, irrespective of whether inference was required or not.	-No main effect of group or interaction was observed on comprehension accuracy. -No group difference in question response times.
Norbury et al. (2010)	Word learning Memory—recall	High	-No group differences in total number of fixations or proportion of fixations to the face or target object. -Although both groups made significantly more fixations to the face when the speaker was directing gaze at the target object, the TD group made a significantly greater proportion of fixations to the face than the ASD group, during this time window.	-No difference between groups on initially choosing the correct object. -Both groups equally performed better on the biased trials (where model looked toward object). -Immediately after, ASD group recalled greater percentage of correct phonemes than TD peers. -After 4 weeks, ASD group recalled less semantic features than TD group, whose performance improved after 4 weeks.
Reimer et al. (2013)	Vehicle driving	High	-Average vertical position of ASD drivers' gaze was 44% higher than TD drivers. This means they were less often oriented toward objects in low visual field (i.e. dashboard, lead and directly oncoming vehicles) and more oriented toward the horizon (i.e. the active portions of roadway scene). -All drivers tended to fixate on the right side as this is where pedestrians and parked cars were. -With added cognitive demand, only ASD drivers appeared to shift their gaze to the left, suggesting a stronger shift in attention away from a vehicle in front and toward oncoming traffic or the median.	-Two ASD drivers and two TD drivers were involved in a collision while driving the simulated highway. -No group difference between speed limit and lane position of car.
Sansosti et al. (2013)	Reading	High	-ASD participants spent more time fixating and made a greater number of fixations on the sentences than the TD group. -ASD participants made significantly more regressions per passage than TD participants.	-No group differences in response accuracy to the questions. Both groups were able to build the bridging inference to understand the inferences. -Both groups responded more quickly to physical content items than to social content items. -Correlation indicates that the longer the mean fixation duration during passage reading, the less accurate the response to the passage question.
Trembath et al. (2015)	Following instructions	High	-No difference between groups in the amount of visual attention directed to actor's face. -No group difference in amount of visual attention directed to target object. -No group difference in proportion of total fixations on the pictures vs the face (all groups looked at pictures for ~ 70% of time, and to the face ~ 30% of time).	-TD and GDD groups performed significantly better in the picture condition, ASD group performed equally poorly under each condition; therefore they were the only group that did not benefit from pictures. -Positive correlation (.35) between visual attention to pictures and performance for ASD group. -Positive correlation (.40) between receptive language and performance for ASD group.
Vivanti et al. (2014)	Imitation	High	-Children with ASD spent least percentage of time looking at demonstrator's face, and an increased proportion of time looking at her actions compared to TD + GDD children. -ASD children took a longer time to respond to joint attention (follow model's gaze).	-Children with ASD imitated actions less frequently compared to both GDD + TD groups. -Both ASD + GDD groups were significantly less accurate in their imitation compared to the TD group.

Table 2 (continued)

Study	Target behaviour	Design quality	Findings—eye gaze	Findings—target behaviour
				-Imitation accuracy improved with chronological age in the GDD + ASD groups.
Vivanti et al. (2008)	Imitation	High	-No group difference between looking time. Both groups looked to the Action region for a similar amount of time. -Both increased visual attention to the Action region when observing meaningful actions compared with non-meaningful gestures. -ASD group looked approximately half as much at the face than the TD group. -Both groups looked at the face more when observing non-meaningful gestures than when observing meaningful actions. -Visual attention to Action region was correlated with imitation precision for non-meaningful gestures in the ASD group, but not the TD group.	-TD group had overall better motor skills. -Both groups imitated meaningful actions more precisely than non-meaningful gestures. -ASD group less accurate in imitation than the TD group. -ASD group were particularly poor at imitating non-meaningful gestures (those without an obvious goal).
Vivanti and Dissanayake (2014)	Imitation	High	-ASD participants slightly increased their attention to the model's action in the averted gaze condition, compared to the direct gaze condition. -TD participants increased their attention to the face in the direct gaze condition compared with the averted gaze condition, but this was not the case for the ASD group. -Participants with ASD directed their attention to the direct gaze phase of the video (when model looked straight at camera) for approximately half the time compared with TD participants.	-TD performed more accurately than ASD group in the direct gaze condition but not in the averted gaze condition. -In ASD group, imitation performance in the averted gaze condition was correlated with visual attention to model's action, and negatively correlated to the ADOS repetitive behaviour scores in the ASD group. -In ASD group, imitation performance was positively correlated to visual attention to the model's face in the direct gaze condition. -For control group, visual attention was not related to performance for either condition.
Wild et al. (2012)	Imitation	Acceptable	-ASD group spent similar amount of time on and between targets in both types of clip. TD group spent more time between targets in the target clips. -ASD group spent relatively more time looking at targets than between targets compared to TD group in both conditions. -ASD group made more saccades than control group in no-target clips, whereas there was no difference between groups in the target clips. -The TD group spent more time making pursuits. -ASD also spent more time fixating overall, but their fixations were shorter. -Average amplitude (size) of saccades made by ASD group in the no-target clips was significantly smaller than in the target condition, but this was not true of controls.	-ASD group did not modulate their movement for either target or no-target clips, whereas TD group displayed borderline significant modulation for no-target clips.

instructions, (5) driving, and (6) reading. Eye gaze patterns and performance for each skill are reported below:

1. Word learning

Four studies in the review investigated word learning in ASD and TD individuals (range 4.2 to 36.9 years). The focus of "word learning" was on receptive language; in that, participants were required to demonstrate stimulus equivalence with forms of a novel word. Participants viewed a model gaze toward and label the target object (e.g. said "shoe"), or viewed the written word appear on the screen once the model gazed at the target object.

Gaze findings. Participants with ASD displayed atypical eye gaze patterns during word learning tasks. Although ASD and TD individuals made a similar number of fixations to target objects, for similar durations, participants with ASD followed model gaze less frequently and made a lower proportion of fixations to faces overall (Gillespie-Lynch et al. 2013). Participants with ASD were more likely to attend to distractors, particularly those whose features moved or shook (i.e. dynamic distractors; Aldaqre et al. 2015). When distractors were absent, Lucas and Norbury (2014) found that participants with ASD spent more time looking at the written word than TD participants did, when both picture and written forms of the target word were available.

Performance results. The ASD and TD groups identified novel words at around 80% of the time in the presence of static distractors (Aldaqre et al. 2015; Norbury et al. 2010). When dynamic distractors were present, however, participants with ASD correctly identified new words only 50% of the time. When Lucas and Norbury (2014) showed participants the written form of target words, word production (writing), recognition, and comprehension in both groups improved.

2. Memory

Three studies evaluated the impact of eye gaze on memory, specifically on immediate and delayed recall of digits, objects, and words (range 6.7 to 25.5 years).

Gaze findings. Similar gaze patterns were found across groups. Both groups looked at the model's eyes more than their mouth and spent more time looking at a speaking model compared to a silent model (Falck-Ytter et al. 2015). Both groups increased attention to the model's face when the model's gaze was directed toward the viewer, and decreased attention to face when the model averted gaze. In Loth et al. (2011), participants were required to memorise objects after visually scanning a static image of a lounge room. Before viewing the scene, participants read a short passage about either a birthday party or burglary. The TD group spent more time gazing at items relevant to the context (e.g. balloons for birthday scene) than the ASD group, who tended to gaze at items that were neutral or irrelevant to the context (e.g. flowerpot or jewellery for birthday scene).

Performance results. Both groups memorised a similar numbers of digits and objects. The TD group performed significantly better at memory recall when the model gazed at them than when the model's gaze was averted. This trend was not found in the ASD group, who recalled information equally well irrespective of whether the model gazed at them or not (Falck-Ytter et al. 2015). In Loth et al. (2011), there were no group differences in overall number of items recalled; however, participants with ASD recalled more neutral or context irrelevant items, compared to TD participants who recalled more relevant items. Norbury et al. (2010) tested recall of learnt words immediately after the experiment and again after 4 weeks. They found that the ASD group recalled more object names than the TD group immediately after the study. After 4 weeks, the recall scores for the TD group almost doubled while the ASD group's scores showed little change.

3. Imitation

Four studies evaluated imitation skills in participants ranging in age from 3.5 to 30.6 years. Participants were required to imitate a model's gestures, hand movements, and goal-directed actions.

Gaze findings. Overall, the ASD group displayed atypical gaze when imitating. Participants with ASD spent less time overall gazing at the face of the model, compared to TD participants. When the model gazed directly at participants with ASD, they gazed back at the model's face for approximately 50% of the time that TD participants did (Vivanti and Dissanayake 2014; Vivanti et al. 2008). Also, the ASD group did not alter their own gaze behaviour based on whether the model's gaze was directed at or averted from participants: they spent equal time in both conditions gazing at the model's face (Vivanti and Dissanayake 2014). The ASD group spent an increased proportion of time attending to the model's actions compared to TD and GDD groups. When watching clips of a model's hand moving between targets, participants with ASD made less smooth pursuits than TD participants, instead making a larger number of short fixations (Wild et al. 2012). When viewing these clips, the TD group spent significantly more time gazing between the targets than at the targets. In contrast, the ASD group spent equal durations gazing at the targets and between targets (Wild et al. 2012).

Some similarities were observed: both groups increased their visual attention to the action region when viewing meaningful actions (those with goals). Similarly, both groups gazed more at the face region of the model when required to mimic non-meaningful gestures (without an apparent goal) (Vivanti et al. 2008).

Performance results. Participants with ASD imitated actions less frequently than GDD and TD controls, and less accurately than TD controls, especially for mimicry targets (Vivanti et al. 2008). Precision on mimicry targets was positively correlated with visual attention to the action region for the ASD group only (Vivanti et al. 2008). When imitating hand movements, the ASD group were less proficient than the TD group at modulating their hand movements to match the speed and vertical movement displayed by the model.

4. Following instructions

Trembath et al. (2015) evaluated the effect of visual supports to help children (ASD, TD, and GDD) follow instructions (range 3.7 to 4.2 years). Instructions involved asking participants to pick up a target object and place it in a certain container. The presence and absence of picture prompts was manipulated as the independent variable.

Gaze findings. No group differences in visual attention were evident across conditions: both groups directed attention to the model's face and target object for similar durations, and in the presence of pictures, all groups spent approximately 70% of time fixating on the pictures, and approximately 30% of time fixating on the model's face (Trembath et al. 2015).

Performance results. Despite similar gaze behaviour, only the TD and GDD groups performed significantly better when pictures were present. The ASD group performed poorly across both conditions: they were the only group that did not benefit from the visual prompts.

5. Driving

Reimer et al. (2013) used a driving simulator (programmed for a left hand driving lane) to compare car driving skills and the effect of distractions on young adults with and without ASD (range 20.2 to 20.7 years). These researchers induced distraction through (a) a phone task, where participants had to call a doctor's office and book an appointment, and (b) an auditory continuous performance task, which involved listening to a stream of letters and saying "Check" every time the letter *Q* was preceded by a letter *A*. All participants held a valid driver's licence.

Gaze findings. On average, the ASD group's vertical fixation position was 44% higher in the visual field than TD drivers, meaning that ASD drivers tended to orient more toward the horizon, or at a point further along the road scene. TD drivers tended to orient more closely toward their own dashboard, as well as lead traffic (vehicles slightly ahead of them) and oncoming traffic on the opposite side of the road.

Performance results. When researchers induced distractions, only the ASD drivers tended to shift their horizontal gaze position to the left, away from vehicles in front, pedestrians, and parked cars, and instead toward to the median strip. However, no group differences were found on deviation from speed limit or lane position, and an equal number and proportion of participants in each group experienced a collision on the simulator.

6. Reading

Three studies focusing on reading skills evaluated reading rate and comprehension (range 12.6 to 32.4 years). Participants had typical reading ability for their age.

Gaze findings. Reading rate was measured by fixation duration on each word and the passage overall, as well as time spent rereading sections. The ASD group had longer fixation times, made more fixations within sentences, and spent more time overall rereading the passages. Participants with ASD also made more regressions than TD participants to the target word, which supported inferencing, after they read the question (Micai et al. 2017). These findings imply slower reading rates for the ASD group (Au-Yeung et al. 2015; Sansosti et al. 2013). Yet, both groups spent a similar proportion of reading time on each portion of the reading passages. This finding indicated that, while slower, the ASD group read passages in the same manner as did the TD group.

Performance results. Reading comprehension was measured by asking participants comprehension and knowledge questions following passage reading. In Au-Yeung et al. (2015), the ASD and TD groups demonstrated equal accuracy with both literal and non-literal comprehension passages. Similarly, Micai et al. (2017) found that the accuracy and speed of both groups (ASD and TD) on comprehension questions were such that few differences were observed. Finally, Sansosti et al. (2013) noted that both ASD and TD groups were able to infer meaning from passages by linking or synthesising details from the text to their own general knowledge, without marked differences in performance. However, a negative correlation was found between the mean fixation count during passage reading and comprehension accuracy, leading to the conclusion that a higher fixation count, which reflected slower more effortful reading, was associated with less accurate answers; however, there were no group differences on overall comprehension accuracy.

Discussion

This review aimed to answer the following questions: (1) did individuals with autism spectrum disorder (ASD) consistently display atypical eye gaze patterns when actively engaged in tasks? (2) Second, is atypical eye gaze associated with a skill deficit or is atypical eye gaze irrelevant to task performance?

Did Individuals with ASD Consistently Display Atypical Gaze Patterns when Actively Engaged in Tasks?

When people with ASD were actively engaged in tasks, their eye gaze patterns were not consistently atypical across all tasks. Participants with ASD demonstrated typical eye gaze patterns when actively engaged in three of the six tasks (reading, memory, and following instructions), and exhibited atypical eye gaze patterns in the other three tasks (imitation, word learning, and driving). These results are in contrast to past findings where people with ASD consistently displayed atypical gaze when passively viewing stimuli (Chita-Tegmark 2016; Keehn et al. 2013; Klin et al. 2002). In the current review, it appeared that atypical gaze emerged in tasks involving dynamic, or moving visual scenes such as when driving along a road, watching models perform whole-body-actions, and viewing dynamic distractors whose features shook. On the other hand, participants with ASD displayed normal gaze patterns in tasks involving static scenes and pictures, reading text, or viewing a stationary model seated at a table. It is possible that persons with ASD were more likely to be distracted by irrelevant movement of objects or people and unable to filter out this information (Ploog 2010), and therefore gazed atypically at the dynamic scenes. During word learning and driving tasks, this appeared to be the case (see Aldaqre et al. 2015; Reimer et al. 2013). There is evidence to suggest that static pictures or scenes involving minimal movement may benefit learning processes of children who struggle to filter out extraneous stimuli (Alberto et al. 2005). When viewing static pictures, such children were found to have faster acquisition rates and made fewer errors in learning functional skills than when viewing instructional videos.

Chita-Tegmark (2016) argued that people with ASD attend less to social stimuli, and more to non-social stimuli; however, in this review, such a pattern did not emerge. Arguably, the two tasks which involved purely non-social stimuli were driving (viewing a road scene) and reading (viewing text), with differential gaze patterns exhibited by individuals with ASD across these tasks. Hence, the trend of gaze differences was not explained by the amount of social content contained within the visual stimuli, and is more likely explained by the contrast in movements between unmoving text and a highly dynamic road scene.

Following instructions and memory tasks yielded similar gaze durations to eyes for ASD participants and TD controls (see Falck-Ytter et al. 2015; Norbury et al. 2010; Trembath et al. 2015). In these tasks, eyes were a source of social information that facilitated task performance. This finding suggests these individuals were able to overcome this bias for local, specific information (weak central coherence; Happé and Frith 2006) and attend to the global whole. It is possible that active engagement with visual stimuli served as a cue to attend to eyes in order to obtain social information, without needing to overtly prompt the individual. Whether the very presence of a task provides, these cues could be investigated by comparing gaze of individuals with ASD when passively viewing stimuli, to the same individuals' gaze while they actively engage with stimuli.

Eye Gaze Patterns and Skill Deficit

Overall, atypical eye gaze patterns were not associated with a general performance deficit. Concerning imitation, those with ASD who exhibited atypical gaze also imitated less often and less accurately than TD persons (Vivanti and Dissanayake 2014; Vivanti et al. 2008; Vivanti et al. 2014). On the other hand, during driving tasks, individuals with ASD stayed within the speed limit, remained in their driving lane, and avoided accidents despite having atypical eye gaze patterns. Overall, they demonstrated that they were as competent as the TD group (Reimer et al. 2013). In word learning tasks, the ASD and TD groups were equally accurate at identifying objects, after learning the objects' names (Lucas and Norbury 2014; Norbury et al. 2010). Furthermore, participants with ASD recalled more digits than TD individuals in the absence of eye contact (Falck-Ytter et al. 2015), indicating that persons with ASD rely less on eye contact to facilitate memory recall. The weight of evidence suggests that, in the context of task performance, atypical eye gaze patterns in those with ASD represent *different* behaviour, and not skill *deficit*. However, confirmatory data is required to substantiate these conclusions.

Poorer imitation performance could be related to the less developed skill repertoires of younger individuals with ASD. This is relevant given that the word learning and driving studies involved older children and adult participants, who may have fully developed the required skills and learnt adaptive behaviours allowing them to compensate for their differential gaze.

Another possible explanation for imitation-specific impairments in this review is that many children with ASD have a primary deficit in imitation skills (Ingersoll and Schreibman 2006); hence, participants' imitation skills may still have been developing at the time of research. Past eye-tracking research has shown that imitation difficulties in those individuals with ASD occur despite attending correctly to the model (Vivanti and Hamilton 2014). It may be that atypical eye gaze is a correlate of poor imitation skills, rather than the cause of this deficit (Ingersoll and Schreibman 2006). Further research is needed to evaluate whether those on the autism spectrum who demonstrate mastery in imitation skills display atypical gaze while imitating, and similarly to investigate whether these individuals are able to perform successfully across a number of tasks while displaying atypical gaze, providing insight into the nature of adaptive behaviours these individuals may exhibit.

Current interventions targeting gaze remediation may be unnecessary if individuals with ASD are able to perform skills despite atypical eye gaze. Behavioural interventions utilising prompting and reinforcement that aim to teach children with ASD to follow gaze are successful in increasing this behaviour (see Gunby et al. 2016; Klein et al. 2009), but generalisation of this skill has been somewhat limited (Gunby et al. 2016; Wass et al. 2012). Alternatively, teaching a child with ASD imitation skills through active engagement in play or video modelling has shown to increase certain gaze- and attention-related behaviours, such as joint attention (Carpenter et al. 2002; Ingersoll and Schreibman 2006; Rogers and Bennetto 2000), and demonstrated high generalisation rates to novel settings (Ingersoll and Schreibman 2006).

Limitations

Only 15 studies were identified which tracked eye gaze of people with ASD while actively engaged in tasks. The conclusions reached in this review are somewhat attenuated by this small data set. Similarly, eye gaze during active engagement was involved in a narrow range of skills, limiting the generalisability of the findings to other skills. Tracking gaze during active engagement in other skills will add to the limited data in this area and provide further understanding of differential gaze in persons with ASD across tasks.

Conclusion

This review adds to an understanding of eye gaze patterns in people with ASD during active task engagement. Fifteen studies which met inclusion criteria and methodological design standards were identified. A close inspection of these studies resulted in the following conclusions. Individuals with autism spectrum disorder (ASD) did not consistently exhibit atypical gaze during active task engagement. Despite the association between atypical eye gaze patterns and impaired imitation performance, overall, this gaze behaviour was not associated with a general performance deficit. Further research on eye gaze during active task engagement is needed to evaluate what individuals should be attending to while performing tasks, in order to design more successful interventions for people with ASD in developing adaptive skills.

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Conflict of Interest The authors declare that they have no conflict of interest.

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Chapter 5: Reading

Drysdale et al. (2017) reviewed 15 studies comparing performance between individuals with Autism Spectrum Disorders (ASD) and typically developing (TD) individuals in six skills. Gaze was tracked while participants actively engaged with visual stimuli, and overall, a general performance deficit was not found for the ASD group. The findings of this study corroborated past research findings that people with ASD display typical gaze patterns when viewing static pictures as compared to dynamic stimuli (e.g. Kemner & van Engeland, 2003; Riby & Hancock, 2009). The six skills involved in the review were word recognition, memory, driving, gaze following, reading, and imitation. Following this review, reading emerged as a behaviour of interest. Despite slower reading rates of the group with ASD compared to the TD group, equal levels of comprehension accuracy were found, indicating that people with ASD may adopt a more cautious reading strategy and take longer to evaluate their sentence interpretation (Howard, Liversedge, & Benson, 2016). As seems to be the case with research in autism, contradictory results to these online studies typically appear in "offline" tasks i.e. pre-eye-tracking, where studies have examined how well children understand a text after reading (Micai, Joseph, Vulchanova, & Saldaña, 2017). Offline describes gathering data *after the fact*, or following a reading task. In contrast, online refers to gathering data during reading tasks, while the processes involved in reading are happening in real time. Online reading studies, such as those reviewed in Drysdale et al. (2017) have focused on reading behaviour without the responses to questions, hence, there is still a need in this field to examine *what* children with, and without ASD do while reading, to aid their comprehension processes.

Following the systematic literature review, this chapter will focus on the behaviour of reading, a skill for which comparable performance was found for those with ASD and TD individuals, despite slight differences in gaze behaviour. In this chapter, reading competence is operationally defined and reading comprehension difficulties in students with ASD are described. Results from offline studies are compared to online studies. Eye-tracking is the most conducive method to obtain online data. Next, the results of offline studies are compared to the results of more recent (online) studies, which employed eye-tracking, with offline studies typically reporting differences in TD and ASD readers. This leads to an argument of "difference, not deficit", and the argument is made for skill deficits, and not a diagnosis of ASD, contributing to lower reading competence. From there, the cognitive and language skills which facilitate reading competence are explored. This chapter closes with a discussion concerning the notable research gap, that is, the need for identification of gaze skills which facilitate comprehension.

5.1 Reading Competence

Being able to read and comprehend written text broadens learning and communication opportunities, and is not only a vital skill for success in academic, extracurricular, and vocational realms (Nation & Norbury, 2005), but essential in living a healthy and independent live in most societies. As reading is a complex skill involving simultaneous coordination of several component skills it could prove difficult for the reader for a number of reasons (see section 5.5). As reading competence involves a combination of skill performance in (1) decoding and (2) comprehension, a reader can have a difficulty with decoding, comprehension, or both. Decoding refers to the ability to recognise the different sounds and sound blends that combine to make a word (phonological decoding), or the ability to recognise a written form by sight and connect it to its spoken form (orthographic decoding). One fluent in these basic reading abilities is able to read text verbatim, which is a skill necessary for linguistic comprehension. Skilled readers can both decode and comprehend text as well as or better than the majority of their same-age peers, whereas less skilled or poor readers demonstrate a deficit in decoding, comprehension, or both, by performing at a level below that of their chronologically matched controls (Hoover & Gough, 1990). Reading competence difficulties are not transient: 78% of less skilled readers tested at 8 to 9 years of age still had significant reading impairments when tested at 13 to 14 years.

While some children with ASD are known to demonstrate average or above average word and non-word decoding and text decoding skills, reading comprehension often remains an area of particular difficulty. In studies examining reading behaviour in children with ASD, despite strengths in decoding, between 65 to 75% of these students demonstrated below average comprehension skills (Jones, et al., 2009; Nation et al., 2006; O'Conner & Klein, 2004). Nation et al. (2006) identified this weakness as a significant barrier to the advancement of students with autism. Individuals with ASD who do not have an associated learning difficulty are found to have intact performance accuracy for “low level”, basic reading tasks in general (Howard et al., 2016). However, these individuals frequently display impairments in performance for “higher order” reading tasks (e.g. text comprehension and inferencing; Huemer & Mann, 2010). Of the clinical populations, ASD is one of the most extensively researched in regards to reading behaviour (Ricketts, Jones, Happé, & Charman, 2013). The major findings from this body of work will be discussed.

5.2 Results of Offline Studies

5.2.1 Weak Central Coherence (WCC) Evident in Reading

Children with ASD may remember passage details but have difficulty determining and applying the relevant contextual information while reading (Happé & Frith, 2006). In other words, children on the spectrum are able to construct a text-based level of representation i.e. decode text, yet are unable to demonstrate the overall meaning, or capture the gist of the text. As a result WCC is often cited as a reason for reading comprehension failure. Smith Myles et al. (2002) found that while children with ASD were able to answer factual comprehension questions without difficulty after reading a short passage, these children incorrectly answered two-thirds of questions requiring inference. Norbury and Bishop (2002) assessed the ability of children with ASD to construct bridging inferences during passage reading. A bridging inference involves the ability to link the text to commonly-held knowledge. Consider the following example from Singer (1993): *The spy quickly threw his report in the fire. The ashes floated up the chimney.* In order for successful comprehension to take place, the reader must infer that the report burned in the fire, and that burned paper turns into ashes. Children with ASD were able to construct bridging inferences successfully, however their inferences were often inappropriate to the story's context i.e. egocentrically-related (from the child's own experience e.g. "*When Dad puts newspaper into the fire, it goes up the chimney*") rather than based on the story's events (Norbury & Bishop, 2002). Frith (2003) found that children and adolescents with HFA tended to process information sequentially by focusing on the fine details or parts of stimuli, causing them to overlook the "big picture". This phenomenon is also called *monotropism*, an unusual strategy for allocating attention, focusing on one thing at a time and consequently piecing the world together fact by fact. These results all reflect weaknesses in central coherence, and relative strengths in processing local detail.

5.2.2 Phonological Awareness Difficulties

Some children on the autism spectrum show age-equivalent skills in code-related literacy skills i.e. alphabet knowledge and early phonological awareness (Westerveld, Trembath, Shellshear, & Paynter, 2016), however the large standard deviations and ranges reported in these studies point to marked individual differences among children on the spectrum. In a study by Smith Gabig (2010), young school-aged children with ASD exhibited significantly poorer performance in phonological awareness compared to TD peers, despite demonstrating age-appropriate word recognition skills. This finding is similar to the results of Nation et al. (2006), who found that more than 20% of children with ASD were unable to read single words out of context, despite sufficient language and decoding skills. Such a finding demonstrates that children with ASD appear to over-rely on sight-word reading rather than decoding, however this also suggests that these children use context to facilitate their sight word reading, contrasting with the earlier argument that WCC is a reason for comprehension failure (see section 5.2.1). Nation et al. (2006) also reported that children with ASD struggled to decode, or apply letter-sound correspondence to nonsense words (e.g. fizwig). Weaknesses observed with phonological awareness can progress into developmental dyslexia, which is characterised by poor decoding skills despite adequate intelligence and the opportunity to learn. Rather than being underpinned by higher-order language difficulties, it is well accepted that decoding difficulties are due to phonological awareness deficits (Nation & Norbury, 2005). In Nation et al.'s (2006) sample, only 20 out of 32 of the students demonstrated age-appropriate decoding skills, indicating the reading difficulties in this population were not confined to comprehension alone. Ten out 32 participants, however, had reading comprehension deficits that could not be explained by poor word recognition or language skill alone, reflecting that various factors can contribute to reading difficulties.

5.2.3 Theory of Mind (ToM)

Indeed, the use of the Strange Stories by White, Hill, Happé, and Frith (2009), first introduced by Francesca Happé in 1994, demonstrated that ToM impairment predicts poorer reading comprehension outcomes. The Strange Stories were originally designed to assess the ability of children with autism with at least average intelligence to infer mental states of characters in stories. Stories varied in their social content: mental, human, and animal stories included high social content, and natural stories included low content. White et al. (2009) adapted the Strange Stories and presented them to 45 children with ASD and 27 controls (aged 7 to 12 years). The participants read vignettes and were asked to explain why a character said something that was not literally true. Successful performance required attributing mental states such as desires, beliefs, or intentions about others. Children with ASD who showed ToM impairment, on an independent test, performed significantly worse than controls, solely on the stories with high social content (mental, human, and animal stories) i.e. when taking perspective was required. It appeared that the greater the opportunity for attributing mental states during this task, the more impaired the poor ToM group appeared. A subset of children with ASD and intact ToM did not demonstrate the same performance deficit, or at least not to the same degree. The results of this study suggest the poor performance on the mental state stories by this subset of children likely indicates a lack of understanding of mental states, rather than a general comprehension problem. The same children who had difficulty making inferences about human and animal actions were able to successfully infer about natural events. It is possible that due to the context of text used in reading studies, reading comprehension and ToM difficulties both commonly reported in ASD have been confounded over time.

5.2.4 Reduced Attentional Modulation

There is evidence to suggest that attentional modulation contributes to reading difficulties in individuals with ASD. Koolen, Vissers, Hendriks, Egger, and Verhoeven (2012) had TD adults and adults with ASD take part in a "single" or "dual" level reading task where sentences were presented in a serial viewing paradigm. In the dual level task participants had to detect lexical errors (letter substitutions e.g. *the dog barks/berks*) and syntactic errors (verb agreement errors e.g. *she takes the broom and sweep/s the floor*), and the single level task required only one type of error (lexical OR syntactic) to be detected. TD and ASD participants did not differ in performance accuracy or reaction times on either of the two tasks when completed at the single level. However, during the dual task, ASD participants were slower to detect both lexical and syntactic errors, in comparison to the TD group who only showed a slower response for lexical errors. The lack of group differences during single level tasks suggest that lexical (local) and syntactic (global) processing are intact in ASD, however the slowness in detection of both types of errors under dual level conditions demonstrates that when lexical and syntactic information has to be simultaneously monitored, processing became less efficient for the ASD group. Koolen, Vissers, Egger, and Verhoeven (2014) replicated this study with the addition of recording event-related potentials (ERP) during the task. ERPs are electrophysiological responses of the brain to a stimulus. Increased P600 amplitudes for syntactic errors reflected difficulty of language processing during difficult tasks or where simultaneous processing or lexical and syntactic information was required: these increased amplitudes were not evident for this task at the single level. The researchers concluded that reduced attentional modulation results in poor performance for reading tasks, and not atypical linguistic processing. Given reading involves simultaneous co-ordination of component skills, such as decoding and reading comprehension, those individuals with ASD who display reduced attentional modulation may experience disruption in the performance or "flow" of each separate skill. For example, disruption in reading comprehension during reading may result in difficulties with monitoring and integrating information into a coherent whole, thus losing meaning and context of the text.

5.2.5 Eye Movements

Given the majority of reading studies have focused on these constructs (i.e. ToM, WCC, attentional modulation), which are private events that are difficult to operationally define, and thus, observe, quantify, and measure, the focus of reading research has shifted over the last decade to eye movement behaviour. Rayner, Chace, Slattery, and Ashby (2006) conducted an extensive review of the eye movements of young readers, poor readers, and readers with dyslexia, in addition to describing the development of typical readers. Initially, when children first start reading, their fixations tend to be quite long i.e. >350ms in Grade 1 (fixations are typically 200 to 250ms) and up to 30% of beginning readers' fixations are regressions. However, by approximately Grade 4 to 5, fixation durations and saccade lengths have stabilised for children when reading age-appropriate material. Skilled readers will fixate on only every two out of three words in a passage, often skipping over short and predictable words, and sometimes making more than one fixation on a word before moving on. However, this is not the case for poor readers and readers with dyslexia, who exhibit longer fixations, shorter saccades, and more regressions relative to typical readers comparable in age (Ashby, Rayner, & Clifton, 2005). As text becomes more difficult e.g. when readers encounter low-frequency words or homographs, fixation duration and regression counts increase (Rayner et al., 2006). Short regression length is most likely due to oculomotor errors or lexical processes, whereas longer regression lengths largely reflect comprehension failures. In summary, decades of research indicate the following (see Table 2):

Table 2. Eye movements of beginning, developed, and poor readers

Eye Movement	*Beginning Readers*	*Developed Readers*	*Poor readers/dyslexic*
Fixation duration	Long	Short	Long
Fixation count	High	Low (two-thirds)	High
Saccade length	Short	Long	Short
Regression count	High	Low	High

Despite this observed correlation between reading competence and eye movements, it is believed that eye movements are rarely the cause of reading problems: rather they reflect the difficulties that less skilled readers have in decoding and encoding words and understanding text (Rayner et al., 2006). Typically, research on comprehension processes has relied on gross reading time measures. However, if the concern is about exactly when an effect appears, then tracking eye movements is the best measure of moment-to-moment comprehension processes, of which saccades, fixations, and regressions in particular are informative. Regressions refer to backwards eye movements against the normal reading order to a previously read word. An advantage of capturing eye movements is that data can be collected online (in real time) during silent reading and thus uncontaminated by memory demands or articulation processes, and importantly, such data may offer complementary information to supplement widely normed and standardised comprehension assessments in a way that might be useful in planning educational interventions. Identifying the eye gaze behaviours which facilitate, or hinder reading comprehension skills, may be beneficial in informing educational interventions for students with low reading competence.

5.3 Results of Online Studies

The majority of existing research examining differences in reading comprehension between typically and atypically developing readers has relied on the “product” rather than the processes involved in this skill. In the studies described earlier (see section 5.2) comprehension was measured offline as a product of processing (Cain & Nash, 2011). In the following online studies tracking eye movements of ASD and TD readers, fixations less than 80ms and more than 800ms were excluded. Fixation times of less than 80ms are not sufficient for perception of written text, and longer fixation times indicate mind wandering or daydreaming.

Sansosti, Was, Rawson, and Remaklus (2013) recruited 18 adolescents with High Functioning Autism (HFA) and 16 TDcontrols to read a short, two-sentence passage requiring a bridging inference for comprehension, whilst tracking their gaze. After reading, participants responded to a general knowledge question which was either primed or unprimed by the inference. The adolescents with HFA had longer fixation durations and higher fixation counts on the sentences than the TD group (thus longer reading times), as well as making significantly more regressions per passage. Yet no group differences were observed in response accuracy to the comprehension questions, demonstrating that the participants with ASD were able to build the bridging inference and comprehend the passages as well as their TD counterparts. Sansosti et al. (2013) interpreted these longer processing times of participants with ASD as reflecting greater difficulty integrating knowledge, however this should be considered tentative, as it is based upon global eye movement measures that are averaged across the span of reading an entire vignette. Howard et al. (2016) argued that both global and local (moment-to-moment) eye movements measures are required to infer the processes occuring at certain regions of text during reading.

Au-Yeung, Kaakinen, Liversedge, and Benson (2015) recorded eye movements of TD adults and adults with ASD whilst they read statements that could either be interpreted as ironic or literal depending on the passage's context. Again, the two groups performed equally in comprehension accuracy across conditions, yet the ASD group spent more time overall re-reading the passage, suggesting this group either takes longer to construct a global representation, or to decide that their representation is reasonable based on their knowledge of the world. WCC theory predicts that, due to impaired global processing, the ASD group would perceive the ironic utterances literally and ignore the inconsistency between the context and what is uttered. In terms of gaze behaviour, this means that reading times for ironic and literal text portions would be equivalent. However, this study actually found the opposite: adults with and without ASD spent longer reading the passage containing irony, which suggests they had an understanding of the passage, and knew where the ironic statement was contained.

Howard et al. (2016) recorded eye movements of adults with and without ASD as they read sentences that included words manipulated to be either high or low in frequency, in order to examine lexical identification strategies. They also had participants read garden path sentences containing an ambiguous prepositional phrase, to examine the online use of world knowledge through semantic interpretation. A garden path sentence is one that is grammatically correct that starts in such a way that the reader's most likely interpretation will be incorrect (e.g. "Charlie demolished the dilapidated house with a huge crane last year" – the noun "crane" is ambiguous). Participants were required to rate how likely the events described were to occur on a five-point Likert scale. Howard et al. (2016) found that ASD and TD readers hold syntactic preferences, demonstrate use of world knowledge online, and show normal frequency effects during reading, suggesting both groups used a similar strategy and were comparable in performance. The ASD readers were observed to skip target words less often and take longer to read sentences in both experiments, however unlike in Sansosti et al. (2013), longer average fixation durations were not found for this group. The increased reading times for participants with ASD appeared to be wholly due to longer periods of time spent sentence re-reading sentences than the TD group, as well as skipping target words less often and making a higher number of regressions, which appeared to be part of a “checking” strategy adopted by the ASD group. Howard et al. (2016) posited that readers with ASD adopt a more cautious reading strategy and take longer to evaluate their sentence interpretation prior to responding to the question. While this finding of Howard et al. (2016) of slower reading times in readers with ASD is similar to past studies (i.e. Au-Yeung et al., 2015; Sansosti et al., 2013), the idea itself is one which has only recently begun to emerge in the literature. This idea that readers with ASD exhibit merely different behaviour, without being a deficit, is an important step in identifying and recognising strengths in this population, where reported strengths are few and far between. Evidence supporting the “different, not deficit” idea is increasingly emerging.

In light of previous online studies examining reading behaviour without response to questions, Micai et al. (2017) measured eye movements in children with and without ASD while reading and answering multiple choice questions requiring an overt response. Participants with ASD were matched with TD participants on age, expressive and receptive language skill, nonverbal intelligence, and reading skills. Participants read a passage comprising three paragraphs; after each paragraph they were asked a single comprehension question. Text was kept on-screen as questions were shown to participants, including three answer options: the correct answer, a distractor present in the text, and a distractor absent from the text. The ASD and control groups were equally accurate at generating inferences when answering questions about the text, and no differences were found between global paragraph reading and responding times. The results supported the idea that in previous studies where participants were not ability matched, a high proportion of readers with ASD had low language abilities, explaining their poor performance on the experimental tasks (Ricketts et al., 2013). The high degree of emotional and social content contained in the stories may explain their poor performance, rather than a general reading comprehension deficit (White et al., 2009). Since oral language has consistently been found to be a predictor of reading comprehension skills, improved matching between ASD and control groups could result in the disappearance of group differences (Norbury & Bishop, 2002). Interestingly, the ASD group displayed longer gaze latencies on and made more regressions to the target word necessary to produce the inference. This fine-grained local analysis on the target words showed that the groups exhibited subtle differences in their reading patterns that seem indicative of greater effort in producing the inference for the ASD group (Micai et al., 2017). Re-reading reflects attempts to re-engage working memory of prior text segments which are important to readers’ reading goals, however it is unsure if more regressions toward the target word reflect a backtracking technique of reading (i.e. more cautious reading strategy; Howard et al., 2016) or ineffective use of text as seen in poorly skilled readers. The researchers concluded that an equivalent level of inferential comprehension was achieved among groups, however subtle differences were observed in reading comprehension strategies displayed by the ASD group, reflecting the idea of “different, without deficit”.

5.4 Difference Over Deficit – Comparable Reading Competence

With technological advances in the method of eye-tracking, studies utilising fully online measures have resulted in more equivocal comparisons between TD individuals and individuals with autism, with regards to reading comprehension. There have been calls for a shift of emphasis in autism research away from overall performance on tasks and towards the study of the processes and strategies used to perform those tasks (Klin et al., 2002; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). From the eye-tracking literature it is evident that having a diagnosis of ASD alone does not predict reading comprehension deficits, with TD readers and readers with ASD showing comparable levels of reading competence (Au-Yeung et al., 2015; Howard et al., 2016; LaPointe-Speer, 2007; Micai et al., 2016; Sansosti et al., 2013). Children and adolescents with ASD have been found to use both phonological and orthographic decoding strategies when identifying words, to be as accurate as TD peers in the reading of words aloud, and have intact word comprehension (Howard et al., 2016; Saldaña, Carreiras, & Frith, 2009).

It appears that autism is not associated with any one particular reading profile. A shift is therefore required to identify the skills which are necessary for the development of reading comprehension skills in all students, regardless of diagnosis, and pinpointing the aspects of each student’s reading comprehension that are impaired. Difficulties in the skills which support decoding and comprehension must be considered before one can accurately predict whether a given individual with ASD will experience difficulties in reading comprehension (Brown, Oram Cardy, & Johnson, 2013). In the next section, the emphasis will move from ASD, to the skills which facilitate reading success, as identifying an underlying pattern of strengths and weaknesses may point the way to intervention targets (Nation & Norbury, 2005).

5.5 Skills Facilitating Reading Competence

5.5.1 Working Memory & Processing Speed

Difficulties with working memory and processing speed are thought to contribute to the reading comprehension problems of students with ASD (Perfetti, Landi, & Oakhill, 2005). A slower processing speed may cause an individual to be, in turn, slower at accessing previous knowledge, which in turn makes inferencing based on that knowledge more difficult. Indeed, Mayes and Calhoun

(2007) reported that 58% of children in their sample with HFA demonstrated weaknesses in processing speed. For students with working memory difficulties, their ability to hold information in their immediate awareness is compromised, therefore the longer the latency between text reading and question answering, the more impaired these students' comprehension of the text becomes. In more recent studies, e.g. Micai et al. (2017), participants were encouraged to refer back to the text before responding to the reading comprehension questions. Indeed, allowing the text to remain available to these students better reflects common classroom practices as well as situations in the outside world, thus preserving ecological validity.

5.5.2 Oral Language

Language outcomes share a strong correlation with overall IQ and cognitive ability. Evidence from longitudinal studies of typically developing children and children with language impairment show that children with oral language weaknesses prior to school are at increased risk of persistent reading comprehension difficulties (Westerveld et al., 2016), demonstrating the link between early oral language and later reading comprehension skills. Reading is a form of verbal behaviour and relies on a set of highly interactive, yet complex processes i.e. decoding and comprehension, therefore it has been suggested that poor comprehension is not specific to reading, but reflects more general difficulties with understanding language (Westerveld et al., 2016). In Hoover and Gough's (1990) *Simple View of Reading*, reading competence is the product of word recognition/decoding and oral language comprehension, with previous research supporting significant contributions of these two factors to development of reading comprehension (Westerveld et al., 2016). Catts, Hogan, and Adlof (2005) reported that in young stages of reading and those of primary school age, word recognition/decoding explains approximately 27% of variance in reading comprehension, and oral language explains 9% of variance. However, by Grade 8, when decoding skills are fluent and automatic, word recognition/decoding only accounts for 1% of the variance in reading comprehension, while oral language explains 36%. This suggests that oral language ability has important implications for reading development at an early age, and even more so as students progress through their school years.

Nation, Clarke, Marshall, and Duran (2004) tested poor comprehenders and TD children on language skills. No difference was found in phonological awareness with both groups demonstrating intact skills in this area, however the groups differed on their scores in semantics, and morphosyntactic tasks and aspects of language use, such as understanding figurative language. Overall, the language skills of poor comprehenders were characterised by relative weaknesses in the nonphonological aspects of language, ranging from lexical-level weaknesses (e.g. vocabulary) to difficulties with higher order language e.g. grammar. Understanding oral language involves an interactive process of at least five language skills – phonological, morphologic, syntactic, semantic, and pragmatic (Amercian Speech Hearing Association, 1983), with the first, phonological awareness, being crucial for word recognition/decoding skills (see section 5.2.2). It is clear from the literature that language ability is imperative to reading development, however, few studies to date include comprehensive assessments which cover all five of these skills in describing the language skills of participants (Brown et al. 2013).

5.5.3 Oral Reading Fluency

Oral reading fluency (ORF) is in itself a complicated, multifaceted performance that involves a reader’s perceptual skill at automatically translating letters into coherent sound representations, combining those sounds into recognisable wholes and automatically accessing word lexicons (Fuchs, Fuchs, Hosp, & Jenkins, 2001). As reading is a complex task requiring simultaneous coordination across many tasks i.e. decoding and comprehending, the execution of the component skills must become instantaneous. ORF is then achieved when performance is speedy, seemingly effortless, and automatic. Reading comprehension deficits are often associated with slow and effortful decoding, as most of the reader’s processing resources will be dedicated to decoding and therefore unavailable for comprehension (Brown et al., 2013). ORF develops gradually over the primary school years, and is measured as words read correctly per minute. The typical developmental trajectory of ORF is a negatively accelerating curve, with the greatest growth in primary years and less growth in intermediate and high school years. This index allows performance levels to be compared between individuals, and gains and performance slopes can track the development of an individual’s reading competence (Fuchs et al., 2001).

ORF is thought of as a measure of basic reading competence and not a measure of comprehension; however, as LaBerge and Samuels (1974) posited in their *Automaticity Model of Reading*, development of oral reading fluency helps to diminish the amount of attention allocated to decoding, and thus increase the available resources for monitoring comprehension of text. Since reading is a result of simultaneously co-ordinating many component processes within a short time frame, if each component required attention, performance of the complex skill overall would exceed attention load and therefore be impossible. In contrast, if the decoding component was executed automatically, then attentional load would be within tolerable limits, permitting successful performance of the comprehension component, and thus the entire skill (Fuchs et al., 2001). Therefore ORF is frequently considered a necessary skill of overall reading competence, as it is akin to fluent and automatic decoding.

5.5.4 Integrating Semantic Knowledge

Deficits in integrating semantic and interpersonal knowledge with text are likely to lead to difficulties with reading comprehension. According to Van Dijk and Kintsch’s (1983) *Model of*

Comprehension, reading occurs on two levels: (a) the text base, and (b) the situation model, where the text loses its verbatim information representation because it is integrated into a larger structure that makes extensive use of an individual's prior knowledge. Prior knowledge is necessary in building an accurate text model through integrating components of the text with prior knowledge. When we read, we readily combine previous knowledge with the text we read to create a scene, and in some way connection between the words to some knowledge we have about the world must be made in order to comprehend what is written. For less skilled readers, semantic knowledge of words may be restricted in two ways: firstly, possessing a smaller vocabulary than their peers; and, secondly, the depth of representations may be shallow and lacking in detail, for example, less skilled readers may only know one highly specific lexical exemplar rather than a general prototype (Brown et al., 2013). While moderate to severe impairments in semantic knowledge are associated with ASD, this is not evident across the whole population, with some individuals or subgroups demonstrating these deficits and, in contrast, others displaying strengths in this area (Brown et al., 2013).

5.6 The Problem

This section has discussed several theoretical models concerning reading, including *The Simple View of Reading* (Hoover & Gough, 1990), *Model of Comprehension* (van Dijk & Kintsch, 1983), and *Automaticity Model of Reading* (LaBerge & Samuels, 1974). The cognitive skills of working memory, processing speed, phonological awareness, oral language, and semantic knowledge, which faciliate the development of decoding and reading comprehension skills and establish reading competence, have also been discussed. Despite the established research in this area, our understanding of reading behaviour remains incomplete.

Reading constructs which have been widely researched are exactly that, constructs. These constructs e.g. working memory, are often single-score summaries obtained on cognitive or psychoeducation assessments, and used to predict a student's level of reading competence. The issue is that constructs focus on what students "possess" and the product of reading, rather than on what readers *do*, and the processes involved. Secondly, the skill of reading is complex and requires coordination of multiple component skills. When these component skills are loosely defined and so abstract, this adds to the complexity of theories of reading. Thirdly, many of these constructs are thought to be inherent to individuals, where one is born with a given level of processing speed, or ability to integrate information, which cannot be changed easily or in a significant way over one's lifetime. Demonstrating improvement in reading behaviour has been difficult because of a lack of consistent, across-study, operational definitions of reading constructs. Given intervention studies for reading comprehension are difficult to locate (Nation & Norbury, 2005), it follows that intervention programs for reading comprehension are only possible once our understanding of reading comprehension behaviour is more complete.

Starr and Rayner (2001) argued that after 30 years of research, a *reasonable* account of human behaviour during reading exists with consistent data to support it. However, this account is not complete. Arguably, the main focus of reading behaviour now lies in eye movements, and while research has catalogued global measures of eye movements during reading (i.e. fixations, saccades, and regressions), the visual search strategies, or local measures of eye movements that readers use during reading to facilitate comprehension, are relatively unknown.

5.7 The Gap

In the last several decades, theories and models of reading have changed, from seeing reading as primarily receptive processes from text to reader, to interactive processes between the reader and text embodying active engagement (Day & Jeong-suk, 2005). Pressley et al. (2001) found that exemplary first grade teachers had their students write, read, and engage with the text. In contrast, some teachers facilitated passive student engagement, where students took turns reading aloud or listening to their teachers. The use of questions is integral in transitioning students from passively reading to actively engaging with text, and well-designed comprehension questions help students interact with text to create or construct meaning, and think critically and intelligently (Day & Jeong-suk, 2005). Effective teachers are frequently observed asking higher-level questions that go beyond the literal understanding of a text, helping students interact with the text. This can be achieved by ensuring students are able to view text while answering related questions, since questions are designed to teach reading comprehension rather than memory skills. Importantly, while good and poor readers both experience contextual facilitation by having access to the text, the effect is greater for poor readers, who may have a less developed understanding after first-pass reading (Fuchs et al., 2001).

Merely allowing students to access the text during question answering, as well as designing well-constructed comprehension questions, may not be sufficient to improve less skilled readers' comprehension skills. Less skilled readers are particularly disadvantaged by lack of instruction, and even teacher manuals have been reported to lack direct instruction on how to teach comprehension skills to students (Gilroy & Moore, 1988). It is assumed that skilled readers learn the visual-attention strategies which facilitate comprehension through observational learning, as they do not require direct, explicit teaching of these skills; however, for less skilled readers explicit instruction may be required. Eye-tracking studies with a focus on reading have predominantely asked closed Yes/No format questions requiring a button press. Micai et al. (2017) expanded on this format slightly by using a three-option multiple choice format, yet forced answer options of two to three choices encourages guessing. White et al. (2009) changed closed Yes/No question formatting to open questions to ensure that correct answers represented understanding and memory of sentence meaning rather than chance performance. This is a step in the right direction: eye-tracking studies using questions, designed to both evoke, and teach, comprehension strategies should involve a mix of the types of comprehension (e.g. literal, reorganisation, inference) and question form (e.g. Yes/No, Alternative questions, Wh- questions), to encourage the reader to actively engage with written text using visual-attention strategies, rather than guessing. If the question phase is crucial to understanding text, through capture of eye movements and visual-attention strategies, then eye-tracking studies focusing on behaviour during question answering will likely assist our understanding of the gaze skills involved in reading comprehension.

Chapter 6: Empirical Study

Chapter 6 presents a between-groups observational study investigating eye gaze behaviour of Australian primary school students during reading, and question-answering tasks. This empirical study is comprised of two sections, Part A and Part B. Nineteen primary school students had their eye movements tracked while they read and answered questions on age-appropriate texts. Participants were categorised according to diagnostic status (ASD vs TD) and reading competence level (*High* vs *Low*). Based on the research gap identified in Chapter 5, two analyses were conducted. In Part A, a global analysis was undertaken to investigate whether differential gaze behaviour exhibited by students with ASD impacted upon their comprehension accuracy. The results of Part A gave rise to Part B, as a shift in focus was necessary to consider TD participants and those with ASD together, and compare groups based on reading competence, rather than diagnosis. In Part B, a local analysis, designed to identify gaze behaviours exhibited by highly skilled and poorly skilled readers during question answering, was conducted.

6.1 Introduction

Researchers in earlier studies reported that somewhere between two thirds and three quarters of children with ASD have below average reading comprehension skills, despite average or above average decoding skills (Smith Myles, et al., 2002; Nation et al., 2006). However, more recently in studies employing eye-tracking technology to study reading behaviour, individuals with ASD have demonstrated the ability to answer comprehension questions as accurately as TD individuals do (Howard et al., 2016; Micai et al., 2017). The results from studies measuring comprehension following reading only (offline studies) highlight greater differences between readers with ASD and TD readers than results from eye-tracking (online) studies (Micai et al., 2017). The validity of a portion of offline studies has been challenged, as it is evident that perceived impairment in reading in people with ASD has not been found when other paradigms have been employed, such as the homographs paradigm used by Hala, Pexman, and Glenwright (2007).

Since eye-tracking has emerged as a viable technology to measure the gaze of individuals with ASD during reading, this area of study has received considerable interest (Ricketts et al., 2013). Indeed, through the use of eye-tracking, researchers have been able to accurately and precisely observe the moment-to-moment processes of individuals with ASD during reading. This development has allowed eye-tracking researchers to assess comprehension accuracy in addition to examining gaze time during reading. Initially, findings of people with ASD exhibiting longer fixation durations led researchers to conclude that text processing is more demanding and difficult for those with ASD (e.g. Au-Yeung et al., 2015; Sansosti et al., 2013), supporting the longstanding evidence of pre-eye-tracking researchers who reported greater reading difficulties for this group. On the other hand, Howard et al. (2016) have offered an alternative suggestion that the longer fixation durations in those with ASD *do not* reflect text processing and comprehension difficulties, rather, they reflect a more "cautious" approach to reading, where individuals may take longer to evaluate their answer before committing to a response. These individuals were found to have longer reading times overall, which appeared to be wholly due to re-reading sentences, and they have been observed to make more regressions to earlier sections of text, and skip target words less often – these behaviours are consistent with a "checking" strategy which may be a feature of those with ASD. Micai et al. (2017) investigated differences in eye gaze behaviour during reading between children with ASD and TD controls matched on age, language, nonverbal intelligence, reading, and receptive language skills. Although the ASD and TD groups were equally accurate at generating inferences to answer questions about the texts, the ASD group displayed longer durations on the target word necessary to produce the inference, and also made more regressions to the target word, results consistent with Howard et al. (2016). Overall, when matched with TD controls on language skills, individuals with ASD demonstrated intact performance on comprehension tasks, yet displayed subtle differences in the reading comprehension strategies used – what could be termed "different, without deficit" (Drysdale et al., 2017).

Furthermore, there has been a tendency for eye-tracking researchers to rely on fixation duration to explain gaze behaviour during reading. Interpretations about mean and total fixation duration must be considered tentatively, as they are based upon eye movement measures that are averaged across the reading of entire passages. In order to better understand reading behaviour, both global and localised eye movement measures on critical, experimentally manipulated words and regions of a text are required (Sansosti et al., 2013). Current eye-tracking studies have integrated measurement of i) comprehension through question answering, and ii) gaze behaviour during reading. A critical element is missing from this area of study: gaze behaviour during question-answering. School-aged students learning to read, and comprehend, are generally allowed, and even encouraged, to refer back to the text to assist in question answering. How students gather information during comprehension tasks, which can be obtained by analysing the content and location of their eye gaze patterns, is crucial to further our understanding of reading behaviour. Therefore, there is need to analyse students' gaze behaviour toward text during question answering.

The following research questions will be addressed in separate analyses:

1. Does the gaze behaviour exhibited by students with ASD impact upon their comprehension accuracy?
2. What gaze behaviour do highly skilled and poorly skilled readers exhibit during question answering?

6.2 General Method

6.2.1 Recruitment

6.2.1.1 School

A mainstream primary school in Melbourne's western suburbs was approached by the author after ethics approval was obtained from Monash University, the Department of Education (Victoria), and Catholic Education Melbourne (see Appendices A, B, & C respectively). Any students from grade levels one to six were suitable for recruitment. Given this was an observational study exploring reading behaviour in students, a wide range of ages and skills was accepted. School staff were asked to informally approach potential participants and their families to gauge their interest in the project. Potential participants were given an explanatory statement written in plain English, and a consent form if they expressed interest in the study. Once these documents were read, understood, and signed by a student's parents, that student became a participant in the study. The school also provided information on whether participants were typically developing (TD), or had a clinical diagnosis of Autism Spectrum Disorder (ASD), and their current level of reading comprehension skill, as measured by any school-based assessments.

6.2.1.2 Clinic

After obtaining permission from the principal psychologist of a private psychology clinic also located in Melbourne's western suburbs, a one-page flyer advertising the project was put up in the waiting room. Interested families were asked in writing to contact the author directly. If they did so, the study's purpose was explained to them and they were then provided with the explanatory statement and consent forms. Information was also collected on diagnostic status and reading comprehension skill (where possible).

6.2.2 Participants

Nineteen primary-school-aged children ranging from 6 years 3 months to 12 years 2 months of age (M = 9 years 8 months) participated in this study of whom 10 were male and nine female. Of these participants nine were TD and 10 had a clinical diagnosis of ASD. Two organisations were contacted as insufficient numbers of potential participants were available from one location only. Participant consent in this project was voluntary and could be withdrawn at any time. Participants were assigned to one of three grade level groups, each of which included two grade levels (i.e., 1-2, 3-4, and 5-6) to address age ranges. Within each grade level group, participants were categorised according to two criteria:

a) Diagnosis: ASD or TD

b) Reading Competence: *High* or *Low* (see **Error! Reference source not found.**Procedure section)

Therefore, within each grade level group, four distinct subgroups were created: ASD/*High*, ASD/*Low*, TD/*High*, and TD/*Low*. Reading competence, as described in section 5.1, is defined as the combination of skill performance in (1) decoding, and (2) comprehending written language. The categorisation of participants into groups is shown in Table 3 below.

Table 3. Participants categorised by grade, Diagnosis, and Reading Competence group

	ASD/*High*	ASD/*Low*	TD/*High*	TD/*Low*	*Subtotal*
Grade 1-2	2	2	1	0	5
Grade 3-4	2	1	3	1	7
Grade 5-6	0	3	3	1	7
Subtotal	4	6	7	2	*19*

6.2.3 Research Team

The research team was comprised of the thesis author and eight research assistants who, prior to collecting data, completed an eight-hour training course where they were taught to set up the eye-tracking system, design the reading tasks, calibrate participant gaze and run experimental eye-tracking sessions. The training course was satisfactorily completed when each research assistant could independently run through an eye-tracking session using a fellow assistant as a test participant, and accurately collect data. After completing their training, the research assistants were sent to the school and clinic settings to run eye-tracking sessions with participants.

6.2.4 Settings

For participants recruited from the school, all assessment and data collection sessions occurred in a small, window-fronted room at the school so school staff had a clear view of the researcher and participants. Participants recruited from the clinic completed assessment and data collection sessions in one of the clinic rooms, similar in size and appearance to the school setting. Participants were seated facing away from the window and door, in order to minimise distractions, such as people walking past windows.

6.2.5 Materials

6.2.5.1 Woodcock Reading Mastery Tests – Third Edition (WRMT-III)

The Woodcock Reading Mastery Tests – Third Edition (WRMT-III) is an individually administered assessment designed to measure reading readiness and achievement in people aged 4.5 to 80 years. Two parallel forms are available: A and B, and only Form A was used in the current study. This assessment measures reading ability across three areas (Readiness, Basic Skills, and Reading Comprehension) and produces cluster scores that show how well individuals performed in these areas, as well as producing a composite score that represents overall reading ability (Total Reading). Each subtest produces a scaled score that can range from 1 to 19, with scores between 7 and 12 usually considered 'average' (50% of individuals score within this range). Participants were administered all nine subtests of the WRMT-III. The subtest scaled scores contribute to the cluster scores that represent an individual's performance in the three areas of reading ability. A cluster score can range from 40 to 160, with scores from 90 to 109 considered 'average'. The mean score on the WRMT-III is 100 with a standard deviation of 15. Normative sample information was based on scores from a sample of over 5000 individuals aged 4.5 to 80 years. Age-based internal consistency reliability estimates, which were used in the current study, were reported as very good overall (Woodcock, 2011). The average Total Reading reliability cluster is .98 for Form A; mean estimates for the other cluster scores range from .93 to .96. Test-retest reliability corrected correlations between scores are strong to very strong, ranging from .83 to .97, and overall, test performance on the same form of the WRMT-III is stable over short periods of time (over 19 days) with relatively small, but acceptable practice effects (Woodcock, 2011). Inter-rater reliability for the WRMT-III is very high (.99 for both forms). The WRMT-III is found to have high construct validity, as measured through correlations between the WRMT-III and Wechsler Individual Achievement Test – Third Edition (WIAT-III) Total Reading cluster scores. Correlations across the pre-kindergarten through Grade 6 levels are very strong at .89 (Woodcock, 2011). Spoken answers to comprehension questions were hand-recorded verbatim by the research assistants on the WRMT-III Form A Record Form and Supplementary Record Form.

6.2.5.2 Eye-tracking Measures

Eye-movement data was collected using the Tobii X2-30 Eye Tracker, a remote-based non-invasive system. The X2-30 is a device that measures eye movement and position, and estimates point of gaze (where one is looking) to a stimulus. The X2-30 uses a sampling rate of 30Hz (30 frames per second) and achieves a gaze accuracy of 0.4°of visual angle under ideal conditions. The X2-30 utilises a pupil centre/corneal reflection technique by shining infrared light on the cornea of participants' eyes. The X2-30 is suited to young children who may move their heads during testing as it maintains tracking activity within a 20” x 14” area (width x height).

The X2-30 was interfaced with a compatible computer installed with *Tobii Studio v 3.4.6,* a software program used to depict reading stimuli to participants via a 1080 resolution 24” monitor (19 x 20), which displayed text stimuli to participants. The Dell laptop installed with Tobii Studio controlled the presentation of text stimuli.

A Logitech HD Pro Webcam C920 was also connected to the top of the viewing monitor to record the participants’ faces during eye-tracking tasks. The X2-30 was attached to the bottom of the viewing monitor via a magnetic bracket which held it in place. The front of the eye-tracker was positioned at a 45° angle so as to point directly at participants’ eyes above. The set-up of the eye-tracking equipment can be seen in Figure 2 and Figure 3 below:

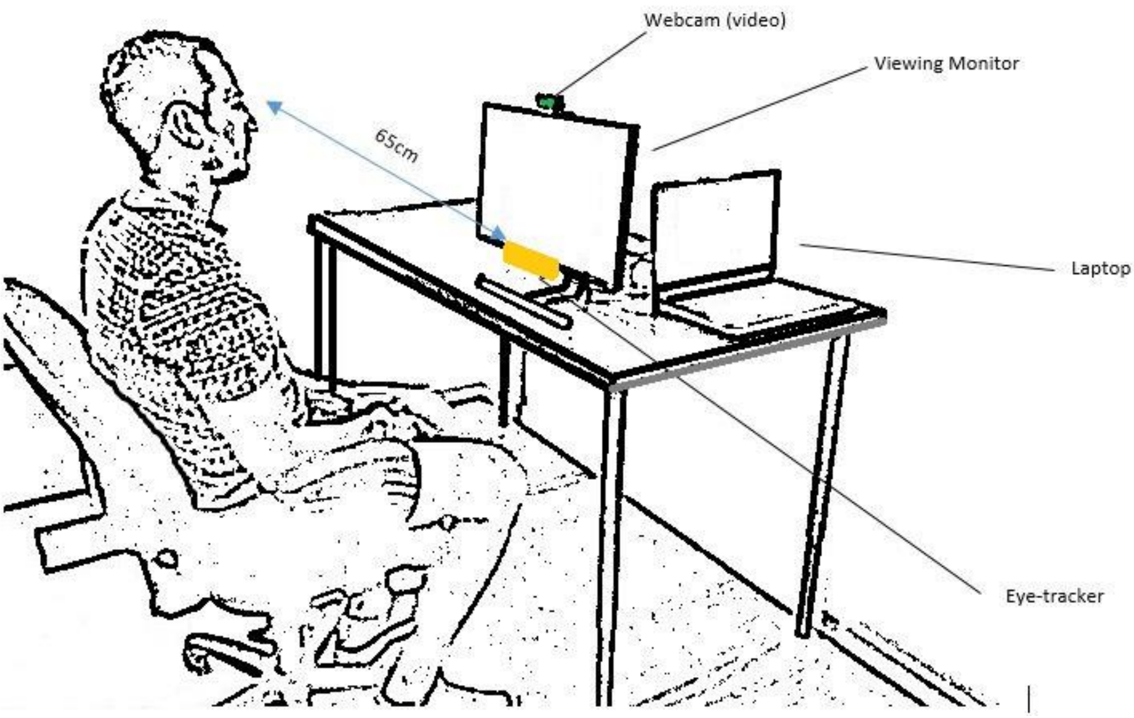


Figure 2. Eye-tracking equipment set-up

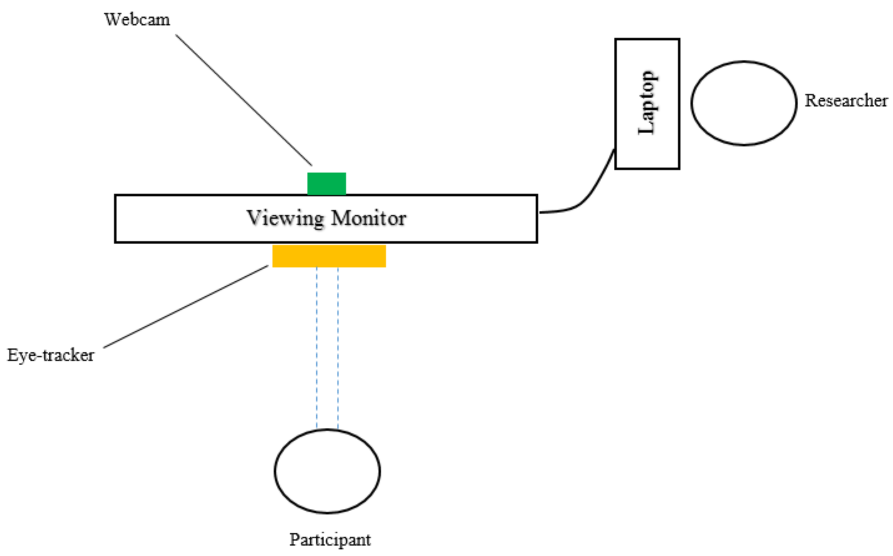


Figure 3. *View of eye-tracking system from above.*

6.2.5.3 Texts

Overall, 28 texts were included across all the primary school grades, with eight texts standardised for Grade 1-2 students, and 10 for both Grade 3-4 and Grade 5-6. Six texts from the *Strange Stories* Collection were used (White et al., 2009), which involved low and high social content. High social content referred to stories about mental states, humans, and animals, where readers were required to infer desires, beliefs, and intentions of living things. Low social content referred to stories which may contain living things, however readers were required to understand physical actions only. Six texts were taken from the *Wechsler Individual Achievement Test – Second Edition* (WIAT-II). The remaining 16 texts were written by the author. Six of these created texts were accompanied by images. Created texts were included in addition to existing texts (*Strange Stories* and WIAT-II) to provide more variety and cover a range of topics and text formats, to minimise the effects of specific-content knowledge on comprehension accuracy. For example, on the *Strange Stories* participants with ASD have demonstrated poorer comprehension performance when the skill of inferring mental states is required to answer comprehension questions. The author aimed to assess general reading comprehension skills by providing a variety of text content.

All texts underwent proofreading by research assistants, who evaluated each text for its suitability for analysis. Unanimous agreement from the research team was required for inclusion of a text for use in eye-tracking sessions. Texts were typed using Microsoft® Word. All text was presented in black monospace Century Gothic font (size 12) on white background with 1.5 line spacing, to ensure adequate space between lines so that ambiguous fixations (slightly above or below the text line) would not be wrongly attributed to a different line of text. Texts were limited to 275 words maximum so they would fit on the monitor without scrolling. Images were added to specific texts, and then files were converted into an image (JPEG file) before being uploaded to Tobii Studio.

Created text difficulty was graded with the Flesch-Kincaid readability formula available on the word processing program Microsoft Word. Flesch-Kincaid provides a grade level estimate by rating text on a United States school grade level, for example, a Grade 3-4 text had a Flesch-Kincaid Grade Level score of above 3.0 and lower than 5.0. Although its rating is based on US grade levels, the Flesch-Kincaid algorithm is one of the most heavily tested formulas which correlates highly with reading comprehension ($r = 0.91$) as measured by reading tests (DuBay, 2006). It is also used extensively across Australia, including by major organisations such as the Department of Health. The equation Flesch-Kincaid uses to test grade level readability is below:

$$(0.39 \times ASL) + (11.8 \times ASW) - 15.59$$

ASL = average sentence length (words/sentences)

ASW = average number of syllables per word (syllables/word)

Note that while the number of paragraphs varied widely across texts and grade levels, the number of paragraphs did not factor into the Flesch-Kincaid formula. Using this formula allowed created texts to be standardised for grade level. However, a readability statistic is fallible in the sense that it does not account for other factors contributing to text difficulty. One such factor is vocabulary, where the text becomes more difficult with more unfamiliar domain-specific words and more, new general educational terms encountered. An effort was therefore made to standardise text difficulty where possible, using the Flesch-Kincaid readability statistic, and cover a range of content. Participants were only ever shown text stimuli appropriate for their grade level. Table 4, Table 5, and Table 6 display text difficulty statistics for each text for the G1-2, G3-4, and G5-6 groups respectively.

Table 4. Text Difficulty Measures for G1-2 Texts.

G1-2	**Low Social**	**High Social**	**Dinner for Peter**	**Beanie Found a Ball**	**Baobab Tree**	**Pet Day**	**George's Car**	**Ballet Concert**
Word Count	94	61	108	75	109	31	64	132
Paragraphs	1	1	9	3	1	4	4	8
Sentences	9	7	14	12	11	5	11	14
Av. Sentences/Paragraph	9	7	1.5	4	11	1.2	2.7	1.7
Av. Word/Sentence	10.4	8.7	7.6	6.2	9.9	6.2	5.8	9.4
Av. Characters/word	3.6	3.7	4.1	3.9	3.9	3.2	3.8	4
Proportion passive sentences	11%	0%	0%	0%	9%	0%	0%	7%
Flesch Reading Ease[1]	94.5	92.5	86	95.5	93.5	100	93.8	91.5
Flesch-Kincaid Grade Level[23]	2.6	2.5	3.1	1.4	2.6	0	1.6	2.8
Lexile Measure	500L-600L	300L-400L	200L-300L	200L-300L	500L-600L	300L-400L	200L-300L	400L-500L

Note. Total word count for Grade 1-2 texts was 674.
Ease of readability is indicated by (1) higher / (2) lower scores – (3) As a US grade level. Text and reader-based quantitative complexity and readability were evaluated with the Lexile Framework of Reading (Stenner, Burdick, Sanford, & Burdick, 2006), which was accessed online (Free Lexile Analyser®, retrieved from <https://la-tools.lexile.com/free-analyze/>).

Table 5. Text Difficulty Measures for G3-4 Texts.

G3-4	**Fishing**	**Volleyball**	**High Social**	**Low Social**	**Cuddles & Speedy**	**Time Capsule**	**Crickets**	**Good Neighbours**	**Camping Weekend**	**Poppy the Puppy**
Word Count	164	141	103	110	138	271	78	100	155	156
Paragraphs	9	15	1	1	6	9	2	6	3	9
Sentences	24	18	6	9	15	19	7	13	15	17
Av. Sentences/Paragraph	2.6	1.2	6	9	2.5	2.1	7	2.6	5	1.8
Av. Word/Sentence	6.8	7.8	17.1	12.2	9.2	14.2	11	7.6	10.3	9.1
Av. Characters/word	3.8	4.3	3.8	3.9	4	3.9	4.3	3.8	3.8	4.1
Proportion passive sentences	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%
Flesch Reading Ease[1]	94.1	86.6	89.2	87.5	87.7	86.2	92.3	94.9	89.9	82
Flesch-Kincaid Grade Level[23]	1.8	3.1	4.4	4	3.3	4.7	3.1	1.9	3.2	4.1
Lexile Measure	400L-500L	500L-600L	700L-800L	600L-700L	400L-500L	600L-700L	700L-800L	400L-500L	500L-600L	500L-600L

Note. Total word count for Grade 3-4 texts was 1416.
Ease of readability is indicated by (1) higher / (2) lower scores – (3) As a US grade level. Text and reader-based quantitative complexity and readability were evaluated with the Lexile Framework of Reading (Stenner, Burdick, Sanford, & Burdick, 2006), which was accessed online (Free Lexile Analyser®, retrieved from <https://la-tools.lexile.com/free-analyze/>).

Table 6. Text Difficulty Measures for G5-6 Texts.

G5-6 Text difficulty	Visit to the Zoo	Cinema	High Social	Low Social	Writing a Great Story	Gobbledeeglue	Budding Actors	Trip to the Snow	Simon's Piano Concert	Yukon Gold
Word Count	206	167	112	95	226	136	248	249	255	223
Paragraphs	16	13	1	1	4	10	5	9	7	3
Sentences	24	17	7	4	18	11	15	20	22	16
Av. Sentences/Paragraph	1.5	1.3	7	4	4.5	1.3	3	2.2	3.1	8
Av. Word/Sentence	8.5	9.8	16	23.7	12.5	11.6	16.5	12.4	11.5	13.3
Av. Characters/word	4.3	4.1	4.2	4	4.3	3.9	4.1	4.4	4.4	4.8
Proportion passive sentences	0%	0%	0%	25%	5%	9%	6%	0%	4%	12%
Flesch Reading Ease[1]	82.7	81.8	76.5	82.4	79.1	85.3	80.5	77.3	71.9	56.6
Flesch-Kincaid Grade Level[23]	3.8	4.2	6.5	6.4	5.3	4.2	6.1	5.5	6	8.6
Lexile Measure	500L-600L	500L-600L	900L-1000L	900L-1000L	500L-600L	500L-600L	900L-1000L	700L-800L	600L-700L	900L-1000L

Note. Total word count for Grade 5-6 texts was 1917.
Ease of readability is indicated by (1) higher / (2) lower scores – (3) As a US grade level. Text and reader-based quantitative complexity and readability were evaluated with the Lexile Framework of Reading (Stenner, Burdick, Sanford, & Burdick, 2006), which was accessed online (Free Lexile Analyser®, retrieved from <https://la-tools.lexile.com/free-analyze/>).

6.2.5.4 Questions

Between five and 10 comprehension questions were written by the author for each created text as a means to assess students' comprehension and understanding. The WIAT-II already contained a set of comprehension questions, and the *Strange Stories* texts contained one question each, designed to assess Theory of Mind (ToM) abilities. Therefore, additional questions were also written for the *Strange Stories* texts. The taxonomy of questions used to assess comprehension was largely influenced by the work of Day and Jeong-suk (2005; see Table 7 below). Question types and formats varied in terms of their response complexity, so as to ascertain a valid estimate level of comprehension ability. For example, Grade 1-2 texts contained more questions requiring literal, or explicit interpretation (Literal and Reorganise) and fewer questions requiring inferential, or implicit interpretation (Inference), the latter of which are more difficult to answer. Grade 5-6 texts on the other hand, contained a more equal balance of Literal, Reorganise, and Inference questions. Question formats included: forced-choice i.e. yes/no, alternatives, true/false; short- and long- open answer; and closed-answer, such as fill-in-the-blank (cloze exercise).

Table 7. Grid for developing and evaluating reading comprehension questions. From Day & Jeong-suk (2005).

Forms of Questions	**Types of Comprehension**
Yes/No	*Literal*
Alternative	*Reorganise*
True/False	*Inference*
Wh- question	Prediction
Multiple Choice	Evaluation
Cloze exercise	Personal Response

Note: forms and types of questions used in the current study are italicised.

The author and research assistants analysed and pilot tested each question for its suitability. Pilot testing was conducted by administering texts and questions to fourth year psychology students. Feedback on question suitability was obtained from pilot-testing and before a question was assigned to a story, consensus of suitability was required from every member of the research team. A similar process was conducted for the appropriate answers for each question. Answers provided by participants were assigned a score of 0, 1, or 2, with higher scores reflecting fuller understanding of the text. For certain questions (e.g. forced-choice format), a maximum score of 1 was assigned for a correct answer. Allocation of question types per grade are summarised in Table 8 below.

Table 8. Breakdown of question types by grade.

	Literal	**Reorganize**	**Inference**	**Total**
G1-2	18	0	2	**20**
G3-4	11	3	8	**22**
G5-6	13	5	7	**25**

6.2.6 Procedure

6.2.6.1 Assessment

Once consent was obtained from their parents or guardians, participants met with the author at either the school or clinic. The author explained the nature of the study and obtained written consent from participants. Participants were told they could withdraw at any time without penalty. The author spent the first 5 min of each assessment session building rapport with participants. The author showed participants the eye-tracking equipment and demonstrated how it worked, to familiarise participants with the procedure and alleviate any anxiety associated with the study. Following rapport building the WRMT-III assessment was administered; this session lasted a maximum of 90 min including frequent 5 min breaks that were offered throughout. WRMT-III Record and Supplementary Record Forms were recorded on by research assistants, and scored by the thesis author. Scores on four indices (Listening Comprehension, Oral Reading Fluency, Basic Skills, and Reading Comprehension) were calculated and are summarised later in this document (see page 83). Participants were then categorised into *High* or *Low* reading competence based on their score: participants who scored 100 and above on both Basic Reading and Reading Comprehension clusters were allocated to the *High* group, and those who scored 99 and below on both clusters to the *Low* group.

6.2.6.2 Eye-tracking

6.2.6.2.1 Calibration

All eye-tracking experimental tasks were run by a research assistant. Participant viewing was binocular, and movements of both eyes were recorded. Head movements were not restrained in this study. During calibration and reading tasks, participants were presented reading stimuli by the laptop installed with Tobii Studio, and viewed stimuli via the connected viewing monitor. Participants sat in a chair with adjustable seat height to ensure the top of the monitor was aligned with the top of the participant’s head. The chair was positioned approximately 65cm away from the front of the monitor. Once participants were seated at the appropriate distance from the eye-tracker, they undertook a five-point calibration procedure before starting the experimental task (see Figure 4).

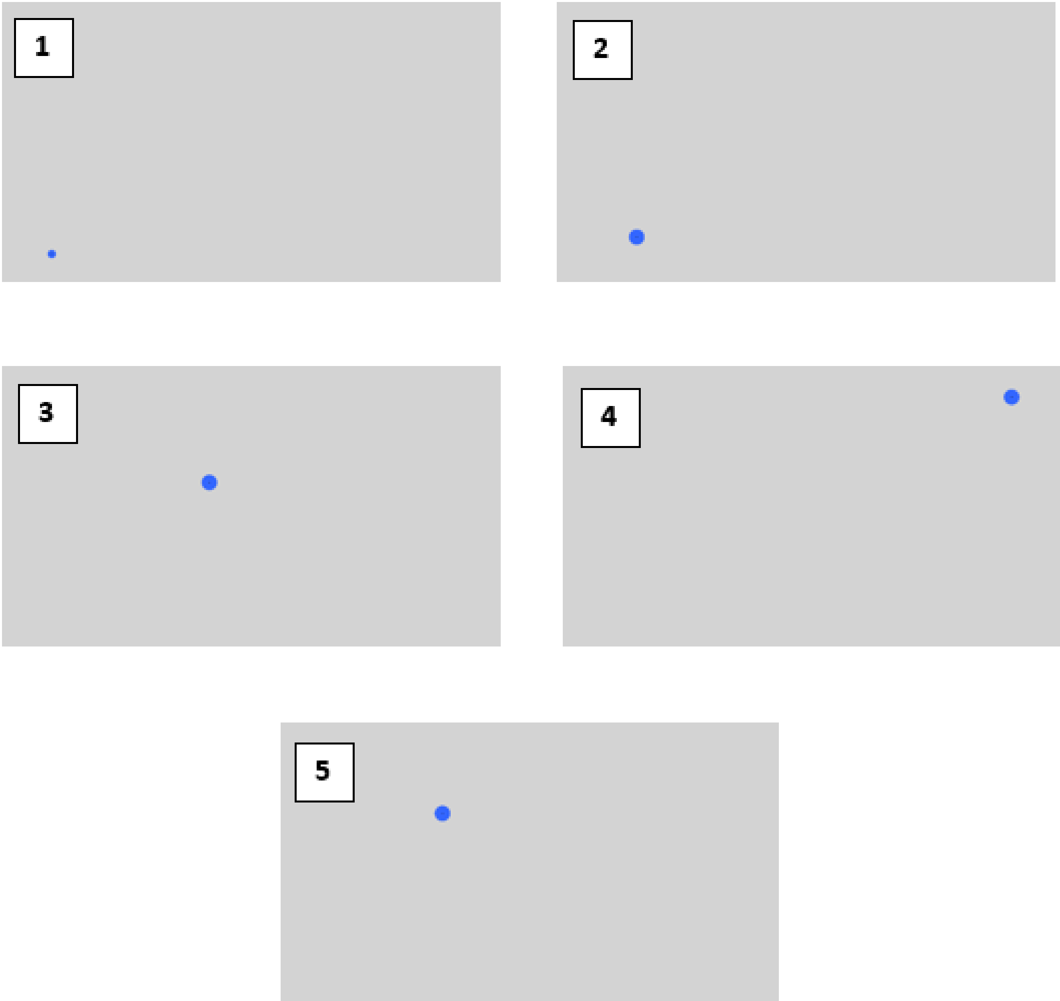


Figure 4. *Images of calibration process. At picture 4, the dot pulsed, growing and diminishing in size, before moving again (picture 5).*

Participants were asked to follow the blue dot with their eyes as it moved throughout the screen and stopped at five locations. While most participants could be calibrated in one attempt a maximum of three calibration attempts were undertaken if needed. While visual acuity was not formally assessed in this study, students with vision difficulties (e.g. wore eye glasses) were still eligible for participation in this study since the Tobii X2-30 has a robust capacity to track eye gaze in the presence of corrective lenses with low data loss. As no participants exceeded the three-attempt threshold, sufficient accuracy was achieved and it was assumed that all participants had adequate vision for participation in the study. If a participant moved significantly e.g. shifted chair position, or left the eye tracker altogether e.g. to go to the bathroom, calibration could be repeated any number of times within a testing session.

6.2.6.2.2 Reading Tasks

Reading tasks were completed over two sessions of 50 min duration for each participant on non-consecutive days. These sessions were video-recorded; allowing recordings to be re-watched if research assistants failed to code answers in-vivo. Research assistants instructed participants to read the entire text out loud from start to finish. The Reading phase began the moment the text stimuli was presented on the monitor, which occurred immediately following calibration via a button press from a research assistant. This phase ended when the participant finished reading the last word of the passage, which prompted the research assistant to switch to a screen containing a black background and white fixation cross via button press, to prevent re-reading during this phase. To begin the Question Phase, the researcher switched back to the text screen again. No time restrictions were imposed during question answering, and participants were encouraged to guess if they were unsure, or to refer back to the text to assist them in answering the question. Text stimuli remained on screen for the duration of the question phase. The research assistant asked a question, to which participants orally answered which the research assistant recorded verbatim for later scoring. The next question was then asked in this same manner until all questions pertaining to a single text were answered, signalling the end of the Question Phase. The research assistant then ended the task via a final button press. Four to five tasks were completed in each individual testing session, which lasted a maximum of 50 min.

6.2.6.3 Data Analysis

Tobii Studio, using a pre-set fixation filter, filtered out all fixations shorter than 80ms as is standard for eye-tracking studies on reading. Tobii Studio was also used to collect data on the following global eye movement measures: overall time spent in phase (Reading and Question), fixation count, mean fixation duration, overall fixation duration, overall saccade duration, visit count, visit duration, and percentage of time spent fixating relative to making saccades. Participant gaze was recorded for both Reading and Question phases with each recording separated by phase.

The Question phase was also broken up into scenes. This is a feature of Tobii Studio which allows a recording to be broken up into subsets of the overall recording. The number of scenes equalled the number of comprehension questions, for example, if a participant answered five questions, five scenes were created for that passage. A scene began at the end of a question-utterance by the researcher and finished at the end of the reply-utterance by the participant. Each scene, therefore, depicted the participant's eye gaze behaviour when answering a single question, which allowed analysis of these recording subsets as discrete events.

Areas of interest (AOIs), pre-defined areas determined by the researcher, were also created using Tobii Studio. Gaze metrics can be calculated when gaze location lies within the boundaries of this area. During the Reading phase, the entire text page became an AOI as well as images (for applicable texts). During the Question phase, AOIs were drawn around the sentence or sentence fragment which contained the answer to each question asked for a particular text e.g. in the G3-4 text *Poppy the Puppy,* for the question "Who is Emily?" the AOI was drawn around the words "…with her owner, Emily". AOIs were equal in height, reaching the lower end of the text on the line above and the upper end of the text one line below, and extended three letter spaces further right and left of the selected answer string (see Figure 5). Tobii Studio was used to extract global gaze metrics from AOIs, and software program SPSS v 25 used to calculate correlation and two-way ANOVA statistics.

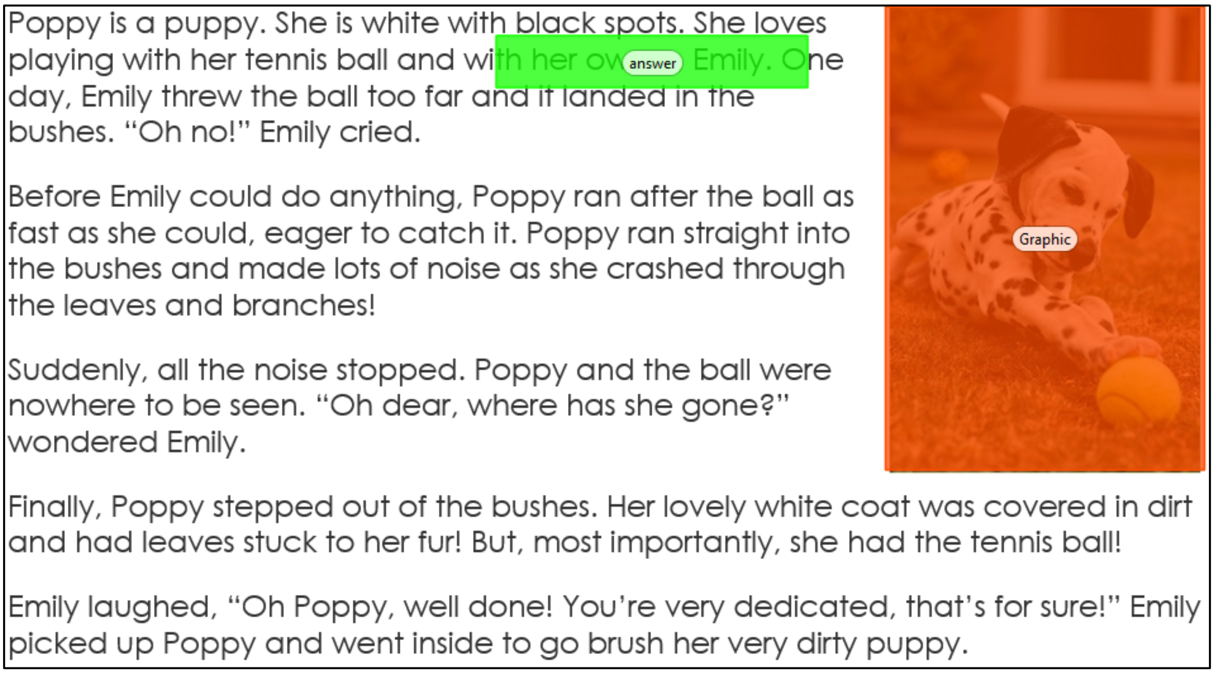


Figure 5. AOI example within a scene. The AOI "answer" is contained within the green rectangle, and the "Graphic" AOI within the orange.

6.2.7 Independent Variables: Part A

All participants were categorised according to two independent variables, each with two levels: diagnosis (ASD or TD), and reading competence level (*High* or *Low*). Therefore, each participant belonged to one of four groups: ASD/*High*, ASD/*Low*, TD/*High*, and TD/*Low*.

6.2.8 Dependent Variables: Part A

6.2.8.1 Comprehension Accuracy

Comprehension scores were obtained by having two members of the research team independently mark the scoring sheet for each text against the predetermined answer criteria. In the event of disagreement on scores, the entire research team would come together to discuss and reach an agreement on that score. Comprehension accuracy scores were added up across all reading tasks completed and converted into an overall percentage ((marks awarded/total possible marks)*100) for each participant.

6.2.8.2 Global Eye Movements

Many eye-tracking studies investigating reading behaviour have reported various global eye gaze measures, with mean fixation duration and fixation count frequently reported in the literature (see Au-Yeung et al., 2015; Howard et al., 2016; Micai et al., 2017; Sansosti et al., 2013). The relationship between eye movements and decoding/fluency is generally understood: faster reading times are associated with lower fixation counts and mean fixation durations, implying greater automaticity of reading and more fluent decoding (Fuchs et al., 2001). Although comprehension processes do begin during first-pass reading, the focus of measurement in the Reading phase has typically been on decoding and reading fluency behaviours. The post-reading Question phase in contrast, measures eye movements while engaged only in comprehension-enhancing activities as participants do not necessarily overtly read the text and have choice in the extent to which they gaze at the text. Global eye movement measures have been used in eye-tracking studies to explain attention patterns to visual stimuli, however in reading studies in particular, it is unknown how or which eye movements contribute to understanding of text. Data was collected on the following global eye movement measures in this study:

i. reading fluency in words/min
ii. overall phase duration (fixations + saccades)
iii. mean fixation duration
iv. overall fixation duration
v. fixation count
vi. overall saccade duration
vii. percentage of time making fixations
viii. percentage of time making saccades
ix. visit duration, and;
x. visit count.

The overall phase duration was a composite measure made up of overall fixation duration and overall saccade duration, to reflect the total amount of time spent in that phase i.e. reading or question-answering. A visit was regarded as the sum of fixations and saccades within an AOI (the entire passage). Visit duration differed from overall phase duration because during a phase, eye movements outside the AOI (i.e. off screen) contributed to overall phase duration, but not to the visit duration.

6.3 Results & Discussion: Part A

Overall, 19 participants read and answered questions on eight to 10 tasks, depending on their grade level. All reading tasks were separated into Reading and Question phases, as the discriminative stimulus (and hence behaviour) differed across these phases. Particular interest was given to the Question phase in this study as, to the author's knowledge, it is the first eye-tracking study to extensively investigate reading behaviour during question answering. A correlation analysis was conducted to evaluate the relationship between each global eye movement measure and comprehension accuracy, for both the Reading and Question phases (see Table 9 below).

Table 9. Correlations of Global Eye Movements with Comprehension Accuracy.

	Reading phase		***Question phase***	
	r	*p*	r	*p*
Reading fluency in words/minute	.62**	.005	-	-
Total time duration (spent in phase)	-.63**	.004	.03	.907
Mean fixation duration	-.58**	.009	-.55*	.015
Overall fixation duration	-.71**	.001	-.03	.901
Fixation count	-.33	.167	.26	.287
Visit duration	-.66**	.002	.06	.808
Visit count	-.01	.966	.18	.471
% fixations	-.39	.097	-.40	.088
% saccades	.39	.097	.40	.088
Overall saccades duration	.05	.829	.20	.410

**Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).
Reading fluency was measured across the reading phase only, as participants were not given direction to read out loud or sequentially during the Question phase.

6.3.1 Reading Phase

Significant correlations were found during the Reading phase between comprehension accuracy and reading fluency, total time duration, mean fixation duration, overall fixation duration, and visit duration (refer Table 9 above). Based on Cohen's (1988) classification on correlation strength, these five, time-based variables were strongly, negatively correlated with comprehension accuracy. This indicates that during the Reading Phase, that as time spent reading decreases (i.e. faster reading time, as the phase ends when all text had been read out loud), comprehension accuracy increases. This finding was expected given the consistency of this finding in the literature – that mastery of decoding and oral reading fluency is associated with better comprehension, and reading comprehension deficits are often associated with slow and effortful decoding (Brown et al., 2013).

6.3.2 Question Phase

During the Question phase, a strong, negative correlation existed between comprehension accuracy and mean fixation duration only (refer to Table 9). In the Reading phase, shorter mean fixation durations reflected more efficient processing of text: less time was spent gazing at or decoding words (or parts of words). However, in the Question phase, participants were not always gazing at the text in a sequential, linear manner, and so the same inference cannot be made for mean fixation duration in this phase. Rather, participants were scanning text and attempting to locate information that would either directly (explicitly stated the answer) or indirectly (provided additional context) assist in successful question answering. It is possible that shorter mean fixation durations reflected enhanced answer searching in the Question phase. In other words, students with this characteristic pattern were able to more rapidly sift through the text to locate salient information. In order to investigate differences in mean fixation duration between ASD and TD, and *High* and *Low* groups, a two-way analysis of variance (ANOVA) was conducted. **Error! Reference source not found.** below depicts the mean fixation durations by diagnosis and group.

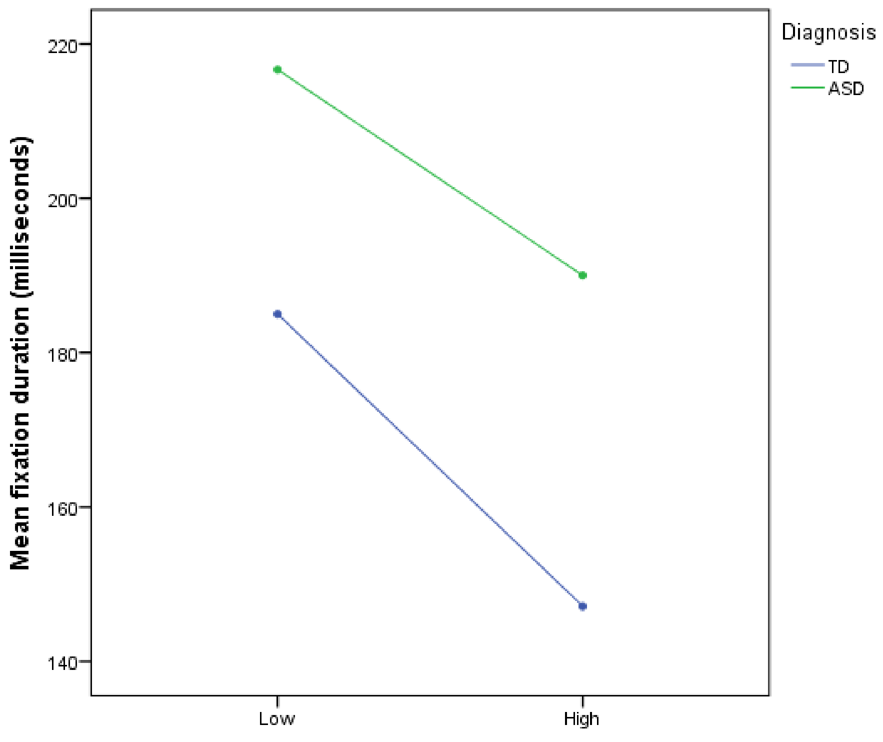


Figure 6. Line graph of mean fixation duration during Question Phase.

A two-way between groups ANOVA was conducted to explore the impact of diagnosis and reading competence on mean fixation duration, measured in milliseconds. Participants were categorised by diagnostic status (ASD or TD), and reading competence (*High* and *Low*). Preliminary assumption testing was conducted to check for normality, linearity, outliers (more extreme than ±3 SDs), and homogeneity of variance, with assumptions met to satisfaction. The interaction effect between diagnosis and reading competence group was not statistically significant, $F(1, 15) = 0.11$, $p = .75$. The main effect for reading competence was also not found to be statistically significant, F (1, 15) = 3.66, $p = .08$. There was a statistically significant main effect for diagnosis, $F(1, 15) = 4.88$, $p = .04$; and this effect size was large according to Cohen's (1988) criteria for partial eta squared (partial $\eta^2 = .25$), with participants with ASD exhibiting longer mean fixation durations than the TD group. This statistically significant finding suggests that a diagnosis of ASD was associated with longer mean fixation durations during question answering, hence, these individuals spent longer gazing at individual words and text portions. Being of typical development on the other hand was associated with shorter mean fixation durations during question answering, and TD individuals spent less time gazing at individual words and text portions.

Results from the previous correlation analysis suggested that shorter fixation durations reflect more automatic reading, hence were associated with higher comprehension scores. In contrast to this association, participants with ASD, regardless of reading competence, fixated for longer than TD readers. This is consistent with recent findings in the eye-tracking/reading/ASD literature, and provides further evidence supporting the argument by Howard et al. (2016) – that readers with ASD utilise a more cautious reading strategy, spending longer on answer evaluation before responding to the question. Initially, this slower, more cautious reading strategy was thought to reflect difficulties with processing, however the ASD + *High* group were highly accurate in their responding (83% questions correct), and therefore demonstrated solid understanding of the text. This skilled performance contrasted with the TD + *Low* group, who answered 55% of comprehension questions correctly, yet these groups displayed almost equal mean fixation durations. A second two-way ANOVA was conducted to evaluate whether reading skills in individuals with ASD are intact, in spite of "different" gaze behaviour.

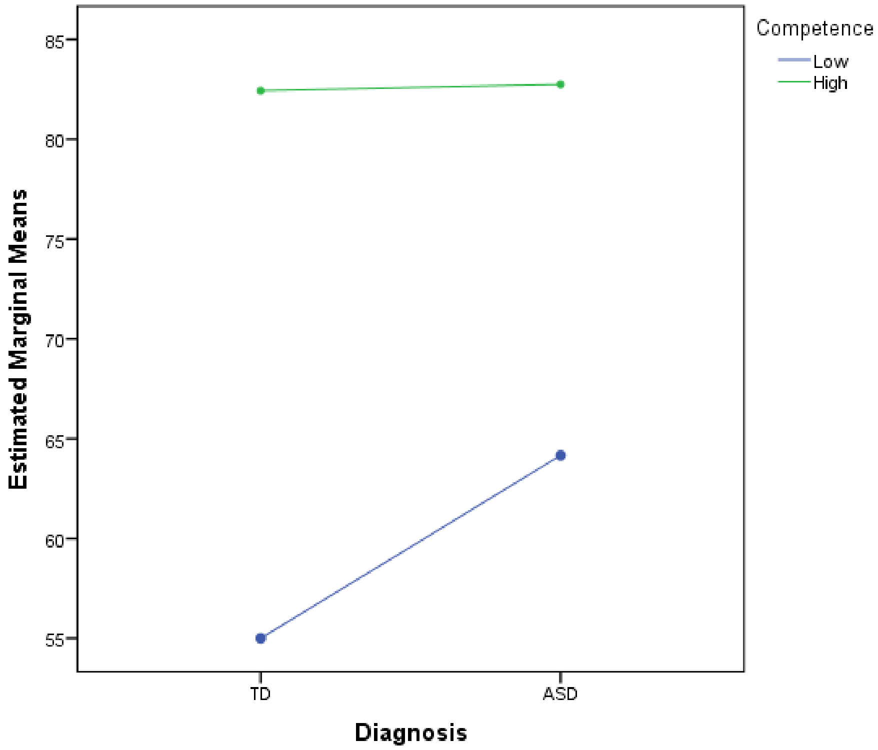


Figure 7. Line graph of comprehension accuracy - by diagnosis and competence group.

In the second two-way between groups ANOVA, the impact of diagnosis and reading competence on comprehension accuracy was explored (see Figure 7 above). Identical processes of preliminary assumption testing were conducted, again, with assumptions being met to satisfaction. The interaction effect between diagnosis and reading competence was not statistically significant, F (1, 15) = 1.11, p = .31. This time there was a main effect of reading competence on comprehension accuracy, F (1, 15) = 29.93, $p < 0.01$, with a large effect size (partial $\eta^2 = 0.67$) and no main effect was found for diagnosis on comprehension accuracy. This means that *High* group participants were significantly more accurate than those belonging to the *Low* group in answering comprehension questions, and that TD participants and those with ASD were equal in their comprehension accuracy.

6.4 Remarks on Part A

From the results, and despite different gaze behaviour it was evident that there were similar levels of comprehension accuracy for both ASD and TD participants, with the ASD group performing slightly better. The main difference between groups was in mean fixation duration, or how long students spent fixating on each word, or part of a word, before shifting their gaze. There is a general consensus that during oral reading, mean fixation duration is directly related to reading speed, as decoding strongly influences when to move your eyes during reading – this is the process that drives gaze through text (Rayner, Yang, Castelhano, & Liversedge, 2010). This means that rapid decoding often results in shorter durations of fixations, as successfully reading a word provides a discriminative stimulus to make a saccade to the next word. However, in the Question Phase, where students were presumably scanning for the answer and not necessarily re-reading, a blanket rule of “more speed” did not translate to better comprehension success for all participants. Regardless of reading competence, participants with ASD exhibited longer fixation durations in the Question Phase than TD participants, without impact on their comprehension accuracy. Such a result is compatible with the idea of a local processing style, also found in people with ASD. This preference or style of a more cautious and slower search may enhance accuracy when they are allowed the opportunity to slow down and search more thoroughly. Indeed, Mayes and Calhoun (2007) reported that 58% of children with high functioning ASD in their sample had slower processing speeds, which means they may be slower at accessing previous knowledge, or reflect caution on these children’s part when completing such tasks. A slower processing speed means that searching and processing visual stimuli will only be affected if the student is under time pressure, or not given sufficient time to complete the task. For example, the majority of secondary school and university examinations are time-based, disadvantaging those readers with slower processing speeds. Consequently, test or examination scores may not reflect actual ability or depth of knowledge of a content area, where students with slower decoding/scanning speeds may underperform. Additionally, a diagnosis of ASD shares high co-morbidity with anxiety disorders, which can specifically be related to test anxiety, creating further problems for students with ASD and poor readers, and leading to underperformance on timed tests. In the current study, reading tasks were not timed; it would be interesting to observe mean fixation duration of participants with ASD during question answering on timed and untimed reading tasks. Presumably, if these students were forced to gaze for shorter intervals they may underperform or make more errors when answering questions. Consistently providing extra time, however, on examinations and tests for students with ASD may attenuate this apparent disadvantage.

In light of the current results, differences in global eye movement measures may not be linked to how well written text is comprehended or understood. Rather, differences in mean fixation durations between the TD and ASD groups in the present study may better reflect different behavioural topography, rather than function. This means, regardless of whether gaze is of long or short duration at each word read, the text is processed and understood in the same way, making eye gaze duration largely irrelevant. Therefore, global eye movement measures may not reveal information about the facilitation of text comprehension as these measures largely reflect *when* and *how long* gaze is fixated, but the gap in the knowledge base may be better addressed by focusing on *what* students are gazing at when answering questions about text.

However, this raises another question: what are students with low reading competence failing to gaze at when answering questions about text? As written text is a visual stimulus in which readers must search for an answer, the answer could be as small as a single word and as large as a whole paragraph. Yet written text is complex in that even for short passages hundreds of distractors lie within close spatial proximity to the answer – the region of text relevant to answering a particular question. For example, individual letters and words appear in close spatial proximity to each other. It is important to consider that while infants and children with ASD often display enhanced visual search (Gliga et al., 2015), their performance is affected when distractor stimuli appear in relatively close spatial proximity to the target (Broadbent, 1991). It is possible that readers with autism and low competence exhibit gaze difficulties in visually locating the answer. In Part B of this study, the aim is to answer the following questions: (a) what are students, regardless of diagnosis, gazing at when answering comprehension questions? and (b) is exhibiting these gaze behaviours related to comprehension accuracy?

6.5 Method: Part B

6.5.1 Independent Variables: Part B

Two independent variables were used in Part B – reading competence level (*High* or *Low*) and grade cluster (G1-2, G3-4, and G5-6).

6.5.2 Dependent Variables: Part B

A task analysis of gaze behaviours exhibited by participants with high reading competence when answering comprehension questions was constructed (see Table 10). According to Cooper, Heron, and Heward (2007), a task analysis "involves breaking a complex skill into smaller, teachable units, the product of which is a series of sequentially ordered steps or tasks" (p.437). In the current study, the complex task was question-answering, and the purpose for constructing the task analysis was to determine the behaviours or sequence of behaviours that are both necessary and sufficient to answer questions efficiently. However, it is useful to keep in mind that what one person might have to perform may not be identical to what another person needs to achieve the same outcome (Cooper, Heron, & Heward, 2007). Since this study is exploratory in nature, and novel in tracking eye movements during the Question phase, the aim of the current analysis was in part to complete the task analysis.

Gaze behaviours were identified by observing the recordings of competent individuals (students with high reading competence), then operationally defined which allowed their use by each student to be measured. A definition for the answer portion of a text (herein described as the *answer)* is necessary in describing reading gaze behaviours. The *answer* refers to a portion of text within the passage that explicitly contains information, or requires an inference, to answer the question asked of a participant. For example, in the G5-6 text *Piano*, for the question "Who was Simon's teacher?" the answer in the text is the following AOI: "his teacher is Miranda". After thorough observation of the reading task recordings the following behaviours were identified and became the dependent variables for Part B:

i. Comprehension Accuracy (see section 6.2.8.1)
ii. Use of Supplementary Information (yes or no)
iii. Locating Answers (yes, partial, no)
iv. Answer Search Strategy (*Automatic*, *None*, *Supplementary Information*, *Linear*, *Haphazard*)
v. Latency of first fixation to answer (duration in seconds)
vi. Scans Text Before and After Answer (yes or no)
vii. Re-Reading (yes or no).

Table 10 (on the following page) presents a detailed explanation of the dependent variables.

Table 10. Operational Definitions of Reading Gaze Behaviours Exhibited by Participants with High Competence

Behaviour	Definition
Reading fluency	Words read aloud per minute.
Mean fixation duration	Average time duration of a fixation on the passage
Use of supplementary information (SI)	Supplementary information (SI) is defined as visual stimuli within the passage separate from the text body, yet accompanying the text. SI may contain text e.g. a caption, however usually does not. Examples include pictures, graphics, tables, figures, and charts. Gaze to SI involves at least one visit to this AOI, and at least one fixation within this area (≥80ms). 
Answer Search Strategy	The manner in which the participant locates (fixates on) the answer. The answer is **located** when ≥2 consecutive fixations moving from left to right within the answer AOI have been made. For gaze on an answer location to be counted, fixations needed to be made on ≥50% of the words involved in the answer, rounded up to the nearest number. For example, if an answer contained four words, fixations needed to be made

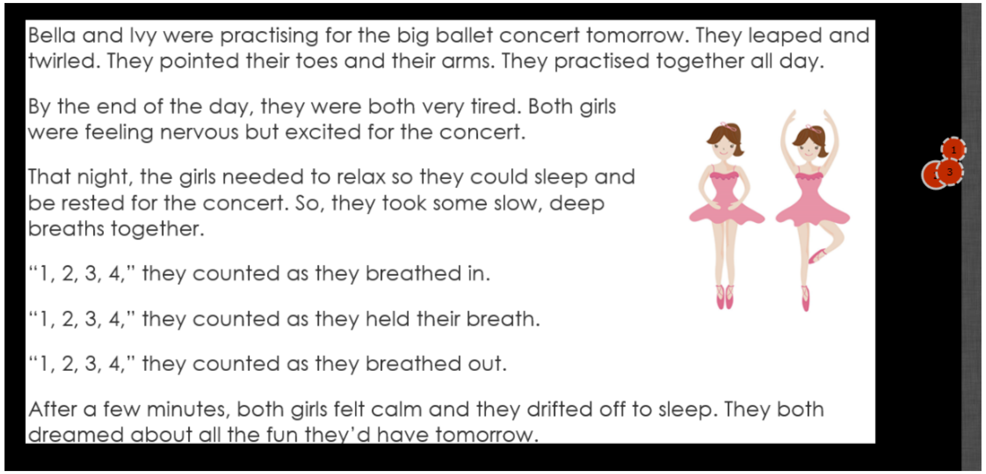
on at least two of the words within the answer. Similarly, if the answer contained five words, fixations were required on at least three of the words within the answer.

1. Automatic

Answer is already fixated on by the time researcher finishes asking question OR answer is located within 3 fixations (regardless of saccade direction).

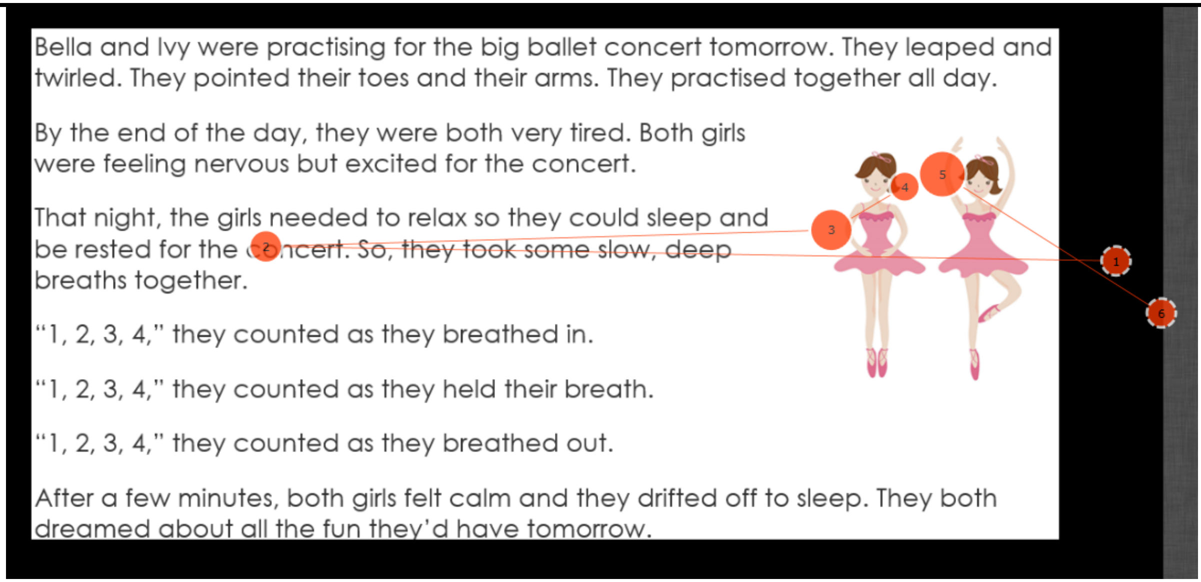
2. None

Text is not fixated on i.e. participant gazes off-screen OR participant verbalises answer and makes ≤3 fixations to text without locating answer.



3. Supplementary Information (SI)

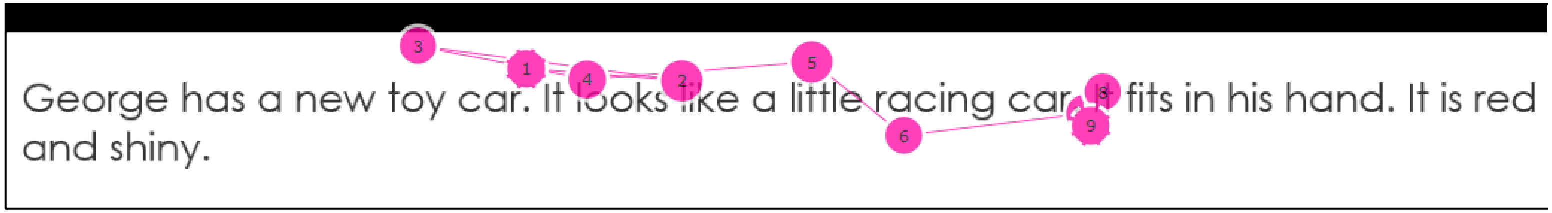
More than 50% of fixations within a scene are on the SI AND ≤10 fixations are made to the text. Answer may be located but relatively few fixations in this AOI.



4. Linear

Fixations move in a fashion that reflects re-reading. Gaze progresses from left to right, and may shift up or down one line at a time. ≥1 fixation is made per line of text i.e. lines cannot be skipped.
Regressions (backward saccades) to words in the current or previous sentence, or line are made, however the participant continues to scan text generally in this linear fashion.

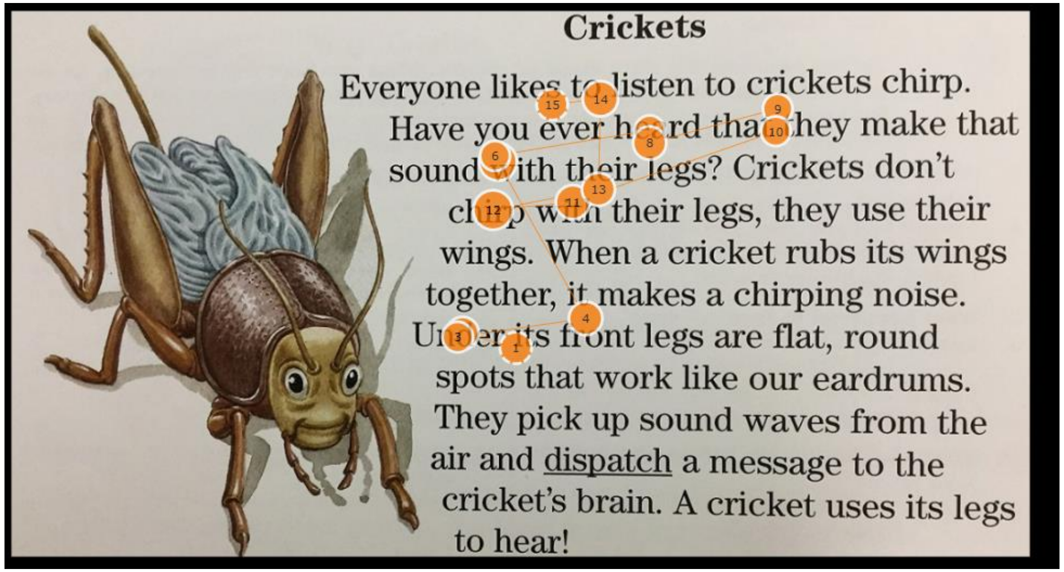
When scanning the end of a paragraph, the participant will proceed to the beginning of either the <u>following</u> (below) or <u>preceding</u> (above) paragraph. Participant may shift gaze from text to SI, and upon shifting gaze from SI will return to the previously fixated line of text within 3 fixations.



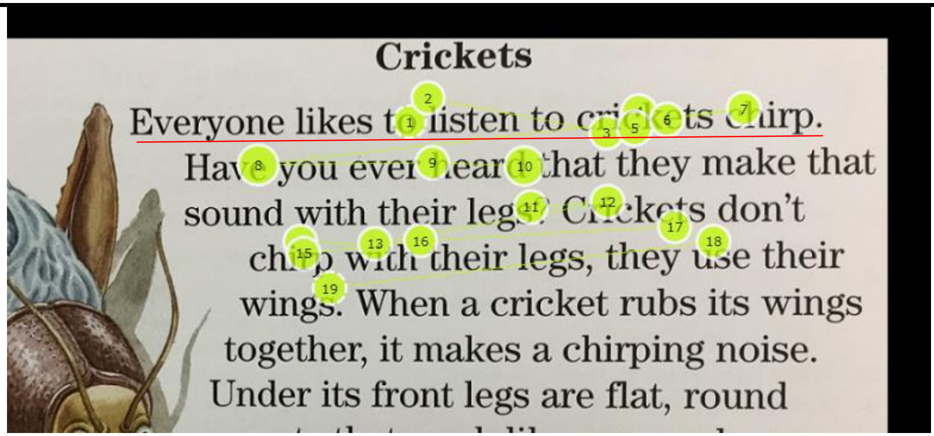
5. Haphazard

Fixations move in a fashion that does not generally reflect re-reading. Consecutive fixations skip more than 1 line in an up or down direction. Saccades move right to left generally.

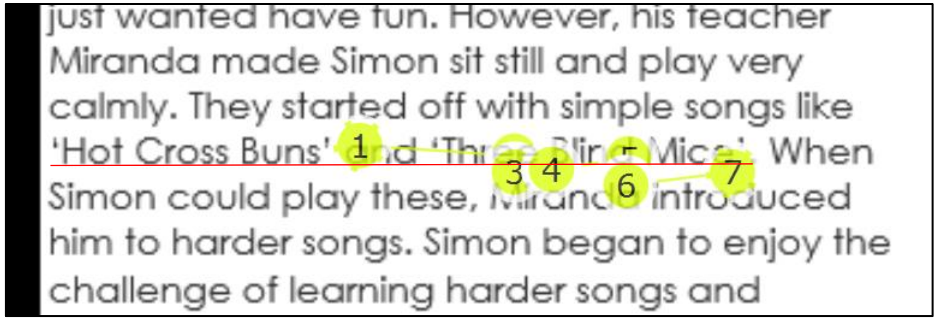
Participant may shift gaze from text to SI, and upon shifting gaze from SI will not return to the previously fixated line of text within 3 fixations (i.e. a new line of text is fixated).



Latency of 1st fixation to answer	Time elapsed since end of question-utterance by researcher, until the participant first fixates on the answer AOI.
Scans Text Before and After Answer	The regions of text directly adjacent to the answer AOI often contain important information relating to the context of the question asked. This behaviour can only occur once the answer AOI has been **located**: ≥2 consecutive fixations moving from left to right within the AOI. At any time after the answer has been **located**, the participant makes ≥2 consecutively linear (left → right) fixations on EITHER the line or sentence preceding the answer OR the line or sentence following the answer. *answer AOI underlined in red.

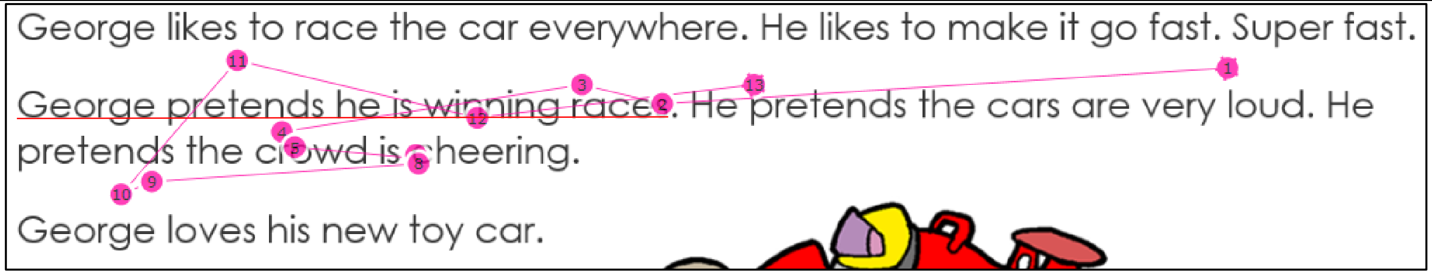


example of reading information after the answer

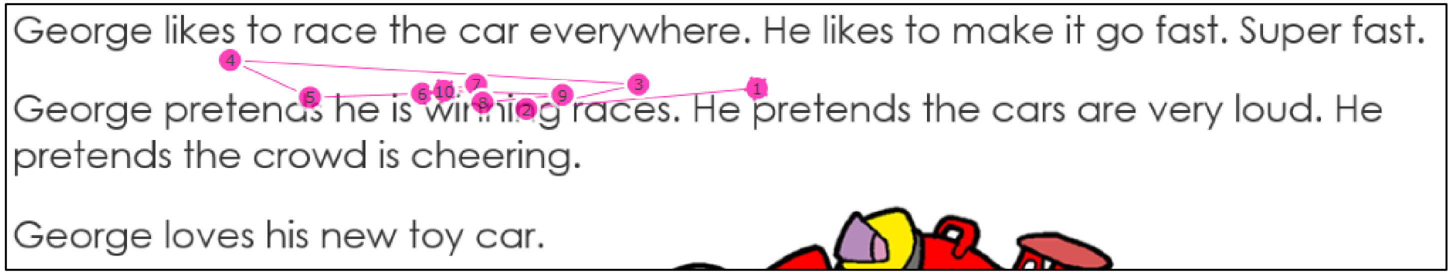


non-example

Re-reading answer	Once AOI has been **located** (≥2 consecutive fixations moving from left to right within the AOI) and participant gaze then leaves this AOI (i.e. fixation made outside this area) for the first time, the answer has been read once. Every time this sequence occurs again within a scene, it counts as a single re-read e.g. if participant has located answer and leaves area, then <u>fixates again</u> on answer and leaves, and <u>fixates once more</u> on the answer at the end of the scene, this counts as 2 re-reads. *answer AOI underlined in red.



Example of gaze returning to AOI – counts as 1 re-read.



Non-example of gaze returning to AOI – no re-reading.

6.6 Results & Discussion: Part B

Task analysis and subsequent measurement of gaze behaviour was undertaken on 12 texts, four from each grade level cluster. Texts containing both supplementary information (SI) and text components were chosen, primarily so gaze behaviour to text while SI was available (or competed as a stimulus) could be analysed. Because the scores and skills in the overall sample ranged over a continuum, the performance of the six students with the lowest and six students with the highest comprehension scores were analysed, in the hope that more discernible differences in reading behaviour would be revealed. Students scoring the highest scores all belonged to the *High* reading competence group, and those scoring the lowest all belonged to the *Low* group. Students' diagnostic status was disregarded, and both the *High* and *Low* subsets contained a mix of those with ASD and TD participants. Two participants represented each grade cluster in both the *Low* and *High* subsets, so that sufficient data was available for analysis at the grade level and comparisons could be made. Table 11 lists participant performance on the reading passages and WRMT-III scores:

Table 11. Participant Descriptive Characteristics, Comprehension Accuracy and Assessment Scores

Student	Gender	Grade	Age (years: months)	Diagnosis	Reading Competence	WRMT-III Basic Skills	WRMT-III Reading Comprehension	WRMT-III Listening Comprehension	WRMT-III Oral Reading Fluency	Comprehension Accuracy
AG**	M	3	8:3	TD	Low	82	87	86	93	**44%**
KL**	M	5	10:10	ASD	Low	93	77	79	89	**46%**
DM	M	6	11:8	ASD	Low	59	77	86	70	**63%**
RB**	M	2	9:3	ASD	Low	93	85	80	89	**65%**
EF**	F	4	9:9	ASD	Low	82	88	77	82	**65%**
HO**	F	5	10:8	TD	Low	80	91	90	86	**66%**
EW	F	5	11:3	ASD	Low	72	86	110	87	**72%**
SM	F	4	10:0	TD	High	118	102	85	104	**72%**
LP**	M	2	7:5	ASD	Low	93	98	103	96	**74%**
JG	F	4	10:0	ASD	High	121	106	103	105	**78%**
KS	F	3	9:2	TD	High	113	100	90	105	**80%**
LJ	F	1	7:5	ASD	High	126	109	91	110	**81%**
DI	M	6	12:2	TD	High	114	112	111	97	**81%**
MI*	M	3	9:4	TD	High	118	113	100	97	**83%**
ZI*	M	6	12:2	TD	High	103	100	87	93	**83%**
IG*	F	1	6:3	ASD	High	132	124	135	140	**86%**
JC*	M	3	9:9	ASD	High	110	115	112	98	**86%**
ER*	F	5	10:6	TD	High	123	109	116	111	**86%**
ZC*	M	2	8:2	TD	High	102	117	109	107	**92%**

Note: Reading competence of participants categorised according to WRMT-III Reading Comprehension score. *High*: SS ≥ 100. *Low*: SS ≤ 99. Participants are ranked from lowest to highest comprehension accuracy.
Participants belonging to *Low* Reading Competence group are shaded in grey, participants belonging to *High* Reading Competence group are unshaded.
Participants included in the *High* subset are denoted with *, participants included in the *Low* subset are denoted with **
Descriptive labels for SS of WRMT-III scale scores: Well below average (≤69); Below Average (70-84); Average (85-115); Above Average (116-130); Well above Average (≥131).

DM was excluded from the *Low* subset because he failed to complete all reading tasks, and EW was not included as two G5-6 participants with lower scores were selected for analysis. Literal, Reorganise, and Inference question types were included in subsequent analysis, because these questions involved a specific answer that was always included in the text. Gaze behaviours for which results will be shown and discussed in the following sections are: gaze to supplementary information (SI), locating answers, the search strategy used in locating answers, partial answer location, re-reading, and scanning information preceding and following the answer string.

6.6.1 Use of Supplementary Information

Supplementary Information (SI) refers to visual stimuli within the passage separate from the text component, e.g. pictures, graphics. Gaze behaviour to SI was measured for each scene i.e. one participant answering one question. Gaze to SI was counted if the participant made at least one fixation to this AOI. In a given scene, whether participants made one or 20 fixations on SI, it was counted as “Gaze to SI” for that scene. Figure 8 displays the Gaze to SI count for participants by grade level.

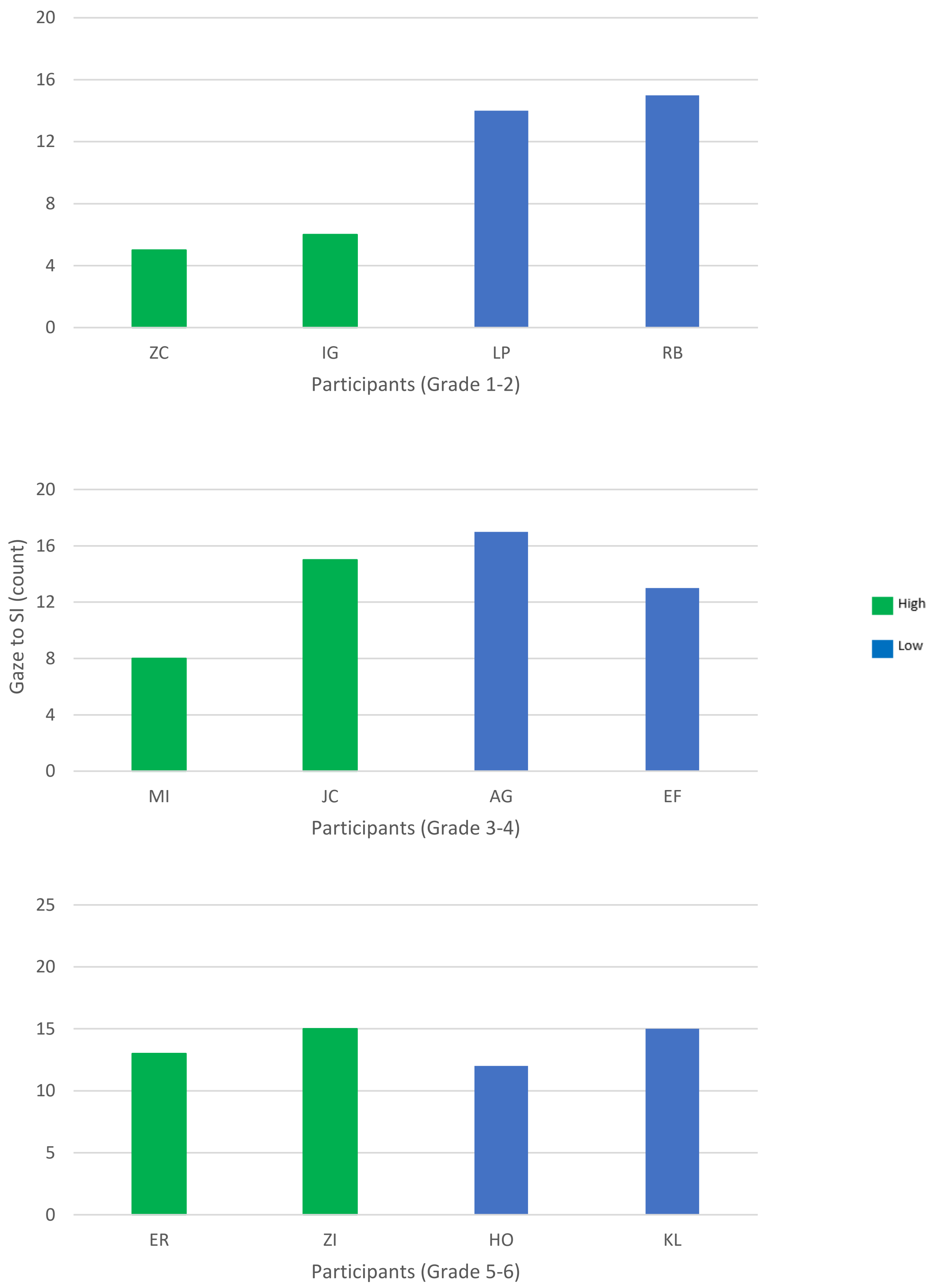


Figure 8. Participants Gaze to Supplementary Information by Grade Level – All questions (Literal, Reorganise, and Inference). Maximum possible count for G1-2 = 20, G3-4 = 22, G5-6 = 25.

For Figure 8 and following graphs, participants belonging to the *High* group are represented by a green bar or data point, and those belonging to the *Low* group are represented by a blue bar or data point. From visual inspection of the bar graphs above, it appears that readers from both groups gazed to SI a similar amount when answering questions. The biggest difference in this behaviour was evident with the younger primary school students (see Figure 8) – the students with low reading competence gazed to SI more often than the students with high reading competence (*Low* = 70 – 75% of questions; *High* = 25 – 30% of questions). Three of the six participants in the *High* group gazed to SI on less than a third of questions, while the other three participants gazed to SI in at least half of the questions. The *High* group participants who gazed less to SI were the youngest in this subset. The gaze to SI count was graphed alongside comprehension accuracy (see Figure 9), represented by the number of questions awarded full marks for their answer:

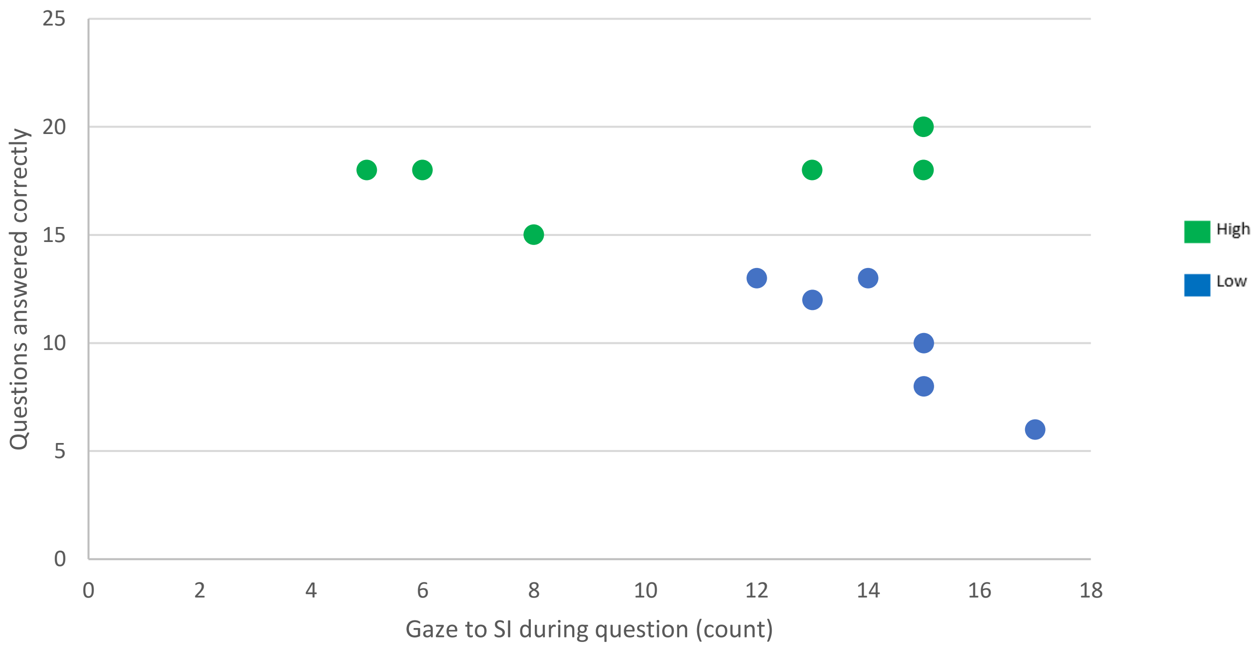


Figure 9. Scatterplot of Gaze to SI and Comprehension Accuracy

In light of the data presented in Figure 9, gaze to SI appeared to be associated with worse performance in answering comprehension questions. The more one gazed to SI the less accurately they answered questions, possibly reflecting greater difficulty with understanding the text. This linear, negative correlation between gaze to SI and questions answered correctly emerged only for the *Low* group; for the *High* group however, number of questions answered correctly did not appear to change depending on whether gaze to the SI occurred or not.

Previous research on eye-gaze patterns with preschool-aged TD children suggests storybook reading is a picture-focused activity, with children gazing more at pictures than the text (Evans, Williamson, & Pursoo, 2008). As children enter primary school they gradually begin to spend more time looking at the text, and use a skill called fast-mapping to create a visual image of orthographic word forms. Fast-mapping is a process of learning novel orthographic word forms through a rapid, associative pairing of pictures with labels, to form words (Crumrine, Owens, Adams, & Salamone, 2010). Children acquire mental orthographic word images through fast-mapping within implicit storybook reading contexts after minimal exposures. When children with well-developed fast-mapping skills can recognise and recall visual representations of words, it frees up cognitive, memory, and attentional resources for comprehending or composing text (Apel, 2009; Crumrine et al., 2010). Therefore, fast-mapping is a crucial skill for reading and writing success. In light of the discrepancy in gaze to SI between *High* and *Low* participants in G1-2, it is possible that the two *High* participants exhibited less picture looking because they were more efficient at recalling orthographic word forms, due to well-developed fast-mapping abilities. The two *Low* participants may have attempted to associate word and picture forms, and hence exhibited higher rates of gaze to SI. It is possible that their fast-mapping skills were inefficient, or slower to develop.

This explanation makes sense given the similar levels of gaze to SI behaviour in the older age groups, as students have stopped relying on using fast-mapping to consolidate mental representations of orthographic word forms. Perhaps as students with high reading competence become older, they tend to gaze at pictures and graphics more often. As text difficulty increases in later primary school years, and reading material moves from picture story books to novels and chapter books, it is plausible that students encounter SI at a much lower frequency than in early primary school years. Therefore, the presence of SI may be more “novel”, leading to a return of frequent gaze to pictures, similar to behaviour observed in preschool children. Interestingly, Crumrine (2012) found, in her sample of 5 to 7 year olds, that the children with ASD were able to fast-map novel images and text at a similar rate to TD children, despite having fewer fixations and shorter fixation durations to novel stimuli.

In the present study, although both participants in the G1-2 *Low* group had ASD, so did IG in the G1-2 *High* group. Regarding the sample as a whole, gaze to SI tended to correspond with reading competence rather than diagnosis. Another possibility is that, when text becomes more difficult, students with high reading competence understand that SI can enhance their understanding of the passage beyond the text level, and therefore it is more salient. For students with low reading competence, regardless of age, pictures may be an unwelcome distractor: it appears that a greater tendency to gaze at pictures may indicate greater difficulty with text, and therefore poorer understanding of what is being read.

6.6.2 Locating Answers

When asked comprehension questions, failing to locate the answer to a question within text forces participants to recollect passage content from memory. To evaluate whether locating and gazing upon the answer aids comprehension accuracy, participants’ performance on this skill was analysed. Inference questions, where answers were not explicitly stated in the passage and required an inference, were analysed separately to Literal and Reorganise questions, where answers to the questions were stated explicitly in the text. Although answers to Inference questions were contained in the passage, the answer was not explicitly stated and required the participant to infer meaning from the answer portion. Table 12 below contains some examples of answers to inference questions:

Table 12. Examples of inference questions

Text	Question	Answer in text	Inference required
George's Car (G1-2)	Why were the crowd cheering?	"…he is winning." "…the crowd is cheering."	That the crowd is cheering because he [George] is winning [the race].
Poppy the Puppy (G3-4)	How did Emily feel when Poppy didn't come out of the bushes?	" 'Oh dear, where has she gone?' wondered Emily."	That Emily was feeling worried/scared/upset [because she couldn't see Poppy].

6.6.2.1 Literal & Reorganise

Figure 10 displays answer locating behaviour by grade level clusters. Data for participants in the *High* reading competence group is depicted by a green bar, and those in the *Low* reading competence group by a blue bar.

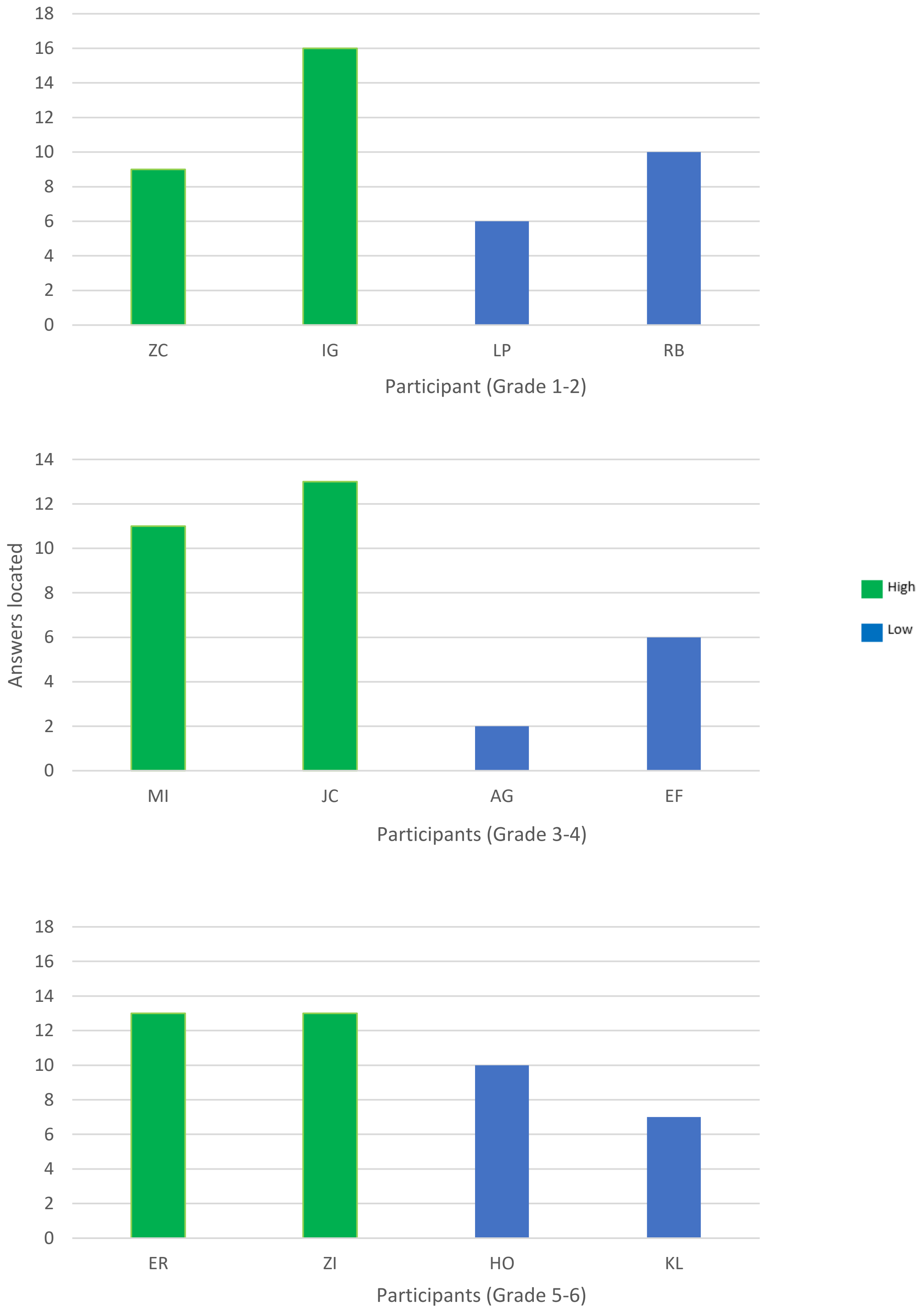


Figure 10. Answers Located on Literal & Reorganise Questions by Grade Level. Maximum answers located for G1-2 =18, G3-4 = 14, G5-6 = 18.

Figure 10 above shows that students with high reading competence located the answer more often than students with low reading competence. For the G3-4 and G5-6 clusters, this pattern was more obvious; however, for the G1-2 cluster the participant RB (*Low* group) actually located more answers than ZC (*High* group). ZC likely represents an outlier – he answered questions more often based on memory and has an overall comprehension accuracy of 92%, the only participant to score over 90%. This suggests he preferred to answer questions based on memory, given he located answers on Literal and Reorganise type questions only half of the time (nine out of 18 questions = 50%). For the participant RB, while he found more answers than ZC, he was not as successful in his comprehension accuracy (65% overall). This discrepancy will be explored further in later sections (see 6.6.4), and demonstrates that locating answers in text is a necessary but not sufficient condition for comprehension. ZC seems to be an exception, however; he read G1-2 texts which are shorter in length, and had the second fastest reading speed in the G1-2 group (111.44 words per minute); the combination of these two factors therefore resulted in short latencies between the Reading Phase (when information was first accessed) and the Question Phase, when this information was required to be retrieved. The short latencies between phases may have facilitated question answering from memory.

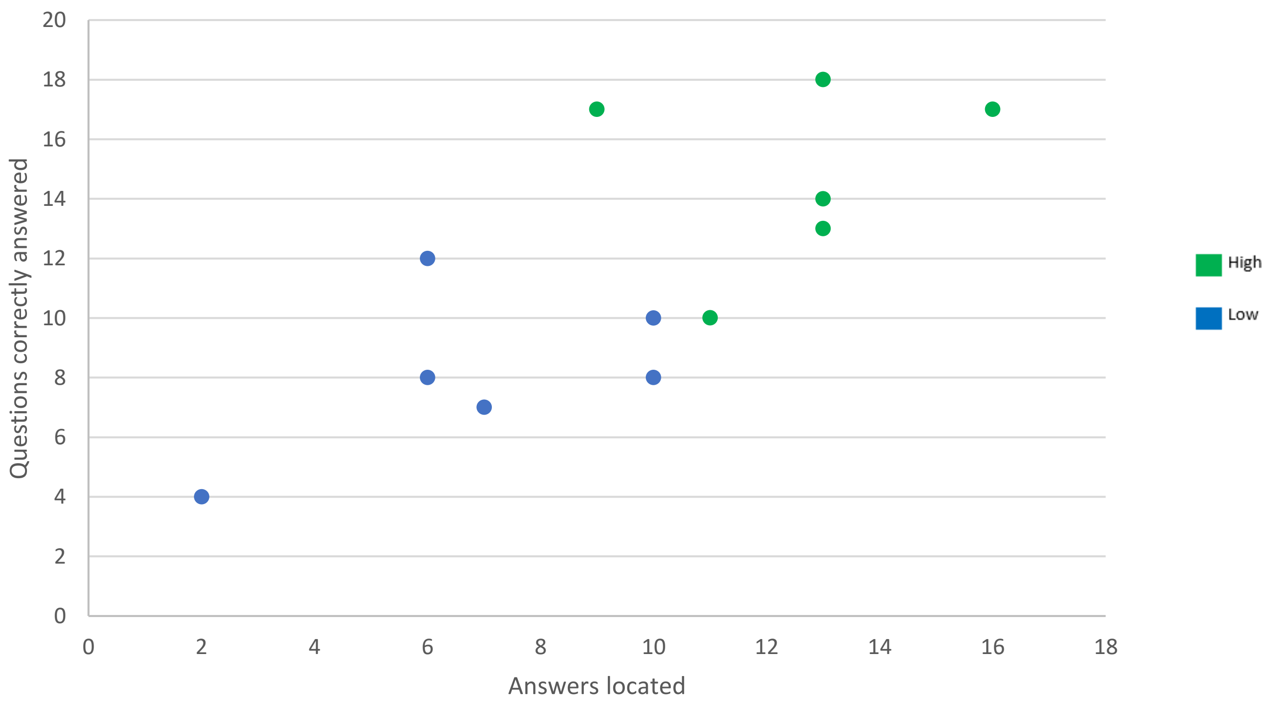


Figure 11. Literal and Reorganise Questions - Scatterplot of Comprehension Accuracy and Answers Located.

Figure 11 depicts the relationship between successful answer location and comprehension accuracy. Generally, there is a linear, positive correlation between answers located and comprehension accuracy, that is, as locating answers increases so does comprehension accuracy. Again, these relationships are most clear with G3-4 and G5-6 groups, whereas the younger age group of G1-2 alone does not yield this relationship (see Figure 12, Figure 13, Figure 14 below).

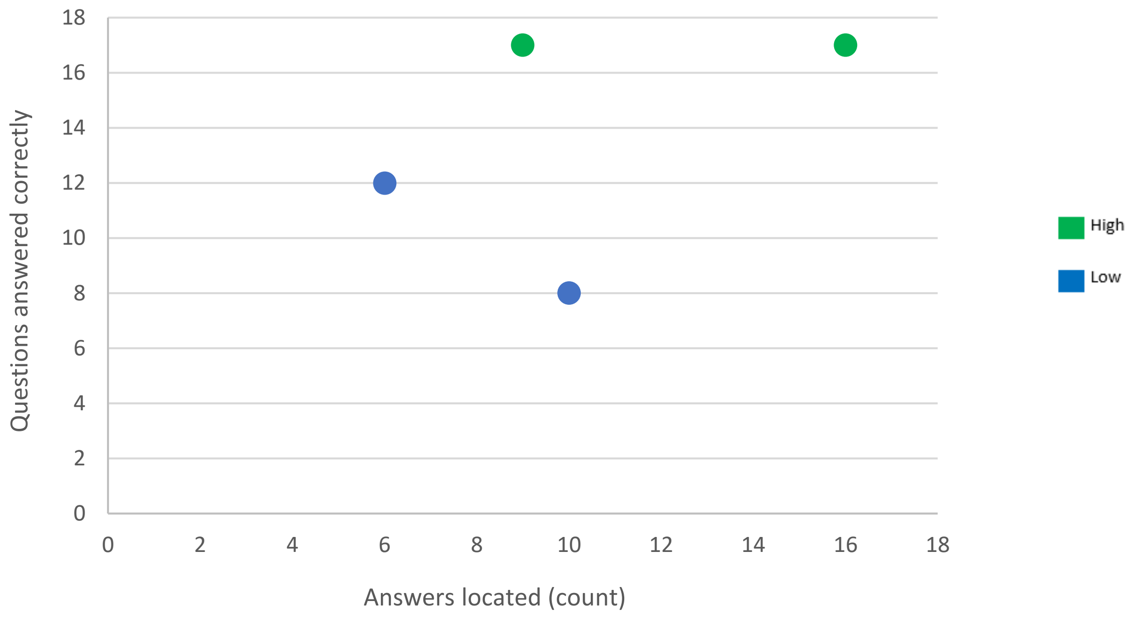


Figure 12. Grade 1-2 Scatterplot of Comprehension Accuracy and Answers Located

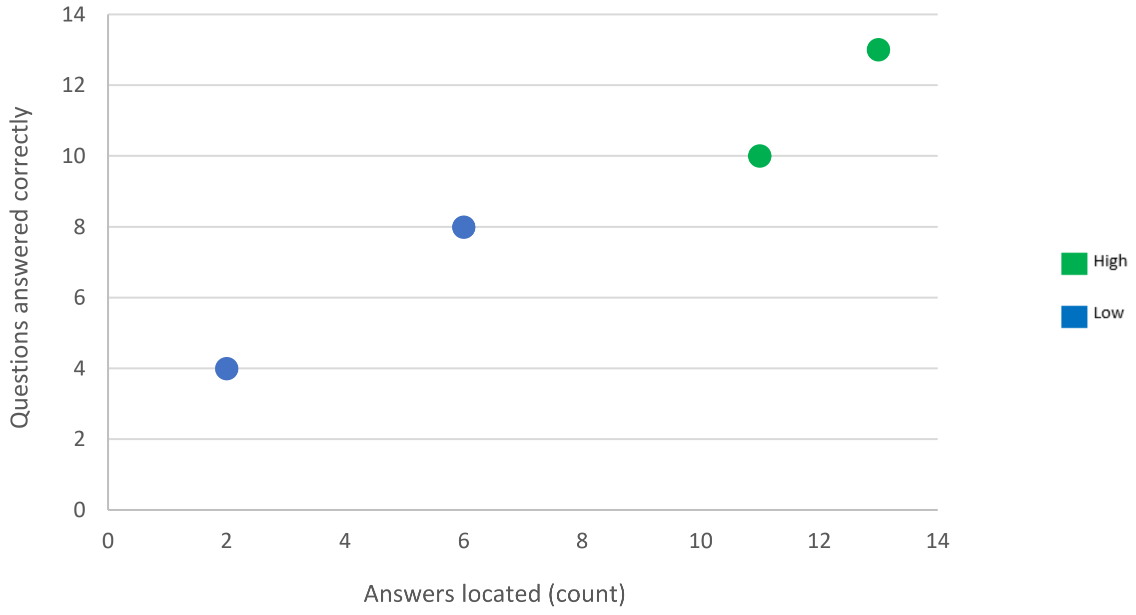


Figure 13. Grade 3-4 Scatterplot of Comprehension Accuracy and Answers Located

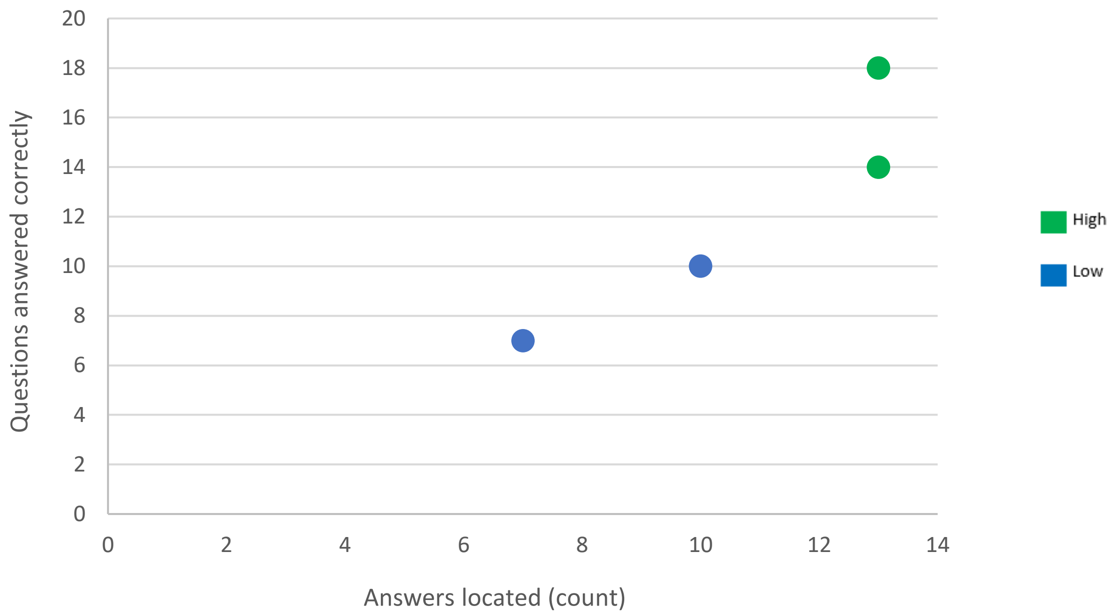


Figure 14. Grade 5-6 Scatterplot of Comprehension Accuracy and Answers Located

6.6.2.2 Inference

Answers to inference questions were not explicitly stated in the passage, but required the participant to link their own knowledge to the answer (e.g. that people said “Oh dear” when they were feeling worried or upset – see Table 12). In light of this, it was predicted that higher rates of answer locating may not have resulted in higher comprehension accuracy for Inference questions. However, Figure 15 below shows a positive, linear correlation between the two on Inference questions. While a smaller number of Inference questions overall were included in this study, the results suggest that locating the answer is important in aiding comprehension accuracy for explicit and implicit question types. With Inference questions, locating the answer appears to be a necessary component to answering the question and therefore understanding the text. Students cannot make inferences without first finding the information in the passage.

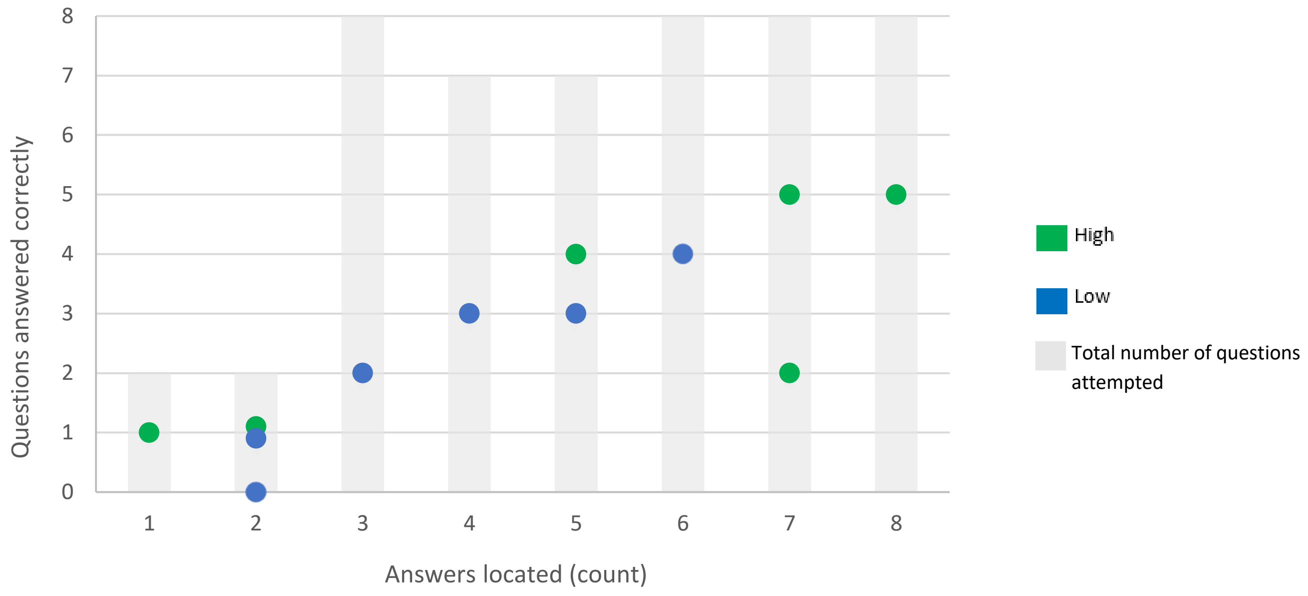


Figure 15. Inference Questions - Scatterplot of Answer Location and Comprehension Accuracy

In Figure 15, it appears that some members of the *High* group demonstrated low rates of answer locating for Inference questions, however this was not the case. Given Inference questions require an inference and so are more difficult to answer than Literal and Reorganise questions, a smaller number of Inference questions were assigned to the G1-2 participants. G1-2 participants only answered two inference questions in the four texts analysed: hence the two green data points located at (1, 1) and (2, 1) do not necessarily indicate that comprehension accuracy for these students was lower.

6.6.2.3 Remarks on Locating Answers

What can often look like a simple act of searching for information is in fact a complex process. If students are unable to locate information in text in a strategic and effective manner, then all other reading activities which facilitate comprehension are impeded, as the student cannot get beyond this point (Henry, 2006). Therefore, locating answers in text can be considered a “gateway” skill or behavioural cusp to comprehension (see section 2.4.2 for explanation of this term). This gaze behaviour can also generalise to students developing efficient visual search strategies to locate useful information on the Internet and other information communication technologies, a new literacy skill needed to successfully read and write in today’s digital age (Henry, 2006).

Reading comprehension has often been operationalised as text recall, however locating answers is an entirely separate process to text recall. This distinction is related to the concept of transfer-appropriate processing (Bransford, Franks, Morris, & Stein, 1979), which states that text recall is only determined by the depth of processing during the initial reading phase, whereas reading comprehension is determined by the relationship between how information is initially encoded (text recall during Reading Phase), and how it is later retrieved (answer locating during Question Phase). Therefore, one would not necessarily expect positive transfer from gains in text recall to generalise to tasks of locating information in text: these are two separate processes. A factor analysis by Guthrie and Kirsch (1987) confirmed that locating answers and text recall are independent practices, and locating answers would appear to improve how initially read information is later retrieved.

From the results, a tentative conclusion could be drawn: that locating answers facilitates comprehension accuracy. The positive linear correlations between these two variables for both text explicit (Literal and Reorganise type) and text implicit (Inference type) questions support this conclusion, however, even with an accumulation of evidence using the current methodology, such evidence would not fulfil the stringent criteria needed to provide support for a direct causal hypothesis between locating answers and comprehension accuracy. For now, however, it is quite the leap to generate a theory of answer locating predicting comprehension accuracy from these preliminary findings. However, if this theory is correct, then it may provide an effective method to avoid reading problems in primary school-aged students, and is therefore worthy of further investigation.

In the current study participants were required to read the text once prior to question answering, which has been found to enhance recall of details and events relating to the text (Cataldo & Oakhill, 2000; Cerdán, Vidal-Abarca, Martinez, Gilabert, & Gil, 2009). The finding that the *High* group were more efficient at locating answers than the *Low* group when asked specific questions is consistent with one previous study (Cataldo & Oakhill, 2000). Cataldo and Oakhill (2000) measured answer locating behaviour of 24 fifth grade students in the UK, who were categorised as either good or poor comprehenders. They found that while the groups did not differ in their performance on spatial memory tests (i.e. they were equal in their ability to remember locations of individual words in text), the good comprehenders were better at remembering the order in which specific words appeared in a text. Cataldo and Oakhill (2000) reported that superior search strategies may arise because of their better memory for the order of events in a text. This may be true for participants in the current study, as both the *High* and *Low* group made equal attempts at looking for the answer, and chose not to search for the answer on 10% of trials (see Table 14). However, participants in the *High* group may have chosen not to search for the answer because they recalled information without the need to search, whereas the *Low* group were more inefficient in their search, yet did not recall where to look. Cataldo and Oakhill (2000) identified six search strategy behaviours:

i. Reads the text again from beginning
ii. Reads from where he/she was for the previous answer

iii. Undirected searching: jumps from one paragraph to another; seems unaware of what he or she is looking for
iv. Reads text very quickly (skims)
v. Directed searching: reads a point, recognises that is not the right one, and goes directly to the right point or page
vi. Goes directly to the right point

Cataldo and Oakhill (2000) described issues with these search strategy descriptions being poorly defined, leading to difficulty in differentiating between behaviours e.g. skimming (iv) could look like strategy (i), (ii), or (v), as measurement occurred by researchers watching video footage of participants. In general, they found that good comprehenders used efficient search strategies significantly more often than poor comprehenders. A strength of the current study is that eye-tracking improved the ability to objectively and accurately measure the search strategies, and that each strategy was more clearly defined (see section 6.6.3), and thus, measured with less ambiguity.

6.6.3 Answer Search Strategy

By task analysing participant eye gaze behaviour during the Question Phase, specifically during each scene or question answering opportunity, a number of answer-locating gaze behaviours were identified: *None, SI (Supplementary Information), Haphazard, Linear, and Automatic*. See section Table 10**Error! Reference source not found.** for operational definitions of these gaze b ehaviours/search strategies. A single search strategy was used each time a participant answered a question, and therefore a frequency count for the use of each search strategy was obtained. Table 13 displays the search strategy use count by participant, and whether use of a search strategy resulted in successful answer location for that question.

Table 13. Frequency count of each Answer Location Search Strategy used during Question Phase.

Student	**Answer located**	**Strategy Used**					**Total**
		None	**SI**	**Haphazard**	**Linear**	**Automatic**	
ZC	Y			**1**	**3**	**8**	***12***
	N	**8**			**1**		***9***
IG	Y			**2**	**7**	**10**	***19***
	N	**1**		**1**			***2***
MI	Y			**2**	**9**	**10**	***21***
	N				**1**		***1***
JC	Y			**5**	**2**	**13**	***20***
	N	**1**		**1**			***2***
ER	Y			**3**	**8**	**8**	***19***
	N	**3**		**3**			***6***
ZI	Y			**10**	**5**	**8**	***23***
	N			**2**			***2***
LP	Y			**2**	**2**	**7**	***11***
	N	**3**	**3**	**3**	**1**		***10***
RB	Y			**4**	**1**	**12**	***17***
	N			**1**	**3**		***4***
AG	Y			**3**		**7**	***10***
	N	**3**		**8**	**1**		***12***
EF	Y		**1**	**3**	**2**	**10**	***16***
	N	**1**		**2**	**3**		***6***
HO	Y			**3**	**3**	**9**	***15***
	N	**4**		**6**			***10***
KL	Y			**7**	**3**	**2**	***12***
	N	**2**	**2**	**6**	**3**		***13***

Note: when answer was not located (N), *Automatic* strategy could not be counted by definition, due to the nature of the search strategy, that the answer *was found* within three fixations. When answer was located (Y), *None* strategy could not be counted by definition, since less than three fixations were made on the text. If the participant did fixate three times or less, yet located the answer, then this was deemed use of *Automatic* search strategy.

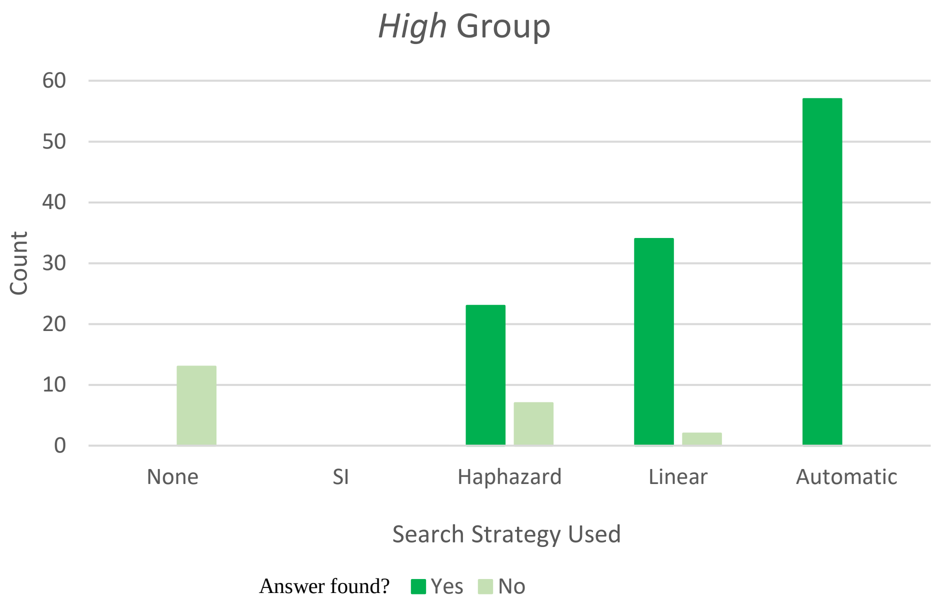


Figure 16. High Group - Frequency of Answer Locating Search Strategies Used.

Figure 16 shows the collective group frequencies for each search strategy used by students with high reading competence. The *Automatic* strategy was the dominant strategy used by this group (count = 57), indicating they were able to locate answers quickly and efficiently on 42% of trials. This may have been affected by the quicker reading times of this group, resulting in shorter latencies between the Reading Phase, where information from the passage was first accessed by these students, and the Question Phase, where these students were asked to recall this information (by answering questions). If this is true, and students were able to recall information, or at least recall where this information was located, they still demonstrated a preference to locate the answer and confirm what they may or may not have already known. This is also evident through the relatively low count for the *None* strategy, which by its definition means the answer was not found when using this strategy. Use of the *None* strategy implies students guessed or recalled the answer without searching for it because they made three or less fixations to the text overall. Participants in the *High* group located the answer more often than they guessed without accessing the text at all.

The *Linear* strategy was the second most preferred strategy (count = 36), closely followed by the *Haphazard* strategy (count = 30). While both *Linear* and *Haphazard* strategies yielded success in locating the answer, the *Linear* strategy was more successful (*Haphazard*: 77% success rate; *Linear*: 94%), which could be why it was used more by these students when answer location was not immediately recalled. While pictures and graphics were gazed upon by these students when answering questions, these students also gazed upon the text regions. To be counted as using the *SI* strategy, pictures and graphics were to be gazed at exclusively with ≤10 fixations made to the text; hence, the *SI* strategy was not used by any student in the *High* group. They preferred to search the text to inform their answer, and may have gazed upon SI to supplement information from the text only, rather than use SI primarily to answer questions. Comparative search strategies of the *Low* Group are presented in Figure 17, below:

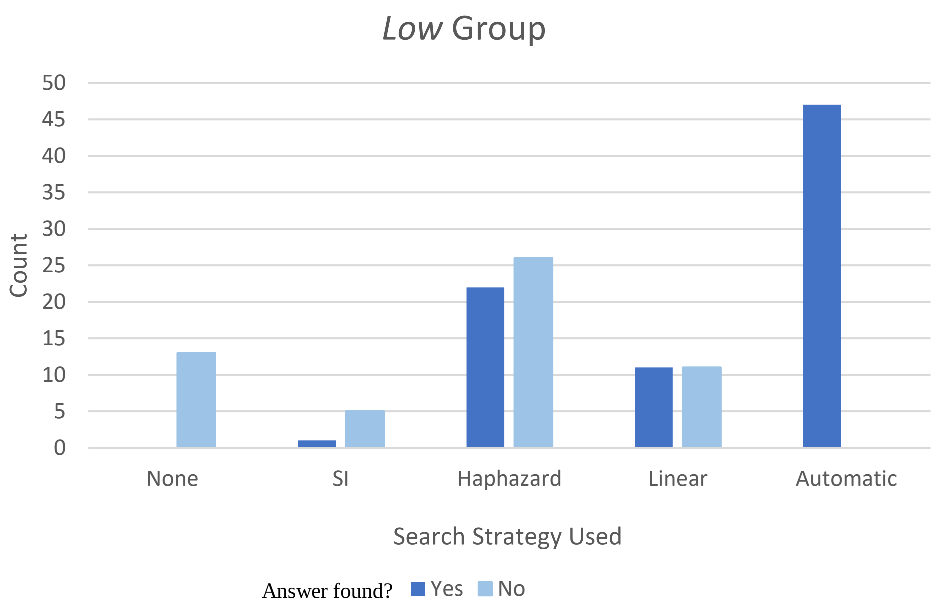


Figure 17. Low Group - Frequency of Answer Locating Search Strategies Used.

Interestingly, the *Low* group also preferentially used the Automatic search strategy (count = 47), suggesting that these students were also able to locate the answer quickly and efficiently on 35% of trials. The breakdown of percentages for each strategy used per group is presented in Table 14.

Table 14. Percentages of Answer Location Search Strategy Use per Group

Search Strategy	**High Group**	**Low Group**
None	10%	10%
SI	0%	4%
Haphazard	22%	35%
Linear	26%	16%
Automatic	42%	35%

Such frequent use of the *Automatic* search strategy by the *Low* group is a surprising result: this implies that the slower reading times of this group, and therefore longer latencies between Reading and Question phases, does not greatly affect the ability of these students to recall where the answers are located within the text. Similarly, their rates of using *None* as a strategy i.e. not accessing the text during question answering, are equal to that of the *High* group, suggesting that these students are attempting to locate answers to the same degree as the *High* group. In actuality, the *Low* group preferred the *Haphazard* search strategy (count = 48) to the *Linear* search strategy (count = 22), yet both strategies yielded chance or less-than-chance success in locating the answer (*Haphazard*: 46%; *Linear*: 50%). A possible explanation for this difference in search strategy preference for the *Low* group, when the *Automatic* strategy fails, is explored in Table 15 below.

Table 15. Average Duration of First Fixation to Answer

Student	Haphazard	Linear	Automatic
ZC	1.33*	3.59	0.55
IG	1.82	2.01	0.23
LP	1.99	2.32	0.94
RB	1.83	5.25*	0.18
MI	3.31	4.88	0.64
JC	4.93	2.96	0.48
AG	4.40	n/a	0.05
EF	2.71*	12.57	0.30
ER	1.36	2.48	0.62
ZI	4.22	2.09	0.40
HO	4.01	3.29	0.19
KL	5.22	3.24	0.07
High	2.83	3.00	0.49
Low	3.36	5.33	0.29

Note: n/a is listed when a student did not use that strategy. Averages marked with a * indicate these values are based on one occurrence only. Shaded rows indicate student belongs to *Low* group, and unshaded indicates student belongs to *High* group. EF is the sole participant to use SI strategy and successfully locate answer. The duration to first fixation on answer for SI search strategy was 10.88.

Table 15 displays the average duration for each participant to first fixate on the answer, by each search strategy used. *SI* was omitted from this table as this strategy was used to successfully locate the answer on only one occasion, and resulted in a long duration of 10.88s. Group averages for each search strategy are also provided. As expected, the *High* group had faster answer location times than the *Low* group when using the *Haphazard* and *Linear* search strategies, yet the *Low* group were faster at locating the answer using the *Automatic* strategy, or when they could recall answer location. The most notable difference in this table is the *Linear* search strategy times between groups: whereas it took students with high reading competence 3.00s on average to locate an answer, it took the students with low reading competence 5.33s on average. Considering the slower reading rates of the *Low* group helps to make sense of this difference, as the *Linear* strategy essentially involves re-reading text, as it appears, from left to right. It seems that using *Linear* was more effortful in the *Low* group, and hence these students preferentially used the *Haphazard* strategy, which requires less effort. The *Haphazard* strategy relies more on random chance, rather than on skill, in locating the answer, as the text is gazed at and searched in an arbitrary manner. If success of the *Haphazard* strategy revolved entirely around chance, the *High* and *Low* groups would be expected to demonstrate similar rates of effectiveness when using this strategy, however the *High* group had 77% success when using this strategy (see Table 16 below). Reasons for this difference require further investigation.

Table 16. Success Rates of Search Strategies in Locating Answers

Search Strategy	**High Group**	**Low Group**
Haphazard	77%	46%
Linear	94%	50%

While poorer decoding skills could be argued to explain why the *Linear* strategy was less effective when used by the *Low* group (50% success) compared to the *High* group (94% success) in locating answers, this explanation alone does not suffice. Students with low reading competence tended to exhibit inefficient use of the *Linear* search strategy. This is evident in Figure 18 below:

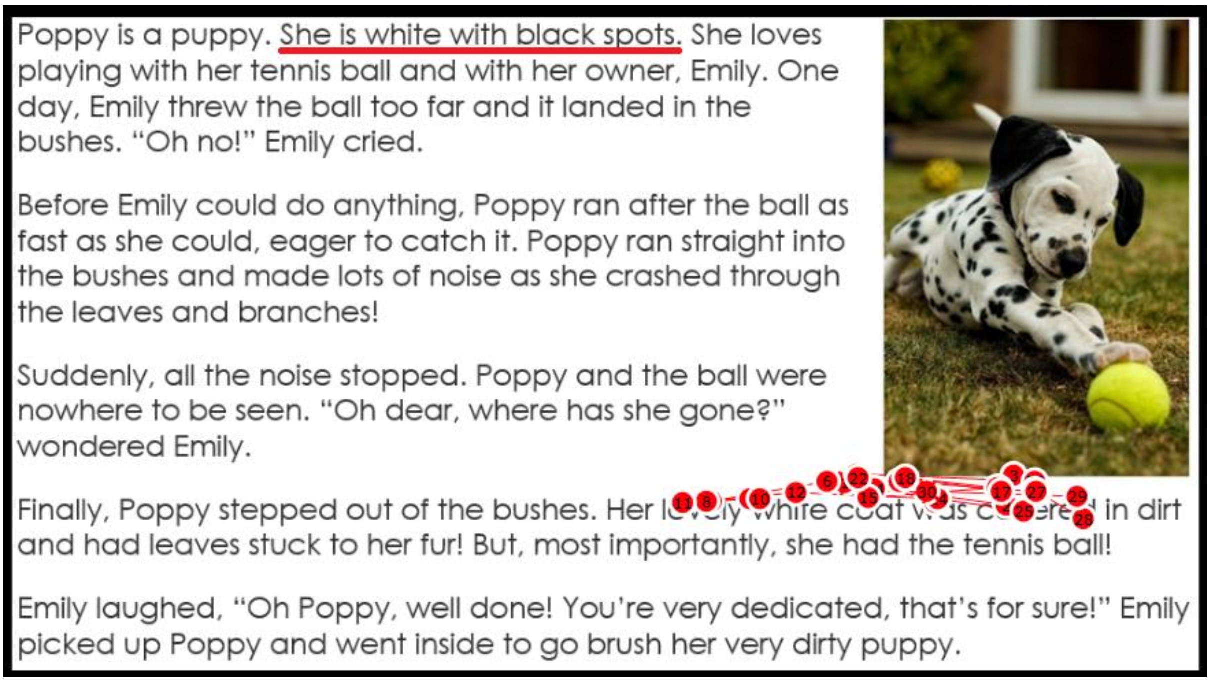


Figure 18. AG gaze for G3-4 text Poppy the Puppy. Answer is underlined in red. AG fixates (count = 30) on five words using Linear search strategy. Answer is not located. Question: "Poppy is white with ___ ___" (fill in the blank).

When using the *Linear* search strategy, students with low reading competence tended to gaze at limited areas of text, for example, they gazed upon or re-read one or two sentences of a paragraph. If the answer was not contained within this section, instead of shifting gaze away from this section, they would make a regression back to the beginning of the initially fixated area, and re-read the same text portion again. Due to not "moving on" in the same linear fashion, this restricted behaviour resulted in failing to locate the answer. In this example AG has found the word "white" (a word within the answer portion) yet has disregarded other parts of the text where the word "white" appeared – this may be because it is too effortful to search the text and so AG treated this sentence as the answer portion. This failure of the *Linear* strategy coupled with weaknesses in decoding skills, may result in linear search behaviour being punished in students with low reading competence, hence the low rates of use.

6.6.3.1 Remarks on Search Strategies

Both groups exhibited similar usage rates of the *Automatic* strategy, implying that being permitted to read the text once before answering questions creates an overall representation of the text, helping to guide the search for information in the question-answering process. In studies where advance reading of text was not permitted, students mainly focused on the information related solely to the questions and disregarded the rest of the information in the text (Cerdán et al., 2009). During skilled reading, incidental recall of locative information occurs and this is thought to be independent of comprehension – adults can often remember *where* information is located, even without remembering the content of what was read (Cataldo & Oakhill, 2000). However, telling participants the location of information does not help them recall the content of the text – hence locating an answer alone is necessary, but not sufficient for comprehension, and students should be encouraged to re-read the answer, as well as contextual information in the immediate vicinity of the answer, to better understand the text. These skills are considered more extensively in later sections (see sections 6.6.5 and 6.6.6 below).

Although memorisation of answer location has been reported in adults, in the current study, all primary-school-aged participants were observed to remember *where* answers were located – even the *Low* group did this on 35% of questions, evident through their use of the *Automatic* strategy. Participants with low reading competence appeared to struggle on the occasions when they did *not* recall answer location immediately, and either demonstrated inefficient use of *Linear* strategy, or avoidance of this technique.

An explanation for this decreased frequency of the *Linear* search strategy can best be conceptualised through Response Efficiency (RE) (Horner & Day, 1991). RE is examined in terms of three variables: (i) physical effort, (ii) rate of reinforcement, and (iii) time delay between presentation of the discriminative stimulus and reinforcer delivery. Behaviours compared on RE must have functional equivalence i.e. under control of the same antecedent stimuli and consequences, with one behaviour replacing the other typically because it is more efficient. For example, reading aloud and reading silently may both serve as a response that results in automatic reinforcement (stimulation from reading). Reading silently however may be more *efficient* if it requires less effort than reading aloud, did not result in reprimands from other people sharing public spaces (which may not be the case for reading aloud), and the individual can read more words silently than they can aloud in a given time. Reading silently, therefore would increase under these circumstances and reading aloud would be expected to decrease. Horner and Day (1991) documented the role of RE for problem behaviour maintained by escape, and were unsure whether this would generalise to behaviours maintained by automatic, social, or tangible reinforcement, however, RE holds for the following example. The *Linear* and *Haphazard* search strategies are both members of the same response class: their function is to locate an answer (tangible-mediated reinforcement). They are both under control of the same antecedent: question asking. Yet the *Haphazard* search strategy is exhibited more often than the *Linear* strategy for those in the *Low* group.

Physical effort. Consider that since the *Automatic* strategy has not been used, it can reasonably be assumed that the student has not recalled answer location and hence commences her scan. Since students in the *Low* group have poor decoding skills, the *Linear* strategy involves a greater amount of physical effort, since the students are systematically gazing from left to right, top to bottom, to find the answer. It is assumed these students are reading words they gaze upon to check their relevance to the answer being searched for. The *Haphazard* strategy on the other hand involves low physical effort, as the student is trying to "get lucky" by gazing upon the answer by chance and minimising the amount of decoding involved. There is no system involved and the student may even gaze upon the same word multiple times, yet do not check word-by-word, line-by-line.

Rate of Reinforcement. After using the *Linear* strategy, participants in the *High* group were reinforced for this behaviour on an almost continuous, 1:1 schedule, however this behaviour (locating the answer) was reinforced only 50% of the time for participants in the *Low* group. Participants in the *Low* group demonstrated ineffective use of this strategy, by only gazing at a limited portion of text, a problem which may be compounded by their poor decoding skills. The *Haphazard* strategy was less likely to be reinforced for both groups, however for the *Low* group this value (46%) was almost equal to the rate of reinforcement for using the *Linear* strategy. Therefore, both strategies are reinforced at a similar rate.

Time delay. The time delay between presentation of the discriminative stimulus (i.e. text shown again on display monitor) and reinforcer delivery (i.e. finding the answer) of each search strategy was calculated by taking the group average of the time to first fixation on the answer. For the *Low* group, the *Linear* strategy yielded the answer on average after 5.33s, and the *Haphazard* strategy after 3.36s, thus using the *Haphazard* strategy resulted in the *Low* group finding the answer more quickly. This probably reflected the poor use of *Linear* by this group, rather than the efficient use of the *Haphazard* strategy, since the latter relies mostly on luck. In comparison, the *High* group exhibited similar time delays (*Haphazard* = 2.83s, *Linear* = 3.00s), and resulted in an almost even split between using the two strategies. The RE results are summarised in Table 17 below:

Table 17. Response Efficiency of Linear and Haphazard Search Strategies for Students with Low Reading Competence.

Response Efficiency Measures	**Linear**	**Haphazard**
Physical Effort	High	Low
Rate of Reinforcement	50%	46%
Time delay (between discriminative stimulus and reinforcement	5.33s	3.36s

Based on the data above, for participants in the *Low* group, the *Haphazard* search strategy was a more efficient response than the *Linear* search strategy, hence it was exhibited more frequently by these students. Since the *Linear* strategy is the most effective strategy at locating answers when the answer location is not recalled, students with poor comprehension skills need to be explicitly taught this skill. In order to make the *Linear* strategy more efficient, students must improve their decoding skills;

as decoding becomes more fluent, the physical effort involved and the time delay from discriminative stimulus to reinforcer will be reduced. Similarly, these students need to be taught how to examine text in a systematic way, in its entirety instead of in portions. Using an errorless teaching strategy to do so will ensure students receive a denser rate of reinforcement i.e. locating answer on every occasion, which will lead to an increased frequency of this behaviour.

6.6.4 Partial Answers

Partial answer locating, where at least one fixation was made on the answer, but on less than 50% of the words in the answer string, was observed twice as much for the *Low* than the *High* group, which is summarised in Table 18 below.

Table 18. Comprehension Accuracy when Answers were Partially Located – All Question Types

Competence Group	**Questions Answered Correctly**	**Correct Marks**
High	4/7 (57%)	10/14 (71%)
Low	1/16 (6%)	10/31 (32%)

Denominator indicates the number of occasions an answer was located partially, and numerator indicates questions answered correctly when answer was partially located.

Table 18 shows that for participants in the *Low* group, partial answers were found on 16 occasions, and only seven occasions for participants in the *High* group. This was the case for ZC (*High*) who found a partial answer only once, and RB (*Low*) who found a partial answer four times. The higher frequency of partial answers for the *Low* group indicates that after these students gazed upon part of the answer, they did not identify the gazed-upon words as relevant to the question being asked, and continued their search, rather than fixating on the whole answer. When students with high reading competence first gazed at the answer, usually they stopped their search, which was evident from a greater concentration of fixations around the answer portion, and generally reading from left to right (see Figure 19 below).

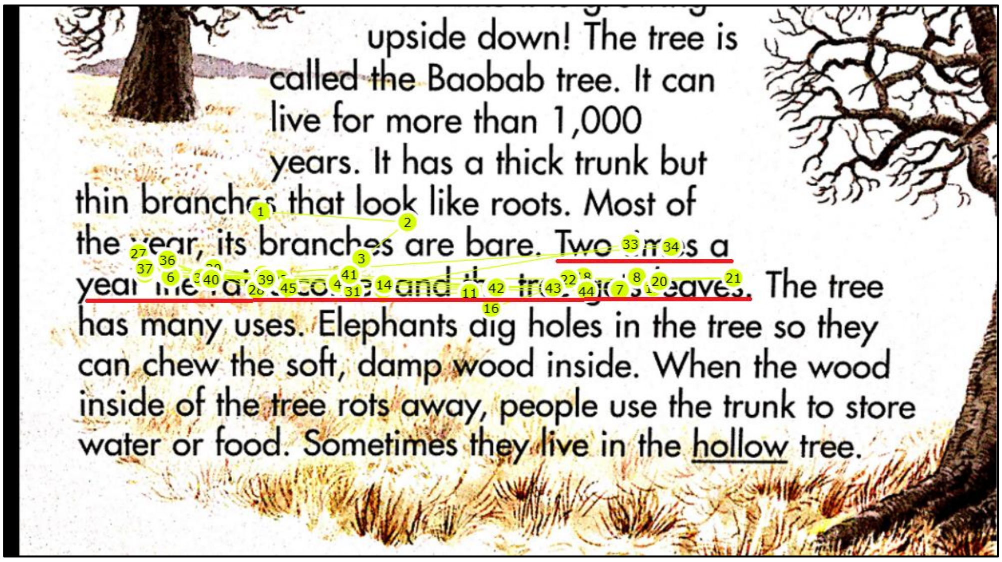


Figure 19. ZC gaze on G1-2 text Baobab Tree.
Answer underlined in red. Once answer is gazed upon (fixation 3), ZC's gaze moves forward and back over the answer, fixations cluster around answer area (45 fixations made).

When students with low reading competence partially locate an answer, despite fixating upon the answer, they tended to continue to search using the *Haphazard* strategy. This was evident in students' gaze shifting to a new line of text, rather than continuing to fixate on the answer or surrounding text. Another behaviour evident in students with low reading competence was after first gazing at the answer portion, they restricted fixations to only a part of that sentence, and did not continue to make fixations to the right i.e. they did not continue to read (see Figure 20 below).

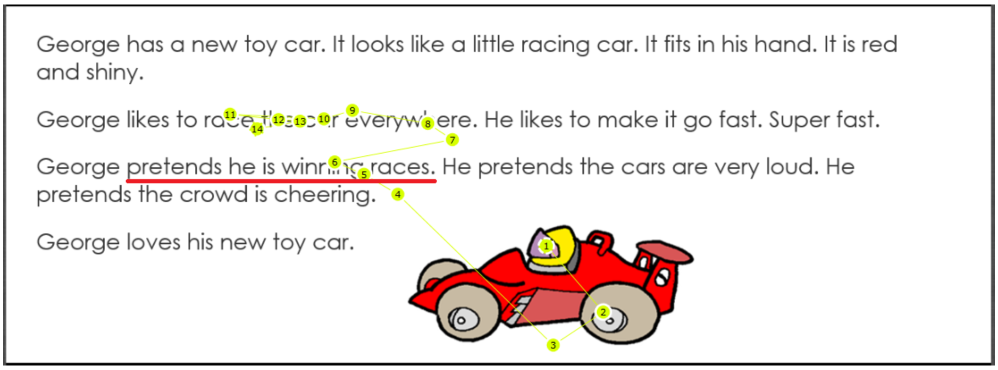


Figure 20. RB gaze on G1-2 text George's Car.
Answer underlined in red. Once answer is gazed upon (fixation 5), RB shifts gazes to line above, fixations clustered away from answer (14 fixations made).

Importantly, despite participants answering an equal number of questions, those in the *Low* group found partial answers twice as often as the *High* group. However, when an answer was partially found, the *High* group answered these questions correctly 57% of the time, compared to the *Low* group who only answered 6% of the questions correctly. This indicates that unless students with low reading competence located an entire answer, they were relatively poor at correctly answering that question. While they may have obtained partial marks for a question, they miss the "bigger picture" needed to understand the text in full. Students with high reading competence may be compensating for partially located answers by using other gaze behaviours identified in this study, which will be discussed in a later section (see section 6.6.6).

6.6.5 Re-reading

Table 19. Answers Re-read by Participant

Student	Did student re-read?		% of Answers re-read	Total	Average
	Yes	No			
ZC	3	9	25%	5	1.67
IG	10	9	53%	20	2.00
MI	14	7	67%	40	2.86
JC	15	5	75%	32	2.13
ER	11	7	61%	27	2.45
ZI	15	7	68%	35	2.33
LP	6	5	55%	16	2.67
RB	5	12	29%	8	1.60
AG	3	7	30%	6	2.00
EF	5	11	31%	8	1.60
HO	5	10	33%	12	2.40
KL	6	6	50%	9	1.50

Note: For "Total" and "Average" columns values refer to the count of re-reading behaviour i.e. IG re-read the answer 20 times. She exhibited this behaviour in 10 passages ("Yes" column).

Table 19 displays the frequency count of answers re-read, once located by participants, as well as the proportion of answers where the answer was re-read to where it was not i.e. located yet read once only. The total number of times each participant re-read answers across all passages is listed under "Total", as well as the average number of times a single answer was re-read, when re-reading occurs for a question. The average count for re-reading varied minimally across all participants (range 1.50 to 2.86 re-reads per answer). Participants varying in reading competence level did not appear to vary in the amount of times they re-read an answer, when re-reading occurs. However, as indicated by the data, and shown below (Figure 21, Figure 22, and Figure 23), students with high reading competence re-read the answer more times overall.

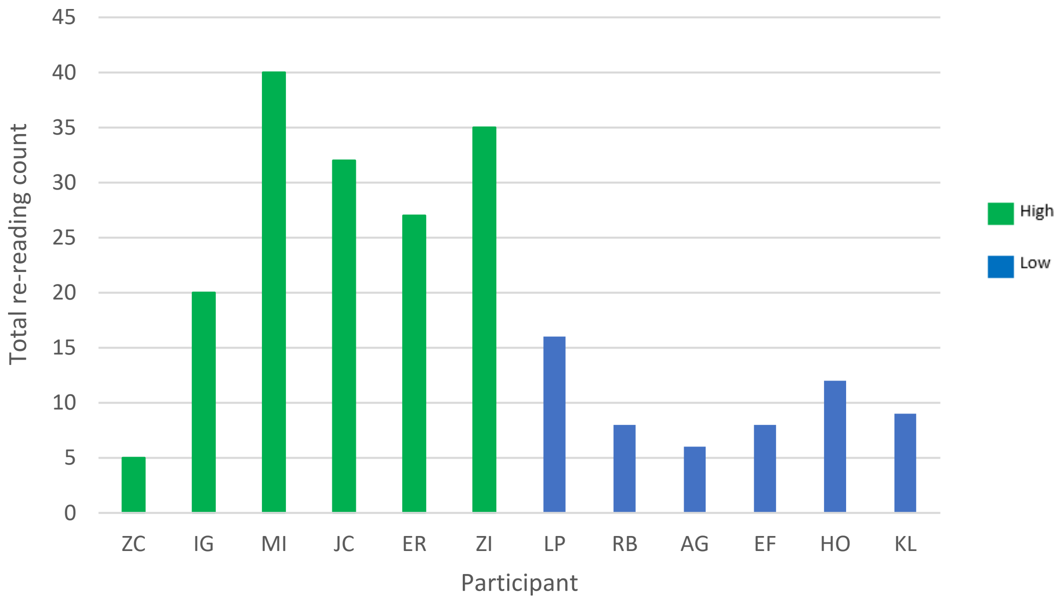


Figure 21. Total number of re-reads, per Participant and Group.

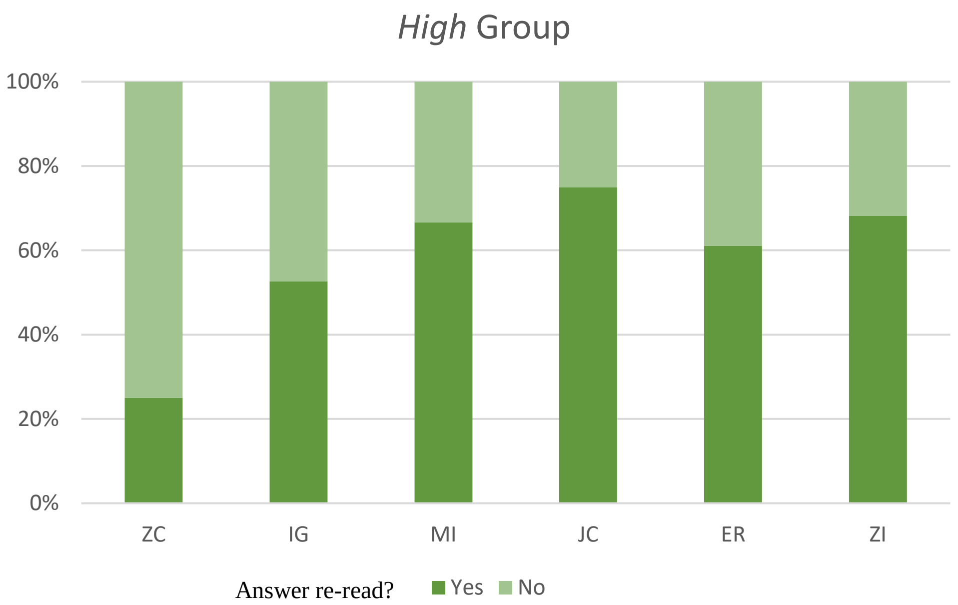


Figure 22. High Group - Proportion of Answers Re-read.

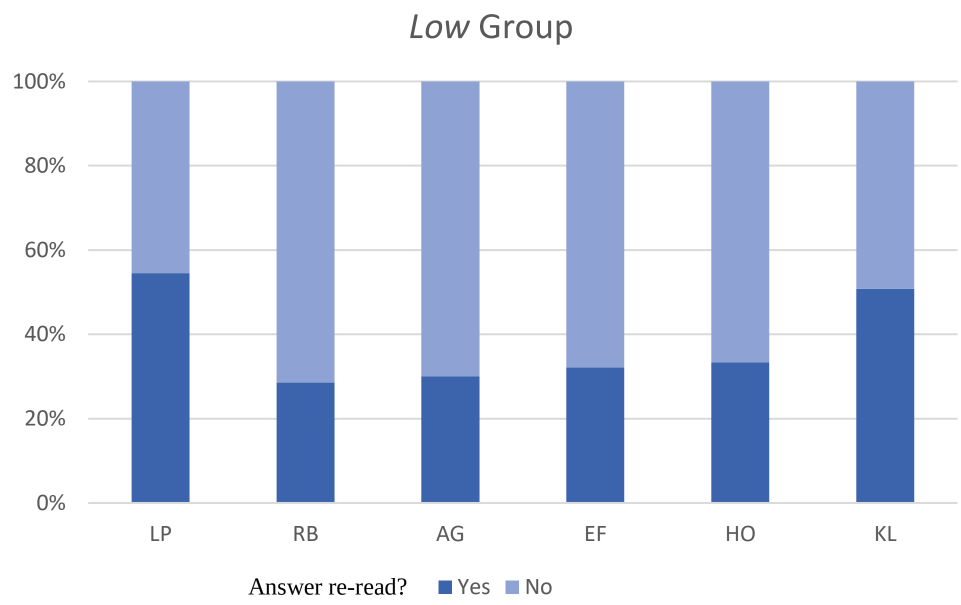


Figure 23. Low Group - Proportion of Answers Re-read.

This means that students with high reading competence engaged in re-reading proportionally more than students with low reading competence, although when re-reading occurred, all students tended to re-read the answer between one and two times. Logically therefore, students in the *High* group engaged in this process of re-reading at a higher rate, and re-read more answers, more often. The relationship between re-reading and comprehension accuracy is summarised in Figure 24:

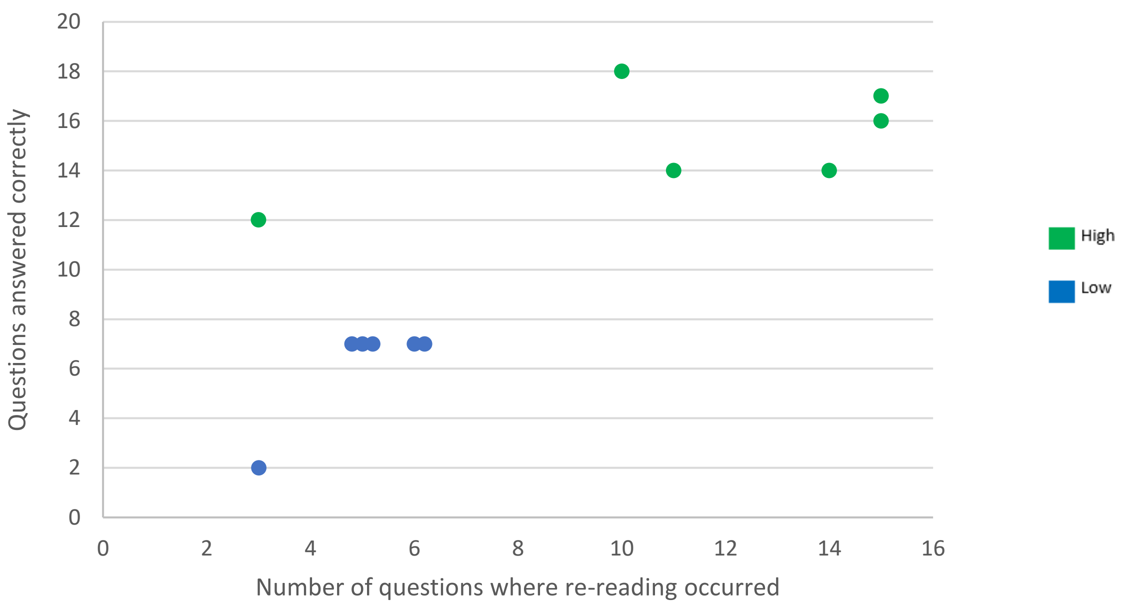


Figure 24. Scatterplot of Comprehension Accuracy and Re-reading

Figure 24 shows the two groups, *High* and *Low*, as distinct clusters, with participant ZC (3, 12) as an outlier (low re-reading, high comprehension accuracy). The group differences in this scatterplot appear quite distinct – the low group re-read less, and had lower comprehension accuracy, and the *High* group re-read more with high comprehension accuracy. Several gaze behaviours have now been identified that appear to facilitate comprehension – answer locating, use of gaze strategy to locate answer, and re-reading are all associated with higher comprehension scores. However, causation cannot be inferred. It is possible that students with high reading competence simply re-read more often, yet without impact on their understanding of text. The association between re-reading and comprehension accuracy is broken down further in Figure 25.

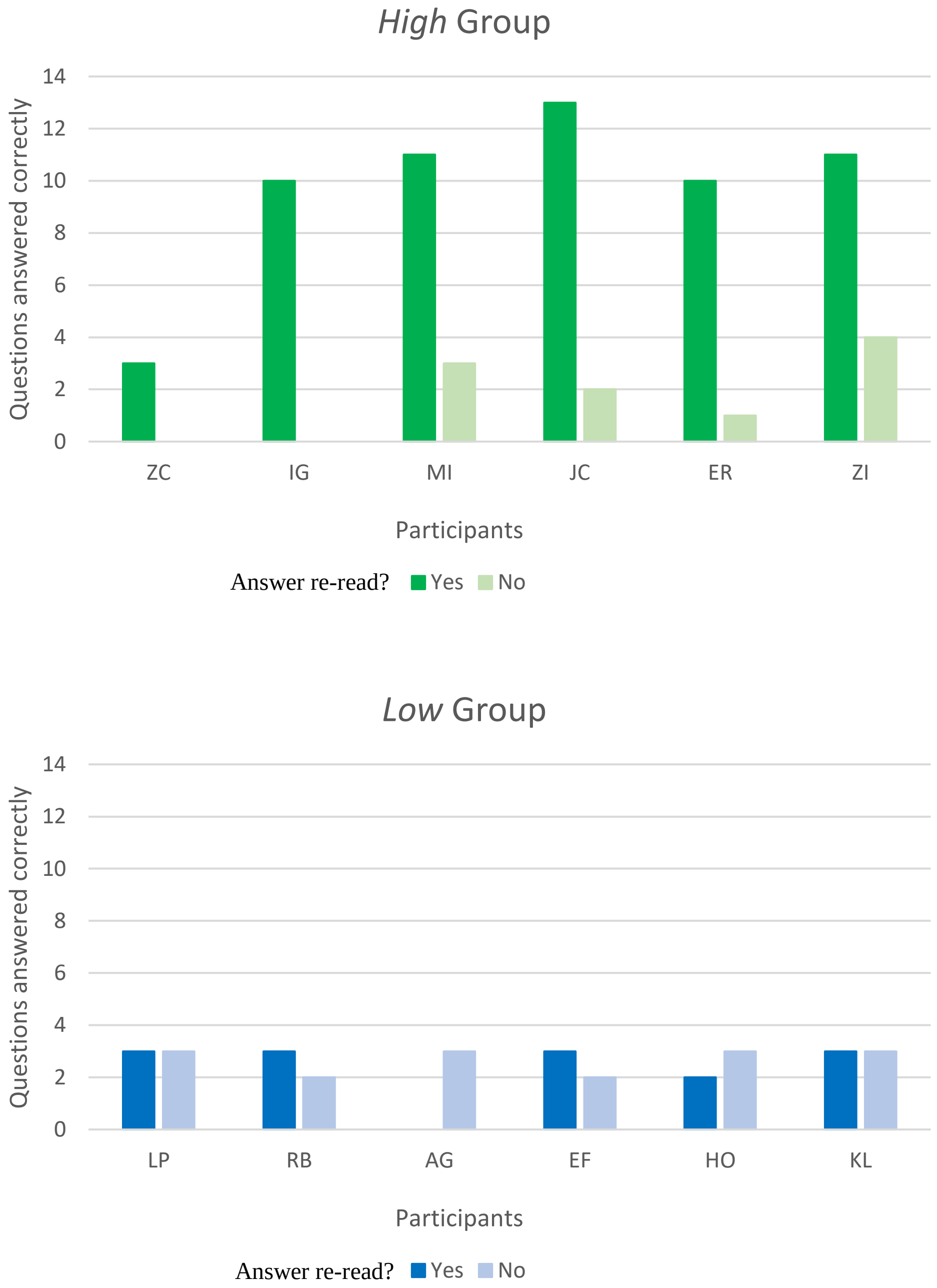


Figure 25. Re-reading Rates during Correct Answers.

What Figure 25 helps to illustrate is that for the *High* group, re-reading was mostly associated with more correct answers. In fact, for two of the *High* group participants, ZC and IG, on every occasion where they re-read the answer at least once, they answered the question correctly. Such a pattern did not hold for the *Low* group: re-reading did not seem to be associated with comprehension accuracy, where most of the participants in this group scored at or around 50% accuracy after re-reading the answer portion. This is an interesting finding, as within the literature, re-reading receives little support and is considered a passive strategy which minimally aids comprehension. For students with low reading competence, this may be true, however for students with high reading competence, re-reading the answer portion appears to facilitate comprehension accuracy. A reason for this discrepancy in the usefulness of re-reading between groups may lie in the text portions surrounding the answer. It could even be possible that as students become more competent readers, they re-read text more often to check their understanding, and the increase in checking also results in an increase in reading competence. Certainly, for students with low reading competence, like using the *Linear* search strategy, re-reading the answer portion is a cognitively demanding task and so occurs less.

6.6.6 Scans Text Before and After Answer

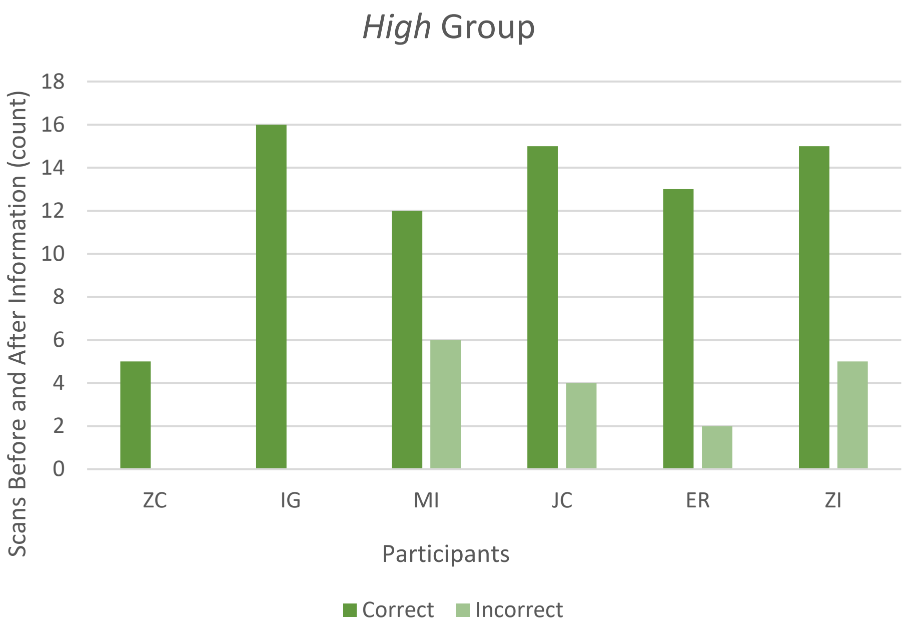
In addition to re-reading the answer, reading or scanning the text portions directly adjacent to the answer portion: that is, the information immediately preceding and following the answer was another behaviour displayed by students with high reading competence in the task analysis. Table 20 displays whether either information before the answer, after, or both, was visually scanned by the participants ("Yes"), or whether these text portions were not gazed upon ("No").

Table 20. Frequency Count of Scanning Before and After Information

Student	**Count**		**%**
	Yes	**No**	
ZC	5	7	42%
IG	16	3	84%
MI	18	3	86%
JC	19	1	95%
ER	15	3	83%
ZI	20	2	91%
LP	6	5	55%
RB	11	6	65%
AG	4	6	40%
EF	12	4	75%
HO	7	8	47%
KL	5	7	42%

Note: Shaded rows indicate *Low* group; unshaded rows indicate *High* group.

For the *High* group, five out of six participants exhibited this gaze behaviour over 80% of the time after locating the answer; ZC, again, demonstrated low rates of this strategy, providing further evidence to his "outlier" status within this data set. The average proportion of scenes where this strategy was used was 80% for the *High* group, as compared to the *Low* group with an average of 54%. From the *Low* group, EF (75%) and RB (65%) showed higher rates of scanning before and after information than they did re-reading, and the following analysis (see Figure 26) was completed to evaluate whether this strategy also facilitated comprehension accuracy.



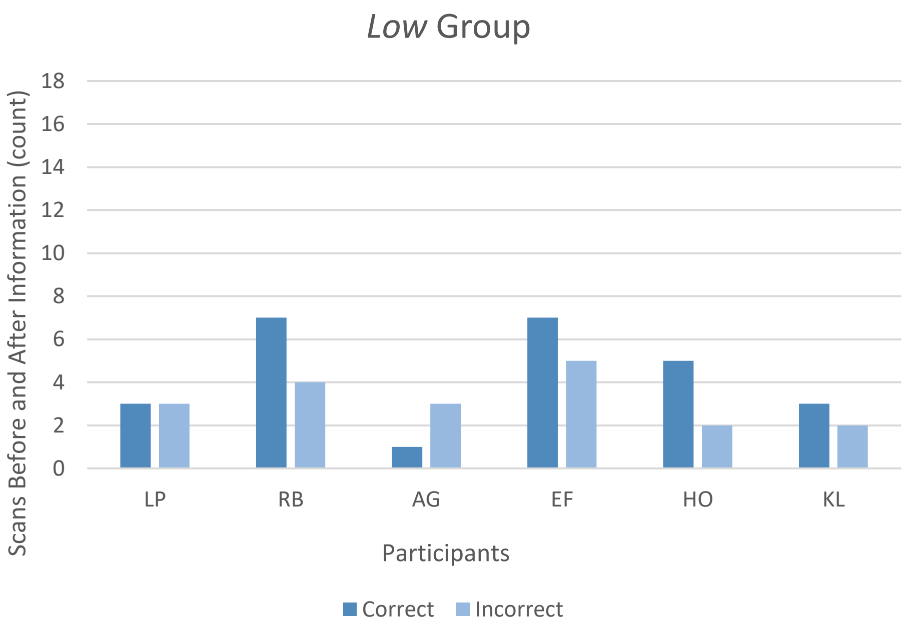


Figure 26. Frequency of Scanning Before and After Information for Correct and Incorrect Question Answering

As expected, the *High* group, who exhibited this behaviour more often, also were accurate in their comprehension more often than the *Low* group. Overall, participants in the *Low* group had more success in answering comprehension questions when they scanned information before and after the answer, than they did when re-reading the answer. A reason for this result could be that by scanning or re-reading information before and after the answer, participants obtained contextual information. For example, in the G1-2 text the *Baobab tree*, a question was "What does the word 'hollow' mean in the passage?" For a student to re-read the word "hollow" as it appeared in the text over and over would not help them understand its meaning, yet reading the preceding sentences i.e. "…people use the tree to store water and food. Sometimes they live in the hollow tree." may provide a contextual clue that to be hollow, might mean to possess a hole or empty space. Participants often encountered questions about the meaning of words, as they were frequently asked in the WIAT-II passages. A noteworthy finding was the comprehension performance of participants RB and EF, who both correctly answered seven comprehension questions when they scanned before and/or after information. As discussed earlier, these two participants had the highest rates of scanning before and/or after information behaviour in the *Low* group, thus providing preliminary evidence that this strategy is helpful in facilitating understanding of text, perhaps through provision of contextual information and cues. What may be interesting to investigate is whether using both strategies of re-reading and scanning before and after information, together, would result in better understanding of text, or whether re-reading is only valuable to the reader if he has first obtained contextual information.

Chapter 7: General Discussion & Conclusion

The final chapter has been written to summarise and synthesise the findings of the Empirical Study, and to discuss the practical implications arising from the findings. The chapter then discusses considerations of this study, its limitations, and suggestions for areas of future research. Finally, this chapter concludes with a summary of the entire thesis.

7.1 Synthesis of findings from Empirical Study

Eye gaze behaviour of primary school students with and without ASD during reading and question-answering tasks was measured using eye-tracking technology. Students with ASD exhibited longer mean fixation durations on text during question answering, however these longer durations did not impact upon their comprehension accuracy. This finding highlights that a shift from a deficit-focused conceptualisation of this population is needed as, in spite of different gaze behaviour, a universal reading deficit did not exist for those with ASD. Time restrictions in examination or test settings may negatively affect the ability of students to ASD to decode/read text, and comprehend what they are reading, and therefore provision of extra time is recommended in such situations.

A focus of the empirical study was to identify those gaze behaviours both necessary and sufficient in answering questions successfully, rather than the sequence of behaviours, as this was observed to differ amongst the observed individuals. Gaze to Supplementary Information (SI) did not appear to facilitate comprehension accuracy, rather, it can be seen to reflect difficulty in reading or a lag in the development of fast-mapping abilities. In the current study, younger students with poorer reading competence spent more time gazing at pictures than those with skilled reading competence, but students in middle and upper primary grades seemed to engage in similar rates of gaze to SI (levels similar to younger students with poor reading competence), irrespective of their level of reading competence.

Locating answers within text is a necessary, but not sufficient, skill for comprehension. In the present study this skill was associated with answering questions correctly, regardless of whether the question was text explicit or implicit (Pearson & Johnson, 1978), and preliminary evidence exists for its status as a behavioural cusp, leading to the development and use of other gaze skills, such as re-reading and scanning information preceding and following the answer. The contingencies surrounding gaze behaviour during reading are summarised in Figure 27 and Figure 28 below. Locating answers is thought to be a separate process from reading comprehension, and therefore can be targeted by remedial programs and educators with the view of improving comprehension skills.

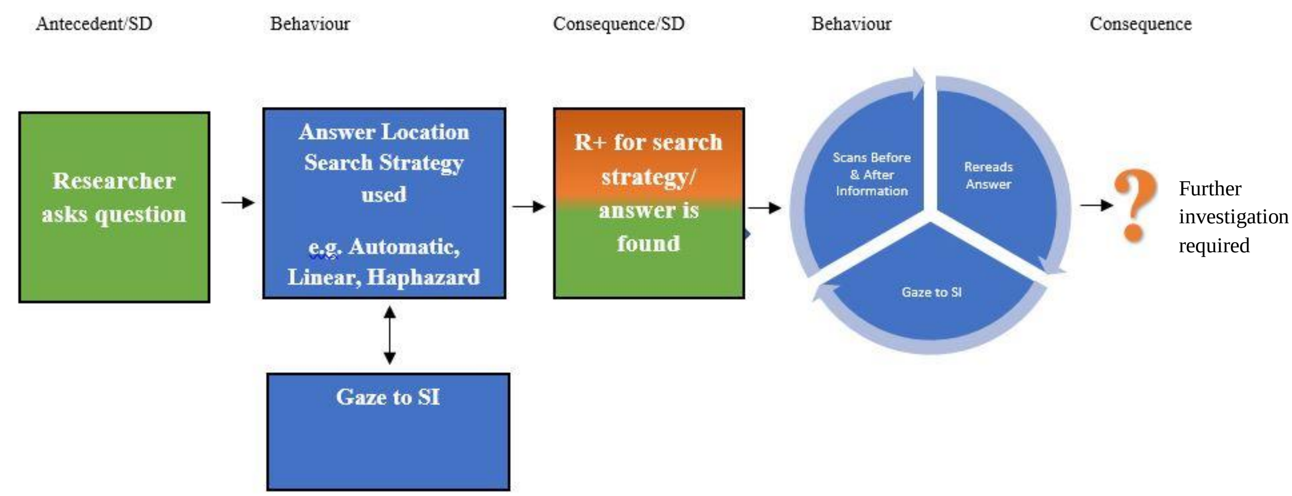


Figure 27. Contingency map - successful answer location

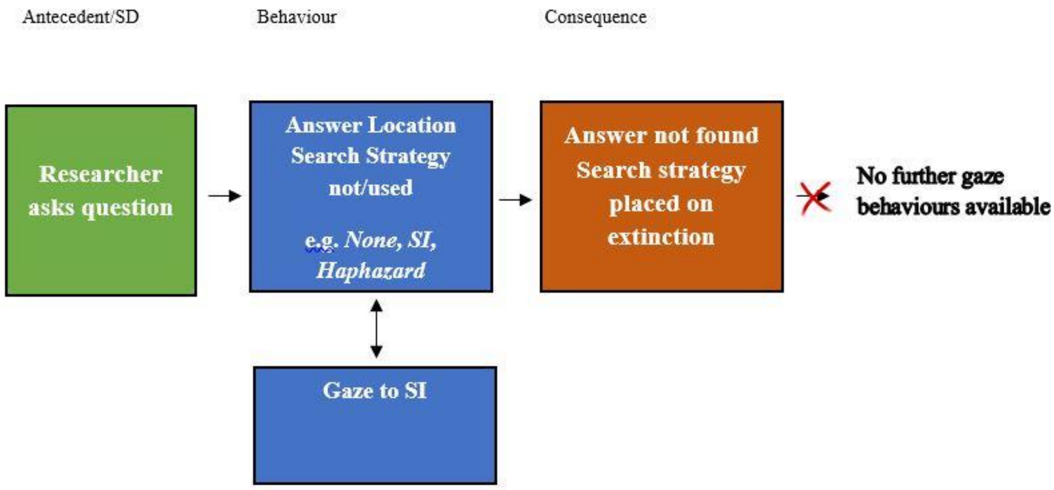


Figure 28. Contingency map - failed answer location

The skills of re-reading and scanning information preceding and following the answer only became available to the student once the answer was located, and use of these two strategies was associated with better comprehension accuracy. However, further investigation is needed to better understand the underlying mechanisms of these gaze skills. The number of times an answer was re-read did not affect the likelihood of comprehension accuracy, yet those who re-read the answer proportionally more (on more occasions), or displayed this skill more consistently answered more questions accurately. For participants in the *Low* group, scanning information preceding and following the answer resulted in improved comprehension accuracy more than when the answer was re-read. These two skills may be interdependent and have overlapping components, and therefore a component analysis is recommended to further our understanding of the relationship between the two and how their use can improve students' understanding of text.

All students in this study, regardless of their reading competence, demonstrated recall of answer location, and were able to orient gaze to that location automatically (within three fixations) on at least one-third of opportunities. For students with low reading competence, when answer location was not recalled i.e. the *Automatic* search strategy could not be used, they tended to exhibit the *Linear* search strategy in a faulty manner or not at all. Response efficiency (RE) was measured for the *Linear* and *Haphazard* strategies, with the *Haphazard* strategy rated as a more efficient response for the *Low* group: therefore, students with low reading competence selected this strategy and other ineffective strategies i.e. *SI*, over the *Linear* strategy.

7.2 Implications

There are three notable implications arising from the present study. Firstly, for students with low reading competence, improving decoding skills should be the focus of intervention and remediation. While it is not within the scope of this thesis to address evidence-based interventions for decoding remediation, the benefits of improved decoding skill on reading comprehension, and the proficiency of reading-related gaze skills, are invaluable. As reading is a complex performance requiring simultaneous coordination across many tasks, execution of component skills must be instantaneous (Fuchs et al., 2001). Fluent decoding skills lead to short inter-response times between reading of individual letters and words, allowing students to preserve gestalt and meaning of text during reading, as well as the efficient use of the *Linear* search strategy during question answering. Improvements in decoding skill would reduce the response effort involved in using the *Linear* strategy to systematically search text for the answer, thereby improving the efficiency of this behaviour by reducing time between presentation of the discriminative stimulus and reinforcer (locating answer). Hence, the *Linear* strategy would become a viable, functional replacement behaviour competing for selection with the *Haphazard* strategy, which in this study was preferred by students with low reading competence. Fluent decoding would relieve pressure on older students in timed examinations, who can therefore focus more on understanding meaning and content. Similarly, for younger students, this may result in decreased gaze to SI and increased gaze to text, and encourage development of fast-mapping abilities to learn new orthographic word forms.

Secondly, once decoding ability improves and becomes more fluent, educators can explicitly teach students with low reading competence effective use of the *Linear* search strategy. While highly skilled readers appear to exhibit this skill without formal instruction, poorly skilled readers demonstrate inefficient use of this skill; they examined only a narrow portion of the text and thereby failed to locate the answer on more than half of occasions when this strategy was employed. Educators are encouraged to use errorless teaching, a teaching procedure in which the student is prompted prior to the response, so that a correct response is made by the student each time i.e. successfully locates answer. Most-to-least prompting is recommended for use by the educator in order to promote accuracy with the least possible amount of errors (and associated frustration), with prompts to be gradually faded. Students would be instructed to point at the words matching their gaze location, and scan left to right, line by line, as if reading. The educator would begin teaching by providing a visual prompt e.g. highlighting/underlining the answer, and as the student begins to gain competence in this skill, remove the visual prompt and instead provide a gestural prompt. If the student continues to shift gaze after locating the answer i.e. make errors, then educators may be required to use a verbal prompt to pre-correct the student.

Thirdly, eye-tracking was useful in identifying strengths and weaknesses of students with high and low reading competence during comprehension tasks. Not only does eye-tracking have utility in exploring and identifying gaze behaviours in visual tasks requiring fine detail, such as reading or visual search, but could also be adapted for use in intervention. Such an intervention could be integrated within a computer program or application which systematically teaches users the *Linear* search strategy for locating answers. Users would perform reading tasks similar to those in the current study, and when asked questions, the program would provide visual prompts to the user about where to look. When the answer is located and fixated upon, the program reads the answer out to the user. An intervention of this nature would eliminate the need for an instructor while still providing effective teaching. For students with poor decoding skills this feature would result in decreased physical effort engaging in this strategy, as the program reads the answer for the student, hence improving the response efficiency of this search behaviour and therefore increasing the likelihood of selecting the *Linear* search strategy during question answering. There are additional benefits of the digital medium, with younger children, with and without ASD, demonstrating greater receptivity to use of this technology in learning (Corbett & Abdullah, 2005). Motivating and reinforcing stimuli can also be built in to such a program to help maintain the interest and attention for students with attentional difficulties.

7.3 Considerations

In light of the success of eye-tracking in the current study in identifying gaze behaviours related to reading comprehension, and the possible role of eye-tracking in intervention, there may also be scope for this technology to be utilised in the context of reading assessment. For example, the trajectory of individual reading development could be tracked with the use of this technology, by analysing the gaze behaviour demonstrated by kindergarten children prior to school entry, and after their first year of primary school. Taking repeated measures over time could help to identify the skills that have developed or remain under-developed, to assess for reading readiness, and also to identify students suitable for early intervention of reading difficulties. Admittedly, this would be an ambitious use of eye-tracking, as the data collection and assessment process is quite lengthy and therefore may not be a viable option for schools and their time-poor staff; such assessment may therefore remain the preserve of specialists.

It is also interesting to consider the learning mechanism of gaze behaviour during reading, since students with high reading competence appear to learn ways to analyse and search in text without formal instruction. Observational learning is one such mechanism, through watching more capable peers and skilled adult models i.e. parents and teachers. Admittedly, such observation of fine-grained visual behaviour is most difficult, however, current classroom practices in Australian primary schools provide additional cues for students about gaze location: notably, reading aloud and directional tracking. Directional tracking is pointing to words as they as read in a left to right manner, to teach students the proper order of letters and words. Students attending to these cues in the classroom are therefore more likely to observe how teachers and more capable students gaze to text.

Effective interventions which demonstrate positive reading comprehension gains have incorporated interactive dialogue between readers and adults, or more capable peers (Woolley, 2016), a socially-mediated task where the student is actively engaged. Clay (1998) found that the quality of environment and quantity of reading affects level of reading competence. Even for deaf children, more time spent reading, being in a classroom that selected reading and reading-related activities, and more cooperative child-parent interactions during shared book reading were found to lead to greater reading achievement (Limbrick, McNaughton, & Clay, 1992). Clay (1998) concluded that interacting with children engaged in any kind of literacy activity increases literacy awareness and therefore comprehension – children demonstrate better understanding of narratives when there has been extended discussion about the stories. It appears that reading, as a type of verbal behaviour, is essentially a social activity, involving communication between speaker and listener in alternating roles, and its underlying mechanisms can be linked back to use of the gaze search strategies and answer location skills that are prominently explored in this thesis. In the case of a teacher or parent sharing a reading activity with a child, the adult assumes the role of speaker by asking a question e.g. “What do you think the wolf will do next?”, or making a comment about the text “That wolf is mean”. The child, who in this case is the listener, searches the text in order to gather more information to answer the question, give their opinion, or provide evidence to confirm or disconfirm the comment uttered by the adult. The child’s response may come in the form of a textual i.e. “He said, ‘I will huff and puff, and blow your house down!’” or intraverbal response e.g. “He is mean! He’s going to blow down their house!”, and is likely to be positively reinforced through social attention from the adult, and possibly through automatic reinforcement, as the child receives stimulated by the gain in knowledge about the story’s events. Therefore, the likely future occurrence of the gaze search strategy and locating answer behaviour increases. On the other hand, children who are not privy to shared reading opportunities do not receive this reinforcement, and may not learn to search text. Interestingly, this process of shared reading bears striking similarities to Reading Recovery, an intervention program widely used in Australian schools. Again, development of reading skills occurs when the task is shared, possibly through observational learning and the contingencies surrounding gaze search strategy and answer locating behaviour.

7.4 Limitations

Several considerations are relevant in the extrapolation of these findings to other situations. It would, therefore, be prudent to replicate this study with another, larger, sample of primary school students to evaluate the generalizability of these strategies. To isolate ASD symptomatology from broader intellectual deficits, we included only high-functioning children who attended mainstream primary school. The conclusions made regarding equal performance of participants with ASD and TD participants in comprehension accuracy cannot therefore be generalised to all people on the autism spectrum. However, the findings of this study notably support that having ASD alone does not predict reading comprehension deficits, and that individual skills of participants must be considered (see Brown et al., 2013).

The questions used in reading tasks were more difficult than those used in previous eye-tracking and reading studies. While question difficulty was not objectively measured, according to Day and Jeong-suk’s (2005) taxonomy, the open answer format (Wh- questions), which featured predominantly in the current study, is of higher difficulty and a more robust demonstration of comprehension, than the forced answer format (e.g. Yes/No, True/False, multiple choice). This is because in a forced answer format, the chance of correctly guessing the answer is substantially increased, compared to open answer format questions. This is due to the requirement for an intraverbal response over a textual response, which at least has point-to-point correspondence despite no formal similarity between the discriminative stimulus (text) and response (vocal). Intraverbal responses on the other hand, do not share point-to-point correspondence or formal similarity, and hence participants answering open answer format questions must search the text for the answer in order to inform their intraverbal response. For some of the participants in the current study with lower language skills, answering open answer format questions was a difficult task, and may have caused low levels of distress. Regardless, including more difficult question formats than previous studies, resulted in better discrimination between participants with high and low levels of reading competence, whereas in previous studies often participants have scored near ceiling, perhaps masking true differences between TD and ASD groups.

Lastly, the length of eye-tracking sessions deviated from recommendations for people with ASD made by van der Geest et al. (2002), who stated that several minutes is an optimum time to ensure high stability in the data recording. In the current study, especially for students with low reading competence who were slower at reading, the reading task frequently exceeded the 4 min mark, and while these participants sometimes appeared fatigued, (i) again, it provided a representative estimate of their behaviour during age-appropriate reading tasks, and (ii) the quality of gaze data did not seem to be affected. For younger children, short data collection sessions are best for minimising potential “drift” in calibration accuracy (Sasson & Elison, 2012), and this should be considered in future studies.

7.5 Future Directions

This study is one of the few if not the first to use eye-tracking to identify those gaze behaviours linked to finding answers to comprehension questions within text. Regardless of the limitations, there is enormous potential in this area, and specifically, scope to conduct a component analysis on the skills of re-reading answers, and scanning information preceding and following the answer. While both these skills were found to be associated with comprehension accuracy, they do overlap and, therefore, it would be beneficial to understand the effects that attention to local detail (re-reading) and attempting to understand the gist through reading contextual information (scanning) has on the facilitation of comprehension accuracy.

7.6 Overall Conclusions

This thesis began by exploring selective attention deficits displayed by individuals with Autism Spectrum Disorders (ASD), specifically, Weak Central Coherence, a processing bias for local/detail-specific information over global forms. Interest in this area has led to research utilising eye-tracking as a technique to overtly measure selective attention behaviour, through measurement of eye gaze patterns. Although researchers have clamoured for consensus on whether those with ASD demonstrate atypical eye gaze patterns overall, patterns which then contribute to the attending difficulties associated with this population, the results have been mixed. Importantly, it was identified within the current thesis that in the majority of these studies, participants were passively rather than actively engaged with visual stimuli. There is evidence to suggest that active engagement itself provides a cue to attend the global whole, and so, if this process is unimpaired in those with ASD, active engagement studies may report more equivocal eye gaze patterns between individuals with ASD and typically developing (TD) individuals.

A systematic review was undertaken to compare eye gaze patterns of those with ASD and TD individuals during active task engagement across six skills, one of which was reading. Individuals with ASD demonstrated typical eye gaze patterns when actively engaged in three tasks depicting static pictures, and atypical eye gaze patterns when actively engaged in three tasks depicting dynamic stimuli i.e. moving images and simulations. Importantly, however, differential eye gaze patterns displayed by individuals with ASD across tasks was irrelevant to task performance, suggesting that these gaze patterns were different, without impacting on participants' ability to attend to the global whole.

As eye gaze patterns of highly skilled TD readers and readers with ASD were examined, a desideratum regarding the eye gaze patterns of poorly skilled readers was highlighted. The aim of the Empirical Study was to identify the gaze behaviours used by students with, and without, ASD to facilitate and improve their understanding of text. Rayner et al. (2006) stated that eye movements are rarely the cause of reading problems: rather they reflect the difficulties that less skilled readers have in decoding and encoding words, and understanding text. While the latter part of this statement is consistent with eye-tracking data obtained, the current results suggest that visual-gaze skill deficits hinder students' ability to make sense of, and analyse the text they are reading. Therefore, assessment and intervention in gaze skills may improve a student's ability to more effectively analyse written text and better understand written material.

Students with high reading competence were not more accurate at question answering simply because they were "smarter" – they were able to locate answers more often than students with low reading competence (see Figure 29 below), which then provided reinforcement for the search strategy used, in addition to a new discriminative stimulus to re-read, or scan information immediately preceding and following the answer. As accurate question answering was dependent on first locating the answer, it can be said with reasonable confidence that students with high reading competence performed the visual-gaze skills which were shown to facilitate comprehension accuracy more frequently than did those students with low reading competence.

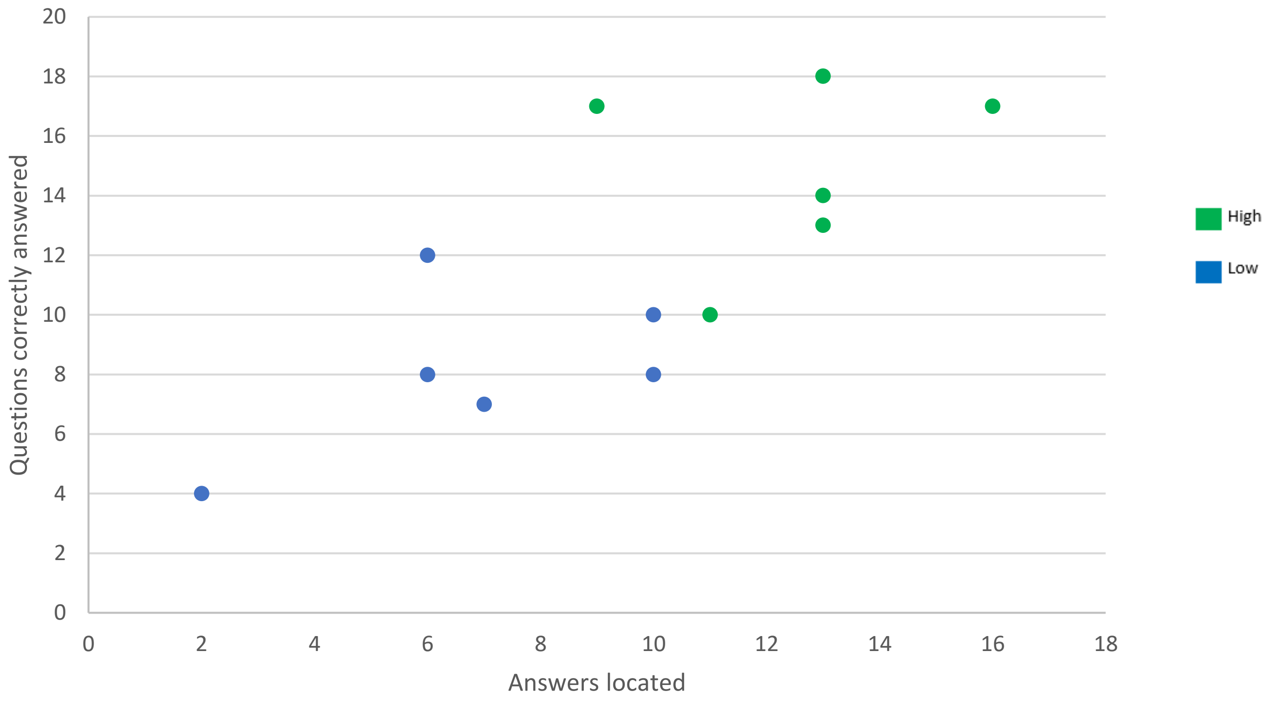


Figure 29. Literal and Reorganise Questions - Scatterplot of Comprehension Accuracy and Answers Located (Duplicate of Figure 11)

Regardless of whether or not they were diagnosed with ASD, students with low reading competence (i.e. low decoding and reading comprehension skills) demonstrated visual-gaze skill deficits during question answering tasks. These students were found to gaze at pictures and supplementary information more than those highly skilled readers. They gazed at words and correctly located answers less than students with high reading competence, and they selected ineffective, chance-level search strategies (i.e. *Haphazard*) over effective, sequential search strategies (i.e. *Linear*). If this problem is not given adequate attention by education staff and parents, these students can become susceptible to secondary problems associated with low academic performance, such as avoidance of school, academic tasks, and opportunities, and greater levels of school-related anxiety, social stigma, and self-esteem issues.

The way to prevent these students becoming disillusioned with reading (and school) is three-fold: firstly, improve these students' decoding skills, which will result in decreased physical effort with reading, and hence scanning text. Secondly, explicitly teach the sequential *Linear* search strategy using errorless teaching, improving the likelihood that students will correctly locate answers within text. Thirdly, to reduce the time and effort required of time-poor teachers and educators, invest in eye-tracking programs which aim to teach text analysis by visually prompting students where to allocate gaze in order to successfully locate the answer. These findings in particular can have a significant impact on the way in which reading comprehension difficulties are assessed and treated, but also understood by educators, and therefore become an integral part of school curriculums. Interestingly, despite the author's attempt to separate the processes of decoding and comprehension into separate, concrete skills throughout the thesis, the final recommendation involves intervention in both of these domains - suggesting that the interaction of these two skills is far more important than was first realised.

This thesis will end where it began: with a focus on Autism Spectrum Disorders. The results of the systematic literature review and empirical study in this thesis supported the notion of "different, without deficit", which is further illustrated in Figure 30 below:

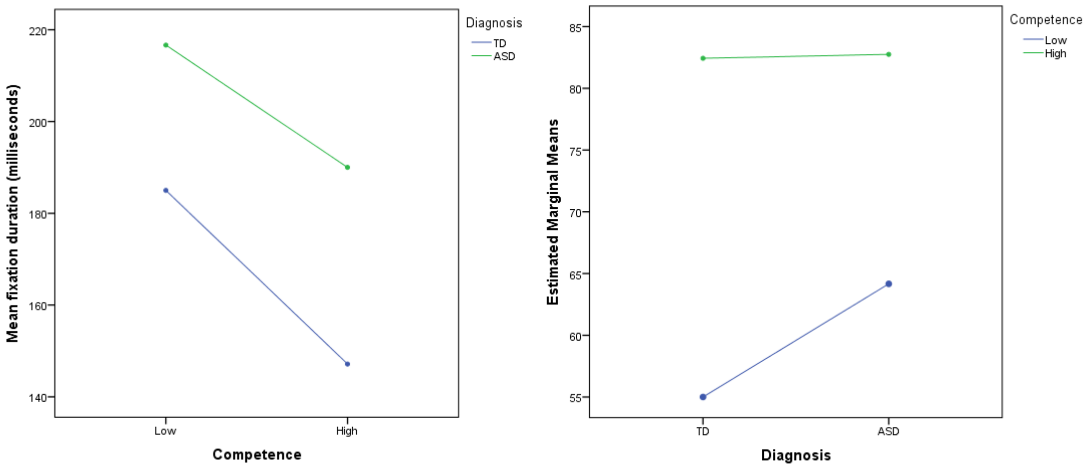


Figure 30. Line graph of mean fixation duration during Question Phase (Duplicate of Figure 6) & Line graph of comprehension accuracy (Duplicate of Figure 7).

A take home message from this study is that while <u>all</u> individuals diagnosed with ASD exhibited long gaze times when reading (atypical eye gaze behaviour), ultimately, it did not affect their comprehension accuracy. Those students who were accurate in their comprehension consistently used the comprehension-facilitating gaze skills outlined in this thesis, and those who were inaccurate demonstrated an inability or inconsistency in these skills. This finding provides evidence to support the notion that atypical eye gaze patterns, different to those exhibited by neuro-typical people, do not negatively impact the performance of people with ASD on tasks such as reading. For those with ASD, eye gaze behaviour during reading, can be considered *different, without being classed as a deficit.*

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Appendices

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APPENDICES

Appendix A

Monash University Human Research Ethics Committee

Approval Certificate

This is to certify that the project below was considered by the Monash University Human Research Ethics Committee. The Committee was satisfied that the proposal meets the requirements of the *National Statement on Ethical Conduct in Human Research* and has granted approval.

Project Number: 1111
Project Title: Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye-Tracking Technology
Chief Investigator: Dr Angelika Anderson
Expiry Date: 30/03/2022

Terms of approval - failure to comply with the terms below is in breach of your approval and the *Australian Code for the Responsible Conduct of Research*.

1. The Chief Investigator is responsible for ensuring that permission letters are obtained, if relevant, before any data collection can occur at the specified organisation.
2. Approval is only valid whilst your hold a position at Monash University.
3. It is responsibility of the Chief Investigator to ensure that all investigators are aware of the terms of approval and to ensure the project is conducted as approved by MUHREC.
4. You should notify MUHREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
5. The Explanatory Statement must be on Monash letterhead and the Monash University complaints clause must include your project number.
6. Amendments to approved projects including changes to personnel must not commence without written approval from MHUREC.
7. Annual Report - continued approval of this project is dependent on the submission of an Annual Report.
8. Final Report - should be provided at the conclusion of the project. MUHREC should be notified if the project is discontinued before the expected completion date.
9. Monitoring - project may be subject to an audit or any other form of monitoring by MUHREC at any time.
10. Retention and storage of data - The Chief Investigator is responsible for the storage and retention of the original data pertaining to the project for a minimum period of five years.

Thank you for your assistance.

Professor Nip Thomson

Chair, MUHREC

CC: Dr Brett Furlonger, Professor Dennis Moore, Mr Bradley Drysdale

List of approved documents:

Document Type	File Name	Date	Version
Supporting Documentation	BD_permission letter	23/01/2017	1
Psychological inventories	WJIVTechnicalManual	03/02/2017	1
Explanatory Statement	BD_explanatory statement_PARENTS	10/03/2017	2
Explanatory Statement	BD_explanatory statement_SCHOOLS	10/03/2017	2
Consent Form	BD_assent form_CHILD	10/03/2017	2
Consent Form	BD_consent form_PARENTS	10/03/2017	2
Questionnaires / Surveys	BD_Intake form	22/03/2017	2

Page 1 of 1

Appendix B

Department of
Education & Training

2 Treasury Place
East Melbourne Victoria 3002
Telephone: 03 9637 2000
DX210083

2017_003313

Mr Bradley Drysdale
8 Glenelg Place
TAYLORS LAKES 3038

Dear Mr Drysdale

Thank you for your application of 10 February 2017 in which you request permission to conduct research in Victorian government schools titled *Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye Tracking Technology.*

I am pleased to advise that on the basis of the information you have provided your research proposal is approved in principle subject to the conditions detailed below.

1. Department approved research projects currently undergoing a Human Research Ethics Committee (HREC) review are required to provide the Department with evidence of the HREC approval once complete.

2. The research is conducted in accordance with the final documentation you provided to the Department of Education and Training.

3. Separate approval for the research needs to be sought from school principals. This is to be supported by the Department of Education and Training approved documentation and, if applicable, the letter of approval from a relevant and formally constituted Human Research Ethics Committee.

4. The project is commenced within 12 months of this approval letter and any extensions or variations to your study, including those requested by an ethics committee must be submitted to the Department of Education and Training for its consideration before you proceed.

5. As a matter of courtesy, you advise the relevant Regional Director of the schools or governing body of the early childhood settings that you intend to approach. An outline of your research and a copy of this letter should be provided to the Regional Director or governing body.

6. You acknowledge the support of the Department of Education Training in any publications arising from the research.

VICTORIA
State
Government

7. The Research Agreement conditions, which include the reporting requirements at the conclusion of your study, are upheld. A reminder will be sent for reports not submitted by the study's indicative completion date.

I wish you well with your research. Should you have further questions on this matter, please contact Youla Michaels, Project Support Officer, Insights and Evidence Branch, by telephone on [redacted] or by email at [redacted]

Yours sincerely

[redacted]

John Tomaino
A/Director
Insights and Evidence

9/05/2017

VICTORIA State Government

Appendix C:

Research Application 0601: Outcome (Approved)

Dear Mr Drysdale

Congratulations, your research application, 0601 - 'Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye Tracking Technology: Focus on Reading Comprehension', has been approved by Catholic Education Melbourne.

I am pleased to advise that your research application is approved in principle subject to the eight standard conditions outlined below.

1. The decision as to whether or not research can proceed in a school rests with the school's principal, so you will need to obtain their approval directly before commencing any research activity. You should provide the principal with an outline of your research proposal and indicate what will be asked of the school. A copy of this email of approval, and a copy of notification of approval from your organisation's/university's Ethics Committee, should also be provided.

2. A copy of the approval notification from your institution's Ethics Committee must be forwarded to this Office (if not already provided), together with any modifications to your research protocol requested by the Committee. You may not start any research in Catholic schools until this step has been completed.

3. A Working with Children (WWC) check – or registration with the Victorian Institute of Teaching (VIT) – is necessary for all researchers visiting schools. Appropriate documentation must be shown to the principal before starting the research in the school.

4. No student is to participate in the research study unless s/he is willing to do so and consent is given by a parent/guardian.

5. Any substantial modifications to the research proposal, or additional research involving use of the data collected, will require a further research application to be submitted to Catholic Education Melbourne.

6. Data relating to individuals or the school are to remain confidential and protected in line with the Privacy Act 1988 (Commonwealth).

7. Since participating schools have an interest in research findings, you should consider ways in which the results of the study could be made available for the benefit of the school community.

8. At the conclusion of the study, a copy or summary of the research findings should be forwarded to Catholic Education Melbourne. It would be appreciated if you could submit this via email to research@cem.edu.au.

I wish you well with your research study. The information provided in your proposal is now closed for further changes. If you have any queries concerning this matter or need to make amendments in the future, please contact Ms Shani Prendergast at research@cem.edu.au.

Yours sincerely

Mr Jim Miles

DIRECTOR ENTERPRISE SERVICES
Catholic Education Melbourne

Appendix D:

EXPLANATORY STATEMENT

Parents

Project: Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye Tracking Technology

Angelika Anderson (Chief Investigator)
Faculty of Education, Monash University
Phone: [redacted]
email: [redacted]

Bradley Drysdale (PhD Candidate)
Faculty of Education, Monash University
Phone: [redacted]
email: [redacted]

You are invited to take part in this study. Please read this Explanatory Statement in full before deciding whether or not to participate in this research. If you would like further information regarding any aspect of this project, you are encouraged to contact the researchers via the phone numbers or email addresses listed above.

Who is suitable for this research?
I am seeking the participation of children aged between five and eighteen years, either who are developing typically or who have been diagnosed with Autism Spectrum Disorder (also known as autism).
I am interested in differences in looking patterns when these children are reading. Therefore, children who are suitable for this research project can either have:
(a) strong or competent reading comprehension abilities, or
(b) weak or underdeveloped reading comprehension abilities.
If you believe your child has weak or undeveloped comprehension abilities, they may benefit more from this project, as they will be given the chance to improve their comprehension skills through the use of an intervention learning program.

What does the research involve?
Firstly, this project will investigate differences in looking behaviour in those with poor reading comprehension skills compared to those with strong reading comprehension skills. Looking behaviour will be measured with a Tobii X2-30 Eye-Tracker; a safe, non-invasive instrument which can reliably measure gaze patterns. Using the eye-tracking data, we will infer what children with poor comprehension skills *should* be attending to, based on what children with good comprehension skills are looking at. Eye movements will be tracked while participants are reading, and answering questions assessing their comprehension and understanding of the text.

Secondly, children with poor comprehension skills will be given the opportunity to improve these skills by participating in a learning intervention (Reciprocal Teaching or Behavioural Skills Training), shown to be effective in teaching these skills to school-aged children. This project will measure gaze patterns displayed by these children before undergoing the intervention, during the intervention, and after the intervention, to evaluate changes in looking behaviour. **At least one teacher will be present during each reading session. Researchers therefore will be accompanied, or at least in sight of a teacher when conducting this research.**

MONASH University

What is required?

The first half of the study involves the child reading a series of passages on a computer screen. The child will then be asked a series of questions about the text, to evaluate their understanding and comprehension. The child's gaze will be tracked during the reading and question answering phases. Instances of a child reading may be video-taped, to allow us to know whether the child is attending to the screen or away from it.

There will be a total of about 2 reading sessions; with each session lasting a maximum of 60 minutes. We will aim for each child to read and demonstrate comprehension on 5 to 10 passages, and he or she will be given approximately 10 minutes per reading passage, with brief breaks in between.

Initially you will be asked to participate in a brief interview to identify your child's strengths and weaknesses as well as his or her suitability for this project. You may also be asked to fill out a brief questionnaire before the project; to describe your child's reading habits and diagnosis (if required), which should take about 30 minutes to complete.

The child will also be required to undertake one session with the researcher prior to eye-tracking. This session will involve a formal assessment of reading ability, as well as a chance for your child to familiarize themselves with the eye-tracker, and researcher, to alleviate any potential nervousness or anxiety about the process. This session will last a maximum of 90 minutes.

The second half of the study involves the researcher spending one-on-one time with the child (accompanied by a teacher) participating in the intervention. The researcher will explicitly teach each specific comprehension skill to the child using modelling, rehearsal, and feedback strategies – then the child will have the opportunity to demonstrate these skills whilst reading text and answering questions about the text. The child's gaze will be measured in each session. Sessions will last 30 minutes and occur three to four times a week for a maximum of six weeks.

I do not expect you or your child to experience any discomfort by being involved in this project beyond the small investment of time. Every effort will be made to minimize any disruption to your family routines and to fit in with your schedule as best as possible. Your participation will directly assist in furthering our understanding of what children with underdeveloped comprehension skills are looking at when reading text and attempting to answer text-related questions, as well as what children with success at reading comprehension look at when reading. Regardless of your child's reading ability, I would be very grateful for your participation as it will lead to greater understanding of this issue.

Consenting to participate in the project and withdrawing from the research

Being in this study is voluntary and you are under no obligation to consent to participation. If you are willing to participate in the project, please sign and return the consent form to the researcher. **If you do consent to participate, you may withdraw this consent at any time.** You will not be penalized for the withdrawal of your child in any way. If you wish to withdraw, please contact me via email (bradley.drysdale@monash.edu) or telephone (0412 304 407).

If at any time you or your child are experiencing distress due to being involved in the project, please contact the Chief Investigator immediately to make the matter known. Alternatively, you can ring Beyondblue (1300 22 46 36), Parentline Victoria (13 22 89 – 8am to midnight, 7 days a week), or Kids Helpline (1800 55 1800).

MONASH University

Confidentiality

Your and your child's confidentiality will be protected throughout the project. No real names will appear on any documents or data files. Pseudonyms (different initials or names) will be used from the outset. Only the researchers will have access to the raw data. No names will appear in any reports or publications arising from this work.

Storage of the data collected will adhere to the University regulations and kept on University premises under lock-and-key in a password-encrypted hard drive for 5 years. After 5 years the data (including any video footage) will be permanently deleted from the hard drive. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

The findings are accessible for 12 months following completion of the project. If you wish to receive a summary of the results, it will be provided to you at the end of the research project. Please phone me (Bradley Drysdale) on [redacted] or email at [redacted]

If you have a complaint concerning the manner in which this research <insert your project number here> is being conducted, please contact:

Executive Officer, Human Research Ethics
Monash University Human Research Ethics Committee (MUHREC)
Building 3e Room 111
Research Office
Monash University VIC 3800

[redacted]

Thank you.

[redacted]

Bradley Drysdale

PhD Candidate

Appendix E

EXPLANATORY STATEMENT

Schools

Project: Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye Tracking Technology

Angelika Anderson (Chief Investigator)
Faculty of Education, Monash University
Phone: [redacted]
email: [redacted]

Bradley Drysdale (PhD Candidate)
Faculty of Education, Monash University
Phone [redacted]
email: [redacted]

You are invited to take part in this study. Please read this Explanatory Statement in full before deciding whether or not to participate in this research. If you would like further information regarding any aspect of this project, you are encouraged to contact the researchers via the phone numbers or email addresses listed above.

Who is suitable for this research?
I am seeking the participation of approximately 10 children aged between five and eighteen years, either who are developing typically or who have been diagnosed with Autism Spectrum Disorder (also known as autism).
I am interested in differences in looking patterns when these children are reading. Therefore, children who are suitable for this research project can either have:
(a) strong or competent reading comprehension abilities, or
(b) weak or underdeveloped reading comprehension abilities.
If you believe a child at your school has weak or undeveloped comprehension abilities, they may benefit more from this project, as they will be given the chance to improve their comprehension skills through the use of an intervention learning program.

What does the research involve?
Firstly, this project will investigate differences in looking behaviour in those with poor reading comprehension skills compared to those with strong reading comprehension skills. Looking behaviour will be measured with a Tobii X2-30 Eye-Tracker; a safe, non-invasive instrument which can reliably measure gaze patterns. Using the eye-tracking data, we will infer what children with poor comprehension skills *should* be attending to, based on what children with good comprehension skills are looking at. Eye movements will be tracked while participants are reading, and answering questions assessing their comprehension and understanding of the text.

Secondly, children with poor comprehension skills will be given the opportunity to improve these skills by participating in a learning intervention (Reciprocal Teaching or Behavioural Skills Training), shown to be effective in teaching these skills to school-aged children. This project will measure gaze patterns displayed by these children before undergoing the intervention, during the intervention, and after the intervention, to evaluate changes in looking behaviour. **At least one teacher will be present during each reading session. Researchers therefore will be accompanied, or at least in sight of a teacher when conducting this research.**

MONASH University

What is required?
The first half of the study involves the child reading a series of passages on a computer screen. The child will then be asked a series of questions about the text, to evaluate their understanding and comprehension. The child's gaze will be tracked during the reading and question answering phases. Instances of a child reading may be video-taped, to allow us to know whether the child is attending to the screen or away from it.
There will be a total of about 2 reading sessions; with each session lasting a maximum of 60 minutes. We will aim for each child to read and demonstrate comprehension on 5 to 10 passages, and he or she will be given approximately 10 minutes per reading passage, with brief breaks in between.

Parents of each participant will be contacted to complete a brief interview to identify their child's strengths and weaknesses as well as his or her suitability for this project, which should take about 30 minutes to complete.
Teachers or other staff may also be asked for additional information concerning a child's reading habits. Participants will also be required to undertake one session with the researcher prior to eye-tracking. This session will involve a formal assessment of reading ability, as well as a chance for each child to familiarize themselves with the eye-tracker, and researcher, to alleviate any potential nervousness or anxiety about the process. This session will last a maximum of 90 minutes.

The second half of the study involves the researcher spending one-on-one time with the child (accompanied by a teacher) participating in the intervention. The researcher will explicitly teach each specific comprehension skill to the child using modelling, rehearsal, and feedback strategies – then the child will have the opportunity to demonstrate these skills whilst reading text and answering questions about the text. The child's gaze will be measured in each session. Sessions will last 30 minutes and occur three to four times a week for a maximum of six weeks.

If participating schools are willing and have a spare office or room available for these sessions to run, as well as after-hours storage of the eye-tracking equipment, for the six week duration, this would benefit the project by reducing setting-up time. Schools that are unable to allocate such a space are still welcome to participate.

I do not expect your staff or students to experience any discomfort by being involved in this project beyond the small investment of time. Every effort will be made to minimize any disruption to your routines and to fit in with your schedule as best as possible. Your participation will directly assist in furthering our understanding of what children with underdeveloped comprehension skills are looking at when reading text and attempting to answer text-related questions, as well as what children with success at reading comprehension look at when reading. Regardless of the students' reading ability, I would be very grateful for your participation as it will lead to greater understanding of this issue.

Giving permission for the school to participate and withdrawing from the research
Being in this study is voluntary and you are under no obligation to agree to participation. **If you do give permission for the school to participate, you may withdraw this consent at any time.** You will not be penalized for the withdrawal of permission in any way. If you wish to withdraw, please contact me via email (bradley.drysdale@monash.edu) or telephone (0412 304 407).

MONASH University

The identity of your students and school will remain confidential and be protected throughout the project and no real names will appear on any documents and data files. Storage of the data collected will adhere to the University regulations and kept on University premises under lock-and-key in a password-encrypted hard drive for 5 years. After 5 years the data (including any video footage) will be permanently deleted from the hard drive. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

The findings are accessible for 12 months following completion of the project. If you wish to receive a summary of the results, it will be provided to you at the end of the research project. Please phone me (Bradley Drysdale) on [redacted] or email at [redacted]

If you have a complaint concerning the manner in which this research <insert your project number here> is being conducted, please contact:

Executive Officer, Human Research Ethics
Monash University Human Research Ethics Committee (MUHREC)
Building 3e Room 111
Research Office
Monash University VIC 3800

Tel: [redacted] Fax: [redacted]
Email: [redacted]

Thank you.

[redacted]

Bradley Drysdale

PhD Candidate

Appendix F:

MONASH University

CONSENT FORM

Parents

Title: Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye-tracking Technology

Chief Investigator: Angelika Anderson
Faculty of Education, Monash University
NOTE: This consent form will remain with the Monash University researcher for their records.

I/We ____

parent/parents/ legal guardian of

____ (child's name)

____

____ (address)

voluntarily consent (1) myself/ourselves, and (2) my/our child, to participate in a Monash University research project as specified above.

I have had the project explained to me, and I have read the Explanatory Statement, which I keep for my records. I understand that agreeing to take part means that:

I consent to the following:	***Yes***	***No***
I agree to be interviewed by the researcher.	☐	☐
I agree to make myself available for a further interview if required.	☐	☐
I agree to complete questionnaires asking me about my child's strengths, weaknesses, and special interests.	☐	☐
I agree to allow my child to undergo a formal assessment of reading comprehension skills conducted by the researcher.	☐	☐

MONASH University

I agree to allow the research team to track my child's eye movements whilst reading texts and answering questions pertaining to these texts.	☐	☐	
I agree to allow the research team to video-record my child while he/she is reading texts and answering questions pertaining to these texts.	☐	☐	
I agree to have my child participate in the reading comprehension intervention program, which has been explained to me in the Explanatory Statement, and by the researcher.	***Yes*** ☐	***No*** ☐	***n/a*** ☐
I agree to have the researcher contact a staff member at my child's school to obtain information about my child's reading ability.	***Yes*** ☐	***No*** ☐	
I understand that my and my child's participation is voluntary, that we can choose not to participate in part or all of the project, and that we can withdraw at any stage of the project without being penalised or disadvantaged in any way.	☐	☐	
I understand that any information I provide is confidential, and that no information that could lead to the identification of any individual will be disclosed in any reports on the project, or to any other party.	☐	☐	
I understand that all data will be kept in a secure storage and accessible to the research team. I also understand that the data will be destroyed after a 5 year period.	☐	☐	

Name of the Parent: ____

Signature: _________________________ Date: ___________________

Name of Parent: ____

Signature: _________________________ Date: ___________________

Appendix G

MONASH University

ASSENT FORM

Children or Adolescents (aged 5 – 18 years)

Project: Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye-tracking Technology

Chief Investigator: Angelika Anderson
Faculty of Education, Monash University

PhD Candidate: Bradley Drysdale
Faculty of Education, Monash University

I have been asked to join in this study. Bradley, or my parents have explained it to me and I have had a chance to ask questions about it. I understand what this research project is about and would like to join in.

I want to be involved in this project. If I change my mind and want to stop that is okay. No one will be angry with me if I change my mind. I know that if I have any questions I can ask my parents or the researcher at any time.

I agree to:	Yes	No
Do some reading tasks with the researcher to see what I find easy and what I need help with.	☐	☐
Let the researcher track my eyes on the computer.	☐	☐
Read sentences on the computer screen.	☐	☐
Let the researcher take video of my face while I read.	☐	☐
Answer questions about the sentences that the researcher asks me.	☐	☐

Name ______________________________ *Date* __________

Signature ______________________________

Appendix H

Dear Parents and Carers,

Monash University is running a new research study, investigating the looking (gaze) patterns of typically developing students and students with ASD while reading text and answering comprehension questions. Gaze patterns will be measured using a Tobii X2-30 Eye-tracker.

Who are we looking for?
We are inviting parents who have a child/adolescent aged 5-18 years and are typically developing OR diagnosed with ASD, and have difficulty with reading comprehension skills.

What is involved?

- As the parent/primary caregiver, you will be required to complete an information pack and meet briefly with the research team (30 min).
- Your child will meet the research team, who will familiarise the child with the eye-tracker and assess his/her language and reading skills (2 hr).
- Your child will read 5-10 passages on a computer screen and asked a series of questions about the text. All this will happen while the eye-tracker records your child's eye movements, requiring no extra effort on your child's behalf. Brief breaks will be taken in between reading tasks. This will be completed over 2 separate sessions lasting 1 hr in duration (2 x 1 hr).

We'd also love your help!
We are also seeking parents of children who do not have difficulty with reading comprehension to participate in our research. If you know of another family at your school who have a child with developed reading comprehension skills and are willing to participate, please pass on our contact details to them. *Thank you!*

How your participation helps
You will help us to understand gaze differences between accomplished and developing readers, which will help us develop ways to help improve reading comprehension in students having difficulties with these skills. After conducting this research, your child is eligible to complete a learning intervention aimed to improve reading comprehension skills.

If you are interested in or have any questions regarding the research, you can call or email **Bradley Drysdale (PhD Candidate)**, who will be happy to provide you with more information.

[redacted]

Appendix I:

SCHOOL OF THE GOOD SHEPHERD

88 South Circular Road, GLADSTONE PARK. 3043
P.O. BOX 2400 GLADSTONE PARK. 3043
T: 9338 7686 **F:** 9335 2586
Email: principal@soggladstonepark.catholic.edu.au

19th April 2017

PERMISSION LETTER FROM SCHOOL

Project: Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye Tracking Technology

Angelika Anderson (Chief Investigator)
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Dear Angelika Anderson,

Thank you for your request to recruit participants from School of the Good Shepherd Gladstone Park for the above-named research.

I have read and understood the Explanatory Statement regarding the research project **(Investigating Visual Attention in Individuals with Autism Spectrum Disorder using Eye Tracking Technology: 1111)** and hereby give permission for this research to be conducted.

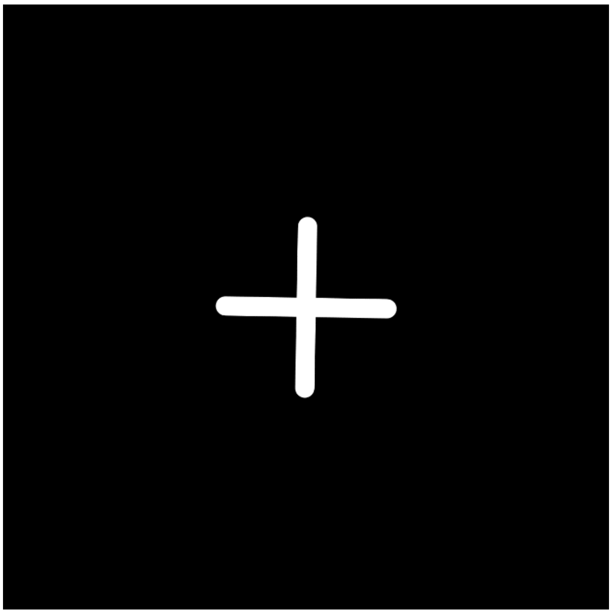
Yours sincerely,

[redacted]

Fran Drysdale
Principal

Appendix J:

Fixation cross between Reading and Question phases



Visit to the Zoo (G5-6)

It was school holidays. On Sunday, Grandpa visited Tom and Becky.
"Now you have free time. We can spend a whole day in the zoo," he said.
The following day they were there, looking at the animals.
"I love it here, my favourite place in town," said Tom.
"And this is my favourite treat," said Becky, ice-cream in hand.
They went to the Butterfly House. Pretty winged creatures were flying everywhere. They were standing on rocks and plants.
"They look like colourful pixie dust," said Becky.
"You read a lot of fairy tales," laughed Tom.
Grandpa took them to a place full of people.
"Chimpanzees look a lot like us!" he said.
"That's because we are cousins in the animal family tree," said Becky.
At 12.30 pm they had lunch. Half an hour later, they were going to the see the tallest animal on Earth.
"Giraffes normally live in Africa," Tom explained. "They can eat green leaves from trees."
Grandpa, Tom and Becky returned home in a very crowded train. There, Becky lost her new fluffy koala.
"Never mind," she sighed, "I can make another one myself."
"Tomorrow I will contact my friends," said Tom. "This visit gave me some great ideas for a school project."

Fishing (G3-4)

It was spring time. Bob met Alice on Friday. He said "Days are now warm and sunny. Let's go fishing!"
The following day they were in a boat. The lake was calm. "It looks like a mirror," said Alice.
Bob gave Alice a can of worms. "Yuk, I don't like them," said Alice. "They are what we need for a good catch," explained Bob.
Exactly at noon they threw the lines into the water.
Fifteen minutes later, Alice pulled out a jumping barramundi. She tossed it happily into a basket.
Bob fished out an old boot. He looked at it with a sad face.
Bob and Alice returned home. One had a basket full of fish. The other had lines, hooks, worms and an old boot.
"Bob, come to my place tomorrow. I will cook a yummy barramundi meal," said Alice.
Bob had a great dinner there. He took the old boot. Alice filled it with soil. It looked nice as a flower pot.

Going to the Cinema (G5-6)

On a winter evening Dad said: "Now days are short and cold. Good time to go to the movies."
"'Scientists of the Sea' opened today," said Jack.
"So let's go to the cinema tomorrow," said Mum.
"Great," said Amy, "I love this movie."
On Saturday afternoon, Dad, Mum, Jack and Amy were at the cinema. They were buying sweets in the foyer.
"These are my favourites," said Amy, holding a pack of Tim Tams.
"Lots of people here," said Dad.
"It must be a very good movie," observed Mum.
'Scientists of the Sea' started at 2:00 sharp. Two hours later people were happily leaving the cinema.
"Wow, it had fantastic special effects," said Jack.
Mum bought some surprise gifts for the children.
"Thanks, Mum, I will read it in one day," said Amy looking at the book, 'Choose your Own Scientist Adventure'.
"Wow Mum, thanks! We will play this for hours," said Jack reading the cover of the computer game 'Navigate the Seas on a Science Ship'.

Volleyball on the Beach (G3-4)

It is a warm summer day.
"It is so nice here," says Jill, lying on the beach.
"Hold on, you must use these." Dan gives Jill a sunhat and sunscreen.
"Hey guys, what about some volleyball practice for tomorrow's match?" asks Joel.
Everyone gets ready for volleyball.
But not Jill.
"I want to finish this story," she says, holding 'Space Adventure' in hand.
On Tuesday, the beach teams 'Walruses' and 'Seagulls' hold the volleyball match.
Jill is not playing. She is the umpire.
Time is over. "This is the winning team," Jill says, holding the hand of the 'Seagulls' captain.
"Congratulations!" say all the players.
Jill asks Joel: "Can you please bring that stuff next to the sand castle?"
Joel gives Jill an Esky.
"Here there is a nice treat for everyone," Jill says.
She gives every player an icy pole.

Physical Stories (LOW SOCIAL) G1-2

Bob and Jim are best friends. They are both 10 years old. Bob has brown hair, green eyes and is over 5 feet tall. Jim looks very different to Bob. He has blonde hair and blue eyes and he is much smaller than Bob. Bob and Jim go on an outing to the fun fair. They go on lots of rides. For the last ride of the day they decide to go on the big rollercoaster. But there is a sign which says: For safety reasons, no persons under 5 feet are allowed on.

Physical Stories (LOW SOCIAL) G3-4

Sam decides to go on a long walk to get some fresh air. Just after leaving the house, the wind begins to pick up and it starts to rain. Luckily Sam always has an umbrella with him. He quickly puts up the umbrella and wraps his coat tightly around him. Suddenly a gust of wind blows the umbrella straight out of Sam's hand. It lands in a large, very prickly bush. Sam manages to run and fetch it before it blows off again. He is pleased to find it all in one piece. As he walks home, he notices that his head is starting to get wet despite the umbrella.

Physical Stories (LOW SOCIAL) G5-6

Clare is having her room redecorated; her mother is painting the walls and having new curtains hung. Before, Clare's room was pink and white with thin net curtains but now the walls are dark red, and brand new thick and expensive velvet curtains have been put up. On the first morning in her new room, Clare fails to wake up at the normal time. As her mother rushes to get her out of bed for school, Clare says it must be too early to get up because it "feels like the middle of the night."

Mental State Stories (HIGH SOCIAL) G1-2

One day Aunt Jane came to visit Peter. Peter loves his aunt very much. But today she is wearing a new hat. Peter thinks the new hat is very ugly indeed. Peter thinks his aunt looked much nicer in her old hat. But when Aunt Jane asks Peter, “How do you like my new hat?” Peter says, “Oh, it’s very nice.”

Mental State Stories (HIGH SOCIAL) G3-4

During the war, the Red army captures a member of the Blue army. They want him to tell them where his army’s tanks are; they know they are either by the sea or in the mountains. They know that the prisoner will not want to tell them, he will want to save his army, and so he will certainly lie to them. The prisoner is very brave and very clever, he will not let them find his tanks. The tanks are really in the mountains. Now when the other side asks him where his tanks are, he says, “They are in the mountains.”

Mental State Stories (HIGH SOCIAL) G5-6

Helen waited all year for Christmas, because she knew at Christmas she could ask her parents for a rabbit. Helen wanted a rabbit more than anything in the world. At last Christmas Day arrived, and Helen ran to unwrap the big box her parents had given her. She felt sure it would contain a little rabbit in a cage. But when she opened it, with all the family standing round, she found her present was just a boring old set of encyclopedias, which Helen did not want at all! Still, when Helen’s parents asked her how she liked her Christmas present, she said, “It’s lovely, thank you. It’s just what I wanted.”

Dinner for Peter (G1-2)

Peter was playing with Ralph, his teddy bear. His Mum came in and said, "It's time for dinner".

"Okay, Mum," said Peter.

Peter put his teddy away. Then, he went to the sink and he washed his hands. He was ready for dinner.

Peter sat on the dining chair. "Can I have some vegetables?" Peter asked his Mum.

Mum gave Peter some mashed potatoes. Peter liked mashed potatoes.

When dinner was over, Peter said, "Thank you Mum", and she said "You're welcome Peter".

"Can I play with my teddy now Mum?" asked Peter. "Okay, Peter" his Mum said.

Then Peter went and played with Ralph his teddy bear.

Beanie Found a Ball (G1-2)

My dog Beanie found a ball at the park. It was a smooth orange ball.

Beanie loves to run. He ran after the orange ball when I threw it.

Beanie found another ball. It was a squeaky red ball. Beanie loves to chew things. He chewed the squeaky red ball.

Beanie found another ball. It was a spiky green ball. Beanie loves to play. He played with the spiky green ball and rolled it around.

Cuddles & Speedy (G3-4)

My family just adopted a puppy and a turtle from the animal shelter. "What should we name them?" asked Dad. My sister Sophie and I had to decide.

"We should name the puppy Cuddles," I said. "We should name the turtle Speedy," said Sophie. We all agreed, then my family took Cuddles and Speedy home.

Sophie and I gave Cuddles and Speedy a nice bath. "They smell nice and fresh!" said Mum, "Would you like to feed them?" she asked us. "Sure Mum!" we both said. I gave Cuddles some doggy treats, and Sophie have Speedy a slice of apple.

My family played with both Cuddles and Speedy until we were all tired.

"It's time for lunch" said mum. So we all washed our hands and went to the dining table.

Mum made us sandwiches. They were delicious.

Making a Time Capsule (G3-4)

"I'm going to make a time capsule," Anna expressed to her parents at the breakfast table one morning. "Sounds lovely Anna, just be careful no bugs get inside, you know that they love time capsules as homes!" her Dad said. Anna laughed, and shook her head, "No, Dad. They will not get inside! I am going to make sure I seal it up perfectly so nothing will be able to get in".

Her dad asked, "What is a time capsule? Is it something to travel through time in?"

Anna giggled, "No, Dad. I'm building a box that will be like a memory box. Some students buried it thirty years ago and just dug it up! It had so much old stuff in it, like pictures, art work, school work, books, magazines and yo-yo's!" Anna ran to her room to find things to put in her time capsule. She grabbed her favourite book, some old photos, and anything else she could find to put in her time capsule.

Next, she started to look for a box that she could use as the time capsule to hold her things. Anna was confused, she was not sure what would be suitable to bury. She asked her dad, "What could I use as a time capsule to bury deep in the ground?"

"I've got just the thing!" her dad exclaimed, "Come with me!" Together, Anna and her Dad ran into the garage and found an old plastic container to use as a time capsule. "That's perfect!" said Anna, as she raced to get her things to start creating her time capsule to bury at school.

Writing a Great Story (G5-6)

Anna loved reading and writing. English was her favourite class. Her teacher gives students topics to write about every night in their exercise book. When her teacher told the students that Wednesday's topic would be their choice Anna was pleased! She knew just what to write about. She wanted to write about unicorns.

Anna asked her teacher how she could find out more about unicorns so she could write a great story. Her teacher was so happy she wanted to learn more before she started to write. Her teacher said to her that she could go to the library where all the books are kept and ask the helpers to find books about unicorns.

Anna made her way to the library. She was so excited that she skipped the whole way there. She asked the library helpers to help her find a book on unicorns. They told her they had just the one for her. Anna smiled when they handed her the big book of make-believe animals. She borrowed the book straight away and went home to read till she learnt all that she needed to. She felt she was finally ready to write a great story on unicorns!

On Thursday morning, Anna handed her story on unicorns to her teacher. She was so excited to see what her teacher thought after all her hard work!

Budding Actors (G5-6)

Jack and Luke were twelve years old. They had known each other since childhood, growing up in the city of Melbourne, both in the same apartment block. Jack was tall and lanky, while Luke was short, and strong. Jack's hair was always falling over his eyes, while Luke wore his black hair spiked up high with lots of hair gel.

Both Jack and Luke had a dream of someday becoming famous actors. Every chance they had, the boys would perform at recess and lunch for anyone that wanted to watch.

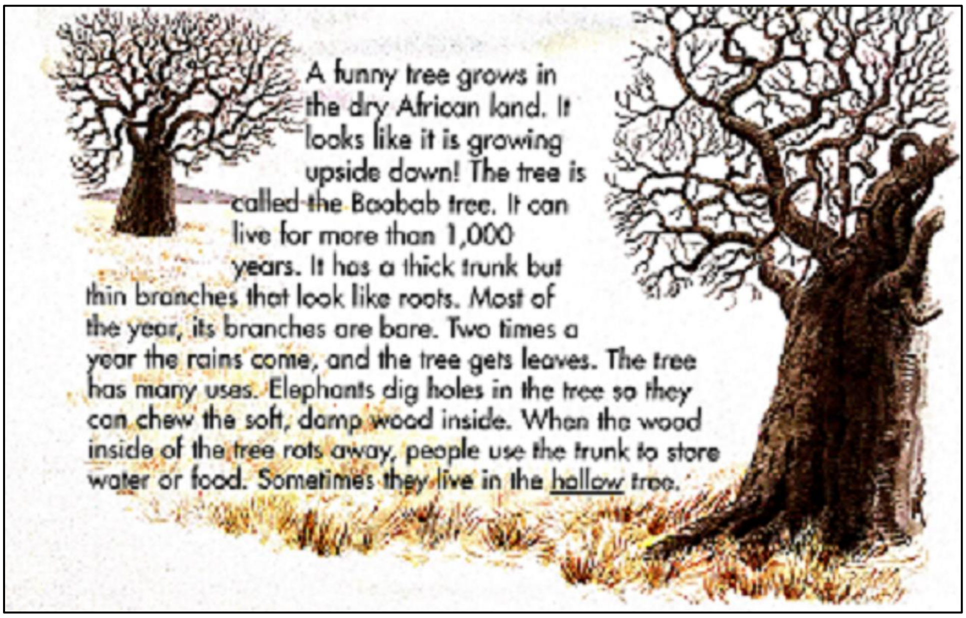
While most children their age were into football or bike riding, Jack and Luke dreamt of becoming famous actors to live in New York City to follow their passion of acting.

One day, a teacher waved to Luke to come over and talk. He explained to Luke that he had a spot in a school play and was impressed by his excitement and passion. He told Luke that he only had one spot available and he would like him to come along. Luke was so excited but he felt sad for Jack. Luke explained to the teacher that although he was very thankful for the offer, he would only join if Jack could to. The teacher said he would see what he could do.

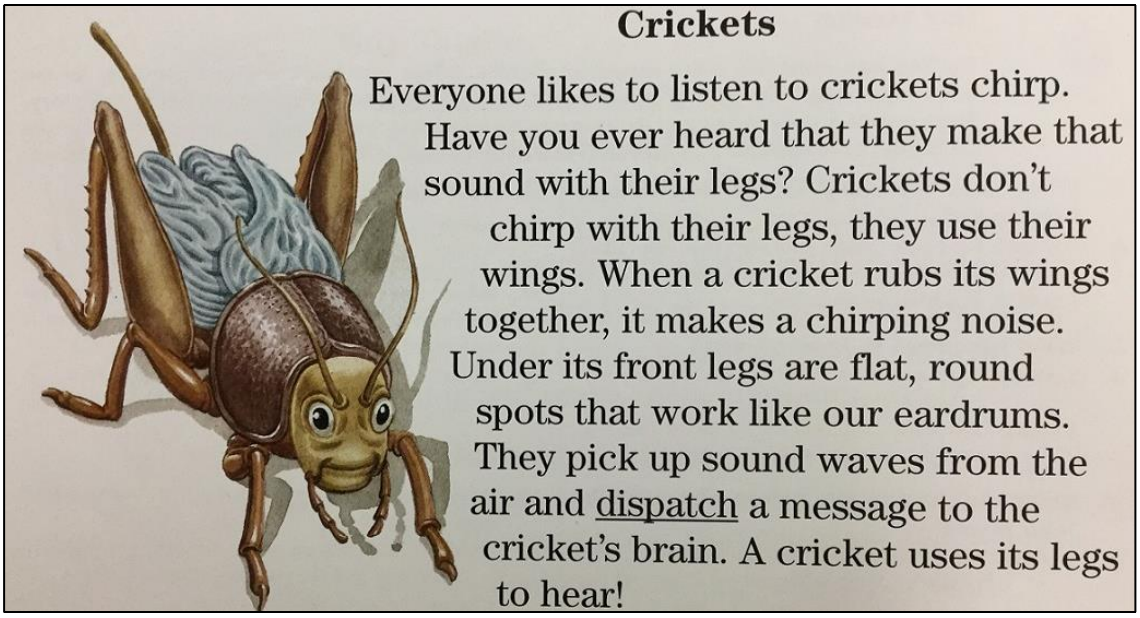
To great the surprise of both Jack and Luke, the teacher approached them both the following morning, to extend his invitation to both of the budding actors. This was the start of something big.

WIAT: Pet Day (G1-2)

WIAT: Baobab Tree (G1-2)



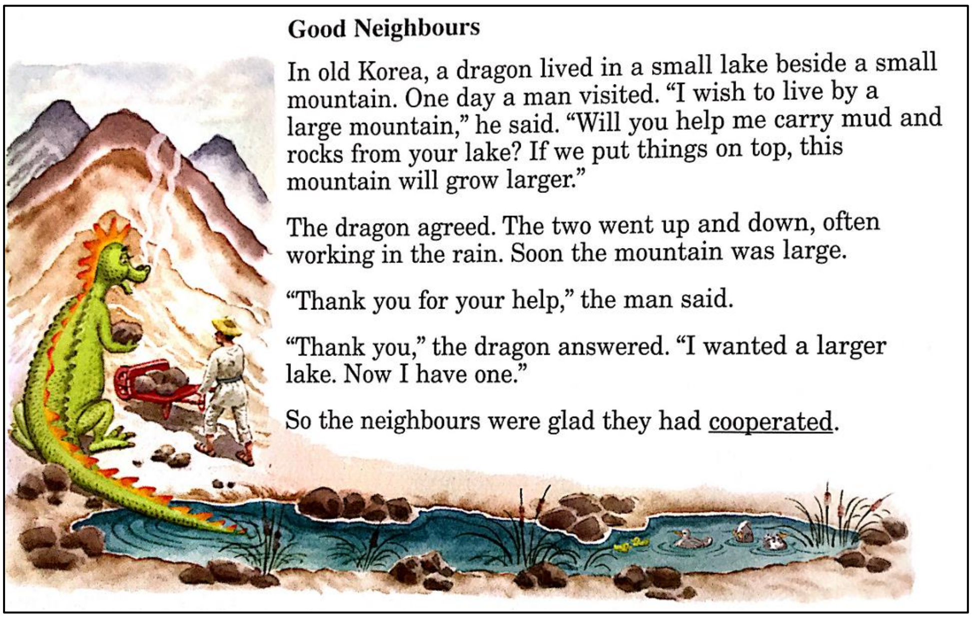
WIAT: Crickets (G3-4)



Crickets

Everyone likes to listen to crickets chirp. Have you ever heard that they make that sound with their legs? Crickets don't chirp with their legs, they use their wings. When a cricket rubs its wings together, it makes a chirping noise. Under its front legs are flat, round spots that work like our eardrums. They pick up sound waves from the air and dispatch a message to the cricket's brain. A cricket uses its legs to hear!

WIAT: Good Neighbours (G3-4)



Good Neighbours

In old Korea, a dragon lived in a small lake beside a small mountain. One day a man visited. "I wish to live by a large mountain," he said. "Will you help me carry mud and rocks from your lake? If we put things on top, this mountain will grow larger."

The dragon agreed. The two went up and down, often working in the rain. Soon the mountain was large.

"Thank you for your help," the man said.

"Thank you," the dragon answered. "I wanted a larger lake. Now I have one."

So the neighbours were glad they had cooperated.

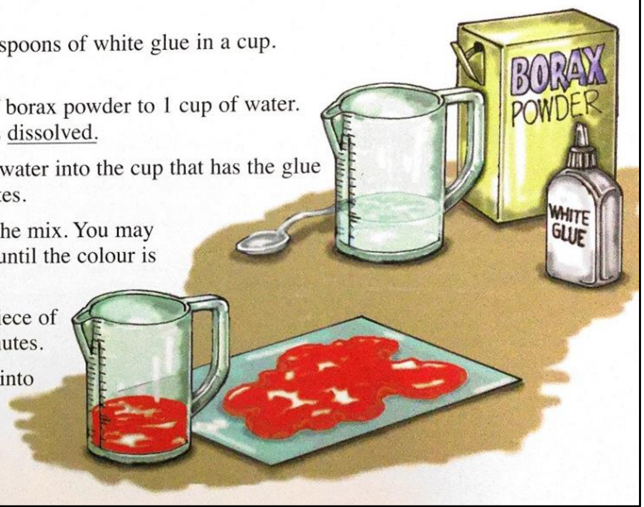
WIAT: How to Make Gobbledeeglue (G5-6)

Science fun you can do at home!

HOW TO MAKE GOBBLEDEEGLUE

Follow these easy steps:

1. Put 2 teaspoons of water and 4 teaspoons of white glue in a cup. Stir with a spoon.
2. In another cup, add 2 teaspoons of borax powder to 1 cup of water. Stir with a spoon until the borax is dissolved.
3. Add 4 teaspoons of the borax and water into the cup that has the glue and water, and mix for three minutes.
4. Add 2 drops of food colouring to the mix. You may choose your favourite colour. Stir until the colour is mixed well.
5. Put the Gobbledeeglue mix on a piece of plastic and leave it alone for 3 minutes.
6. Pick up the Gobbledeeglue, roll it into a ball, and watch it bounce!
7. Sit the Gobbledeeglue ball on the piece of plastic and see what happens next.



WIAT: Yukon Gold (G5-6)

YUKON GOLD Starring Johnathan Dupre, Elise Young, and Piers Janal

Daily News, Gary Callahan: *Yukon Gold* mixed wilderness adventure and family conflict into a sometimes-interesting story. The Jasso family is in Seattle when they hear about the Yukon gold rush. Shortly after they board a ship for Alaska, outlaws attack them. Then they must hike the Chilkoot Pass, a cold and harsh wilderness. Luckily for the Jassos, they meet Leaping Fish, a young Native American. He helps them survive while he guides them to Dawson City. *Yukon Gold* has some exciting moments, such as when the father is attacked by a grizzly. Unfortunately, the story is hackneyed, and the ending holds no surprises. ★★

North America Press Service, Diana Fernandez: *Yukon Gold* is about one family's experiences during the last gold rush. Buried within this exciting adventure tale is the story of two teenagers fighting to become independent. Ed Jasso dreams of gold and sets off for Yukon during the Gold Rush of 1898. His teenage children, Charlie and Helen, go with him on the uncertain journey. Charlie rebels against going because he does not want to chase his father's dreams. The family encounters one danger after another. They are robbed in Alaska and barely survive the wilderness, only to face a fierce grizzly bear. If you see just one movie all summer, see *Yukon Gold*. ★★★★

George's Car (G1-2)

George has a new toy car. It looks like a little racing car. It fits in his hand. It is red and shiny.

George likes to race the car everywhere. He likes to make it go fast. Super fast.

George pretends he is winning races. He pretends the cars are very loud. He pretends the crowd is cheering.

George loves his new toy car.

Ballet Concert (G1-2)

Bella and Ivy were practising for the big ballet concert tomorrow. They leaped and twirled. They pointed their toes and their arms. They practised together all day.

By the end of the day, they were both very tired. Both girls were feeling nervous but excited for the concert.

That night, the girls needed to relax so they could sleep and be rested for the concert. So, they took some slow, deep breaths together.

"1, 2, 3, 4," they counted as they breathed in.

"1, 2, 3, 4," they counted as they held their breath.

"1, 2, 3, 4," they counted as they breathed out.

After a few minutes, both girls felt calm and they drifted off to sleep. They both dreamed about all the fun they'd have tomorrow.

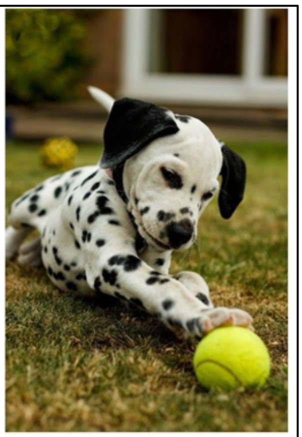
Camping Weekend (G3-4)

My family and I are going camping this weekend. We're going to a campground by a lake. There will be lots of other families there. Some will have caravans and some will have tents. Some will have campfires to do all their cooking and washing. My family will be sleeping in tents. Mum and Dad in one, and my sister and I in another.

My sister and I like to go swim in the lake with the other kids. There's also a bunch of other things to do like hiking, fishing, and kayaking. We spend a lot of time outside. During the night we like to sit around the campfire. We like to roast marshmallows and sing songs. That is my favourite part of camping.

At the end of the weekend my family and I will pack up the tents and head home. I'm sad to leave but I can't wait to come back!

Poppy the Puppy (G3-4)



Poppy is a puppy. She is white with black spots. She loves playing with her tennis ball and with her owner, Emily. One day, Emily threw the ball too far and it landed in the bushes. "Oh no!" Emily cried.

Before Emily could do anything, Poppy ran after the ball as fast as she could, eager to catch it. Poppy ran straight into the bushes and made lots of noise as she crashed through the leaves and branches!

Suddenly, all the noise stopped. Poppy and the ball were nowhere to be seen. "Oh dear, where has she gone?" wondered Emily.

Finally, Poppy stepped out of the bushes. Her lovely white coat was covered in dirt and had leaves stuck to her fur! But, most importantly, she had the tennis ball!

Emily laughed, "Oh Poppy, well done! You're very dedicated, that's for sure!" Emily picked up Poppy and went inside to go brush her very dirty puppy.

A Trip to the Snow (G5-6)

"Hurry up Ella, before it gets dark!"

Ella followed her mother through the snow. Winter was a dangerous time of year for deer. The heavy snow meant there was little for the deer to eat. The snow also meant that the deer left tracks, which meant hunters could easily follow them if they weren't careful. Luckily, Ella's mother knew this and sometimes led Ella and her brother Jasper across roads to break up their tracks.

They arrived at the road. "Now remember," Mother said, "look carefully, and if you see a car, don't look into the headlights."

Ella and Jasper agreed and slowly followed their mother onto the road. They looked around carefully.

All of a sudden, a truck appeared at the top of the hill and started heading straight towards them!

"Run!" yelled Mother, as she and Jasper scrambled to safety on the other side of the road. Ella had made the mistake of looking into the headlights. The lights were as bright as a hundred suns and Ella could not see or think about anything else. The truck rushed closer and closer. Finally, Ella's instincts kicked in and she scrambled out of the way – the truck barely missing her. The truck made a loud, blaring noise on its way past, making Ella run even faster. Ella rushed to catch up with her mother and brother. She was breathless and dazed. After checking to see if she was okay, the three deer continued through the snow to safety.

Simon's Piano Concert

Simon loved playing the piano. However, it had taken Simon a long time to get to this point.

Simon's parents knew music was very good for the brain. So, they decided to enrol him in piano lessons. They hoped it would help Simon in school and give him a hobby.

At first, Simon didn't like his piano lessons. He just wanted have fun. However, his teacher Miranda made Simon sit still and play very calmly. They started off with simple songs like 'Hot Cross Buns' and 'Three Blind Mice'. When Simon could play these, Miranda introduced him to harder songs. Simon began to enjoy the challenge of learning harder songs and started practicing in his own time to get better.

One day, Simon's school announced they were having a talent contest. Simon told his teacher about it and she encouraged him to enter. So, Simon entered and practiced harder than he had ever practiced before.

Finally, the day was here. When Simon sat down at the piano, his hands were shaking and his breath was shallow. He took a deep breath, laid his hands on the keys, and began to play his song.

Simon had never focused so hard on anything before. His fingers seemed to move across the keys effortlessly, almost automatically. Finally, when he was finished and he stood up to take his bow, the applause was enormous. He was awarded first place in the talent contest!

Even now, many years later, Simon still remembered that victory and still loved playing the piano.

Appendix K:

Visit to the Zoo

Grade 5/6 Text 1

Q. 1 Why did Tom and Becky have free time?
1: Because it was school holidays
0: Conceptually different answer

Q. 2 On what day did Grandpa take the children to the zoo?
1: On Monday.
0: Conceptually different answer

Q. 3 What is Tom's favourite place in town?
1: The zoo.
0: Conceptually different answer

Q. 4 What is Becky's favourite treat?
1: Ice-cream.
0: Conceptually different answer

Q. 5 Who visited the Butterfly House?
1: Grandpa, Tom and Becky.
0: Conceptually different answer

Q. 6 What looks like colourful pixie dust?
1: The butterflies.
0: Conceptually different answer

Q. 7 Who reads fairy tales?
1: Becky.
0: Conceptually different answer

Q. 8 Who are cousins in the animal family tree?
1: Chimpanzees and humans.
0: Conceptually different answer

Q. 9 At what time did Grandpa, Tom and Becky go to visit the giraffes?
1: At 1.00pm.
0: Conceptually different answer

Q. 10 Where do giraffes eat green tree leaves?
1: In Africa.
0: Conceptually different answer

Q. 11 Where did Becky lose her fluffy koala?
1: On the train.
0: Conceptually different answer

Q. 12 What is Becky going to make herself?
1: (Another) (fluffly) koala.
0: Conceptually different answer

Q. 13 When will Tom contact his friends?
1: On Tuesday.
0: Conceptually different answer

Fishing

Grade 3/4 Text 1

Q.1 Why does Bob say that the days are warm and sunny now?
2: Because it is spring(time)
1: Because it was spring(time)
0: Conceptually different answer

Q.2 What day did Bob and Alice go fishing?
1: On Saturday
0: Conceptually different answer

Q.3 What looked like a mirror?
2: The lake. (Best answer)
1: A lake.

Q.4 What did Alice dislike?
2:The (can of) worms. (Best answer)
1: A (can of) worms

Q.5 At what time did Alice catch the first barramundi?
1: At 12.15.
0: Conceptually different answer

Q.6 What did Alice toss into a basket?
2: The barramundi. (Best answer)
1: A barramundi
0: Conceptually different answer

Q.7 What did Bob look at with a sad face?
2: At a boot
1: At the boot
0: Conceptually different answer

Q.8 Where did Bob have dinner?
1: At Alice's (house) (place).
0: Conceptually different answer

Q.9 What did Alice fill with soil?
2: The boot.
1: A boot.
0: Conceptually different answer

Q.10 What looked like a nice flower pot?
2:The boot.
1: A boot
0: Conceptually different answer

Going to the Cinema

Grade 5/6 Text 2

Q.1 Why are days short and cold now, according to Dad?
2:Because it is winter.
1: Because it was winter.
0: Conceptually different answer

Q. 2 What day did Mum suggest going to the movies?
1: Saturday.
0: Conceptually different answer

Q. 3 What movie does Amy love?
1: "Scientists of the Sea"
0: Conceptually different answer

Q.4 What is Amy's favourite sweet?
1: Tim Tams
0: Conceptually different answer

Q.5 Where were lots of people?
1: At the (cinema ('s) (foyer).
0: Conceptually different answer

Q.6 What time did the movie finish?
1: At 4.00 (p.m.)
0: Conceptually different answer

Q.7 What was Amy's surprise gift?
1: A book (called "Choose your own Scientist Adventure")
0: Conceptually different answer

Q.8 What was Jack's surprise gift?
1: A computer game (called "Navigate the Seas on a Science Ship")
0: Conceptually different answer

Q.9 What will Amy read in one day?
2:The book ("Choose your own Scientist Adventure)
1: A book ("Choose your own Scientist Adventure)
0: Conceptually different answer

Q. 10 What will Jack play for hours?
2:The computer game ("Navigate the Seas on a Science Ship").
1: A computer game ("Navigate the Seas on a Science Ship")

Volleyball on the Beach

Text 2 3/4 Grade

Q. 1 Where is it very nice, according to Jill?
2: (On) the beach
1: (On) a beach
0: Conceptually different answer

Q. 2 What must Jill use?
2: A sunhat and sunscreen
1: The sunhat and sunscreen
0: Conceptually different answer

Q. 3 What day are the guys having some practice for the volleyball match?
1: On Monday
0: Conceptually different answer

Q. 4 What story does Jill want to finish?
1: "Space Adventure"
0: Conceptually different answer

Q. 5 Who is the umpire?
1: Jill (is).
0: Conceptually different answer

Q. 6 What team wins the match?
1: (The) Seagulls.
0: Conceptually different answer

Q. 7 What is there next to the sand castle?
2: An Esky
1: The Esky
0: Conceptually different answer

Q. 8 Who brings the Esky to Jill?
1: Joel (does).
0: Conceptually different answer

Q. 9 Where are the nice treats?
1: In (side) the Esky.
0: Conceptually different answer

Q.10 Who hands out the icy poles?
1: Jill (does).

0: Conceptually different answer

Physical Stories (LOW SOCIAL) Grade 1-2

Q1. Why does only Bob go on the rollercoaster?

2: Reference to Jim being too short for the ride or Bob being taller enough (Jim is less than 5 feet)

1: Reference to Jim being short or Bob being tall or both; No reference to height in comparison to the limit (Jim is shorter than Bob)

0: Reference to irrelevant to incorrect facts (Jim doesn't like rollercoasters)

Q2. Who are the main characters?

2: Bob and Jim

1: Bob or Jim (at least 1 of 2 correct)

0: Wrong or irrelevant

Q3. What does Bob look like?

2: Brown hair, green eye and over 5 feet
(at least 2 of 3 correct)

1: Brown hair, green eye and over 5 feet
(at least 1 of 3 correct)

0: Wrong or irrelevant

Q4. What does Jim look like?

2: Blonde hair, blue eyes and smaller than bob
(at least 2 of 3 correct)

1- Blonde hair, blue eyes and smaller than bob
(at least 1 of 3 correct)

0: Wrong or irrelevant

Q5. What was the last ride of the day?

2: The big rollercoaster

1: A rollercoaster

0:Wrong or irrelevant

Physical Stories (LOW SOCIAL) Grade 3-4

Q1. Why is Sam getting wet?

2: Reference to the bush making holes in the umbrella

1: Reference to either the bush or to holes in the umbrella

0: Reference to irrelevant or incorrect factors (it was raining, he hasn't got an umbrella)

Q2. Can you describe the bush in this story?

2: Large and very prickly

1: Large or Very prickly

0: Wrong or irrelevant

Q3. Why is Sam pleased he found his umbrella?

2: Because it was all in one piece

1: Because it was raining

0: Wrong or irrelevant

Q4. Why is Sam outside?

2: To go on a long walk and to get some fresh air

1: To go on a long walk and to get some fresh air
(at least 1 of the 2 correct)

0: wrong or irrelevant

Q5. What is Sam wearing?

1: Coat

0: Wrong or irrelevant

Physical Stories (LOW SOCIAL) Grade 5-6

Q1. Why did Clare oversleep?

2: Reference to the room being darker after redecoration (her room is dark now that she has thicker curtains)

1: Reference to redecoration; no reference to this making the room darker

0: Reference to irrelevant or incorrect factors (she's too tired, she doesn't want to go to school)

Q2. What happened in this story?

2: Clare has her room redecorated (room painted, new curtains) and Clare sleeps in.

1: Clare has her room redecorated (room painted, new curtains) and Clare sleeps in.
(1 of 2 correct)

0: Wrong or irrelevant

Q3. What did Clare's room used to look like?

2: Pink and white and had net curtains

1: Pink and white
Had net curtains
(at least 1 of 2 correct)

0: Wrong or irrelevant (e.g. just pink or just white)

Q4. What does Clare's room look like now?

2: Dark red walls and velvet curtains

1: Dark red walls or velvet curtains
(at least 1 of 2 correct)

0: Wrong or irrelevant

Q5. The velvet curtains were more expensive than the net curtains?

1: True

0: False/Other

Mental State Stories (HIGH SOCIAL) Grade 1-2
Q1. Why does he say that?
2: reference to white lie or wanting to spare her feelings; some implication that this is for aunt's benefit rather than just for his, desire to avoid rudeness or insult
1: reference to trait (he's a nice boy) or relationship (he likes his aunt); purely motivational (so she won't shout at him) with no reference to aunt's thoughts or feelings; incomplete explanation (he's lying, he's pretending).
0: reference to irrelevant or incorrect facts/feelings (he likes the hat, he wants to trick her)

Q2. Peter is Jane's nephew

1: True

0: False

Q3. How does Peter feel about Aunt Jane?

2: Reference loving his aunt.

3: positive feeling

0: irrelevant or wrong

Q4. What does Peter think about Aunt Jane's new hat?

2: Very ugly

1: Doesn't like it

0: Irrelevant or wrong

Q5. What does Peter think about Aunt Jane's old hat?

2: He likes it better than the new hat

1: He like it

0: irrelevant or wrong

Mental State Stories (HIGH SOCIAL) Grade 3-4
Q1. Why did the prisoner say that?
2: reference to fact that other army will not believe and hence look in other place, reference to prisoner's realization that that's what they'll do, or reference to double bluff
1: reference to outcome (to save his army's tanks) or to mislead them
0: reference to motivation that misses the point of double bluff (he was scared)

Q2. What is happening in this story?
2: There is a war
The Red Army has a prisoner
The Red Army is looking for the tanks.
The prisoner knows where the tanks are
(at least 2 of 4 these answers will score a 2)1- 1 out of 3?

1: Only 1 of the above answers

0: Irrelevant or wrong

Q3. What is the Red army looking for?

2. The blue army's tanks

1. Tanks

0. Irrelevant or wrong

Q4. Will the Blue army member tell the truth?

1:True

0: False

Fill in the blank.
Q5. The tanks are in the mountains or by the ___?

1: Sea

0: Other

Mental Stare Stories (HIGH SOCIAL) Grade 5-6
Q1. Why did she say this?

2: reference to white lie or wanting to spare their feelings; some implication that this is for parent's benefit rather than just for her, desire to avoid rudeness or insult

1: reference to trait (she's a nice girl) or relationship (she likes her parents); purely motivational (so they won't shout at her) with no reference to parent's thoughts or feelings; incomplete explanation (she's lying, she's pretending)

0: reference to irrelevant or incorrect facts/feelings (she likes the present, she wants to trick them)

Q2. What happened in this story?

2: Helen wanted a rabbit for Christmas/ She opened her presents/ She got encyclopedias (at least 2 out of 3 correct).

1: Helen wanted a rabbit for Christmas/ She opened her presents/ She got encyclopedias (at least 1 out of 3 correct).
0: wrong or irrelevant

Q3. How did Helen feel about the encyclopedias?

2:She felt they were boring

1: she didn't like them

0: wrong or irrelevant

Q4. Who was there when Helen opened her present?

2. Her family

1. Her parents

0: wrong or irrelevant

Q5. Helen wanted the encyclopedias for Christmas (T/ F)

1: False

0: True/ other

Dinner for Peter (Grade 1-2)
Q1. Who was Ralph?
1: (Peter's) teddy bear
0: Other

Q2. What was Peter doing before dinner?
1: Playing with ralph OR his teddy bear
0: Other

Q3. Why did Peter wash his hands?
1: So he could have clean hands before eating dinner OR
Because he was having dinner OR
So he could have clean hands
0: other

Q4. Peter does not like mashed potatoes.
1: False
0: True/other

Q5. What meal did Peter have in the story?
a. Breakfast
b. Lunch
c. Dinner

1: Dinner
0: Other

Q6. What did Peter want to do after dinner?
1: Play with Ralph/teddy bear
0: Other

Beanie found a ball (Grade 1-2)

Q1. Is Beanie a cat or a dog?
1: Dog
0: any other animal or answer

Q2. Beanie was playing in the backyard
1: False
0: True

Q3. What colour was the ball that Beanie chewed?
1: Red
0: other colour

---

4. How many balls did Beanie find?
1: three balls
0: any other number

---

5. What did Beanie do with the orange ball?
1: He ran after the orange ball
0: Other

---

6. The green ball was squeaky
1: False (It was spiky)
0: other

---

7. He played with the ____ ____ ____ and rolled it around
2: Spiky green ball
1: Squeaky green ball …. Spiky red ball …..
0: Other

---

8. Do you think Beanie likes to play in the park? (opinion)

Cuddles and Speedy (Grade 3-4)
Q1. Was Sophie my sister or my friend?
1: my sister
0: other

Q2. What did they do after they gave Cuddles and Speedy a bath?
2: Fed them food OR
Gave cuddles some doggy treats and speedy a slice of (some) apple
1: gave cuddles doggy treats OR gave speedy a slice of apple
0: other

Q3. What animals did they adopt?
2: Dog and Turtle
1: Dog, Turtle
0: Other

Q4. What did they name the turtle?
1: Speedy
0: Other

Q5. Who is Cuddles?
1: The dog
0: Other

Q6. Did they adopt a kitten?
1: No
0: Other (yes/ I don't know)

Q7. Why was everyone tired?
1: they were playing with the animals/pets/dog and turtle/ cuddles and speedy
0: other

Q8. Did they adopt their neighbour's pets?
1: No (from the animal shelter)
0: Other (yes/ I don't know)

Making a Time Capsule (G3-4)

Q.1 Can you describe the main things that happened in the story?
2: Students at Anna's school dug up their old time capsules so Anna wanted to make one. Her dad helped her find a time capsule and she put her favourite things in it.
1: Anna made a time capsule
0: None.

Q.2 Where did Anna get the idea to make a time capsule?
2: Other students from her school had made a time capsule, so Anna wanted to.
1: School
0: None.

Q. 3 What did Anna put in her time capsule?
2: Her favourite book, old photos, and anything else she could find.
1: One of above.
0: None.

Q. 4 Why was Anna interested in making a time capsule?
2: To make a memory box of her favourite things to bury and discover years later.
1: Because other students had done it
0: Other.

Q. 5 Where did they find a container for the time capsule?
2: Her garage, specifically.
1: Home
0: other

Q. 6. Anna wanted to put her favourite book in the time capsule.
1. True
0. False

Q. 7 Her Dad wanted to put his newspaper from breakfast in Anna's time capsule.
1. False
0. True

Q. 8 Was Anna scared bugs would get inside her time capsule?
1. No (Her dad was)
2. Yes

Q. 9 Did the other students put their old shoes in the time capsule?

1. No

0. Yes

Writing a Great Story (G5-6)

Q. 1 Can you describe the main things that happened in the story?
2: Anna was given a homework task to write about whatever she wanted. She wanted to write about unicorns so went and borrowed a book to do so.
1: wrote a story on unicorns OR borrowed a book on unicorns
0: other.

Q. 2 Why was Anna excited about her English homework?
2: She was allowed to write what she wanted to and could write about unicorns
1: To write about unicorns
0: Other

Q. 3 What did Anna do to learn more about unicorns?
2: She went to the library to borrow a book to learn more about unicorns.
1: Read a book
0: other

Q. 4 Who helped Anna find a book on unicorns?
1: The library helpers
0: The teacher

Q. 5 Who owned the book on make believe animals? (Inference question)
1: The school/library
0: Anna, teacher, other.

Q. 6 What was Anna's reaction when she handed in her final story?
2: She was excited/happy and proud that she had learnt about Unicorns and written a great story!
1: She was excited/happy/anything similar
0: Other.

Q. 7 Did Anna also want to write about horses?
1. NO
0. Yes

Q. 8 Anna was nervous to go to the library:
1. False
0. True

Budding Actors (G5-6)

Q. 1 How old were Jack and Luke?
1: Twelve years old
0: Other

Q. 2 Can you describe the main things that happened in the story?
2: Jack and Luke loved acting and were approached by a teacher who had one open place in a play. He first asked just Luke, but they wanted to act together so the teacher came back and asked both of the boys.
1: Jack and Luke liked acting / any singular event
0: None.

Q. 3 What were most boys their age doing?
2: Playing football and bike riding
1: One of: playing football OR bike riding.
0: Other.

Q. 4 What did the boys enjoy doing in their spare time?
2: Acting out scenes of plays at recess and lunch

1: Acting
0: Other

Q. 5 What city did the boys want to act in in the future?
1: New York City
0: Other

Q. 6 Why did the teacher only approach one of the boys?
2: Because he was impressed with the acting and he thought he only had one space available. He thought Luke was the better actor (more inferencing type answer)
1: Because he liked the acting OR had a space in the play available
0: Other.

Q. 7 Why did Luke not want to join the play without Jack?
2: Because they were best friends and wanted to act together
1: One of above
0: Other

Q. 8 How did Luke feel when the teacher first didn't ask Jack to join the play? (inferencing question)
2: Upset/sad/disappointed/felt bad for Jack as they wanted to act together
1: A singular relevant emotion
0: Other

Q. 9 The teacher gave an offer to both boys. True/False

WIAT: Pet day (Grade 1-2)

Q1. What can students bring to school on pet day?

2 points: Response must include dogs, cats, and birds.

1 points: Naming only 1 or 2 animals is a 1 point response/ pets/ only 1 pet/ animals.

Q2. Josie has a bird. How should she bring it to school?

2 points: in a cage/ put it in a cage

1 point: in a box with holes

Q3. What will happen if Tim has the best pet for Pet Day?

2 points: He will win a prize/ he will get a prize.

1 point: He will win/ He will get a ribbon.

Q4. Jody wants to bring 3 pets, but her teacher said, "Look at the poster." Why do you think her teacher said that?

2 points: because you can only bring on pet.

1 point: That would be too many/ so it won't be so crowded.

Q5. What does "pets must be on a leash" mean? (point to where leash is underlined in the passage.

2 points: Response must describe what a leash is and its purpose.

1 point: any response that indicates a restraint is required to participate

WIAT: BAOBAB TREE (G1-2)

Q. 1 Where does the Baobab tree grow?
2 points: in Africa/ the African lands
1 point: in dry lands/ where the elephants live

Q. 2 When does the tree get leaves?
2 points: when it rains/ when the rains come
1 point: two times a year

Q. 3 Why do elephants dig holes in the tree?
2 points: Response must make reference to chewing wood and that the wood is damp.
1 point: because they are hungry/ to chew wood.

Q. 4 What are two ways that people use the Baobab tree?
2 points: Response must refer to storage and living in the tree.
1 point: to store water and food/ to live in.

Q. 5 What does the word *hollow* mean in the story? (point to the word)
2 points: empty/ open space inside the tree.
1 point: a hole/ the centre of the tree.

Q. 6 What would be a good title for this story?
2 points: The Baobab Tree/ The Upside-Down Tree
1 point: Trees in Africa/ A Funny Tree

WIAT: Crickets (G3-4)

Q. 1 How does a cricket make a chirping sound?
2 points: response must make reference to wings *and* rubbing them together.
1 point: with its wings.

Q. 2 Which of the sentences in the story tells an opinion?
2 points: response must refer to the first sentence.
No partial credit.

Q. 3 Where are a cricket's eardrums?
2 points: under its front legs
1 point: under its feet/ under its legs

Q. 4 What do some people believe about crickets that is not true?
2 points: They chirp with their legs.
1 point: They don't use their wings to make noise.

Q. 5 What is the meaning of the word *dispatch* in the passage? (point to word)
2 points: to send/ send a message to its brain
1 point: to tell something to someone

Q. 6 How does a cricket use its legs to hear?
2 points: response must include accurate mention of at least *two* of the following: eardrums, picks up sound waves, dispatch to the brain.
1 point: picks up sound waves/ uses its legs to get sounds.

WIAT: Good Neighbours (Grade 3-4)

Q1. Where did the dragon live?

2 points: response must include at least *two* of the following: Korea, lake, mountain.

1 point: in a lake/ in Korea.

Q2. What did the man want?

2 points: response must include a reference to living, mountain, and (large) size.

1 point: to live in the mountain

Q3. What does *cooperated* mean in this story? (point to the word)

2 points: response must include working together to mutual advantage

1 point: work together.

Q4. What made the dragon's lake larger?

2 points: response must focus on the lake (not the mountain) *and* indicate the removal of something that impacts size.

1 point: putting rocks on the mountain.

Q5. What lesson could be learned from this story?

2 points: response must refer to the mutual benefit of cooperation.

1 point: response refers only to friendship *or* cooperation.

WIAT: HOW TO MAKE GOBBLEDEEGLUE (G5-6)

Q. 1 What three ingredients must you have to make Gobbledeeglue?
2 points: response must include, in any order: Borax (powder), (white) glue, and water.
1 point: response must include any three things listed in the passage.

Q. 2 Why must you do Steps 1 and 2 before you can do Step 3?
2 points: because they have to dissolve before Step 3.
1 point: because it won't combine right.

Q. 3 How does Gobbledeeglue change after Step 4?
2 points: it has colour
1 point: colour

Q. 4 What do you do right after the first time you put Gobbledeeglue on a sheet of plastic?
2 points: leave it alone for 3 minutes
1 point: nothing.

Q. 5 What would you predict would happen if you tried to pull Gobbledeeglue apart?
2 points: it would probably stretch
1 point: it won't bounce or go back together

Q. 6 What is the meaning of the word *dissolved* in Step 2? (point to the word)
2 points: the powder melts into liquid - not clumpy
1 point: to let it break down/ is disappears.

WIAT: Yukon Gold (Grade 5-6)

Q1. What were two dangers encountered by the family on their journey?

2 points: response must include at least *two* of the stated or implied dangers.

1 point: response includes at least *one* of the dangers.

Q2. According to Diana, why doesn't Charlie want to go to the Yukon?

2 points: because he doesn't want to chase his father's dreams/ his goals and desires differ from his father's.

1 point: because it wasn't his idea.

Q3. According the reviewers, what are two main themes or ideas in Yukon Gold?

2 points: response must refer to wilderness adventure and family conflict.

1 point: response includes at least *one* of the themes.

Q4. Diana gave Yukon Gold although Gary gave it two. What did Gary dislike about the movie?

2 points: he didn't like that is was so predictable (hackneyed)/ the story was too predictable/ the boring ending.

1 point: the ending.

Q5. What is the meaning of the word *hackneyed* in Gary's review?

2 points: banal/ trite/ overused/ same story ending as in other movies.

1 point: too predictable - you can tell what's going to happen before it ends.

Georges Car (G1-2)

Q. 1 What does George's toy car look like?
2: References at least two of: red, shiny, little racecar.
1: One of those answers
0: none of those answers

Q. 2 What does George pretend to do?
2: Two of these.
1: One of; Race his car, win races, make loud noises.

Q. 3 How does George feel about his new toy car?
1: He loves it. (Happy or excited).

Q. 4 Why is the crowd cheering?
2: because the car/his car/George is winning.
1: because they are happy/excited OR because there is a race.
0: irrelevant answer.

Q. 5 Where does the car fit?
1: in his hand

Q. 6 He likes to make the car go fast.

1. True

0. False

The Ballet Concert (G1-2)

Q. 1 What were the girls practising for?
2: Big ballet concert
1: One of; ballet concert, concert, big concert, ballet
0: Irrelevant answer

Q. 2 How did the girls feel <u>before</u> they did their breathing exercise?
2: Nervous and excited
1: Nervous OR excited

Q. 3 How did the girls feel <u>after</u> they did their breathing exercise?
1: Calm
0: Irrelevant answer

Q. 4 What did the girls dream about?
2: The fun they'd have at the ballet concert tomorrow
1: One or two of: fun OR ballet concert OR tomorrow
0: Irrelevant answer

Q. 5 Describe the main things that happened in the story.
2: Refer to: girls practicing for the ballet concert; girls feeling nervous; girls doing breathing/deep breathing/breathing exercises to try and help them relax; girls relaxing and going to sleep
1: Refer to: Girls practicing for ballet concert; girls doing breathing/deep breathing/breathing exercises
0: Refer to: One or none of the above story points

Q. 6 The girls counted to 5 as they breathed deeply:

1. False

0. True

Camping Weekend (G3-4)

Q. 1 Do you think this person is happy or sad to be at the camp ground?
1: Happy
0: Sad/irrelevant answer

Q. 2 How do you think this person feels when they leave the camp ground?
2: Sad BUT ALSO excited to come back
1: Sad OR excited to come back
0: Irrelevant answer

Q. 3 What is this person's favourite part of camping?
2: Roasting marshmallows AND singing songs.
1: Roasting marshmallows OR singing songs.
0: Irrelevant answer

Q. 4 Where does this person spend most of their time at the camp ground?
1: Outside
0: Inside/Irrelevant answer

Q. 5 What is this story about?
2: Refer to: A person going camping with their family; that person saying what they like to do at the camp ground; leaving the camp ground and being excited to come back
1: Refer to: A person going camping with their family
0: Irrelevant answer

Q. 6 Would the campground be a good holiday location? Prove your decision using information from the text.
2: Gives 'Yes/No' answer, uses at least two points of evidence from the text
1: Gives 'Yes/No' answer, uses one point of evidence from text
0: Only gives 'Yes/No' answer, or no answer at all

Q. 7 The children can do hiking, fishing, and kayaking at the camp ground:

1. True

0. False

Poppy the Puppy (G3-4)

Q. 1 Who is Emily?
1: Poppy's owner
0: Irrelevant answer

Q. 2 Did Emily throw the ball into the bushes accidently or on purpose? Justify your answer using information from the text.
2: Accidentally because she cried 'Oh no!'
1: Accidentally
0: On purpose/irrelevant answer

Q. 3 How do you think Emily felt when Poppy didn't come out of the bushes?
1: Worried/Upset/Scared

0: Irrelevant answer

Q. 4 How do you think Emily felt when Poppy finally did come out of the bushes?
1: Happy/Relieved
0: Irrelevant answer

Q. 5 Why did Emily say Poppy was 'dedicated'?
2: Because she ran through the bushes to get the ball/tried her hardest to get the ball/got the ball even though it was hard
1: Because she got the ball
0: Irrelevant answer

Q. 6 Describe the main things that happened in the story.
2: Refer to: Poppy playing with Emily; Emily throwing ball into the bushes; Poppy chasing after the ball; Poppy coming out of the bushes with the ball; Poppy being dirty; Emily laughing and going to brush her
1: Refer to: Emily throwing ball into the bushes; Poppy chasing after the ball;
0: Refer to one or less of the above story points

Q. 7 How would the story have been different if Poppy was a lazy puppy?
2: Refer to: Poppy wouldn't have chased after the ball; Emily would have had to go get the ball
1: Refer to: Poppy wouldn't have chased after the ball
0: None of the above points

Q. 8 Poppy made very little noise as she made her way through the leaves and branches:
1. False
0. True

Q. 9 Poppy is white with ___ ___ .
1: Black spots
0: Irrelevant answer

A Trip to the Snow (G5-6)

Q. 1 Who is Jasper?
1: Ella's brother
0: Irrelevant answer

Q. 2 What was the "loud, blaring noise" that the truck made?
1: Its horn
0: Irrelevant answer

Q. 3 How do you think Ella felt when she was in front of the truck?
1: Scared/Terrified/Worried
0: Irrelevant answer

Q. 4 Describe the main things that happened in the story.
2: Refer to: Ella and family going through the forest in winter; the family crossing the road; truck coming down the road and nearly hitting Ella; Ella getting out of the way of the truck; family continuing on safely
1: Refer to: The family crossing the road; truck coming down the road and nearly hitting Ella
0: Refer to: one or less of the above story points

Q. 5 Why is winter a dangerous time of year for the deer?
2: Refer to: the deer having little/no food AND leaving tracks because of the snow
1: Refer to: the deer having little/no food AND leaving tracks
0: One of less of the above points

Q. 6 Ella felt breathless and dazed after she was nearly hit by the truck:
1. True
0. False

Q. 7 What did Mother say to Ella and Jasper before they crossed the road?
1: Look carefully AND don't look into the headlights
0: One or less of the above answers

Q. 8 Does the word 'dazzled' describe how Ella was feeling when she was looking into the headlights?
1. Yes
0. No

Q. 9 How would the story have been different if the truck did not come down the road?
2: Refer to: family crossing the road safely; Ella not being in danger
1: Refer to: family crossing the road safely OR Ella not being in danger
0: Refer to: none of the above points

Simon's Piano Contest (G5-6)

Q. 1 Who is Miranda?
1: Simon's piano teacher
0: Irrelevant answer

Q. 2 What simple songs did Simon play when he was first learning the piano?
1: 'Hot Cross Buns' and 'Three Blind Mice''
0: One or none of the above answers

Q. 3 How did Simon's feelings about piano lessons change?
1: Refer to: (at first) he didn't like/hated it, then he liked/loved it
0: Irrelevant answer

Q. 4 How did Simon feel when he was about to play in the talent contest?
1: Nervous/anxious/worried/scared
0: Irrelevant answer

Q. 5 By the end of this story, Simon still loves to play the piano:
1. **True**
0. False

Q. 6 Why did Simon's parents sign him up for piano lessons? Give three reasons from the text.
2: Refer to three of: they knew music was very good for the brain; the hoped it would help Simon in school; they hoped it would give Simon a hobby.
1: Refer to two or less of the above reasons.
0: Refer to none of the above reasons

Q. 7 How would the story have been different if Miranda had just let Simon have fun, and had not taught him how to sit still and play calmly?
2: Refer to: Simon would not have gotten better at piano; Simon would not have entered and won the talent contest
1: Refer to: Simon would not have gotten better at piano OR Simon would not have entered and won the talent contest
0: Refer to: none of the above answers

Q. 8 His fingers seemed to move across the keys ____, almost ____
1: Effortlessly; Automatically
0: Irrelevant answer

Q. 9 Why did Simon do so well at the talent contest?
1: He practiced very hard/a lot
0: He practiced/irrelevant answer

Q. 10 What is this story about?
2: Refer to: Simon; how he loves playing the piano; how he started playing the piano/started piano lessons; how Simon won a talent contest
1: Refer to: How Simon won a talent contest OR how Simon loves playing the piano
0: Irrelevant answer

Appendix L:

Student	Letter Identification	Phonological Awareness	Rapid Automatic Naming	Word Identification	Word Attack	Listening Comprehension	Word Comprehension	Passage Comprehension	Oral Reading Fluency
IG	106	118	105	131	126	135	131	113	140
LJ		100	96	120	126	91	105	113	110
ZC		108	103	109	95	109	114	118	107
LP	104	104	96	96	91	103	96	100	96
RB				95	92	80	86	85	89
JC				108	112	112	115	113	98
MI				111	123	100	103	122	97
KS				108	117	90	95	103	105
AG	104	74	93	87	80	86	90	86	93
JG				124	114	103	113	98	105
SM				124	110	85	104	101	104
EF				82	84	77	94	84	82
ER				125	116	116	113	105	111
EW				74	73	110	92	82	87
HO				82	81	90	96	87	86
KL				94	93	79	83	74	89
ZI				111	95	87	101	100	93
DI				114	112	111	104	118	97
DM				62	59	86	83	73	70

Appendix M:

G1-2 **Texts**	***Low Social***	***High Social***	***Dinner for Peter***	***Beanie Found a Ball***	***Baobab Tree***	***Pet Day***	***George's Car***	***Ballet Concert***	***TOTAL***	**% accurate**
TOTAL	10	9	6	8	12	10	9	10	74	
RB										
Comp Accuracy	8	3	6	7	6	7	6	5	48	**65%**
Reading Phase	59.51	40.6	76.06	44.19	96.83	23.59	41.77	100.08	482.63	
Question Phase	64.92	98.65	64.31	73.09	73.57	83.84	57	110.59	625.97	
LP										
Comp Accuracy	8	8	5	8	3	9	8	6	55	**74%**
Reading Phase	154.37	75.87	195.62	105.51	260.19	30.8	71.66	280.67	1174.69	
Question Phase	89.35	88.02	56.32	182.96	124.81	67.25	84.01	82.89	775.61	
LJ										
Comp Accuracy	10	6	5	8	10	8	5	8	60	**81%**
Reading Phase	39.75	26.49	53.78	38.03	61.67	18.19	28.55	60.18	326.64	
Question Phase	84.13	117.73	55.43	85.61	100.83	74.65	80.95	69.58	668.91	
IG										
Comp Accuracy	10	7	5	8	9	10	9	6	64	**86%**
Reading Phase	58.63	33.12	59.44	44.5	83.94	17.32	41.22	68.38	406.55	
Question Phase	65.95	98.17	106.2	123.79	113.02	125.51	113.03	122.1	867.77	
ZC										
Comp Accuracy	10	6	6	8	11	10	9	8	68	**92%**
Reading Phase	49.08	27.04	54.17	34.19	71.44	17.26	33.5	74.06	360.74	
Question Phase	67.51	91.57	110.49	144.68	161.65	81.85	60.28	129.09	847.12	

Comp accuracy = number of marks given based on answers to comprehension questions
Reading Phase/Question Phase = duration in seconds.

Appendix N:

G1-2 Eye Movements	Reading Fluency	Mean Fixation Duration	Fixation count	Overall Fixation Duration	Overall Saccade Duration	Overall Visit Duration	Visit count	% fixation	% saccades
RB									
Reading Phase	83.29	0.22	1929	426.15	49.16	475.31	26	90%	10%
Question Phase		0.17	2273	393.44	127.6	521.04	96	76%	24%
LP									
Reading Phase	34.22	0.34	3217	1107.98	59.97	1167.95	33	95%	5%
Question Phase		0.26	1406	362.94	72.82	435.76	60	83%	17%
LJ									
Reading Phase	123.07	0.19	1486	288.2	37.39	325.59	22	89%	11%
Question Phase		0.19	1390	257.3	160.3	417.6	74	62%	38%
IG									
Reading Phase	98.88	0.23	1624	375.1	26.79	401.89	22	93%	7%
Question Phase		0.18	2963	518.87	125.11	643.98	150	81%	19%
ZC									
Reading Phase	111.44	0.15	1874	274.15	82.44	356.59	29	77%	23%
Question Phase		0.14	1268	171.55	86.93	258.48	132	66%	34%

Reading fluency is measured in words read aloud per minute. Reading fluency was only measured in the Reading Phase when participants were required to read out loud.

Appendix O:

G3-4 Texts	*Fishing*	*Volleyball*	*High Social*	*Low Social*	*Cuddles & Speedy*	*Time Capsule*	*Crickets*	*Good Neighbours*	*Camping Weekend*	*Poppy the Puppy*	*TOTAL*	% accurate
TOTAL	17	13	8	9	10	14	12	10	11	13	117	
SM												
Comp Accuracy	13	6	5	7	10	11	8	5	7	12	84	72%
Reading Phase	78.86	69.71	47.34	44.34	62.13	111.4	37.43	46.75	61.93	61.79	621.68	
Question Phase	187.34	205.21	161.68	76.58	74.33	144.65	103.88	69.56	96.58	184.61	1304.42	
EF												
Comp Accuracy	12	11	5	5	10	5	4	5	7	12	76	65%
Reading Phase	155.04	145.79	86.75	126.11	107.23	212.97	68.8	64.95	107.53	114.78	1189.95	
Question Phase	251.33	183.55	121.45	130..02	100.73	201.33	208.74	184.08	153.05	230.3	1634.56	
AG												
Comp Accuracy	3	7	5	2	10	9	3	3	5	4	51	44%
Reading Phase	180	166.61	101.78	112.39	160.95	298.92	82.42	102.29	148.4	149.97	1503.73	
Question Phase	297.16	231.41	142.02	93.38	96.38	207.25	126.55	98.64	117.69	215.2	1625.68	
JC												
Comp Accuracy	16	13	7	5	10	12	9	8	10	11	101	86%
Reading Phase	64.6	82.68	53.26	54.8	81.22	135.96	40.91	55.87	83.81	82.52	735.63	
Question Phase	121.05	161.63	100.34	63.41	91.87	264.29	127.19	104.35	185.42	202.98	1422.53	
MI												
Comp Accuracy	16	13	5	6	10	13	8	5	10	11	97	83%
Reading Phase	88.38	82.18	43.54	51.62	68.37	122.23	42.6	52.48	68.04	80.79	700.23	
Question Phase	199.56	157.04	191.2	95.25	105.22	283.26	296.35	157.31	194.79	294.82	1974.8	
JG												

Comp Accuracy	16	10	6	6	10	11	7	7	8	10	91	78%
Reading Phase	84.48	73.51	41.48	52.51	73.93	115.41	38.56	54.61	68.65	69.41	672.55	
Question Phase	173.64	187.84	74.43	83.08	92.14	147.41	121.37	127.6	152.66	150.53	1310.7	
KS												
Comp Accuracy	14	11	8	5	10	9	8	7	10	11	94	80%
Reading Phase	115.66	132.44	56.55	77.44	78.83	192.53	50.43	62.7	80.5	73.59	920.67	
Question Phase	293	227.94	155.43	185.74	88.25	499.04	198.54	128.67	163.33	201.49	2141.43	

Comp accuracy = number of marks given based on answers to comprehension questions
Reading Phase/Question Phase = duration in seconds.

Appendix P:

G3-4 Eye Movements	Reading Fluency	Mean Fixation Duration	Fixation count	Overall Fixation Duration	Overall Saccade Duration	Overall Visit Duration	Visit count	% fixation	% saccades
SM									
Reading Phase	136.66	0.17	2820	488.99	118.61	607.60	35	80%	20%
Question Phase		0.17	3170	544.26	152.24	696.50	66	78%	22%
EF									
Reading Phase	71.40	0.23	4154	964.35	178.58	1142.93	57	84%	16%
Question Phase		0.21	2732	567.03	272.95	839.98	138	68%	32%
AG									
Reading Phase	56.50	0.26	5311	1391.16	101.83	1492.99	43	93%	7%
Question Phase		0.19	3366	629.20	141.45	770.65	147	82%	18%
JC									
Reading Phase	115.49	0.13	4241	570.56	174.73	745.29	59	77%	23%
Question Phase		0.14	3906	566.07	256.32	822.39	197	69%	31%
MI									
Reading Phase	121.33	0.10	4691	483.16	220.90	704.06	69	69%	31%
Question Phase		0.11	6679	754.70	332.66	1087.36	130	69%	31%
JG									
Reading Phase	126.33	0.22	2476	554.71	102.69	657.40	35	84%	16%
Question Phase		0.25	2815	693.73	118.43	812.16	93	85%	15%
KS									
Reading Phase	92.28	0.13	4884	619.44	257.31	876.75	129	71%	29%
Question Phase		0.14	4994	704.36	311.58	1015.94	211	69%	31%

Reading fluency is measured in words read aloud per minute. Reading fluency was only measured in the Reading Phase when participants were required to read out loud.

Appendix Q:

G5-6 **Texts**	**Visit to the Zoo**	**Cinema**	**High Social**	**Low Social**	**Writing a Great Story**	**Gobble-deeglue**	**Budding Actors**	**Trip to the Snow**	**Simon's Piano Concert**	**Yukon Gold**	***TOTAL***	**% accurate**
TOTAL	13	13	9	9	12	12	15	12	13	10	118	
KL												
Comp Accuracy	7	8	5	2	9	5	6	3	7	2	54	46%
Reading Phase	136.2	100.9	67.56	61.53	139.29	110.58	184.89	204.91	168.64	216	1390.5	
Question Phase	175.48	149.2	63.56	101.1	105.17	149.12	135.88	163.06	264.36	191.32	1498.25	
EW												
Comp Accuracy	7	12	8	8	9	2	12	9	11	7	85	72%
Reading Phase	118.02	105.29	73.34	48.73	128.63	98.86	142.54	154.22	161.03	194.27	1224.93	
Question Phase	185.81	154.86	134.57	88.23	111.76	175.96	125.29	143.07	158	142.92	1420.47	
ZI												
Comp Accuracy	12	13	8	9	10	7	10	10	11	8	98	83%
Reading Phase	109.46	90.62	57.93	44.97	120.96	91.21	118.89	119.58	124.55	177.26	1055.43	
Question Phase	196.14	182.07	72.45	72.11	152.57	152.65	128.04	179.33	174.1	162.5	1471.96	
DI												
Comp Accuracy	13	13	8	9	12	6	10	9	10	6	96	81%
Reading Phase	88.21	70.56	47.6	36.04	81.17	66.27	94.44	102.82	106.57	137.84	831.52	

Question Phase	201.13	162.11	86.82	122.97	144.7	241.61	183.56	174.67	190.02	305.49	1813.08	
ER												
Comp Accuracy	12	13	8	7	12	8	12	11	13	6	102	86%
Reading Phase	79.96	74.64	40.44	32.88	81.89	65.16	105.91	97.06	99.76	113.86	791.56	
Question Phase	224.05	133.84	123.78	111.638	192.02	174.44	214.76	146.52	210.83	168.44	1700.318	
HO												
Comp Accuracy	9	12	5	6	9	2	11	10	10	4	78	66%
Reading Phase	140.26	125.93	95.21	58.74	129.68	97.75	163.52	176.57	205.64	232.43	1425.73	
Question Phase	163.5	126.18	50.69	52.99	97.75	118.98	108.44	119.66	212.86	128.95	1180	
DM												
Comp Accuracy	10	12	4	3	6						35 (56)	63%
Reading Phase	172.77	147.4	89.79	71.21	161.03						642.2	
Question Phase	157.27	167.42	96.68	115.64	121.76						658.77	

Comp accuracy = number of marks given based on answers to comprehension questions
Reading Phase/Question Phase = duration in seconds

Appendix R:

G5-6 Eye Movements	Reading Fluency	Mean Fixation Duration	Fixation count	Overall Fixation Duration	Overall Saccade Duration	Overall Visit Duration	Visit count	% fixation	% saccades
KL									
Reading Phase	82.07	0.24	4750	1157.88	110.29	1268.17	53	91%	9%
Question Phase		0.25	2866	709.85	284.07	993.92	71	71%	29%
EW									
Reading Phase	93.16	0.18	4996	913.82	189.02	1102.84	61	83%	17%
Question Phase		0.18	3174	572.86	223.87	796.73	188	72%	28%
ZI									
Reading Phase	108.13	0.17	4789	791.6	172.24	963.84	23	82%	18%
Question Phase		0.15	5869	855.5	295.13	1150.63	39	74%	26%
DI									
Reading Phase	137.24	0.14	3545	507.96	238.12	746.08	26	68%	32%
Question Phase		0.14	6405	871.46	513.4	1384.86	55	63%	37%
ER									
Reading Phase	144.17	0.16	3395	554.24	20.34	574.58	71	96%	4%

Question Phase		0.18	3725	653.43	346.42	999.85	105	65%	35%
HO									
Reading Phase	80.04	0.22	4989	1120.93	159.93	1280.86	75	88%	12%
Question Phase		0.18	3077	565.15	134.22	699.37	102	81%	19%
DM									
Reading Phase	75.30	0.23	2234	514.05	124.64	638.69	30	80%	20%
Question Phase		0.23	1180	269.93	52.62	322.55	30	84%	16%

Reading fluency is measured in words read aloud per minute. Reading fluency was only measured in the Reading Phase when participants were required to read out loud.

Appendix S:

Descriptive Statistics

Dependent Variable: CompPercent

Competence	Diagnosis	Mean	Std. Deviation	N
Low	TD	55.00	15.556	2
	ASD	64.17	9.908	6
	Total	61.88	11.077	8
High	TD	82.43	6.079	7
	ASD	82.75	3.948	4
	Total	82.55	5.184	11
Total	TD	76.33	14.292	9
	ASD	71.60	12.322	10
	Total	73.84	13.137	19

Levene's Test of Equality of Error Variances[a]

Dependent Variable: CompPercent

F	df1	df2	Sig.
1.422	3	15	.275

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Competence + Diagnosis + Competence * Diagnosis

Two-Way Analysis of Variance (ANOVA): Between Subjects Effects of Reading Competence and Diagnosis on Comprehension Accuracy

Dependent Variable: CompPercent

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	2105.229[a]	3	701.743	10.513	.001	.678	31.538	.991
Intercept	76309.955	1	76309.955	1143.166	.000	.987	1143.166	1.000
Reading Competence	1998.157	1	1998.157	29.934	.000	.666	29.934	.999
Diagnosis	84.966	1	84.966	1.273	.277	.078	1.273	.185

Reading Competence * Diagnosis	73.843	1	73.843	1.106	.310	.069	1.106	.167
Error	1001.298	15	66.753					
Total	106707.000	19						
Corrected Total	3106.526	18						

a. R Squared = .678 (Adjusted R Squared = .613)

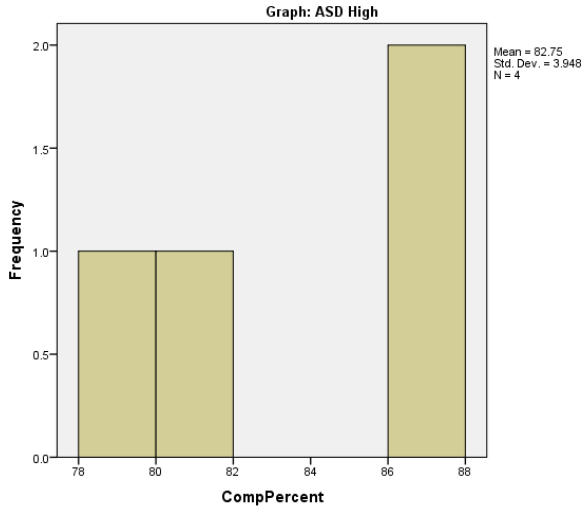
b. Computed using alpha = .05

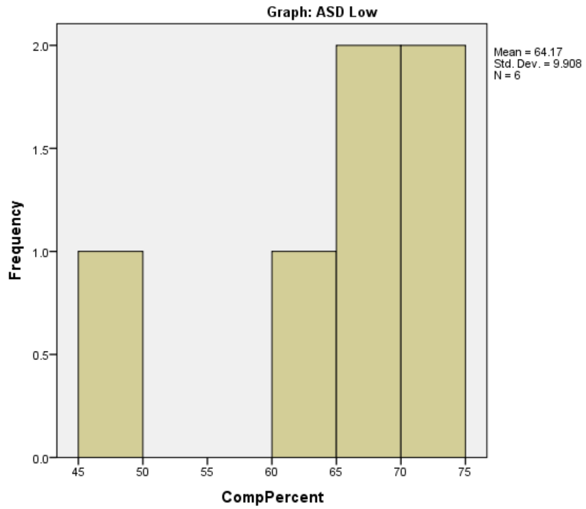
Diagnosis

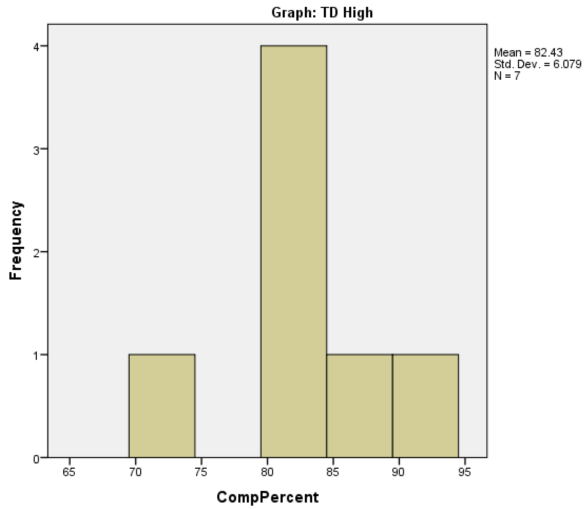
Dependent Variable: CompPercent

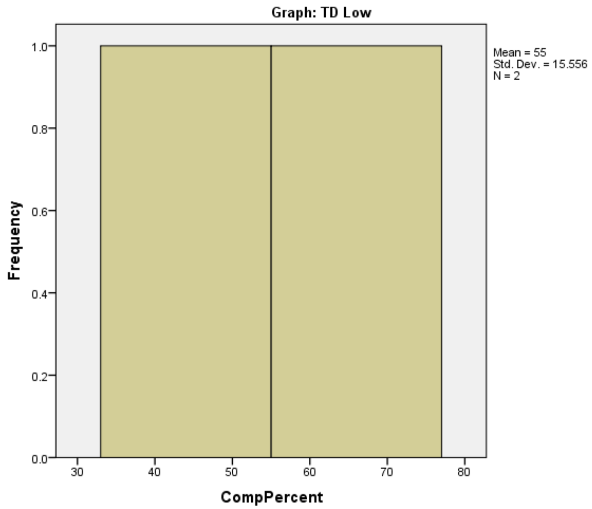
Diagnosis	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
TD	68.714	3.275	61.733	75.696
ASD	73.458	2.637	67.838	79.079

Appendix T:


Graph: ASD High
Mean = 82.75
Std. Dev. = 3.948
N = 4
Frequency
2.0
1.5
1.0
0.5
0.0
78
80
82
84
86
88
CompPercent


Graph: ASD Low
Mean = 64.17
Std. Dev. = 9.908
N = 6
Frequency
2.0
1.5
1.0
0.5
0.0
45
50
55
60
65
70
75
CompPercent


Graph: TD High
Mean = 82.43
Std. Dev. = 6.079
N = 7
Frequency
4
3
2
1
0
65
70
75
80
85
90
95
CompPercent


Graph: TD Low
Mean = 55
Std. Dev. = 15.556
N = 2
Frequency
1.0
0.8
0.6
0.4
0.2
0.0
30
40
50
60
70
80
CompPercent

Appendix U:

Descriptive Statistics

Dependent Variable: Mean fixation duration - question time

Competence	Diagnosis	Mean	Std. Deviation	N
Low	TD	.1850	.00707	2
	ASD	.2167	.03670	6
	Total	.2088	.03441	8
High	TD	.1471	.02289	7
	ASD	.1900	.04546	4
	Total	.1627	.03744	11
Total	TD	.1556	.02603	9
	ASD	.2060	.04033	10
	Total	.1821	.04224	19

Levene's Test of Equality of Error Variances[a]

Dependent Variable: Mean fixation duration - question time

F	df1	df2	Sig.
1.376	3	15	.288

Tests the null hypothesis that the error variance of the dependent variable is equal across groups.

a. Design: Intercept + Competence + Diagnosis + Competence * Diagnosis

Tests of Between-Subjects Effects

Dependent Variable: Mean fixation duration - question time

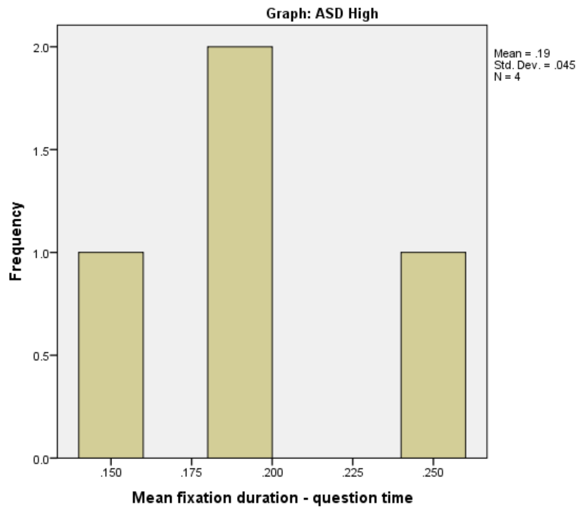
Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[b]
Corrected Model	.016[a]	3	.005	4.958	.014	.498	14.873	.820
Intercept	.515	1	.515	479.197	.000	.970	479.197	1.000
Competence	.004	1	.004	3.655	.075	.196	3.655	.432
Diagnosis	.005	1	.005	4.876	.043	.245	4.876	.542

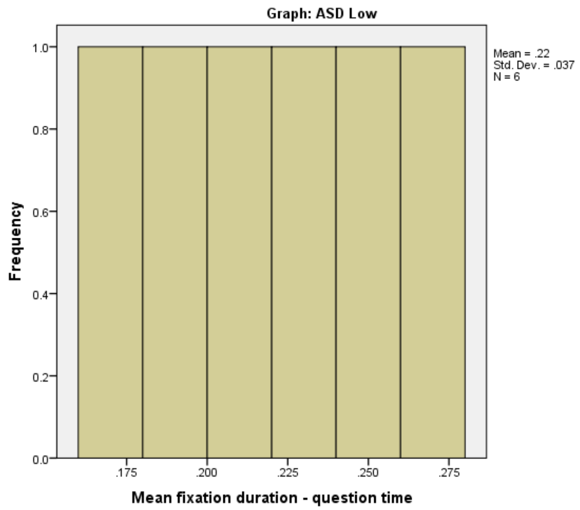
Competence * Diagnosis	.000	1	.000	.110	.745	.007	.110	.061
Error	.016	15	.001					
Total	.662	19						
Corrected Total	.032	18						

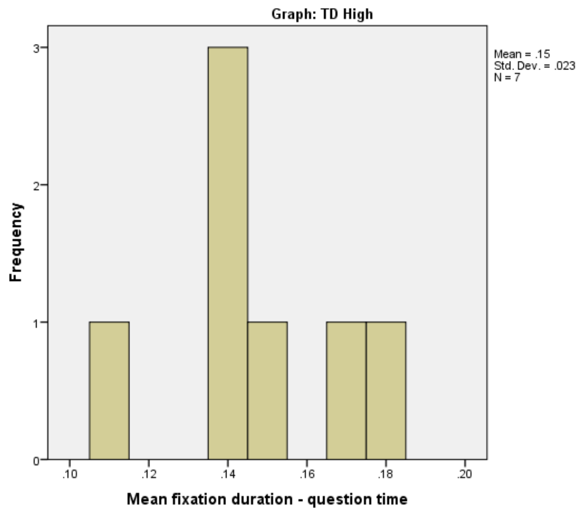
a. R Squared = .498 (Adjusted R Squared = .397)

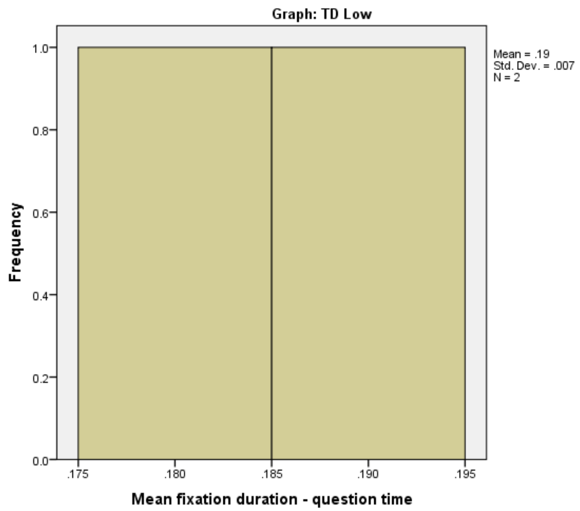
b. Computed using alpha = .05

Appendix V:


Graph: ASD High
Mean = .19
Std. Dev. = .045
N = 4
Frequency
Mean fixation duration - question time


Graph: ASD Low
Mean = .22
Std. Dev. = .037
N = 6
Frequency
Mean fixation duration - question time


Graph: TD High
Mean = .15
Std. Dev. = .023
N = 7
Frequency
Mean fixation duration - question time


Graph: TD Low
Mean = .19
Std. Dev. = .007
N = 2
Frequency
Mean fixation duration - question time