Perceptual Experiences of Adult Dyslexia

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Abstract

Perceptual Experiences of Adult Dyslexia

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This dissertation consists of four primary research studies collectively reporting on the perceptual experience of adults with dyslexia. Sequentially, these studies validate a screening tool for adult dyslexia, investigate the experience of adults with dyslexia and add to our knowledge of the role of visual attention in dyslexia. Data for study 1 was collected as part of a larger research collective within the Concordia Vision lab. Data for studies 2, 3 and 4 was collected as part of one large data collection effort lasting three years. Methods for data analysis span qualitative and quantitative efforts, parametric and non- parametric as well as both traditional null hypothesis testing and Bayesian statistics. Findings from these studies extend our knowledge of adults with dyslexia, deepening our understanding of dyslexia as a lifelong disorder. This thesis focuses on perception in dyslexia, enhancing our understanding of the role of perception as a possible causal deficit, with the overall aim of better understanding what it means to have dyslexia in adulthood.

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Contribution of Authors

This dissertation is composed of four separate research papers. The papers used original data collected throughout 2019-2023. In collaboration with Dr. Aaron Johnson, I designed and created all research studies as well as conducted all statistical analyses and prepared manuscripts for submission. For study 1, Vanessa Soldano and Dr. Léon Franzen helped with data collection, and Karine Elalouf helped to perform data analysis. Severina Ferreira-Lopes helped in the material preparation and data collection of study 3.

In the completion of my dissertation and related research, I was supported by the Social Sciences and Humanities Research Council (grant 767-2022-1603) and Fonds de recherche du Québec – Société et culture (FRQSC; grant 282985). Most recent versions of each study can be found on my personal OSF repository. Study 1 (https://doi.org/10.1002/dys.1797) has been published in *Dyslexia*. All other studies are current under review by peer reviewed journals. I declare that I am the sole author of the entire dissertation document below.

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CHAPTER 1:
GENERAL INTRODUCTION

Reading is a learned behaviour. In today's society, reading is an essential part of daily life, pervasive across all aspects of our existence. From reading labels at the grocery store, understanding street signs, browsing a menu, and scrolling on the phone to using a computer the act of reading is omnipresent (Burden, 2008). For the most part, reading is taught early in grade school and quickly becomes second nature thereafter. This, however, is not the case for everyone. Reading difficulties can arise from a variety of biological and environmental factors, such as intellectual disabilities, vision or hearing impairments, neurological conditions or injuries, adverse circumstances (i.e.; economic or environmental disadvantage, lack of instruction, etc.) or difficulties in speaking and understanding the language. In the absence of these conditions, a clinical diagnosis can be assumed, known as a Specific Learning Disability (SLD; American Psychiatric Association, 2013; also see Odegard et al., 2024).

The DSM-5 outlines specific criteria for diagnosing a Specific Learning Disability (SLD). According to the DSM-5, individuals with SLD exhibit difficulties in acquiring and using academic skills, such as reading, writing, and/or mathematics (American Psychiatric Association, 2013). The DSM-5 stipulates that the individual must (1) experience difficulty in either reading, comprehension, spelling, written expression, understanding number concepts or mathematical reasoning within the last six months despite the provisions of targeted interventions. (2) These difficulties must cause problems in school, work or everyday activities, the difficulties must substantially affect academic skills in that the student is performing below expectations for their chronological age. Adults seeking diagnosis must provide a substantive documented history of impairment. (3) Learning difficulties must begin during school age even if difficulties do not manifest until later academic demands exceed the individual's capacities. (4) Lastly, learning difficulties cannot be better accounted for by another condition (American Psychiatric Association, 2013). In addition to diagnostic criteria, the DSM-5 highlights the severity of symptoms with the use of severity specifiers; mild, moderate and severe. The inclusion of severity marks in the DSM-5 speaks to the changing view of dyslexia as a spectrum. The DSM-5 also outlines specifiers to be companied with diagnosis, which stipulates specific areas of impairment in one or more domains: reading, written expression or mathematics. The shift away from specific diagnostic categories to the use of specifiers in outlining the nature of impairment,

emphasizes the intersecting nature of SLDs. Dyslexia, diagnostically referred to as a SLD in reading, is a term that was first used in 1887 by German ophthalmologist Rudolf Berlin. He coined it to describe a case of a boy who had severe difficulties learning to read and write, despite normal intelligence and vision. In today's zeitgeist, dyslexia is often used to refer to a general impairment in reading (American Psychiatric Association, 2013). However, the symptoms of dyslexia and its cognitive underpinnings are complex.

Dyslexia is a neurobiological disorder, spanning throughout the lifespan, marked by slow and laboured reading, a deficit in processing speed, and difficulties with accurate and/or fluent word recognition and decoding abilities (Catts et al., 2024; Lyon, Shaywitz & Shaywitz, 2003; Pizzigallo, et al, 2023). Individuals with dyslexia report problems with word and letter retrievals, have difficulty memorizing information, experience trouble learning languages and struggle with letter-sound correspondence (Lyon et al., 2003; Rayner et al., 1989; Wagner et al., 2020). A hallmark symptom of dyslexia is the reversal of letters both spatial and sequentially, reported by both children and adults alike (Peter, Albert, & Gray, 2021; Peter, Albert, Panagiotides, et al., 2021; Treiman et al., 2014). Individuals with dyslexia report having secondary emotional and social effects, including lower self-esteem (Brunswick & Bargary, 2022; Ingesson, 2007; Livingston et al., 2018; Welton, 2023), decreased self-confidence (Livingston et al., 2018; Welton, 2023), difficulty forming social relationships and being picked on by peers (Holmes et al., 2021), describe instances of embarrassment and shame (Alexander-Passe, 2015; Jacobs et al., 2022; Welton, 2023) as well as comorbid mental health difficulties (Livingston et al., 2018; Vieira et al., 2023; Wilmot et al., 2023) and attentional deficits (ADHD; Boada et al., 2012).

In the research of individuals with dyslexia, special attention is given to children experiencing reading difficulties and children at risk of developing dyslexia with the stated aim of investigating and developing targeted early interventions (Franceschini et al., 2013; Y.-S. G. Kim et al., 2022; Kwon et al., 2007). That said, despite the growing initiative for targeted interventions and the development of compensatory strategies, reading difficulties persist throughout the lifespan in differing degrees (Carioti et al., 2021; Odegard et al., 2024). Additionally, many researchers choose to study dyslexia in children, as there are fewer external influences and individual differences at play. Once the phonological and reading processes systems have reached maturity in adulthood, direct comparison within the population of adults

with dyslexia becomes increasingly difficult and scientifically complex (Premeti et al., 2024). Identifying and studying dyslexia in adulthood is a twofold challenge.

For the most part, adults who self-identify as having dyslexia were diagnosed with dyslexia during childhood or adolescence and maintained their identity as an individual with dyslexia. There is however a subset of adults who identify as having dyslexia, who receive a diagnosis in adulthood, through a documented history of learning difficulties, as outlined in criteria three of the DSM-5 for SLD (American Psychiatric Association, 2013). Furthermore, some individuals never received an official diagnosis of dyslexia, despite longstanding learning difficulties, who self-identify as having dyslexia. In the literature, these individuals are often the by-product of self-reported dyslexia as a criterion for a study's inclusion and can be excluded from analysis despite their unique experience as an individual who self-identifies as having dyslexia (Brusick & Batgary, 2022; Nalavany et. al., 2011). For individuals diagnosed in adulthood or who self-identify as having dyslexia, under the assumption of a valid early screening, it is presumed that their learning difficulties did not fully manifest until later in life when academic demands exceeded their capacities (i.e., time constraints, complexity of reading/writing tasks, academic loads; American Psychiatric Association, 2013).

Screening tools are one way that these individuals may begin their journey of self-understanding. While not diagnostic like a clinical assessment, screening tools serve other functions in that they are often more cost-effective compared to a clinical psychological assessment, they can be used prior to seeking formal assessment and can be administered in large settings without the need for specialized training or equipment. Screening tools can therefore be used to identify individuals for further assessment and evaluation by professionals to confirm a dyslexia diagnosis (Trevethan, 2017). While in practice, a checklist for adult dyslexia could prove helpful for these aforementioned reasons, few, if any, checklists are freely available, are self-administered and are both valid and reliable. Such a tool could be used as a tool for adults questioning their past and present reading and academic difficulties and for researchers studying an adult population of dyslexia.

In chapter 2 in this dissertation, I validated the Adults Dyslexia Checklist (Stark et al., 2025). Using both univariate and multivariate analyses, I aimed to validate the widely used and freely available Dyslexia Adult Checklist. The aforementioned checklist first appeared in the British Dyslexia Association Handbook in 2001, and again in the British Dyslexia Association

Employment and Dyslexia Handbook in 2009, both written by Smythe and appears on the British Dyslexia Association website as a screening tool for the public. I firstly used a univariate statistical approach to validate this checklist which is easily digestible for practitioners and scientists. Using traditional statistical coefficients such as Cronbach's alpha for reliability and measures of sensitivity and specificity in investigations of predictive validity, I aimed to reach a broader audience of readers, encouraging the use of validated measures. Our secondary analysis was directed at psychometricians, using multivariate statistics, aimed at meeting the current best practices in validation techniques. The validation of such tools is not only considered best practice but is also a necessary step before being widely distributed. Public access to such results is also paramount for transparent research and replication of results.

Post identification, adults with dyslexia and who self-identify as having dyslexia share common reading difficulties. These difficulties in reading are often associated with other difficulties as outlined above, as well as secondary effects socially and emotionally. Socio-cultural theory posits that an individual's sense of identity is affected by what is valued by society and culture, which today is closely linked to literacy, educational and occupational success (Smythe & Everatt, 2001). Social and emotional problems in children with dyslexia have been linked to a critical period of early and middle school when instruction is literacy-based (Ingesson, 2007; McNulty, 2003). It is during this period that students begin to encounter unexplained difficulties and question their intelligence and motivation. Individuals report feeling as though others think they are 'lazy' or 'stupid' and described experiencing trauma related to reading out loud in class (Lock & Layton, 2001; McNulty, 2003). While a large body of research has investigated the social and emotional effects of dyslexia in children, there is limited research looking at adults (Livingston et al., 2018; Wilmot, Hasking, et al., 2023).

High rates of anxiety and depression in adults with dyslexia are suggested to be the product of continued low self-esteem and internalizing problems from childhood and adolescence (Klassen et al., 2011; McNulty, 2003). A Canada-wide sample of 670 individuals with a self-reported learning disability (including ADHD), between the ages of 15 and 44, reported having higher levels of distress, depression, anxiety disorders, suicidal thoughts, visits to mental health professionals, and poorer overall mental health than were persons without disabilities (Wilson et al., 2009). Furthermore, adults (ages 30-44) were more likely to report having suicidal thoughts, depression and distress compared to the adolescent sample (ages 15–

21). Previous research investigating self-reported experiences of dyslexia have described instances of embarrassment and shame (Alexander-Passe, 2015; Jacobs et al., 2022; Welton, 2023), higher rates of comorbid mental health difficulties (Livingston et al., 2018; Vieira et al., 2023; Wilmot, Pizzey, et al., 2023), decreased self-confidence and lower self-esteem (Brunswick & Bargary, 2022; Ingesson, 2007; Livingston et al., 2018; Welton, 2023; Welton, 2023) as well as difficulty forming social relationships and being picked on by peers (Holmes et al., 2021).

Of increased interest in research on adult dyslexia is the age at which the individual was diagnosed with dyslexia. Some researchers believe that early identification of dyslexia is linked to overall greater well-being and higher academic achievement through the development of compensatory strategies (Gibson & Kendall, 2010; McNulty, 2003; Ingesson, 2007; Livingston et al., 2018). In that same vein, when compensatory strategies are not learned, this can lead to negative effects on their emotional well-being, irrespective of early identification (Carawan et al., 2015). Additionally, receiving a late diagnosis has been linked to negative impacts on one's confidence, adjustment, and self-perception, in addition to their friends' and families' reactions to dyslexia (Gibson & Kendall, 2010, as cited in Livingston et al., 2018).

In chapter 3, I conducted an exploratory analysis, using a mixed-method approach, investigating the perceived experience of adults with dyslexia, considering their age of diagnosis and overall experience of dyslexia, rated as positive, neutral or negative. Here, I used a mix of forced choice yes and no questions, Likert-type scales and or one-word answers. Qualitative analysis was conducted based on answers to the question "Is there anything you would like us to know about your experience of having dyslexia?". The results from this description of the dyslexia experience will provide researchers and partitioners with extensive insight into the experience of individuals with dyslexia, quantitatively and qualitatively, as well as shed light on potential protective and risk factors for individuals with dyslexia in developing a negative experience of their dyslexia.

While there is a clear need to better understand the experience of adults with dyslexia given their continued symptomatology and secondary symptoms into adulthood, many researchers remain preoccupied by the lack of consensus on the etiology of dyslexia. Over the past few decades, two dominant learning causal theories have emerged as the leading theories on Dyslexia: (1) the phonological deficit theory (Snowling, 1981; Vellutino, Fletcher, Snowling, & Scanlon, 2004), and (2) the perceptual deficit theory (Lobier, Zoubrinetzky, & Valdois, 2012;

Stein, 2001, 2014, 2018; Stoodley & Stein, 2013; Vidyasagar & Pammer, 2010). Phonological processing is defined as the ability to access, process and manipulate speech sounds (Milladge & Blythe, 2019; Seidenberg & McClelland, 1989). The process of reading requires the learning of associations between (1) the visual forms of printed words, (2) their associated speech sounds, and (3) their meanings. The goal of reading is to connect meaning to visually presented text. To make meaning from written text there must be a connection between orthography and semantics, which involves phonological processing, defined as the ability to access, process and manipulate speech sounds (Milladge & Blythe, 2019; Seidenberg & McClelland, 1989).

Theorists of the phonological deficit speculate that dyslexia is caused by a deficit in one or more of these dimensions, (1) phonological awareness, (2) verbal short-term working memory, and (3) lexical retrieval (Ramus & Szenkovits 2008; Snowling, 2019; Snowling, Hulme & Nation, 2020; Szenkovits & Ramus, 2005). Despite being the leading causal theory of dyslexia, the phonological deficit theory is neither necessary nor sufficient to account for dyslexia (Castles & Coltheart, 1993; Peterson, Pennington, Olson, & Wadsworth, 2014; Siok & Tan, 2022; Snowing, 1981, 2019; Wagner et. al., 2020). It is for this reason that many dyslexia researchers adhere to a multi-deficit theory for dyslexia, based on the findings that deficits in either camp, phonological or perceptual can occur independently of the other in individuals with dyslexia (Bosse et al., 2007; Kristjánsson & Sigurdardottir, 2023; Snowling & Hulme, 2024).

Although not a new causal theory, the perceptual deficit theory remains understudied in the dyslexia literature, despite recent interest (Kristjánsson & Sigurdardottir, 2023). Within this theory, researchers are investigating differences in both (1) ocular motor control, and (2) visual attention. Unique to the study of perceptual investigations is its bottom-up nature. That is, both ocular motor control and visual attention are bottom-up processes, which are less impacted by learning effects and compensatory strategies (Kristjánsson & Sigurdardottir, 2023). That said, the more naturalistic the paradigm is, the more top-down influences have an effect (Rayner, 2014). One study previously conducted at the Concordia Vision Lab found that individuals with dyslexia used a different visual sampling strategy, having different in their eye movement patterns, compared to typical readers when reading standardized texts (Franzen et al., 2021). These findings stand in contrast to phonological theories, whereby interventions for dyslexia use phonological interventions to enhance reading abilities, leading to stark individual differences in

phonological abilities based on the intervention quantity, quality and type. As a result, the study of adults with dyslexia becomes increasingly challenging when investigating phonology.

The study of visual attention consists of multiple overlapping concepts, each associated with unique psychophysiological paradigms, all investigating the magnitude of information processing within a single fixation (Gavril et al., 2021). Additionally, within the different paradigms, a variety of interacting factors and manipulations can be studied, changing the construct being investigated, such as peripheral acuity, crowding, and positional uncertainty (Legge et al., 2007). Although not further investigated in this dissertation, the underlying structure of our visual field is that with increased eccentricities from central vision, acuity decreases as the number of cone receptors decrease and rod receptors increase (Curcio, 1990). Therefore, given the structure of our visual field, it makes sense that, irrespective of stimuli manipulation, the further into the periphery the less acuity we have and the less accurately one can recognize letters (Legge et al., 2001, 2007). Furthermore, crowding, also referred to as lateral masking in reading research, uses flanking letters to interfere with letter recognition (Martelli et al., 2009; Rosen et al., 2014; Strasburger, 2020). In experimental paradigms, crowding effects can be manipulated by increasing the number of visual elements, blurring flankers or changing the spacing between the flankers and target items (Kristjánsson & Sigurdardottir, 2023). Lastly, letter position plays a critical role in the size of the visual span. Many visual attention paradigms ask participants to recite item strings, receiving complete scores only when letters are reported in the correct positions (Legge et al., 2007). Researchers have found that at greater eccentricity, participants make increasing errors in terms of letter position recall, referred to as spatial reversals (S. T. L. Chung et al., 2003). Researchers are interested in manipulating the sequence of letters, for example when studying letter reversals in individuals with dyslexia (Peter, Albert, & Gray, 2021; Peter, Albert, Panagiotides, et al., 2021).

In Chapters 4 and 5 of this dissertation, I investigate factors influencing visual attention, with the greater aim of better understanding lower-level visual processing occurring in adults with dyslexia when reading. In Chapter 5, I use a paradigm from the field of cognition and perceptual attention, the oddball paradigm, as a way of studying sustained visual attention using static stimuli and behavioural measures. The oddball paradigm has been established for use in both visual and auditory experiments (Blundon et al., 2017). In these tasks, participants are sequentially presented with either one of two stimuli. Participants are asked to respond to one of

the choices, the target, but must withhold a response to the other alternative, the distractor (Blundon et al., 2017; Gomez et al., 2007). Researchers using the visual oddball paradigm aim to investigate short-term memory, lexical access and perceptual attention and discrimination (Gomez et al., 2007). Such experiments have manipulated shapes by varying their size (K. H. Kim et al., 2008), looking at feature absent vs. present stimuli (Blundon et al., 2017), while others explore lexical decisions with open and closed-class words (Gordon & Caramazza, 1982) and nouns and orthographically regular nonwords (Measso & Zaidel, 1990). Except for Rüsseler and colleagues (2003), who found no performance differences in adults with and without dyslexia on a visual oddball task using *X* distractor and *O* target stimuli, no other researcher has used the visual oddball task to explore behavioural differences in a sample of individuals with dyslexia. That said, researchers have investigated adults with dyslexia in auditory oddball tasks, noting behavioural differences between individuals with and without dyslexia (Fosker & Thierry, 2004, 2005; Rüsseler et al., 2003).

Here the oddball paradigm is employed using single-item stimuli, manipulating the spatial orientation of letters. In addition, I use multi-letter stimuli, introducing flankers, and manipulating the position of letters at the second and fourth letter position to investigate positional uncertainty. In doing so, I investigate both lexical access and perceptual discrimination in adults with dyslexia. Furthermore, the use of spatial and sequential reversals taps into a distinct but related field of dyslexia research and visual attention. Serial position effects stipulate that fundamentally strings of letters and numbers are processed differently from objects. That is, letters (and numbers) in the first and central position are most accurately identified in a force choice target search paradigm using five character strings (Tydgat & Grainger, 2009). By manipulating letters in the second and fourth letter position I introduced positional uncertainty and the concept of crowding, having flankers on each side of the target letters.

In chapter 4 of this dissertation, I investigate visual attention in adults with dyslexia, employing the moving gaze-contingent moving window paradigm in studying the visual perceptual span in adults with dyslexia. The perceptual span is understood as the number of letters, or orthographic units, that can be processed at a single glance by the foveal and parafoveal vision (Frey & Bosse, 2018; McConkie & Rayner, 1975; Rayner, 2014). Here, a predetermined window size is generated in which letters not included in the window are replaced with a mask. This mask is typically indicated by random letters or X's. As the reader moves their

eyes across the text, the window follows, keeping a consistent window for the duration on that trial. An individual's perceptual span is inferred by the size of the window whereby the reading rate is equivalent to the reading rate when reading without a window (McConkie & Rayner, 1975; Rayner et al., 2010). Previous research has found the perceptual span to be asymmetric. A typical reader is said to have a perceptual span of 3-4 characters to the left of fixation, and 14-15 characters to the right of fixation (Frey & Bosse, 2018; McConkie & Rayner, 1975; Rayner, 2014; Rayner et al., 1980).

The perceptual span is influenced by both top-down and bottom-up influences, such as peripheral acuity and crowding. Unique to the perceptual span compared to other measures of visual attention is its face validity, top-down and reader-related factors as the paradigm closely resembles naturalistic reading (Rayner, 2014). These top-down and individual influences make studying the perceptual span more intricate in adulthood due to the development and influence of learning effects and compensatory strategies (Kristjánsson & Sigurdardottir, 2023). The foveal-load hypothesis stipulates that the perceptual span decreases in size based on the difficulties of what is being processed in the fovea (Henderson & Ferreira, 1990; Frey & Bosse, 2018; Rayner et. al., 2003). Under this hypothesis, the size of the perceptual span is affected by both reader-related (i.e.; linguistic knowledge, age; Rayner, 1986) and content-related (i.e.; word frequency and syntax difficulties; Henderson & Ferreira, 1990). In one study, the introduction of parafoveal magnification on the gaze-contingent moving window paradigm to compensate for the loss of visual acuity at increased eccentricity found no difference in the size of the perceptual span as a result of parafoveal magnification, concluding that the perceptual span is not simply the result of acuity limitations, alluding to top-down influences (Miellet et al., 2009).

Chapter 4 of this dissertation aims to explore these reader-related influences of the foveal-load hypothesis by replicating the original experiment by Rayner and colleagues (1989) by investigating the perceptual span of individuals with dyslexia. Rayner and colleagues (1989) studied the perceptual span of two samples of individuals with dyslexia via a case study of a university professor with dyslexia and a sample of two additional individuals with dyslexia. Across different conditions, the perceptual span of the individuals with dyslexia was smaller compared to the control sample. This difference in perceptual span was reported as evidence for a potential subtype of individuals with dyslexia who present with visual-spatial deficits and selective attentional deficits marked by a smaller perceptual span. I employed the gaze-

contingent moving window paradigm with X's as a mask, asymmetric window sizes of 3, 7, 11 and 15 visible characters to the right of fixation, a large sample of individuals with dyslexia, standardized texts, and analyzed our data using both null hypothesis significance testing and Bayesian statistics. Results from this study will increase our understanding of top-down influences affecting the perceptual span and will replicate highly cited evidence for a protentional attentional deficit in individuals with dyslexia.

The four experimental chapters that make up this dissertation tell the story of adult dyslexia, starting with screening for dyslexia, understanding the experience of those with dyslexia and deepening our knowledge of the role of visual attention in adult dyslexia. For the most part, dyslexia is often diagnosed in childhood, identified by teachers and diagnosed by a professional, to receive target interventions and develop compensatory strategies. That said, dyslexia is developmental and spans throughout the lifetime. Therefore, there is a need to extend our knowledge on adult dyslexia, of individuals who were diagnosed in childhood, as well as individuals who received a diagnosis later or those who self-identify as having dyslexia. By studying bottom-up and top-down processes in adults with dyslexia, it is possible that researchers could uncover etiological underpinnings for dyslexia as well as discover novel interventions for early remediation. The overall aim of this dissertation is to better quantify and qualify what it means to have dyslexia in adulthood.

Research Objectives

The aim of my thesis is to better quantify and qualify the perceptual experience of what it means to have dyslexia as an adult. Particularly, this thesis will look at three broad domains within the dyslexia literature: screening, individual experience and visual attention in dyslexia. While broad in their scope, when taken together, the chapters provide a holistic overview of individuals with dyslexia, from identification and understanding of what it means to have dyslexia from the individual's perspective to studying the underlying mechanisms behind these reading difficulties. This dissertation has 4 main objectives:

> ***Objective 1****: Validate the Dyslexia Adult Checklist, a screening tool currently being used by partitioners and researchers in classifying and screening adults with dyslexia.*

Objective 2*: Understand the experience of adults with dyslexia, from a qualitative and quantitative approach based on their age of diagnosis and perceive experiences rated as negative, neutral or positive.*

Objective 3*: Replicate and extend the previous research investigating the perceptional span of adults with dyslexia using a sample size calculated to detect the effect size of interest.*

Objective 4*: Investigate spatial and sequential letter reversals in adults with dyslexia using the oddball paradigm as a way of studying sustained visual attention.*

Study 1*: Validation and Reliability of the Dyslexia Adult Checklist in Screening for Dyslexia*

In chapter 2, I address the first research objective, with the stated aim to validate the Dyslexia Adult Checklist in a sample of adults with and without dyslexia using both univariate and multivariate statistical approaches. The Dyslexia Adult Checklist is a commonly used screening tool, despite the lack of publicly available psychometric properties. This study will therefore address this gap in the literature by verifying the reliability and validity of the checklist, while also examining the underlying structure of this checklist. This manuscript explores the following two hypotheses:

Hypothesis 1*. I hypothesize that individuals with dyslexia will score higher on the checklist compared to typical readers and that the checklist will demonstrate both sensitivity and specificity.*

Hypothesis 2*. I theorize a single-factor solution, whereby the checklist measures the single construct of dyslexia.*

Study 2*: Understanding the Experience of Adults with Dyslexia: A Quantitative and Qualitative Analysis*

In chapter 3, I address the second research objective using a mixed-method approach to explore how the occurrence and timing of a dyslexia diagnosis influence individuals' experiences, rated as positive, neutral or negative. A descriptive analysis was conducted on a wide range of predicator variables, taken from the literature. Some of the predictor variables of interest include perceived reading severity, family dyslexia diagnosis, self-reported comorbidities, viewing the self as disabled, seeing oneself as stupid, feeling frustration and

empowerment, being perceived as lazy by others, and holding oneself back on experiences and opportunities because of their dyslexia. A qualitative reflexive thematic analysis was undertaken to complement the descriptive findings, providing a comprehensive understanding of dyslexia experiences and secondary effects based on the age of diagnosis. The stated intent of this paper is to provide readers with a detailed account of the experience of, and secondary effects associated with, having dyslexia using both qualitative and quantitative data. This manuscript has the following three hypotheses:

> ***Hypothesis 1****. I hypothesize that individuals in the early assessed group will be more likely to have a positive overall experience of their dyslexia, broadly agreeing with positive statements about their dyslexia and disagreeing with statements that view their dyslexia negatively.*
>
> ***Hypothesis 2.*** *I hypothesize that individuals who view themselves as stupid and who have experienced being perceived as lazy will be more likely to rate their overall experience of dyslexia as negative, with the late assessed and self-identifying groups rating themselves, on average, higher on these scales.*
>
> ***Hypothesis 3.*** *I hypothesize that the qualitative results will mirror our quantitative results as a function of the order of question presentation, priming participant responses.*

Study 3*: Visual Attention in Adults with Dyslexia: Using the gaze-contingent moving window paradigm*

In chapter 4, I address the third research objective using the gaze-contingent moving window paradigm (Rayner et al., 1989) in the study of the perceptual span of individuals with dyslexia. The perceptual span, a measure of visual attention, is defined as the number of orthographic units processed at a single glance and includes both the foveal and parafoveal vision, using a naturalistic reading paradigm. This study aims to replicate original findings from Rayner and colleagues (1989) using standardized texts and sophisticated statistical techniques. This manuscript has the following two hypotheses:

> ***Hypothesis 1.*** *I hypothesize that our sample of individuals with dyslexia will have a smaller perceptual span compared to our control group. It is expected that the magnitude of this difference be smaller than the effect reported by Rayner and colleagues (1989).*

Hypothesis 2. *Additionally, given the erratic nature of eye movements in this population, I hypothesize that our sample of individuals with dyslexia will make more eye movements and fixation longer when reading compared to the control group.*

Study 4: *Investigating spatial and sequential letter reversals in adults with dyslexia: a psychophysiological approach using the oddball paradigm*

In chapter 5, I address the fourth research objective by investigating low-level, bottom-up, visual processing occurring in letter reversals in adults with dyslexia. More specifically, I used the oddball paradigm to look at spatial reversals, the reversals of letters in space such as *b* and *d*, as well as sequential reversals, the reversals of letters within five-letter arrays of non-words and words such as *weird* and *wried.* The oddball paradigm allows for the study of sustained visual attention using static stimuli and behavioural measures. This manuscript has the following hypothesis:

Hypothesis 1. *I hypothesize that across all conditions, our sample of individuals with dyslexia will be less accurate and display an increased reaction time, compared to our control group, in identifying and reacting to both spatial and sequence reversal oddball stimuli.*

CHAPTER 2:

STUDY 1

Validation and Reliability of the Dyslexia Adult Checklist in Screening for Dyslexia

Note: Copy edited version of this study was published in *Dyslexia*, November 2024

Abstract

Dyslexia is a language-based neurobiological and developmental learning disability marked by inaccurate and disfluent word recognition, poor decoding, and difficulty spelling. Individuals can be diagnosed with and experience symptoms of dyslexia throughout their lifespan. Screening tools such as the Dyslexia Adult Checklist allow individuals to self-evaluate common risk factors of dyslexia prior to or in lieu of obtaining costly and timely psychoeducational assessments. Although widely available online, the Dyslexia Adult Checklist has yet to be validated. The purpose of this study was to validate this Checklist in a sample of adults with and without dyslexia using both univariate and multivariate statistical approaches. We hypothesized that the Dyslexia Adult Checklist would accurately distinguish between individuals with a self-reported diagnosis of dyslexia (n=200) and a control group (n=200), as measured by total scores on the screening tool. Results from our sample found the Dyslexia Adult Checklist to be valid (Cronbach's α=0.86), and reliable (sensitivity=76-91.5%, specificity=80-88%). Compared to the originally proposed cut-off score of 45, given the higher sensitivity rate and negative predictive value, we recommend researchers and clinicians use a cut-off score of 40 to indicate possible mild to severe symptoms of dyslexia when using the Dyslexia Adult Checklist.

Keywords: Adult Dyslexia Checklist, checklist, dyslexia, screening tool, validation

Introduction

Dyslexia is a language-based neurobiological and developmental learning disability marked by slow and laboured reading, reading comprehension difficulties, spelling difficulties, problems with word retrieval, poor working memory, difficulties with language acquisition, a deficit in letter-sound correspondence, and the flipping of letters (American Psychiatric Association, 2013; Lyon, Shaywitz, & Shaywitz, 2003; Wagner et. al, 2020). As a specific learning disability in reading, individuals with dyslexia often experience difficulties with daily tasks including word retrieval, recalling addresses, telephone numbers, the days of the week, months of the year, foreign names, and places, as well as early speech production and later articulation difficulties (Share, 2021). These difficulties are not thought to arise from a single deficit, but from multiple contributing factors of biological origin, neurological and cognitive differences, and environmental influences (Erbeli & Wagner, 2023; International Dyslexia Association, 2002; Shaywitz & Shaywitz, 2005; Siegel & Smythe, 2005). Dyslexia is often diagnosed in childhood but persists throughout the lifespan (Lyon, Shaywitz, & Shaywitz, 2003; McNulty, 2003; Swanson & Hsieh, 2009).

While 15 to 20 percent of the general population display some symptoms of dyslexia, not everyone with a diagnosis of dyslexia experiences the same constellation or severity of symptoms (American Psychiatric Association, 2013; Snowling, Dawes, Nash & Hulme, 2012). This inconsistency in symptomology is indicative of a lack of a definitive causal theory for dyslexia. This gap in our understanding of the causes of dyslexia magnifies the inconsistencies when operationally defining and evaluating dyslexia (Pennington, 2006; Siegel & Smythe, 2005; Snowling et al., 2012; Wagner et al., 2020). Our theoretical understanding of dyslexia impacts and influences our ability to consistently and accurately detect, assess, and diagnose individuals with dyslexia. While an overview of theoretical causal theories of dyslexia is beyond the scope of this paper, it is critical that researchers and practitioners alike keep these theories in mind when discussing assessment and screening tools. This is because the basis of these tools is derived from theories, such as the phonological deficit theory, double deficit theory and magnocellular theory of dyslexia (Bosse et al., 2007; Everatt & Denson, 2020; Saskia et al., 2016; Stein, 2001, 2018). Further complicating this issue is the high comorbidity rate for other developmental deficits and neurodevelopmental disorders, such as Attention Deficit/Hyperactivity Disorder (ADHD; a neurodevelopmental disorder categorized by

inattention and/or a hyperactive/impulsive presentation; Dahl, Ramakrishnan, & Spears, 2020; Gooch, Hulme, Nash & Snowling, 2013), dyscalculia (a learning disability affecting a person's ability to understand number-based information and mathematics; Gliksman & Henik, 2018), and dysgraphia (a learning disability affecting a person's written expression and/or fine motor skills; Nicolson & Fawcett, 2011).

The identification of dyslexia allows for timely interventions and specialized support, which can significantly improve outcomes for individuals with dyslexia, as a dyslexia diagnosis is often required to access accommodations and support in educational settings from elementary/primary school to university. Additionally, time of diagnosis can lead to secondary effects on perceived academic and general competence in individuals with dyslexia who acquire a diagnosis later in life, with individuals receiving an earlier diagnosis having an overall better understanding of their diagnosis (Battistutta, Commissaire, & Steffgen, 2018; Brunswick & Bargary; 2022). A diagnostic assessment for dyslexia is typically costly and includes the use of standardized test batteries, such as measures of academic ability, behavioural observations, self-report measures, as well as parent and teacher reports (Andresen & Monsrud, 2022; Everatt & Denson, 2020). However, diagnostic assessments for dyslexia are generally demanding on school systems due to a lack of resources (e.g., access to school psychologists), long wait times, and are costly if conducted privately. In addition, the requirements for diagnosis are often governed by regulatory bodies based on the Country/State/Province where the individual resides (Everatt & Denson, 2020; Yates & Taub, 2003).

Screening tools are generally more cost-effective compared to formal assessments and can be used as a precursor prior to assessment. They are designed to be time efficient, allowing for a quick screening of a large number of individuals. They can be administered in various settings, such as schools or community centers, by educators or healthcare professionals, without the need for specialized training or equipment. This makes them particularly useful for quickly and cost-efficiently screening populations or helping identify individuals who may require further assessment and evaluation by professionals to confirm a dyslexia diagnosis (Trevethan, 2017). Additionally, screening tools can and have previously been used to provide students with access to accommodations when assessments are pending (Everatt & Denson, 2020). Implementing a screening tool for dyslexia allows for systematic data collection and research on the prevalence, characteristics, and outcomes associated with dyslexia. Screening tools can also

provide valuable insights into the effectiveness of various interventions (Leloup et al., 2021; Nukari et al., 2020), help in monitoring progress over time (Bjornsdottir, et al., 2014; Huang, et al., 2020), for multigenerational investigations of dyslexia and further self-understanding (Snowling, Dawes, Nash & Hulme, 2012). While the use of screening tools in the early identification of dyslexia is declining in favour of more functional and procedural changes with the implementation of a Response to Intervention process in school systems (Coyne et. al., 2018; Sharp et al., 2015; Snowling, 2013), validated self-administered tools to identify adults with dyslexia at the individual and research levels continue to be lacking.

One of today's most widely used screening tools for adults is the Dyslexia Adult Screening Test (DAST; Nicolson & Fawcett, 1996, 1997). The DAST is intended to assess adults in higher education. This battery of tests consists of 11 subtasks of which 9 are domain-specific to dyslexia. Some examples of these subtasks include a verbal fluency test and a rapid naming task, which assesses the ability to rapidly retrieve the name of visually presented stimuli. The DAST can be administered in 30 minutes by a qualified professional. Nicolson and Fawcett (1997) found the DAST to be accurate, with a sensitivity rate of 94% and a false positive rate of 0%. However, this study was conducted with a sample size of 165 participants, with only 15 individuals identified as having dyslexia based on the Adult Dyslexia Index (Nicolson & Fawcett, 1997). A follow-up study was conducted with a total sample size of 238 Canadian post-secondary students of which 117 participants had a previous diagnosis of dyslexia (Harrison & Nichols, 2005). Harrison and Nichols (2005) found the DAST to be less than accurate, correctly categorizing only 74% of students with dyslexia as having dyslexia and incorrectly classifying 16% of control participants as benefiting from further assessment. (Harrison & Nichols, 2005). With the intention of using screening tools to reduce wait times and alleviate demands on the system, a high false positive rate could in fact have negative consequences on the system. Additionally, a false negative rate of 26% can have detrimental effects on the careers and quality of life of individuals who could otherwise benefit from further assessment. Similarly, see the Dyslexia Screening Test-Junior/Secondary also created by Nicolson and Fawcett (2004) which is a screening tool that provides a profile of strengths and weaknesses to be used to guide in-school support for students aged 6 years to 11 and 5 months, and 11 years and 6 months to 16 years and 5 months, respectively.

Similarly, to the DAST, the Bangor Dyslexia Test (BDT) was designed to be administered by a qualified professional (Miles, 1983). The BDT can evaluate dyslexia-like characteristics in individuals above the age of seven. The BDT consists of a battery of 10 subtests, mainly comprised of working memory tasks rather than reading and spelling. The BDT was designed based on observational evidence from clinical investigations of memory in individuals with dyslexia. The BDT was validated in a sample of 233 university students, of which 193 students self-identified as having dyslexia. The results indicated that the BDT has a sensitivity of 96.4% and a specificity of 82.5% (Reynolds & Caravolas, 2016). While highly sensitive and specific, the theoretical underpinning of this screening tool, with its focus on working memory deficits, is no longer consistent with the growing literature on the phonological and other deficits of dyslexia (Erbeli & Wagner, 2023; Everatt & Denson, 2020; Franzen, Stark, & Johnson, 2021; Shaywitz & Shaywitz, 2005; Siegel & Smythe, 2005).

The Yale Children's Inventory (YCI) is an 11-scale parent-based rating scale, derived from a definition of learning disabilities suggesting (1) disturbance in attentional processes, (2) disruptive behavioural activities, (3) cognitive skills deficits, or some combination of the three, based on the Diagnostic and Statistical Manual of Mental Disorders, Third Edition (DSM-III; Shaywitz, Schnell, Shaywitz, & Towle, 1986). Based on their sample of 260 parent ratings of typically developing, gifted and learning-disabled children, Shaywitz and colleagues (1986) found the YCI to have an internal consistency that ranged from 0.72 to 0.93 and test/retest correlations of 0.61 to 0.89. However, the YCI's emphasis on attentional deficits is similarly outdated and no longer in line with current theoretical beliefs about dyslexia (Erbeli & Wagner, 2023; Everatt & Denson, 2020; Franzen, Stark, & Johnson, 2021; Shaywitz & Shaywitz, 2005; Siegel & Smythe, 2005).

The Adult Reading Questionnaire (ARQ) is a 15-item self-report questionnaire that assesses literacy, language and organization and was designed to assess dyslexia in adulthood (Snowling, Dawes, Nash & Hulme, 2012). This questionnaire was first validated on a sample of parents of children participating in a larger longitudinal research initiative. The authors of this questionnaire used some questions derived from the Dyslexia Adult Checklist such as "do you find it difficult to read aloud?", "do you ever confuse the names of things?" and "do you confuse left and right?" (Snowling, Dawes, Nash & Hulme, 2012). The result of their factor structure was a four-factor solution with the 11 items of interest making up the Adult Reading Questionnaire

loading onto two factors, termed word reading and word finding. The convergent and divergent validity of individual ARQ items were investigated based on nonverbal ability and vocabulary subtests on the Wechsler Abbreviated Scale of Intelligence as well as reading and spelling skills. Self-reported dyslexia was used for group classification, and sensitivity and specificity of the ARQ as a screening tool for predicting self-reported dyslexia were not investigated. Despite numerous existing screening tools outlined above, there is no true "gold standard" screening tool for adults with dyslexia and many of the available tools are required to be administered by qualified professionals. Smythe (2010) explains that the ideal screening tool for identifying risk factors for further investigation and later diagnosis, or research purposes would be free of charge, easily accessible, self-administered and psychometrically valid and reliable. One screening tool that has the potential to meet these criteria for dyslexia is the Dyslexia Adult Checklist, however, it has not been evaluated to date.

Created by Smythe and Everatt (2001), the Dyslexia Adult Checklist consists of 15 items with various item weightings. It screens for deficits in phonology, word retrieval and orthography, among others. This checklist examines literacy both directly and indirectly. Questions on the checklist ask responders about perceived deficits, except for item 10 which asks about finding creative solutions to problems (see Majeed et al., 2021 for meta-analysis on dyslexia creativity). For example, the question "How easy do you find it to sound out words such as el-e-phant?" examines phonological manipulation difficulties; "Do you confuse visually similar words such as cat and cot?" suggests orthographic confusion; and "Do you confuse the names of objects, for example table for chair?" relates to semantic difficulties. Short-term memory problems are investigated by asking "Do you get confused when given several instructions at once?" and "Do you make mistakes when taking down telephone messages?". Other questions in the checklist such as "When writing, do you find it difficult to organise thoughts on paper?" are more complex, whereby the underlying deficit in this question straddles deficits seen in individuals with both dyslexia and dysgraphia (Smythe & Siegel, 2005). The breadth of questions in this checklist reflects an adherence to a multiple-deficit approach to dyslexia (Erbeli & Wagner, 2023; Siegel & Smythe, 2005). It broadens the definition of dyslexia by considering multiple literary and non-literary sources of deficits, leading to a questionnaire structure that may indicate a one or two-factor solution. This suggests that the correlation between items on the questionnaire may indicate either one overarching construct or two

underlying constructs. The checklist can be found on the British Dyslexia Association website claiming that it contains questions that help predict dyslexia (https://www.bdadyslexia.org.uk/dyslexia/how-is-dyslexia-diagnosed/dyslexia-checklists). However, publicly available information on the structure, development, validity and reliability of this screening tool is limited.

The purpose of this study is to investigate the psychometric properties of the Dyslexia Adult Checklist in an adult sample, by using both univariate reliability and validity measures, as well as multivariate statistical approaches to examine construct validity. This paper will investigate the underlying factor structure of the Dyslexia Adult Checklist. In addition, we will answer the question of whether the Dyslexia Adult Checklist can accurately categorize adults who self-identify as having dyslexia. We hypothesize that individuals with dyslexia will score higher on the checklist compared to typical readers and that the checklist will demonstrate both sensitivity and specificity. Additionally, we theorize a single-factor solution, whereby the checklist measures the single construct of dyslexia. Given the theoretical underpinnings of the phonological and other non-literary deficit theories of dyslexia, and the high number of items in the checklist that inquire about phonological, orthographic, and semantic deficits, analyses were carried out for both one and two-factor solutions with the second-factor representing visual-spatial and short-term memory deficits.

Method

All aspects of this research were conducted in compliance with the regulations outlined by The Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, as well as The Official Policies of the first author's affiliated University, including the Policy for the Ethical Review of Research Involving Human Participants. Informed consent was obtained from the participants after an explanation of the study was given to them. The research protocol was approved by the University's Human Rights Ethics Research Committee (certificates #30009781, #30003975, #30009701 and 30010817).

Participants

A sample of 400 adults was recruited both for in-person and online participation. Targeted advertisements, looking for adults with dyslexia between the ages of 18-49 who are English-speaking, were directed at students in accessibility centres on university campuses across Canada and the United States as well as advocacy groups. Control participants were

mainly recruited from the Department of Psychology Participant Pool at Concordia University in Montreal. Participantswere required to self-identify as having dyslexia, totalling 200 individuals. The remaining 200 individuals did not identify as individuals with dyslexia and therefore made up the control group. The data were divided into two, for exploratory factor analysis (EFA; n = 200) and confirmatory factor analysis (CFA; n = 200), each with 100 control participants and 100 participants with dyslexia (see Table 1 for demographic information).

An *a priori* power analysis, conducted using G*Power 3.1 (Erdfelder, Faul, & Buchner, 1996), tested the difference between two independent means. Using a one-tailed independent samples t-test, a minimal effect size of interest (d = 0.80) based on Stark, Franzen and Johnson (2021), an alpha of 0.05, and a minimal desired power of 0.95, a minimum sample size of 35 participants per group will detect a true effect size greater than 0.794 (Faul et al., 2007).

Measures

Dyslexia Adult Checklist

The Dyslexia Adult Checklist (Smythe & Everatt, 2001) is comprised of 15 questions used to assess aspects of literacy, language and organization. Items require the respondent to rate symptoms of dyslexia on a 4-point Likert-type scale (rarely, occasionally, often, most of the time, or easy, challenging, difficult, very difficult), in which certain questions are assigned a higher weight for the total score. The higher the total score, the higher the risk of having dyslexia. According to Smythe and Everatt (2001), a total score of 45 or more indicates that the respondent is showing signs consistent with mild dyslexia, and a score above 60 as moderate or severe dyslexia. On the checklist, the minimum and maximum possible scores are 22 and 88 respectively.

Apparatus

Data were collected using the online data collection platform within Qualtrics. All data were anonymous and coded, with no link between the participants' identities and their data. Data collection through in-person recruitment was also anonymous and coded.

Procedure

Data were collected as part of three in-person and online studies investigating perceptual aspects of dyslexia. Participants' age and gender identities were collected and used in exploratory analysis. Participants completed the questionnaire using a pen and paper or online, respectively.

Data Analysis

Univariate Analysis

Psychometric properties of the screening tool and other statistical analyses were examined using XLSTAT (Addinsoft, 2021), a data analysis add-on for Microsoft Excel (Microsoft Corporation, 2021, Version 2102), as well as Jeffery's Amazing Statistical Package (JASP: JASP Team, 2020, Version 0.14) statistical software. After screening for any missing values and assessing normality, we obtained descriptive statistics, including means and standard deviations, for total scores on the Dyslexia Adult Checklist. All data were analyzed using Bayes factors and effect size measures. This approach allowed us to identify the strength of evidence for both the null and research hypotheses, alongside traditional significance testing.

Multivariate Analysis

All multivariate analyses were conducted using MPlus 8.6 with a Maximum Likelihood with robust standard errors (MLR) estimation and unit variance identification to set the scale of the latent factor(s). First, a 1 to 4-factor Exploratory Factor Analysis (EFA) was conducted on the data collected from the first 200 participants who completed the Dyslexia Adult Checklist to determine the best-fitting factor structure. Following the investigation of the factor structure for the different EFAs, we selected a final model to replicate using a Confirmatory Factor Analysis (CFA) and an Exploratory Structural Equation Model (ESEM) in another sample of 200 participants who completed the Dyslexia Adult Checklist as a method to confirm the factor structure found with the results of the EFA. There was no missing data in either of the samples. For the ESEM model, *a priori* cross-loadings were "targeted" to approach zero via the rotational procedure thus providing a confirmatory approach to ESEM specifications (Morin et al., 2020). Target loadings were freely estimated for their respective factors.

To avoid reliance on the chi-squared test of exact fit, which is overly sensitive to minor misspecifications, we used sample-size independent goodness-of-fit indices. We used typical interpretation guidelines, which suggest that comparative fit index (CFI) and Tucker-Lewis index (TLI) values should be greater than 0.90 and 0.95, supporting adequate and excellent model fit, respectively. Comparable guidelines for the Root Mean Square Error of Approximation (RMSEA) suggest relying on values smaller than 0.08 and 0.06 to support adequate and excellent model fit, respectively (Hu & Bentler, 1999; Marsh, Hau, & Grayson, 2005). In addition to these fit indices, we also considered the statistical adequacy and theoretical conformity of the different

solutions by examining factor loadings, cross-loadings, uniquenesses, and latent correlations. The same guidelines for the evaluation of model fit were used to evaluate model fit for the CFA and the ESEM.

Data and additional tables and figures are available from the project's OSF repository.

Results

Univariate Statistics

Data Integrity

Our sample used for the statistical analysis comprised 400 participants: 200 individuals with dyslexia (Mean age = 25.29, *SD* = 7.35) and 200 controls (Mean age = 23.36, *SD* = 4.88), and upon inspection, no missing values were found. Individuals in the dyslexia group self-identified as having dyslexia. Given the wide range and severity of symptoms seen in dyslexia, no univariate outliers were removed from the analysis. See Table 1 for demographic information.

In the control group, total scores on the screening tool were non-normally distributed, with skewness of 1.36 (*SE* = 0.17) and kurtosis of 1.89 (*SE* = 0.34). In the dyslexia group, normality was met, with skewness of 0.32 (*SE* = 0.17) and kurtosis of -0.45 (*SE* = 0.34). A Shapiro-Wilk test of normality was performed on the independent samples t-test suggesting a deviation from normality ($W_{\text{dyslexia}} = 0.91$, $p = 0.008$; $W_{\text{control}} = 0.89$, $p < 0.001$). Additionally, Levene's test of equality of variances was violated ($F(1) = 24.47$, $p < 0.001$). In considering these non-normally distributed data, we opted to employ a Welch-independent samples t-test and Glass's delta effect size for comparing group differences (Lakens, 2013). Bayesian and frequentist statistics were conducted for all analyses. Bayes factors were computed to interpret the relative strength of the null hypothesis as compared to the alternative hypothesis (Dienes, 2011; Wetzels et al., 2011), using the JASP default Cauchy prior width of 0.7, as other values only have minimal impact on the results (Gronau, Ly, & Wagenmakers, 2020).

Group Comparison

To compare the mean of total scores on the Dyslexia Adult Checklist between groups, we conducted a Welch's independent samples t-test and a Bayesian independent samples t-test. Both analyses were performed using a directional hypothesis such that total scores in the dyslexia group were hypothesized to be higher than total scores in the control group. Individuals with dyslexia obtained higher scores on the Dyslexia Adult Checklist (*M* = 53.39, *SD* = 11.11) compared to control participants (*M* = 34.27, *SD* = 8.23). The results indicate that there was a

statistically significant difference between the total scores on the screening tool between groups, $t(366.82) = -19.58$, $p < 0.001$, Glass's $d = -1.72$, 95% CI [-∞, -1.50], $BF_{10} = 5.85 \times 10^{56}$, with the dyslexia group obtaining higher scores ($M = 53.39$) than the control group ($M = 34.27$; see Figure 1). The Bayes Factor obtained indicates that we have decisive evidence for the alternative hypothesis, that individuals with dyslexia obtained higher scores on the screening tool than those without dyslexia.

Reliability

The purpose of this paper is to examine the validity of the Dyslexia Adult Checklist. One requirement for statistical validity is reliability. Since data were collected only once from each participant, a single-test reliability analysis, as well as a Bayesian single-test reliability analysis were conducted to ensure that the screening tool consistently reflects the construct it is measuring. For the purposes of this study, reliability was defined by the coefficient Cronbach's alpha (α) and an average interitem correlation. Cronbach's α can be used to quantify the internal consistency of the items within a screening tool (Streiner, 2003). It is used under the assumption that multiple items within the scale measure the same underlying construct. Cronbach's α is affected by inconsistent responses at the item level and test length. According to both frequentist and Bayesian scale reliability statistics, our scores collected from the Dyslexia Adult Checklist were found to be consistent and reliable (15 items; Cronbach's α = 0.86, 95% CI [0.84, 0.87]).

The average inter-item correlation represents how well the items in the screening tool measure the construct that is being evaluated. Using our sample of individuals with and without dyslexia, we found that the Dyslexia Adult Checklist had an average inter-item correlation of 0.35 (95% CI [0.32, 0.38]) when both frequentist and Bayesian scale reliability statistics were conducted.

Predictive Validity

The predictive validity of the Dyslexia Adult Checklist was investigated using a fourfold table and measured by calculating the sensitivity, specificity, and predictive values of scores (see Table 2 and Figure 2). Using the originally proposed cut-off-score of 45 (Smyth and Everatt, 2001), we found our sample to have a sensitivity rate of 76%, and therefore a false negative rate of 24%. Additionally, scores from our sample reflected a specificity rate of 88% and a false positive rate was found to be 12%. Predictive values were likewise calculated yielding a positive predictive value of 86% and a negative predictive value of 79% (Figure 2).

A secondary analysis was conducted using a more conservative cut-off-score of 40 (see Table 2). This analysis revealed that our sample exhibited an increased sensitivity rate of 91.5% and a specificity rate of 80%. Additionally, we found a positive predictive value of 82% and a negative predictive value of 90% (Figure 2). Hence, the adoption of this more conservative cut-off score resulted in improved sensitivity.

Multivariate Statistics

Data Integrity

Multivariate Outliers. To assess for multivariate outliers, the Mahalanobis Distance statistic was investigated. The chi-square critical value table was examined to find the critical value at the 0.01 alpha level with 10 degrees of freedom (for the ten variables), which yields a Mahalanobis Distance of $D^2 = 23.209$ (Raykov and Marcoulides, 2008). With this method, 84 multivariate outliers were identified. Additionally, two scatterplots using the Cook's Distance (x-axis), and the Mahalanobis Distance (y-axis) were created to visually inspect for severe outliers for the sample used in the EFA and the sample used in the CFA. Regarding the scatterplot for the first sample (i.e., EFA sample) three were identified (i.e., Participant ID number 1, 16, 193; see Figure A in OSF repository). Regarding the scatterplot for the second sample (i.e., CFA sample) three were identified (i.e., Participant ID number 5, 57, 137; see Figure B in OSF repository). All analyses were conducted with and without outliers to determine if their presence had an influence on the results. As the results did not change once the outliers were removed, we proceeded to retain the model including the data of all participants.

Factorability of the Matrix. Two Pearson correlations were conducted to investigate potential issues of high co-variance across both samples. For the first sample, the largest correlation observed was between question 1 ("Do you confuse visually similar words such as cat and cot") and question 6 ("Do you re-read paragraphs to understand them?"; $r = 0.59$). Additionally, out of the 106 bivariate correlations, 65 were above .3 (see Table A in OSF repository in OSF repository). The Kaiser-Meyer-Olkin measure of sampling adequacy was conducted and was found to be good ($KMO = .90$).

For the second sample, we likewise found the largest correlation between question 1 and question 6 ($r = .59$). Out of the 106 bivariate correlations, 78 were above 0.3 (see Table B in OSF repository). The Kaiser-Meyer-Olkin measure of sampling adequacy was conducted and was found to be great ($KMO = 0.92$).

Exploratory Factor Analyses

An EFA was conducted using Maximum Likelihood Robust (MLR) and a Geomin (0.5) oblique rotation, with a maximum of 1000 iterations using the MPlus 8.6 software. A parallel analysis was conducted and plotted as a first method to establish the final number of factors (see Figure C in OSF repository). Visual observation of this matrix led us to determine that both the one-factor and two-factor solutions were viable options, as additional factors showed no improvement over randomness. The number of solutions paired with the number of factors fell in line with our predictions. The model fit indices for the one to four-factor solutions are reported in Table C in OSF repository.

In the one-factor solution, model fit indices were adequate in terms of CFI and TLI, and excellent in terms of RMSEA. All factor loadings were positive and statistically significant ($M_{|\lambda|}$ = 0.582, with a few items (i.e., items 5 (0.232), 10 (0.298), and 14 (0.338)) displaying weaker loadings (see Table 3 for a full list of factor loadings for the 1- and 2-factor EFAs). Moving to the two-factor solution, model fit was adequate for CFI and TLI (albeit slightly better than for the one-factor solution), and excellent in terms of RMSEA. The Geomin Factor Correlations indicate a statistically significant correlation (r = 0.545) between Factor 1 and Factor 2. Based on our *a priori* theoretical operationalization of the two factors structure, the target factor loadings for factor 1 ($M_{|\lambda|}$ = 0.455) and factor 2 ($M_{|\lambda|}$ = 0.541) are all statistically significant, however generally lower than for the 1-factor solution. Moreover, we observed the presence of multiple cross-loadings (e.g., items 9, 13, and 15) that indicate rather strong overlap between the factors. Theoretically speaking, these cross-loadings are no more likely to define both factors compared to other items in the questionnaire, while all items may be suited to represent a 1-factor structure based on our 1-factor EFA results. In this sense, it remains unclear whether the one or two-factor solution is best necessitating a full investigation of the factor structure in our second sample. As such, we conducted a 1- and 2-factor CFA using our second sample and compared the 2-factor CFA model to a 2-factor ESEM model with target rotation based on the *a priori* factor structure to investigate whether the same cross-loadings emerge (i.e., displaying stability in the items defining both factors).

CFA & ESEM

The results of the CFA indicated an adequate model fit in terms of CFI and TLI and excellent model fit in terms of RMSEA. All factor loadings for this solution are statistically

significant ($M_{|\lambda|}$ = 0.541) and only one weak loading (i.e., item 10: $|\lambda|$ = 0.190) was present. In fact, item 10 seemed to load weekly in the 1-factor EFA for the first sample as well, indicating that this item may not be as relevant (at least statistically speaking) in terms of defining dyslexia. Interestingly, the 2-factor solution displayed almost identical fit to the 1-factor solution which is likely due to the standardized correlation approaching one (i.e., a 2-factor CFA model with a standardized correlation equal to one between both factors is mathematically equivalent to a 1-factor model). The strong factor correlation for the 2-factor solution is likely due to the presence of substantive cross-loadings (as observed in the first sample) making it clear that ESEM should be favoured over CFA, should a 2-factor solution be retained (Morin et al., 2020). All factor loadings for the 1- and 2-factor CFA models are available in Table 4.

The results of the two-factor ESEM model indicate excellent fit in terms of CFI, TLI, and RMSEA as well as a substantial decrease in the standardized correlation between factor 1 and 2 (r = 0.626). However, once again several cross-loadings were observed, differing from the 2-factor EFA conducted on the first sample (i.e., items 1, 8, 13, & 15). When paired with a standardized correlation between the two factor greater than 0.6 indicates substantive overlap between the two factors in the ESEM model. Moreover, six of the fifteen target loadings were not statistically significant in the ESEM model revealing that the *a priori* 2-factor structure specified is not supported. Standardized factor loadings and uniquenesses for this solution are available in Table F from the OSF repository.

Model Selection

To recap, in the first sample both the EFA and CFA displayed adequate to excellent model fit and both had adequate target loadings with a moderate correlation observed between the two factors in the 2-factor EFA. In the second sample, the 1-factor solution was again adequate in terms of fit and standardized factor loadings, with item 10 systematically displaying a weaker association with the latent constructs across both samples and all models. The two-factor CFA model was ruled out due to the substantive degree of overlap between the two factors. The 2-factor ESEM displayed the greatest amount of fit and an acceptable standardized factor correlation, but the factor structure was not supported based on the strength of the target and cross-loadings. Indeed, composite reliability coefficients for the two-factor solutions, based on the *a priori* factor structure specified, are low for factor 1 in both samples (sample 1: ω = 0.695; sample 2: ω = 0.690) and low for factor 2 in the second sample (sample 1: ω = 0.812;

sample 2: $\omega = 0.505$). Conversely, composite reliability coefficients for the 1-factor solution are excellent in both samples (ω: McDonald, 1970; sample 1 $\omega = 0.889$, sample 2 $\omega = 0.897$). Based on the above results it appears that a 1-factor CFA better captures the underlying factor structure of the scale by doing so in a more stable manner compared to a two, or more-factor solution. These results lend further support in favour of viewing the Dyslexia Adult Checklist as unidimensional.

Factor Scores Comparison with Total Scores

We compared the individual factor scores per participant obtained in the one-factor CFA to the total score per participant obtained on the checklist. This was done to determine if the factor scores predicted total scores on the Dyslexia Adult Checklist. We ran a Pearson correlation and found a large and statistically significant positive association between these two scores ($r = 0.988$, $p < 0.001$, 95% *CI* [0.984, 0.991]), whereby the larger the factor score, the larger the score on the checklist. Looking at specific scores as examples, a participant who received a total score of 25 on the Dyslexia Adult Checklist had a factor score of -1.5. Further, a participant who received a score of 40 on the Dyslexia Adult Checklist received a factor score of -0.1. Finally, a participant who received a score of 78 on the Dyslexia Adult Checklist received a factor score of 2.4. For the full list of factor scores and manual scores, please see Table G in the OSF repository. The consistency between the factor scores and the manual scores lends further support in favour of viewing the Dyslexia Adult Checklist as unidimensional. In addition, the factor scores obtained from the CFA can subsequently be used in the same fashion as the scores obtained by the checklist to determine if an individual has dyslexia where, with replication, a cut-off score or range of scores can be established for diagnostic purposes. This statistical approach helps to avoid the need for arbitrarily defined cut-off scores.

Discussion

The purpose of this study was to investigate whether the Dyslexia Adult Checklist, a widely accessible screening tool, is a valid and reliable measure in identifying adults with dyslexia. As hypothesized, individuals with a self-reported diagnosis of dyslexia obtained significantly higher total scores on the Dyslexia Adult Checklist than individuals without dyslexia. The screening tool was additionally found to be both reliable at the item level (Cronbach's $\alpha = 0.86$), and accurate (sensitivity = 76-92%, specificity = 80-88%) in its screening for individuals with dyslexia. Lastly, a one-factor structure was found, reflecting a single construct of dyslexia.

The Dyslexia Adult Checklist scores are based on the weighted total sum of item responses with the official scoring guideline specifying scores below 45 as indicating "probably non-dyslexic," scores between 45 and 60 representing "showing signs consistent with mild dyslexia" and a score above 60 being indicative of "signs consistent with moderate or severe dyslexia." The simplicity of the scoring system with the provided interpretation is appealing since any respondent can score and understand the results of the screening tool. In our first analysis, we investigated group-level differences using an independent samples t-test. The result of this analysis revealed group-level differences between our sample of individuals with and without dyslexia using complementary null hypothesis significance testing and Bayesian statistics. Given that the checklist was designed with the intention of identifying individuals with dyslexia based on a high overall score, our findings are consistent with our prior hypothesis and the overall objective of the screening tool.

When identifying and classifying individuals of a certain group based on an individual's reported characteristics, such as dyslexia, it is paramount that the tool is both reliable and valid. Reliability is a requirement for statistical validity; a tool cannot be valid if not firstly reliable. In this study, the reliability of our scores was assessed by calculating the coefficient Cronbach's alpha (α) and an average interitem correlation. We found that approximately 14% of the variance in our scores was due to the combined effect of test length and inconsistent responding at the item level, as measured by Cronbach's alpha. Additionally, the items that make up the screening tool are correlated indicating that they measure the same underlying construct; however, they do not repeatedly measure the same characteristics of dyslexia as indicated by the low-to-mid range inter-item correlation. We can therefore conclude that the Dyslexia Adult Checklist is a reliable measure of dyslexia at the item level. That said, to our knowledge, this is the first study to report any reliability coefficients for scores on the Dyslexia Adult Checklist, and so replication is needed to further strengthen and comment on the reliability of this screening tool. In comparison to other existing screening tools, we found the Dyslexia Adult Checklist to have strong reliability ($\alpha = 0.86$) compared to BDT ($\alpha = 0.72$; Reynolds & Caravolas, 2016) and Adult Reading Questionnaire ($\alpha = >60$; Protopapa and Smith-Spark, 2022; Snowling, Dawes, Nash & Hulme, 2012). Future studies should investigate the reliability of this tool over time using test-retest methods, given that dyslexia is a developmental disorder that persists throughout the lifespan (McNulty, 2003).

With reliability assumed, we examined the validity of the scores using sensitivity, specificity, and predictive values. Scores were calculated using the cut-off-score of 45 proposed by Smythe and Everatt (2001), and a more lenient cut-off-score of 40. Sensitivity refers to the ability of the screening tool to correctly classify individuals from the dyslexia group as showing signs of dyslexia, based on a cut-off-score of 45 (Parikh, et al., 2008; Smyth & Everatt, 2001; Trevethan, 2017). Specificity refers to the ability of the screening tool to correctly classify individuals from the control group as not showing signs of dyslexia, by obtaining a score below 45 (Parikh et al., 2008; Smyth & Everatt, 2001; Trevethan, 2017). Our findings indicate a sensitivity rate of 76% and specificity rate of 88% with a cut-off-score of 45. Improvingly, when using a cut-off-score of 40 to indicate signs of dyslexia, we found a sensitivity rate of 91.5% and a specificity rate of 80%. In addition, we calculated positive and negative predictive values as they consider the entire sample, both individuals with and without self-reported dyslexia. At the individual level, should the respondent score above 45, indicating mild to severe symptoms of dyslexia, the probability of that individual having dyslexia is 86%, and 82% when using a cut-off-score of 40. However, should the respondent score below 45, the probability of that individual not having dyslexia is 79%, versus 90% with a cut-off-score of 40. As expected, depending on the cut-off score used, we see a trade-off that occurs between sensitivity, specificity, and our predictive values (Figure 2). With a cut-off score of 45, we have a higher specificity rate and a lower sensitivity, and the opposite pattern emerged with a cut-off score of 40. With a cut-off-score of 40, the high negative predictive value implies minimal false negatives, which is desirable in a screening tool such as this. However, this comes at a trade-off, in this case, a lower positive predictive value which is indicative of more false positives. Given these results, we suggest using the more conservative cut-off score of 40 when using the Dyslexia Adult Checklist, although researchers and practitioners may choose the cut-off score, they desire based on how they wish to use the screening tool.

In comparison to other existing screening tools, Nicolson and Fawcett's (1997) original research study reported a higher sensitivity (94%) and lower false positive rate (0%) compared to our findings from the Dyslexia Adult Checklist using both a cut-off-score of 45 (76% and 12% respectively) and 40 (91.5% and 20% respectively). This is however in contrast to replication findings by Harrison and Nichols (2005), who report a sensitivity rate of only 74%, a specificity rate of 84%, and a false positive rate of 16%. Distinctively, Singleton, Horne, and Simmons

(2009) developed a computerized screening tool using adapted phonological processing, lexical access and working memory tasks. Their test battery can be completed in 15 minutes and for the most part, is self-administered. Using a sample of 70 individuals with dyslexia and 69 controls, the results of their discriminant function analysis based on the composite scale score was a sensitivity measure of 83.6% and a specificity of 88.1%. However, the aforementioned screening tools are either required to be professionally administered or do not rely on self-reporting. Therefore, we are unable to speak to the convergent validity.

We consider our results to demonstrate improved psychometric validity of the Dyslexia Adult Checklist when using a cut-off-score of 40 versus 45 for indicating signs of dyslexia. Given the nature of screening tools, high sensitivity and negative predictive value are paramount in ensuring the usefulness of the tool. This is a stark difference to assessment tools which require a more nuanced balance between sensitivity, specificity, and predictive values (Grimes & Shultz, 2002; see Singleton, Horne, & Simmons, 2009). Within the field of educational screening, it is recommended that screening tools have false positive and false negative rates that are less than 25% (Singleton, Horne, & Simmons, 2009; also see Singleton, 1997). Additionally, Glascoe and Byrne (1993) argue that specificity rates should be at least 90% and sensitivity at least 80% for a test to be regarded as valid. Based on these criteria, the Dyslexia Adult Checklist would be considered valid using a cut-off-score of 40. With a cut-off-score of 45, however, the checklist does not meet these criteria, as its sensitivity rate was found to be only 76%. Given the higher sensitivity rate and negative predictive value when using a more inclusive cut-off-score of 40, we recommend that researchers and clinicians use this cut-off-score to indicate possible mild to severe symptoms of dyslexia when using the Dyslexia Adult Checklist. To our knowledge, this is the first study to assess the validity of the Dyslexia Adult Checklist. For this reason, we are unable to directly compare our findings to previous research using this screening tool.

The results of the EFA allowed us to confirm the possibility of a one or two-factor solution for the Dyslexia Adult Checklist. Upon completion of the CFA, it became evident that a one-factor solution yielded the best fit for the data. This conclusion was drawn based on the consistent factor loadings observed from the EFA to the CFA results, as well as the substantial cross-loading between factors in the two-factor solutions. Dyslexia is an umbrella term encompassing various difficulties experienced by individuals with dyslexia. Consequently, a checklist featuring a single-factor solution is deemed appropriate, where the individual items

assess a broad spectrum of deficits. These findings allow us to interpret that the Dyslexia Adult Checklist effectively captures one underlying construct of dyslexia and, thus, measures the construct it intends to evaluate. This finding stands in contrast to the findings by Snowling and colleagues (2012) in their development of the Adult Reading Questionnaire. As stated in the introduction, the Adult Reading questionnaire is loosely derived from questions from the Dyslexia Adult Checklist by Smythe and Everatt (2001). Here, they found their questions on dyslexia to load into two distinct factors, word reading and word finding. Despite their findings, we hypothesized and found a one-factor solution to best fit our data and the Dyslexia Adult Checklist as it adheres to and asks questions based on a multi-deficit framework, not only focusing on literary outcomes such as word reading and finding.

The present study's design allowed for a sensible way to assess the reliability and validity of the Dyslexia Adult Checklist. Nevertheless, a potential limitation of this study is the generalizability of the results. The results of this study may not hold over other populations or settings as the sample used in our study was mainly recruited from university campuses (Shadish, Cook & Campbell, 2002). Participants in the control and dyslexia groups were recruited both online and in person, as part of multiple research studies, some of which required participants to be educated at the university level. We hypothesized however that individuals taking part in higher-level education would rate their symptoms lower in severity compared to individuals who did not pursue higher education. This would make these individuals more difficult to identify and differentiate from individuals without dyslexia, as their responses may fall closer to the cut-off score. However, this is not what we found. We further hypothesize, should this study be replicated with a more representative sample, that our results would be consistent with this replication. On the other hand, participants making up our control group were university students and therefore may not represent the average reader. Further affecting the generalizability of our findings, the sample used in our study was over-represented by female participants, which is to be expected when sampling from a post-secondary institution (Statistics Canada, 2022). It should be noted that individuals with dyslexia that make up our experimental group, self-identified as having dyslexia and were not required to provide proof of diagnosis to participate in our research study. Additionally, a detailed examination of the difficulties of our dyslexia sample was not undertaken, such as an investigation into comorbidities, perceived severity of dyslexia and family diagnosis, which could impact the generalizability of our

findings. Considering that this study appears to be the first to assess the psychometric properties of the Dyslexia Adult Checklist, future studies should aim to replicate this study on a more diverse and representative sample to allow for even more generalizability.

The Dyslexia Adult Checklist is a self-report screening tool that can be completed and scored without the presence of a qualified professional. Although we may speculate that self-report screening tools may not be as accurate as professionally administered measures, there are many advantages of using self-report screening tools. For instance, individuals may easily identify key traits that they possess and in return, pay close attention to how they respond to questions (Robins, Fraley, & Krueger 2010). As discussed above, screening tools are not diagnostic and should only be used to signal individuals for further assessment, should they wish to pursue additional testing. The self-report nature of the Dyslexia Adult Checklist can therefore act as a precursor for further professionally administered screening tools and later diagnostic testing. Additionally, the Dyslexia Adult Checklist can act as a quick and easy screening tool for researchers investigating adults with dyslexia or conducting reading and literacy-related research in the general population.

As cited throughout the literature, it appears that the Dyslexia Adult Checklist originally appeared in the BDA Handbook in 2001, and again in the BDA Employment and Dyslexia Handbook in 2009, both written by Smythe. We were unable to access copies of these documents from the British Dyslexia Association. Smythe and Siegel (2005) state that the questionnaire was developed based on research, that it is indeed predictive and has been validated in English. However, based on our investigation, there is no further mention of this research study or its results. The validation of such tools is not only considered best practice and necessary prior to being widely distributed, but public access to such results is also paramount for transparent research and replication of results.

Based on the findings from our sample of individuals with and without dyslexia, we recommend a more conservative cut-off-score of 40 on the Dyslexia Adult Checklist when self-administering this screening tool. Currently, the recommended 45 cut-off-score makes it so that individuals taking this screening tool have a higher false negative rate, whereby a higher number of individuals who could possibly have dyslexia may be misclassified as not having severe enough symptoms of dyslexia. This may be problematic, as these individuals may not get access to or believe that they do not need further assessment.

Currently, the use of this tool is twofold; for self-exploration and understanding (British Dyslexia Association, n.d.), as well as for research purposes in group categorization (Franzen, Stark & Johnson, 2021; Stark, Franzen, Johnson, 2022; Vatansever, Bozhilova, Asherson, & Smallwood, 2019). With the current research, we aim to prompt other researchers in the field to report the psychometric properties of screening and assessment tools used in their own research. We eagerly await the replication of our findings and the reporting of psychometric properties from across research samples. Due to the average inter-item correlation being 0.35, future researchers may wish to investigate other types of reliability and validity such as test-retest reliability through longitudinal research and convergent and divergent validity, as well as conduct an item analysis with the aim of condensing the questionnaire by removing highly correlated items. In addition, research should investigate contributing factors affecting scores on the Dyslexia Adult Checklist, such as the perceived severity of dyslexia and perceived support from others. The Dyslexia Adult Checklist makes note of an additional cut-off-score of 60, distinguishing between mild and severe signs which may warrant further investigation. Lastly, researchers may wish to develop new self-administered questionnaires investigating multiple underlying factors of dyslexia more explicitly, such as the Adult Reading Questionnaire, as a predictive screening tool for adults with dyslexia (Snowling et al., 2012). Such a questionnaire can be used to identify profiles of deficits in individuals with dyslexia with the aim of developing more targeted interventions.

As diagnostic tests are generally time-consuming and expensive, screening tools offer an efficient means of self-evaluating common symptoms of dyslexia prior to seeking a clinical diagnosis, in better self-understanding and for use in research. The Dyslexia Adult Checklist is a widely accessible screening tool that we found to be both valid and reliable, though, we recommend using a lower cut-off-score of 40 rather than the 45 proposed by the original authors of the Dyslexia Adult Checklist (Smythe & Everatt, 2001).

Tables and Figures

Table 1

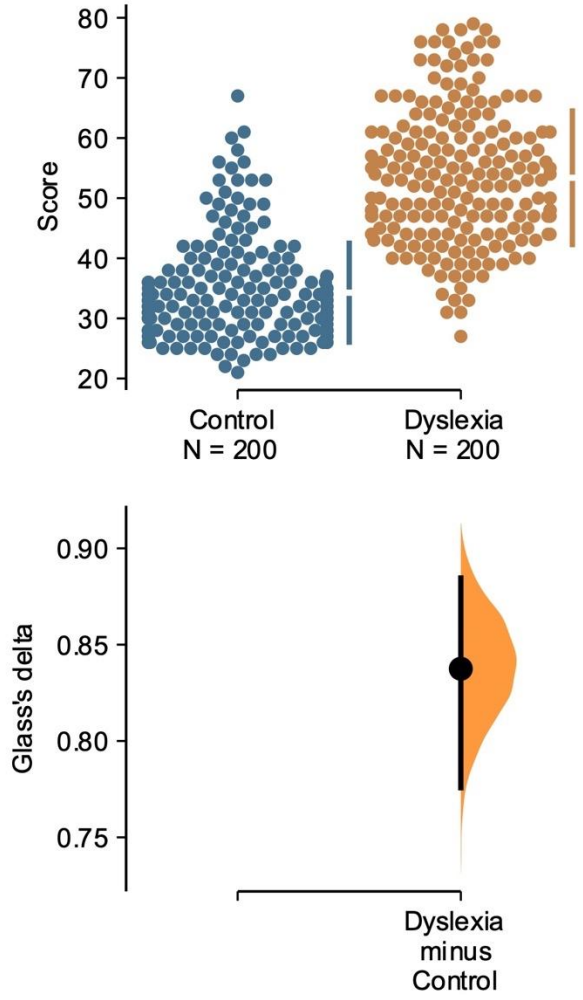
Demographic Information of Groups

	Total Sample (n=400)		EFA (n=200)		CFA (n=200)	
	Control (CON)	Dyslexia (DYS)	Control (CON)	Dyslexia (DYS)	Control (CON)	Dyslexia (DYS)
n	200	200	100	100	100	100
Gender Identity						
Male	46	69	15	32	31	37
Female	152	125	84	68	68	57
Other	1	5	1	0	0	5
Prefer not to answer	1	1	0	0	1	1
m_{age}	23.36	25.29	23.89	23.74	22.82	26.84
sd_{age}	4.88	7.35	5.37	5.30	4.31	8.70
min_{age}	17	18	17	18	18	18
max_{age}	43	58	43	46	40	58

Note. The age range of participants was between 17-58, above that of our initial recruitment parameters of 18-49. Additional measures were taken to ensure that participants above the initial cut-off did not skew results.

Figure 1

Mean Total Score on the Dyslexia Adult Checklist Between Groups



Note. The Glass's delta between Control and Dyslexia is shown in the above Gardner-Altman estimation plot. Both groups are plotted on the left axes; the mean difference is plotted on a floating axis on the right as a bootstrap sampling distribution. The mean difference is depicted as a dot; the 95% confidence interval is indicated by the ends of the vertical error bar.

Table 2

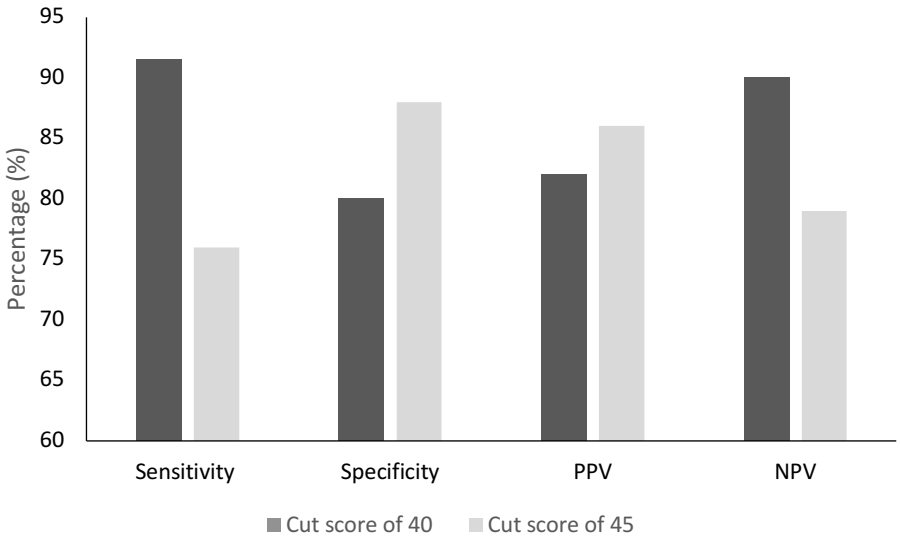
Fourfold tables with cut-off-score of 45 and 40

		Self-Identified	
		Dyslexia (n=200)	Control (n=200)
Cut-off-score of 45	Above 45	152	24
	Below 45	48	176
Cut-off-score of 40	Above 40	183	40
	Below 40	17	160

Note. N=400

Figure 2

Sensitivity, Specificity and Predictive Values Between Cut-Off-Scores Used



Note. Comparison of sensitivity, specificity and predictive values for the Dyslexia Adult Checklist between cut-off-score used. $N = 400$ for each cut-off -core. PPV= positive predictive value; NPV=negative predictive value

Table 3.

EFA One and Two-Factor solutions Geomin Rotated Loadings

	One-Factor Solution		*Two-Factor Solution*			
Items	Factor Loadings (1)	Uniquenesses	Factor Loadings (1)	Uniquenesses	Factor Loadings (2)	Uniquenesses
Item1	0.754* (.04)	0.43	0.269 (.185)	0.437	0.569* (1.65)	0.437
Item2	0.749* (.04)	0.44	0.294* (.086)	0.438	0.548* (.081)	0.438
Item3	0.564* (.051)	0.68	0.538* (.192)	0.615	0.133 (-188)	0.615
Item4	0.612* (.054)	0.63	0.893* (.251)	0.292	-0.102 (.15)	0.292
Item5	0.232* (.073)	0.95	0.208 (.134)	0.938	0.065 (.137)	0.938
Item6	0.643* (.049)	0.59	0.134 (.102)	0.562	0.579* (.098)	0.562
Item7	0.676* (.041)	0.54	0.044 (.105)	0.472	0.702* (.099)	0.472
Item8	0.777* (.034)	0.4	0.242 (.125)	0.389	0.623* (.121)	0.389
Item9	0.649* (.044)	0.58	0.338* (.098)	0.573	0.405* (.102)	0.573
Item10	0.298* (.066)	0.91	0.051 (.117)	0.908	0.273* (.115)	0.908
Item11	0.475* (.056)	0.78	0.408* (.19)	0.746	0.147 (.177)	0.746
Item12	0.675* (.045)	0.55	0.079 (.096)	0.494	0.665* (.085)	0.494
Item13	0.615* (.052)	0.62	0.327* (.129)	0.625	0.37* (.135)	0.625
Item14	0.338* (.082)	0.89	0.39* (.112)	0.838	0.021 (.113)	0.838

Item15	0.661* (.047)	0.56	0.411* (.138)	0.555	0.347* (0.14)	0.555

* $p < .05$

Table 4. Factor Loadings for One and Two-Factor CFA Solutions

Factor Loadings - One-Factor Solution			Factor Loadings - Two-Factor Solution		
Items	Standardized	Uniquenesses	Items	Standardized	Uniquenesses
Factor 1			Factor 1		
AC1	0.725*	0.474	AC3	0.664*	0.559
AC2	0.678*	0.54	AC4	0.543*	0.705
AC3	0.655*	0.571	AC5	0.5*	0.75
AC4	0.536*	0.712	AC9	0.684*	0.533
AC5	0.493*	0.757	AC11	0.588*	0.654
AC6	0.632*	0.601	AC14	0.536*	0.713
AC7	0.709*	0.497	AC15	0.717*	0.486
AC8	0.671*	0.549	Factor 2		
AC9	0.683*	0.533	AC1	0.727*	0.472
AC10	0.16*	0.974	AC2	0.688*	0.526
AC11	0.577*	0.667	AC6	0.641*	0.589
AC12	0.715*	0.488	AC7	0.716*	0.488
AC13	0.555*	0.692	AC8	0.672*	0.549
AC14	0.519*	0.731	AC10	0.165*	0.973
AC15	0.705*	0.503	AC12	0.72*	0.482
			AC13	0.554*	0.693

Note: * $p < .05$

CHAPTER 3:

STUDY 2

Understanding the Experience of Adults with Dyslexia: A Quantitative and Qualitative Analysis

Note: Copy edited version of this study is current accepted for publication by *Annals of Dyslexia*

Abstract

Dyslexia is a neurobiological disorder characterized by persistent difficulties in reading, writing, and spelling. Studying adults with dyslexia is challenging due to diverse experiences, varying ages of diagnosis, and potential comorbidities. This study utilized a mixed-method approach to explore how the timing and occurrence of a dyslexia diagnosis influence individuals' experiences. Descriptive analysis revealed heterogeneous responses concerning age of diagnosis and overall experience, with predictor variables including perceived reading severity, family dyslexia diagnosis, comorbidities, and self-perceptions of disability, intelligence, frustration, laziness, empowerment, and self-restraint. To further investigate these associations, three classification and regression trees (CART) were constructed, showing that individuals diagnosed early or late without comorbidities were more likely to report positive or neutral experiences. A qualitative reflexive thematic analysis identified six themes: (1) internalizing effects of dyslexia, (2) perceived experience of dyslexia, (3) perceived perception by others, (4) shifts in experience over time, (5) acceptance, and (6) coping skills. These qualitative findings complemented the descriptive and CART results, providing a comprehensive understanding of dyslexia experiences and secondary effects based on the age of diagnosis. This combined analysis underscores the importance of early diagnosis and the absence of comorbidities in shaping positive outcomes for individuals with dyslexia.

Keywords: Adult Dyslexia, Experience, Mix-Method, Development

Introduction

Dyslexia is a developmental neurobiological disorder that has a lifelong impact on an individual's ability to read, write, and spell. (Ferrer et al., 2023; Lyon et al., 2003; Nalavany et al., 2011; Rayner et al., 1989; Wagner et al., 2020). Dyslexia is characterized by challenges in accurately and fluently recognizing and decoding words (Vaughn et al., 2024; also see Gearin et al., 2024). In addition, individuals with dyslexia report difficulty memorizing information, experience trouble learning languages and struggle with letter-sound correspondence (Lyon et al., 2003; Rayner et al., 1989; Wagner et al., 2020). The DSM-5 refers to dyslexia as a specific learning disability with a specified indicated impairment in reading. It is explained that individuals with a specific learning disability experience difficulty in either reading, comprehension, spelling, written expression, understanding number concepts or mathematical reasoning causing significant problems in school, work or everyday activities (American Psychiatric Association, 2013).

Lived Experiences of Dyslexia

Individuals with dyslexia have described their experience as spending increased time and effort academically compared to their peers (Holmes et al., 2021). Brante (2013) conducted semi-structured interviews with 7 individuals with dyslexia with the aim of better understanding how respondents explain their reading difficulties. Participants described reading as being demanding, and time and energy consuming. Most participants described guessing the words when reading and the use of context to help in comprehension. Some individuals also described the letters and words as ‘grey or black masses’, and all participants reported experiencing difficulties with grammar (Brante, 2013). These characteristics of dyslexia can lead to secondary emotional and social consequences. In testimonies of self-reported experiences of having dyslexia, individuals report having lower self-esteem (Brunswick & Bargary, 2022; Ingesson, 2007; Livingston et al., 2018; Welton, 2023), decreased self-confidence (Livingston et al., 2018; Welton, 2023), difficulty in forming social relationships and being picked on by peers (Holmes et al., 2021), and describe instances of embarrassment and shame (Alexander-Passe, 2015; Jacobs et al., 2022; Welton, 2023). Many also report comorbid mental health-related difficulties (Livingston et al., 2018; Vieira et al., 2023; Wilmot, Pizzey, et al., 2023).

Cited throughout this literature, individuals with dyslexia reported feeling that their dyslexia impacted their daily lives, both in terms of education and career (Alexander-Passe,

2015; Nalavany et al., 2015). Lock and Layton (2001) emphasized the experience of an individual who was called lazy because of his dyslexia, and other reports recounted the experience of multiple individuals with dyslexia who described feeling stupid until they received their diagnosis (Kale, 2020). Of inspiration to our study, Alexander-Passe (2015) conducted a mixed-method analysis studying 29 individuals with dyslexia who presented with (n=22) and without (n=7) depression, looking at difference, disclosure, labelling, discrimination and perceived stigma associated with dyslexia. Quantitatively, he found that 27% of his sample perceived dyslexia as having a negative impact on their lives, while over 50% saw their dyslexia as positive. Moreover, 39% endorsed feeling that they needed to work harder because of their dyslexia, 12% endorsed that they would take a pill to cure their dyslexia and 62% of the sample endorsed that their dyslexia affected their daily life (Alexander-Passe, 2015).

Despite the difficulties experienced by individuals with dyslexia, they are increasingly being described as differently abled (Everatt et al., 1999; Garner, 2021; Thompson et al., 2015). This emphasis on abilities that are different versus disabled highlights the inherent strengths seen in individuals with dyslexia as a consequence of their neurodiversity (Odegard & Dye, 2024). Shaywitz (2003) introduced the "Sea of Strengths Model of Dyslexia" which categorized dyslexic thinking as *big-picture* and *non-linear* (Garner, 2021). Kale (2020) recounted how some individuals believe that dyslexia is a gift and saw themselves not as dumb, but rather smart in a different way. This way of thinking has led individuals with dyslexia to excel in visual creative occupations, such as art and design, architecture and inventing (Brunswick et al., 2010; Duranovic et al., 2015; Everatt et al., 1999). Furthermore, the character strengths of individuals with dyslexia were investigated, finding that such individuals present with strengths in curiosity, fairness, kindness, judgement, honesty, leadership and humour (Kannangara, 2018). Framing dyslexia as a different ability rather than a disability is believed to influence an individual's self-identity and overall experience of having dyslexia. This perspective can affect their self-perception and the broad, everyday experience of living with dyslexia (Livingston et al., 2018; Thompson et al., 2015).

Early and Late Diagnosis and Intervention for Dyslexia

Another potential contributing factor towards an individual's overall experience and outlook on their dyslexia is age of diagnosis. Early diagnosis and intervention are crucial in helping individuals with dyslexia develop effective coping strategies and achieve their full

potential (Carawan et al., 2016; Gearin et al., 2024; Livingston et al., 2018). Early diagnosis and intervention have been found to be effective in alleviating later difficulties related to dyslexia through the development of adaptive and compensatory strategies, as well as has the possibility to alleviate secondary effects of dyslexia, such as negative self-esteem, lack of acceptance of diagnosis, lower general and academic competence, and decreased motivation (Battistutta et al., 2018; Ingesson, 2007; Livingston et al., 2018). Findings highlight that early academic interventions help develop compensatory literacy strategies in children with dyslexia, while later emotional supports address social and emotional consequences, emphasizing the importance of early identification to prevent negative emotional experiences (Livingston et al., 2018; Nalavany et al., 2015).

Researchers examining the age at which dyslexia is diagnosed often concentrate on the disparities in reading abilities between those with early-onset dyslexia and those with late-onset dyslexia, with the latter commonly being identified during school years. In one study, Battistutta and colleagues (2018) sought to investigate the perceived competence of teenagers with dyslexia as a result of age of diagnosis. They found that teenagers diagnosed earlier had a better understanding of their dyslexia and greater general and academic confidence compared to their late-diagnosed peers (Battistutta et al., 2018). Brunswick and Bargary (2022) investigated university students with and without dyslexia, sub-dividing the dyslexia group into two groups, assessed in childhood (<18 years old) and assessed in adulthood (>18 years old), on the relationship between self-esteem, self-efficacy and estimated intelligence. Early assessment was related to lower self-esteem and self-efficacy, but no difference was found for estimated intelligence compared to non-dyslexic peers. Conversely, compared to unimpaired readers, later assessment was associated with lower self-esteem and estimated intelligence but no difference in self-efficacy. The authors did however note a lack of generalizability of their findings given that their samples were comprised of university students and a relatively small sample size of individuals with dyslexia (n = 72), which limited the statistical power to detect the effect size of interest, as well as limited further exploration between the groups (Brunswick & Bargary, 2022). 2025-08-31 3:27:00 PMAs such, there is a need for further investigation into the effects of age of diagnosis of adults with dyslexia beyond a university sample. Additionally, individuals in this study who self-identified as having dyslexia but reported not having a formal diagnosis of

dyslexia were excluded from the analysis. These individuals represent a unique group of individuals who are underrepresented in the dyslexia literature.

Current Study

Previous researchers have relied on either purely qualitative (Cameron, 2016; Jacobs et al., 2022; Wissell et al., 2025), or purely quantitative methodologies (K. K. H. Chung et al., 2023; Wissell et al., 2021), each of which carries inherent limitations in terms of generalizability. Qualitative studies have provided rich, in-depth insights into individual experiences, but their findings are often constrained by small, non-representative samples. Conversely, quantitative studies offer broader statistical trends but may overlook the nuanced, context-specific aspects of lived experience. This methodological divide has created a gap in the literature, limiting our ability to draw conclusions that are both empirically robust and grounded in real-world experiences. To address this, the current study employs a mixed-methods design, integrating qualitative and quantitative approaches to capture a more comprehensive understanding of adult dyslexia. However, we acknowledge that the use of both methods alone does not guarantee generalizability. Achieving this requires careful attention to sampling strategies and analytic rigor to ensure that findings are both meaningful and applicable across diverse populations.

Here we aim to investigate the contemporary experiences and conditions of adults with dyslexia. To our knowledge, few research studies in dyslexia have used rating scales to measure one's general sense of experience associated with dyslexia. Such a scale could serve to broadly conceptualize experience based on the individual's own interpretation of the question and scale, generalizing findings and opening new pathways for further theoretical investigations. When studying adults with dyslexia, it is increasingly difficult to make causal or correlational links connecting experiences and diagnoses given an individual's age of diagnosis, possible comorbidities, their sense of self, perception of self by others and many more factors.

The questions for these analyses were taken from and inspired by the literature in the field, to provide quantitatively informed test statistics to explain the experiences of individuals with dyslexia (Alexander-Passe, 2015; Cameron, 2016; Ferrer et al., 2022; Lock & Layton, 2001; Nalavany et al., 2015; Sirin Kale, 2020). Using predictor variables from the literature, we conducted an exploratory analysis that utilizes a mixed-method approach with the aim of better understanding the experience of individuals with dyslexia as positive, neutral, or negative, as a result of when and if the individual was diagnosed with dyslexia. Presently, many previous

studies exclusively have used a strictly qualitative or quantitative approach with non-generalizable samples to test definite hypotheses. Given the limited and mixed findings in the literature, we opted to use a mixed-method approach, with a large sample size to reflect differences in experience, in investigating multiple factors that may impact the experiences of individuals with dyslexia.

Our quantitative approach will serve to explore the relationship between age of diagnosis and overall experience on our predictor variables via chi square analysis, descriptive statistics and CART (classification and regression trees) analyses. Here, we hypothesize that individuals in the early assessed group will be more likely to have a positive overall experience of their dyslexia, broadly agreeing with positive statements about their dyslexia and disagreeing with statements that view their dyslexia negatively. Moreover, we hypothesize that individuals who view themselves as stupid and who have experienced being perceived as lazy will be more likely to rate their overall experience of dyslexia as negative, with the late assessed and self-identifying groups rating themselves, on average, higher on these scales.

A Reflexive Thematic Analysis will serve to provide context for and supplement our quantitative research. We hypothesize that the qualitative results will mirror our quantitative analysis given the order of question presentation, priming participant responses. Using this priming effect, the aim of this analysis is to breathe life into participant responses and their experience of having dyslexia. In line with the overall goal of this paper, additional coding will highlight experiences as positive, neutral and negative as well as make note of responses that refer to age of diagnosis.

Method

All aspects of this research were conducted in compliance with regulations outlined by The Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, as well as The Official Policies of the first author's affiliated University, including the Policy for the Ethical Review of Research Involving Human Participants. Informed consent was obtained from the participants after an explanation of the study was given to them. The research protocol was approved by the University's Human Rights Ethics Research Committee (certificate #30009781).

Participants

A sample of 140 adults with dyslexia were recruited both for in-person and online participation. Targeted advertisements were directed at students in accessibility centres on

university campuses across Canada and the United States as well as advocacy groups and associations for individuals with dyslexia and other learning disabilities. All participants self-identified as having dyslexia with or without a formal diagnosis of dyslexia by a qualified professional (Carawan et al., 2016; Nalavany et al., 2011; Wilson et al., 2009). A total of 23 participants were removed from the analysis as 13 participants were suspected bots (from online recruitment), 9 participants were removed as their data questionnaire was incomplete, and one individual did not identify as having dyslexia. This left a final sample of 117 individuals with dyslexia. The age, sex and gender of participants are outlined in Table 1, as well as scores on screening measures of dyslexia (Smythe & Everatt, 2001). Table 2 details self-reported comorbidities (also see OSF repository for scores on the Adult ADHD Self-Report Scale).

Data Collection

All data was collected as part of a larger data collection initiative. Data was collected on either Qualtrics (for online) or on Microsoft Excel (for in-person). Participants were asked to complete a questionnaire which consisted of demographic information, questions about their experience of having dyslexia, the Dyslexia Adult Checklist (Smythe & Everatt, 2001) as well as Adult ADHD Self-Report Scale (Kessler et al., 2005). Questions about individuals' experiences with their dyslexia were generated by the first author based on previous research in the field. Question structure was forced-choice varying from yes/no, Likert-type scales and or one-word answers, except for the last question which asked participants "Is there anything you would like us to know about your experience of having dyslexia?" Participants typed out their responses to this question. Completion of the questionnaire lasted approximately 10 minutes.

Measures

Dyslexia Adult Checklist

The Dyslexia Adult Checklist is comprised of 15 questions used to assess aspects of literacy, language and organization. Items require the respondent to rate symptoms of dyslexia on a 4-point Likert-type scale (rarely, occasionally, often, most of the time, and easy, challenging, difficult, very difficult), in which some questions are assigned a higher weight for the total score (Smythe & Everatt, 2001). The higher the total score, the higher the risk of having dyslexia. According to Smythe and Everatt (2001), a total score of 45 or more indicates that the respondent is showing signs consistent with mild dyslexia, and a score above 60 as moderate or severe dyslexia (also see Stark et al., 2025) Stark and colleagues (2025) found the Dyslexia

Adult Checklist to have a sensitivity rate of 91.5% and a specificity rate of 80% when using a cut-off score of 40, in their sample of 400 individuals with and without dyslexia.

Apparatus

Online data was collected using the online data collection platform Qualtrics. All data was anonymous and coded, with no link between the participants' identities and their data. Data collection through in-person recruitment was administered on Microsoft Excel, anonymous and coded.

Data Analysis

Data was analyzed using a mixed-method approach. Microsoft Excel (Microsoft Corporation, 2023, Version 2102) and Jeffery's Amazing Statistical Package (JASP Team, 2023, Version 0.14) statistical software were used to analyze the quantitative results. Quirkos (2023, Version 2.5.3) was used to analyze the qualitative data. Analysis was completed in three sections: descriptive, qualitative, and quantitative. Using Microsoft Excel descriptive statistics were computed, as medians, means and percentages, for questions using a 5-point Likert scale, a rating scale and yes/no questions, respectively. Responses to questions were analyzed based on age of diagnosis (namely, early assessed, late assessed or self-identifying), as well as by overall rated experience of having dyslexia (positive, neutral and negative). An average collapsed experience score was calculated for each age of diagnosis regardless of their experience score. Henceforth, age of diagnosis refers to the age at which the participants reported being diagnosed with dyslexia, with early assessed referring to those diagnosed before 18 years old ($\leq$ 17 years old), late assessed referring to those over 18 years old ($\geq$18 years old) and self-identifying referring to individuals who self-reported identifying with the dyslexia label despite not having an official diagnosis of dyslexia. Additionally, participants were asked to rate their overall experience of having dyslexia using a ten-point scale ranging from -5 to 5, where a score in the negative was indicative of a negative experience, a score of 0 indicating a neutral experience and a score in the positive range indicating a positive experience. Negative, neutral, and positive ratings were coded based on participants' responses to this scale. This question was presented on Qualtrics as a sliding scale, indicating positive on one side and negative on the other, with neutral indicated in the center with a rating of 0. This question was worded as follows: "Overall, do you consider your experience of having dyslexia to be?"

A Chi-Square test of independence was first conducted using JASP to investigate the relationship between age of diagnosis and overall experience. A Chi-Square value and Cramer's *V* effect size were calculated. For further investigation, the CART analysis was conducted using the R statistical package (Parsnip Version 1.1.1, 2023). This non-parametric statistical model uses a series of dichotomous splits to maximize the sensitivity and specificity of classification, resulting in a decision tree. The use of CART analyses is typically used to assess prediction models. However, in this case, we are investigating the association between the overall experience of having dyslexia and our independent variables based on an individual's age of diagnosis. Here, our dependent variable overall experience of having dyslexia was coded 1 (positive experience), 0 (neutral experience), -1 (negative experience), and -2 (very negative experience). Here, 1 represents all participants who responded between 1 and 5 on the 11-point scale, 0 represents all participants who responded 0, -1 represents all participants who responded -1 and -2, and -2 represents all participants who responded -3, -4 and -5. Our independent predictor variables included demographic information, age and sex, in addition to questions from the descriptive analysis above (see Table 3 which indicates the questions included in the CART Analysis). These variables were chosen based on theoretical rationale and the results of the descriptive analysis above. These variables were given a shorthand for ease of interpretation (Table 4). To investigate an interaction effect between our independent and dependent variables of interest, age of diagnosis and overall experience of having dyslexia, we limited the analysis to three trees for each level of the independent variable. CART constructs a tree that separates the data into the clearest classification groups based on a series of dichotomous decision points, called nodes, where a decision rule is used to split the data. At each node, every split is considered, the split that produces the most 'pure' and homogeneous group. This methodology selects the most important and "best" splits first. The criterion by which decision rules were compared is the Gini criterion measure, a measure of split purity. No other criteria or restrictions were used due to the nature of the data.

To replicate Braun and Clarke's (2006; 2019) findings with a larger sample, a six-phase reflexive thematic analysis method was employed in generating themes as expressed by participants in their written responses to the question "Is there anything *you* would like us to know about your experience of having dyslexia?" Here, we generated, reviewed, curated, and reported on themes that emerged in the data (Braun & Clarke, 2006, 2019). This analysis was

conducted by the first author in collaboration with the last author. We selected this reflexive approach as part of our mixed methodology as it stands in stark contrast to our quantitative results, it is theoretically flexible and can breathe life into the experiences of individuals with dyslexia above and beyond what is possible from an exclusively quantitative approach. Quirkos was used to facilitate this analysis by first generating initial codes at the participant response level, in mapping out preliminary themes and again when reviewing and finalizing themes. Written passages for this analysis were taken verbatim, therefore the quotations in the text contain spelling and grammatical errors.

Results

While primary analysis is reported below, all data, analysis and supplementary materials are available in an open science framework repository.

Chi-Square Test of Independence

To evaluate the relationship between variables age of diagnosis and overall experience of having dyslexia, a Chi-Square test of Independence was conducted. Using non-parametric null hypothesis testing, no statistically significant association was found between our variables and a small effect size (X^2 (18, N=117) = 16.51, p = 0.56, Cramer's V = 0.266; see OSF repository for Chi Square Table).

Descriptive Analysis

Means, medians and percentages were calculated for 17 questions, depending on the question response format. Statistics were calculated by age of diagnosis and perceived experience of having dyslexia. Eight statements were given to participants in which they needed to rate the statements on a 5-point Likert scale from 1 strongly agree to 5 strongly disagree, with 3 as the center point indicating neither agree nor disagree. Of note, *perceived reading difficulty* was rated using a sliding scale from 0 to 10, with 10 indicating most severe. To best denote these results, a mean was calculated. Given the sample sizes of these subgroups, further statistical analyses could not be conducted due to a lack of power, therefore caution should be taken when generalizing these findings to other samples of individuals with dyslexia. Results are in Table 3. Table 4 outlines the questions asked to participants and their respective shorthand used in text.

We found that when asked about individuals' *perceived reading difficulty*, on average early assessed individuals reported having the highest degree of difficulties, with late-assessed individuals reported having an overall negative outlook of their dyslexia scoring the highest on

perceived reading difficulty. Of the individuals with an overall positive outlook of their dyslexia, those assessed early scored on average higher compared to individuals assessed later or those who self-identify as having dyslexia.

Participants were then asked about their *perception of self as disabled.* On average late assessed individuals were most likely to reply yes, with those who rated their overall experience of dyslexia as negative replying yes most often. Interestingly, less than 50% of early assessed individuals rated their overall experience as being neutral or positive, 11% and 33% respectively. Over 50% of individuals across age of diagnosis, irrespective of experience, indicated having a diagnosed *comorbidity*, either another learning disability or a mental health disorder (Table 2). Additionally, 77% of early-assessed individuals endorsed having a family member with dyslexia, while only 64% in the late-assessed group and 67% in the self-identifying group endorsed having family members with dyslexia.

Individuals with an overall positive view of their dyslexia tended to disagree with negative statements about their dyslexia and agreed with statements that viewed their *dyslexia as a gift*, that makes them *differently abled*, *empowered*, and *unique*. Early assessed individuals agreed with the statements that they felt *frustrated* and *exhausted* because of their dyslexia, irrespective of their overall experience. This stands in contrast to the late assessed or self-identifying individuals who have an overall positive experience of their dyslexia who slightly disagreed or disagreed with these statements respectively. Of interest, responses to statements asking about feeling *frustrated* and *exhausted* tended to follow a consistent pattern across age of diagnosis and overall experience. Consistent responses were found for statements asking about feeling *stupid* and *perceived laziness*. The exception to this pattern were individuals diagnosed in adulthood with an overall neutral experience of their dyslexia in which they strongly disagreed with the statements that they felt stupid: however, neither agreed nor disagreed with the statement about *perceived laziness.* Similarly, individuals who self-identify as having dyslexia, who reported having an overall positive experience, disagreed with the statement about feeling *stupid* and slightly agreed with the statement about *perceived laziness.*

For the most part, individuals who reported having an overall negative experience with their dyslexia disagreed with the statement of feeling *empowered*. Individuals who self-reported as having dyslexia and who have an overall positive experience with their dyslexia also disagreed with the statement about feeling *empowered*. They did however agree with statements

about feeling *unique*, seeing *dyslexia as a gift* and seeing people with dyslexia as *differently abled*. Generally, all individuals agreed with or neither agreed nor disagreed with the statements; *unique, dyslexia as a gift* and *dyslexia disappear.* The exception was the early assessed group who reported having an overall negative experience with their dyslexia, who disagreed with the statement *dyslexia as a gift.* Similarly, the self-identifying group who reported having a positive experience slightly disagreed with the statement about making their *dyslexia disappear*. Across age of diagnosis and reported experience, all individuals agreed with the statements about feeling *differently abled* and *working harder.*

In line with their overall experience of dyslexia, individuals who reported having an overall negative experience of their dyslexia agreed with the statements about their dyslexia affecting their career choices and opportunities. Conversely, individuals with a positive experience tended to disagree or only slightly agree with these statements. Of note, the early assessed group who reported an overall neutral experience of their dyslexia, agreed with the statement about *feeling limited,* however, disagreed with the statement about *holding back.*

CART Analysis

To explore the interactions and non-linear associations between the data, three decision trees were established for each level of the independent variable, age of diagnosis (see Fig. 1,2 & 3). The largest and most robust decision tree was for the early assessed group (Fig. 1). This is to be expected given that this group is made up of 61% of our total sample, with 71 participants. Here, 27 participants rated their overall experience of having dyslexia as very negative, closely followed by 26 individuals who rated their experience as negative, 9 participants rated their experience as neutral and 9 as positive. In all, three levels and five-factor splits were identified. The first and most parsimonious split occurred on the variable *holding back,* with participants who answered agreed to this statement most likely to report having a very negative overall experience of their dyslexia. Those who either agreed or disagreed or who disagreed with this statement were most likely to report having an overall negative experience of their dyslexia.

In the second level of analysis, two splits occurred. Of the participants who were more likely to respond with having an overall very negative experience of dyslexia (46%) based on the *holding back* question, 14% of them responded no to having a comorbidity. These individuals were most likely to report having an overall very negative experience, 5 individuals, closely followed by 4 individuals who reported having a neutral overall experience. Similarly, the other

32% of individuals who reported having a comorbidity, were also most likely to report having an overall very negative experience. Following the decision tree, the third level revealed a split based on feeling *empowered*, with 23% of the 32% disagreeing with this statement about feeling empowered. These individuals were most likely to report an overall very negative or negative experience, 10 and 5 individuals, respectively. Of the remaining 10% of individuals who either agreed or either agreed or disagreed with the statement asking about feeling *empowered*, most individuals reported having an overall negative experience. When looking at this branch of the decision tree, it is evident that for those individuals who were diagnosed in childhood, if they agreed with the statement about *holding back,* then they were most likely to report having an overall very negative or negative experience of their dyslexia, irrespective of the questions that followed.

Returning to the second level of analysis of the participants who disagreed or either agreed or disagreed with the *holding back* question (54%), 24% of them responded that they disagreed with the statement asking about feeling *empowered.* These individuals were most likely to report having an overall negative experience. The remaining 30% reported either agreed or either agreed or disagreed with the statement about feeling empowered and similarly were most likely to report having an overall negative experience of their dyslexia, with 8 individuals reporting feeling this way. In this group of individuals, 7 individuals reported having an overall positive experience and 2 individuals an overall neutral experience. Following the decision tree, the final split occurring at the third level revealed that responding agree the statement asking about feeling *stupid* (11%) predicted a negative overall experience. Whereas the remaining participants (18%) who responded either agreed or disagreed or disagreed with this statement were most likely to have an overall positive experience. We can interpret these findings in that individuals who do not feel they were held back on experiences and opportunities because of their dyslexia have a greater likelihood of having an overall positive experience of their dyslexia. Moreover, if endorsed feeling empowered and not stupid, this would further increase their likelihood of having an overall positive experience of their dyslexia. Additionally, on the other side of the decision tree, the likelihood of having an overall neutral or positive experience of dyslexia was 50% for individuals who did not self-report as having a comorbidity. This is in contrast to the majority of individuals who reported having a negative or very negative experience of their dyslexia and self-reported as having a comorbidity. The overall accuracy of

this decision tree in classifying our sample of individuals with dyslexia diagnosed in childhood based on their overall experience of dyslexia was 55%.

The next generated decision tree was for the late assessed group comprised of individuals who were diagnosed with dyslexia during adulthood (Fig. 2). This decision tree has only one level due to the small sample size and stopping rules of CART. Of the 25 participants, the largest proportion reported having a negative overall experience of dyslexia. The first and only level revealed a split on the variable *comorbidities.* Overall, 60% of this group of individuals reported having been diagnosed with a comorbidity, predicting a negative overall experience of dyslexia. Here, 7 individuals reported having an overall negative experience, 6 individuals reported having a very negative experience and 2 individuals reported having an overall neutral experience of their dyslexia. Of those 40% without a comorbidity, 4 reported having an overall positive experience, 3 had a negative experience, and 3 had an overall neutral experience. It is evident that individuals who were diagnosed in adulthood and who reported not having a comorbidity were most likely to report having an overall positive experience of their dyslexia compared to those with a self-reported comorbidity. This decision tree has a prediction accuracy of 44%.

The final generated decision tree was for the self-identifying group (Fig. 3). This decision tree has one level. This group is made up of 21 participants, with the largest proportion of participants reporting having a negative overall experience of dyslexia. The only level revealed a split based on the variable *holding back.* Overall, 57% of this group agreed with this statement, predicting an overall very negative experience of dyslexia, with 8 individuals reporting having an overall very negative experience, 3 individuals reporting having a negative experience and 1 individual reporting having an overall positive experience of their dyslexia. The remaining 43% of individuals reported disagreeing or either agreeing or disagreeing with this statement. Here, most individuals reported having an overall negative experience with 8 individuals and 1 individual reporting having a positive experience. When looking at this decision tree, it is evident that for those individuals who self-identify as having dyslexia, if they agreed with the statement about *holding back* then they were most likely to report having an overall very negative experience compared to those who disagreed or either agreed or disagreed to this statement. This decision tree had a prediction accuracy of 76%.

Reflexive Thematic Analysis

To complement the above analysis, we also conducted a reflexive thematic analysis on qualitative data. Six predominant themes were constructed in the analysis of participants' written responses to the question “Is there anything you would like us to know about your experience of having dyslexia?” The generated themes are (1) the internalizing effects of dyslexia, (2) the perceived experience of dyslexia, (3) the perceived perception of others, (4) shifts in experience over time, (5) acceptance, and (6) coping skills. Subthemes were generated for overarching themes. In line with the greater research question, individuals highlighted both positive and negative experiences across five of the generated themes, highlighted here. Of note, out of the 117 participants in the study, 24 participants chose to not respond to the question prompt.

The Internalizing Effects of Dyslexia

The first generated theme is *the internalizing effects of* dyslexia. Three subthemes were also generated: labelling the self as dyslexic, effects on mental health and sense of self. Some individuals described their relationship with the label of dyslexia and what having a label meant for them, stating that “*I felt stupid most of my childhood and early adolescence, until it was discovered that I had dyslexia*” and “*I have never felt that it was a bad thing but just a nice label to put on things the explain the little parts of me that can see odd to some people*”. Other individuals explained the lasting effects that having a reading disability had on their sense of self, noting lasting effects on their self-esteem, “*It was really difficult in school and my self esteem suffered a lot... Stuff from the past and still can make you feel dumb and less*” while others explained the effects on their self-confidence, “*I think dyslexia has affected my confidence more than anything*,” “*although I look like normal people, but in reading and communication, I am not very confident*” and “*my self confidence is low because of my learning disability*.” One participant expressed increased self-confidence in helping others, “*As an adult with technology I have found what works best for me, and I have developed confidence in sharing my struggles with academics, in hopes of advocating and changing this system for others*.” Another participant explained “*as soon as I got my diagnosis, I felt more confident and better about myself*.” Conversely, a participant explained their experience with dyslexia as:

> *I have had such negative experiences from schooling. I felt stupid and dumb. I always had a strong understanding of what I was being taught but was never able to demonstrate it. It was so discouraging that I just gave up on myself. I was unaware how differently I learned from my peers teachers often seen me as lazy. Even now I have strong desire to*

learn and feed my mind but feel so many challenges that would prevent me from being successful.

Moreover, some participants chose to describe their past and current mental health struggles because of their experience with dyslexia, explaining that "*emotional effects from middle school/high school still linger*" and that "*at the time, my teachers/peers/parents just thought I was slow, so I labelled myself that way for a long time. It affected my mental health and even stopped me from challenging myself academically for a long time.*" One person explained the culminative effects of their dyslexia diagnosis by explaining how:

...not being understood easyly becaus you think diffrently or have difficulty expressing yourself all of which can lead to a lot of anxiety or eaven depression or burnout on the long run as well as low motivation and procrastination, over all not the best but not the worst.

While the experience of individuals was not universally negative, many individuals used words like 'dumb,' 'stupid,' 'lazy,' 'failure' and 'misunderstood' when describing themselves in relation to their dyslexia. This theme of internalizing depicts the effects of dyslexia on their personhood, sense of self, self-esteem, self-worth, confidence, and overall mental health.

Perceived Experience of Dyslexia

While similar to the *internalizing effects of dyslexia*, this theme of *perceived experience* outlines the emotional and behavioural experiences of having dyslexia. Individuals whose responses fall in this theme described their frustration and difficulties that result from their dyslexia as well as the challenges they experience when reading. This theme includes both the behavioural and emotional experiences experienced by our sample of individuals with dyslexia.

When describing behavioural experiences, many people explained needing to reread written passages and taking longer to do tasks that involve reading or writing as well as outlined daily environments and situations where their dyslexia affects them. For example, participants wrote "*Sure sometimes I struggle writing words, we have our bad days. But mostly for me it's reading. Reading takes a lot of my energy because most of the time I need to reread it*", "*having difficulty reading made me guess the word instead of reading it*" and "*I am slow when I write and even slower when I read.*" One participant wrote: "*Dyslexia can make navigating the world a challenge on a daily basis. From reading a menu at a restaurant to going grocery shopping*

these tasks are made more difficult by the way in which our world is structured." While someone else documented:

> *I find that when I am not in an ideal situation, i.e. Airport, signing documents, stressful, tired etc. is very difficult to focus and it becomes next to impossible to read what is happening. even simple thing such as a friend holding something up for me to read on their phone is enough to freeze my concentration.*

When reporting on the emotional experience of having dyslexia, many participants focused on the frustration, difficulty and embarrassment associated with having dyslexia. Participants stated "*It used to be frustrating, but Ive come a long way*," "*It's difficult and frustrating*" and "*In high school and elementary school I would get extremely frustrated with needing more time on tests than other classmates and felt dumb*." Participants shared their embarrassment related to their spelling errors stating "*I commonly make embarrassing grammatical mistakes in emails - I double check emails before I send them and there are still mistakes because I need to go to fast for my brain*" and described their experiences in school as "*I can remember the stress whenever the teacher would start calling out names to read out loud or answer a comprehension question. I for sure have days of just frustration because i can't get something*." While individuals' memories, environment and unique circumstances are different, this theme echoes shared experiences, both emotionally and behaviorally, experienced by individuals with dyslexia.

The Perceived Perception of Others

This theme refers to the labels that are placed on individuals with dyslexia as well as the attitudes, assumptions and beliefs of others as perceived by individuals with dyslexia. When choosing to talk about others, many participants specified the *other* as being teachers, parents, peers, and co-workers. Stating that others labelled them as "slow," "lazy," "defiant," and "air-headed" yet "smart." Participants explained feeling othered as a result of their dyslexia, writing "*I wish all of the adults in my life had just treated me like every other kid instead of making the fact that I am dyslexic a big deal*," "*I wished I could be normal because that seemed like what my parents wanted*" and a "*lot of people have made fun of me for all my life because I cant spell or read as well as others*."

Within this theme is the disclosure of their diagnosis to others, mainly in a work context. While in school, individuals are often outed because of the accommodations they receive. This

changes in the workforce, where disclosure is a personal choice. One participant explained "*I have absolutely no intention of telling anyone at my work about my situation- labels are the worst! People never actually treat you the same way as before a label*." While other participants chose to disclose their diagnosis stating that "*people I work with are really cool and supportive about except when they choose to be asses. It was hard at first*" and "*most employers I have had have been willing to adapt circumstances due to my dyslexia*" resulting in sometimes positive outcomes.

This theme centers around feeling misunderstood and othered by people around them. Here we bear witness to participants' experiences of sharing their diagnosis and the labels placed on them because of their differences, leading to often negative experiences associated with their dyslexia.

Shifts in Experience Over Time

Given that dyslexia is a developmental disorder that persists throughout the lifespan, individuals experience of having dyslexia are likely to shift and change over time. Some individuals in our study chose to highlight this shift in their perspective and symptomatology over time. Individuals noted a decrease in the struggle with dyslexia as they got older, noting "*having dyslexia was more of the challenge when I was a kid but now I have adapted*" and "*used to struggle much more when I was younger…*" Others wrote about their shift in perspective over time, emphasizing an internal growth "*it used to be frustrating, but Ive come a long way. Im way better than my younger self*" and "*I became much more confident, I had fewer issues with spelling and understanding writing, and the want to make dyslexia just disappear went away*."

Another highlighted shift over time was a decrease in symptomatology. Multiple participants attributed their perceived decrease in symptomatology to their participation in remedial programs during elementary school, stating that "*I went through a lot of work and training in elementary school which I feel like has made my dyslexia more mild*" and "*I have been treated for 6 years or so to help with the dyslexia, so I sometimes half forget I have it even if I do suffer from it*." Others made note of more broad shifts over time, stating "*I don't notice it as much as I did in school but once it while comes up with new reading materials/pronunciation, spelling, and when I confuse words in front of others*" and how "*at the beginning was very difficult, but I overcome all the difficulties, now more fluent in reading these problems*."

Their perceived shifts over time denote a change in perspective and attitude toward their experience of having dyslexia. Many participants documented increased struggles when in school and then witnessed a shift as time went on. In some cases, this shift is attributed to the development of strategies.

Acceptance

The next theme is that of acceptance. Here, we define acceptance as experiencing their dyslexia as a matter of fact, without trying to change it. In their acceptance participants stated, "*I don't think having dyslexia is a blessing at all, it makes your life harder…it just part of who I am and just have to work a little harder than some of my friends or classmates to get the same result*". One participant stated:

> *I also don't view it as something that is to be ashamed of because I can't change it and I was born this way, so I just have to find ways around things or fine little tricks to help me with spelling and grammar and all the other stuff.*

Another participant wrote about their own education on dyslexia in shifting their view of it:

> *I was raised by parents who did not have dyslexia. As a child, I hated my dyslexia and wanted it to disappear and wished I could be normal because that seemed like what my parents wanted. By my senior year of high school, I had done my own research and had grown as a person, and realized that dyslexia was not something that would just go away. I stopped pretending that I didn't have it and started being more open and vocal about my thoughts and how people treated kids and adults who had dyslexia… If there was anything I could go back and tell my younger self, or younger dyslexics, it's not that we are differently-abled or smart in a different way its that we are disabled, and that will not change. It's how you deal with being disabled that makes you.*

These responses differ from the other generated themes in that they do not speak of their dyslexia as a positive or negative trait, but rather accept the difficulties that come with having dyslexia and gaining confidence and acceptance despite it. Acceptance, by definition, is a neutral stance where individuals accept the reality of the situation, rather than looking at the situation with a *glass half-empty* or a *glass-half-full* approach.

Coping Skills

The last generated theme outlines the way people learn to cope with their dyslexia both in the world and while at school. Included in this theme is the use of accommodations and tools in school and the workplace, such as text-to-speech and extra time on tests and assignments. Participants in the study noted that while these accommodations can prove to be helpful, these accommodations do not equate to not having a learning disability. Such is the case of these two participants who explained that:

> *Even though I am allowed to use text-to-speech for exams I do not since all my exams are engineering exams. Questions are based around numbers and like one sentence to state what it is that I need to do.*

And:

> *I was fortunate enough to know that I was dyslexic at a young age and was able to afford the extra help and I'm very greatful for that... but it doesn't make all the extra time I need to work on assignments or have had to dedicate to my studies any less frustrating and difficult.*

Nevertheless, many participants noted how these accommodations have proven helpful in academic settings. Such as in the case of these participants who explained how "*the extra time on exams has helped me a lot in being able to read the questions more carefully and having time to double check that what I am writing makes sense*" and "*having accommodations makes a huge difference in my school life.*" More broadly, some participants noted their use of auditory tools, such as text-to-speech programs, to help manage unwanted consequences such as headaches and the exertion of energy when reading. Other strategies noted by participants are the changing of type fonts when reading on the computer and learning tricks to help with spelling and grammar.

Others wrote about paying it forward, working with students with dyslexia. One participant explained "*my personal experience in learning how to manage my dyslexia through developing coping strategies in education have positioned me to become a special education teacher for cycle 1 high school students*" and another participant noted:

> *Having dyslexia has allowed me to develop very specific interests within the education field (currently persuing my degree), particularly I am very passionate about assestive and augmentive technologies and how we can best support students to use them. I grew up in a time where these tools where limited, and supports in school where very different. As an adult with technology I have found what works best for me, and I have developed*

confidence in sharing my stuggles with acadmics, in hopes of advocating and changing this system for others.

Overall, this theme outlined tools and strategies, both specifically and more broadly, that have served to help individuals with dyslexia. While some individuals described using their own strategies as well as new technologies available today, it is apparent that participants felt that tools and accommodations were generally helpful in dealing with the daily struggles of having dyslexia.

Discussion

The purpose of this study was to conduct an exploratory analysis that utilizes a mixed-method approach with the aim of better understanding the experience of individuals with dyslexia rated as positive, neutral, or negative, as a result of when and if the individual was diagnosed with dyslexia. Given the emphasis on reading and reading ability while in school, a majority of our sample self-reported receiving a diagnosis of dyslexia while of school age (61%; ≤17 years old). Additionally, our sample of individuals with dyslexia were most likely to have an overall negative experience of their dyslexia, irrespective of age of diagnosis (75%).

Our descriptive analysis allowed for the investigation of response patterns based on experience and age of diagnosis. Here, we discovered a relatively similar response pattern among individuals with dyslexia across age of diagnosis, irrespective of their overall experience. Our sample saw their dyslexia as something that caused them to hold back on experiences and opportunities, they felt that they needed to work harder than others, and it made them feel frustrated and exhausted. While they did not endorse the feeling of being empowered by their dyslexia, they felt that their dyslexia made them differently abled by being smart in a different way. When further dividing our sample based on overall experience, individuals with an overall positive view of their dyslexia tended to disagree with negative statements about their dyslexia. Conversely, they agreed with statements that viewed their dyslexia as a gift, feeling differently abled, empowered, and unique. As for age of diagnosis, irrespective of overall experience, self-identifying individuals endorsed feeling stupid and felt perceived as lazy. Both early and late assessed individuals did not endorse these statements in either direction. We found no statistically significant evidence for our a priori hypothesis that individuals assessed earlier would have an overall more positive experience of their dyslexia compared to late and self-identifying peers.

Looking at the interaction between age of diagnosis and overall experience, statements *perceived laziness* and *holding back* stood out as having heterogeneous responses. In line with our hypothesis, when asked about *perceived laziness* late assessed and self-identifying individuals, with an overall negative experience of their dyslexia, either agreed or slightly agreed with this statement. This stands in contrast to early assessed individuals. Rather, early assessed individuals who had a negative overall experience neither agreed nor disagreed with this statement. Individuals with a positive overall experience were the only group to disagree with this statement, across age of diagnosis and overall experience, speaking to the impact of the perception of others, a theme that was further explored in one of our generated themes. Although not heterogeneous across age of diagnosis, individuals with an overall negative experience of their dyslexia more so endorsed feeling stupid, with late assessed individuals strongly agreeing with this statement. The statement about *holding back* also led to heterogeneous responses. Here, early-assessed individuals, with an overall neutral or positive experience, disagreed with this statement. Similarly, so did late assessed individuals with an overall positive experience, whereas all other groups agreed with feeling held back because of their dyslexia.

As explored in the introduction of this paper, and the inspiration for our predictor variables, previous research has documented accounts of individuals with dyslexia reporting being perceived as lazy, feeling stupid until they received their diagnosis, feeling that their dyslexia impacted their daily live (both in education and career), while also believing that dyslexia is a gift and seeing the self not as dumb but rather smart in a different way (Alexander-Passe, 2015; Lock & Layton, 2001; Nalavany et al., 2015; Kale, 2020). In our sample of individuals with dyslexia, both perceived laziness and feeling stupid were endorsed, especially by individuals with an overall negative experience of their dyslexia. Similarly, our qualitative results mirror these findings and the statements reported in the literature (Kale, 2020).

Alexander-Passe (2015) studied individuals with dyslexia with and without depression and found that 62% of his sample endorsed that their dyslexia affected their daily life, 39% felt that they needed to work harder because of their dyslexia and 12% would take a pill to cure their dyslexia (Alexander-Passe, 2015). While not directly comparable given the nature of both data sets, 44% of our sample considered themselves to be disabled on a day-to-day basis because of their dyslexia. Further, they agreed to the statement *on a daily basis, my dyslexia affects my work in a negative way*. On average our sample strongly agreed with the statements about needing to

work harder than their peers, and similarly agreed with the statement about taking a pill to make their dyslexia disappear. Overall, the results of this analysis speak to the breadth of primary (i.e., perceived reading difficulty), and secondary effects of dyslexia on the individual's personhood. Furthermore, our findings quantitatively explored individuals who self-identify as having dyslexia.

These statements were then used in a secondary CART analysis to further investigate the associations between overall experience of having dyslexia and age of diagnosis (Table 3). Statements were included in the analysis based on theoretical rationale as well as the results from the descriptive analysis, with an emphasis on including statements with heterogeneous responses. To be expected based on the sample size discrepancy, the decision tree with the most levels was for early assessed individuals. Most splits in the decision tree predicted an overall negative or very negative experience of dyslexia. The most statistically homogeneous groups were defined by responses to statements about *holding back*, feeling *empowered*, feeling *stupid*, and having *comorbidities*. Individuals who did not feel *held back*, felt *empowered*, and did not feel *stupid* were more likely to report a positive experience with dyslexia. Of clinical relevance, 32% of individuals who agreed with the statement about holding back also reported a comorbid diagnosis, while 14% did not. Among those 14%, half reported a neutral or positive experience of their dyslexia, compared to only one person among the 32% with comorbidities who reported a positive experience. The only predictor that resulted in the most homogeneous split for our sample of late-assessed individuals was the question asking about *comorbidities,* in that not having a comorbidity increased their likelihood of having an overall positive or neutral experience of their dyslexia. Lastly, the statement about *holding back* resulted in the only split for our sample of self-identifying individuals, decerning between an overall negative or very negative experience of dyslexia.

In our CART analysis, predictor variables *holding back* and *comorbidity* re-emerged as variables creating parsimonious splits across age of diagnosis, warranting further investigation in further research initiatives. Dyslexia also has a high comorbidity rate with other neurodevelopmental disorders including other specific learning disorders, communication disorders, autism spectrum disorder and ADHD. Additionally, comorbidities have been noted between dyslexia and mental disorders such as anxiety and depression (American Psychiatric Association, 2013). In our sample of individuals with dyslexia, 60% of participants reported

having at least one comorbidity, with the highest proportion of people reporting having comorbid ADHD, followed by an anxiety disorder (see Table 2). Further investigation is warranted to better understand this interaction between comorbidities, neurodevelopmental and mental disorders, experiences of dyslexia and age of diagnosis.

The predictor variable *holding back*, produced from the statement *I find myself holding back on experiences/ opportunities because of my dyslexia* was inspired by research conducted by Cameron (2016). This paper explored the lived experience of three university students with dyslexia from a qualitative lens. The emerged theme *holding back: performance as risk* was centred around academic performance and highlighted a negative feedback loop of wanting to take part in academic contexts, comparing the self to others and ultimately choosing not to out of fear of being judged and self-doubt, culminating in a decreased sense of self-worth (Cameron, 2016). Here, we see that early assessed individuals who agreed with this statement were most likely to have a very negative experience of their dyslexia. Similarly, for individuals who self-identify as having dyslexia, 57% of them agreed with this statement and were most likely to report having a very negative experience. While these associations do not speak to the entire picture, the qualitative link between self-worth and holding oneself back may further explain the negative narrative witnessed in the subset of our individuals with dyslexia. Furthermore, the increased likelihood of having a positive experience related to one's dyslexia, by disagreeing or neither agreeing nor disagreeing with this statement, in conjunction with feeling empowered can speak to the protective nature of feeling worthy. Our generated theme *the internalizing effects of dyslexia* speaks to a sense of self-worth, or lack of it, in that participants used descriptive terms like 'dumb,' 'stupid,' 'lazy,' 'failure' and 'misunderstood' when describing themselves in relation to their dyslexia. For the most part, individuals reported directly on how their dyslexia affected their self-confidence and not self-worth. Given that self-confidence directly relates to one's belief in their abilities versus how one values the self, we argue that holding oneself back from opportunities and experiences directly speaks to the individual's confidence and in turn can affect their sense of self-worth.

Of note, the results from our descriptive analysis demonstrate that a majority of our sample have a family history of dyslexia. These questions were included in our analysis as both a descriptor of our sample and included in the CART analysis as a factor of interest. However, despite being included in the CART analysis, this factor did not result in a split, presumably due

to the homogeneous response pattern of our sample. Ferrer and colleagues (2022) examined the classification accuracy of family history of reading and writing difficulty as a screening measure for dyslexia. They found that family history did not add value to above and beyond pre-established evidence-based screening. In a similar vein to Ferrer and colleagues (2022), we interpret this finding to say that family dyslexia diagnosis does not aid in the prediction of overall experience of dyslexia irrespective of age of diagnosis.

Our last analysis was the reflexive thematic analysis as outlined by Braun and Clarke (2006; 2019). Here, six distinct themes were generated as a result of asking participants the question "Is there anything you would like us to know about your experience of having dyslexia?" These themes were (1) the internalizing effects of dyslexia, (2) the perceived experience of dyslexia, (3) the perceived perception of others, (4) shifts in experience over time, (5) acceptance, and (6) coping skills. As expected, these generated themes further elaborate on and provide context for participant responses in the quantitative portion of this study. While the first three themes elaborate on the aforenoted questions, the last three themes provide context for these responses (i.e.; a shift over time, a shift in perspective, or strategies used to alleviate symptoms of dyslexia). These generated themes are consistent with those observed by previous researchers (Alexander-Passe, 2015; Denhart, 2008; Jacobs et al., 2022; Logan, 2009; Nalavany & Carawan, 2012).

In keeping with the overall aim of this paper, we took note to emphasize both the positive and negative experiences that emerged based on participants' written testimonies. For the most part, participants' responses were coded as negative, either referring to difficulties in the past or present. Of interest, all generated themes were comprised of statements coded as both positive and negative, apart from acceptance, which reflects neutrality. These results speak to the complexity and heterogeneity of the experiences of individuals with dyslexia. In terms of age of diagnosis, six individuals made mention of their age of diagnosis. Interestingly, three of the six individuals diagnosed during school age rated their overall experience of dyslexia negatively. Additionally, two of the three described being diagnosed in adolescence and both described feeling as though they were late to be diagnosed. Two of the other individuals who mentioned their age of diagnosis were diagnosed with dyslexia in adulthood and rated their overall experience of dyslexia as neutral and negative. Both these individuals referred to their age of diagnosis in relation to having later access to accommodations which have since proven

beneficial. Lastly, the sixth person who mentioned age of diagnosis explained never receiving an "official diagnosis" due to the high cost associated with diagnosis. This person's testimony speaks to their internalizing effects and their perceived experience of having dyslexia, stating that adopting this label allowed them to see themselves as "not just stupid."

Putting the results together, we did not find a statistically significant association between age of diagnosis and overall experience of having dyslexia, per our initial hypothesis. That said, diving further into independent predictor variables of interest, heterogeneity in response patterns was observed for variables *perceived reading severity, family dyslexia diagnosis, comorbidities, self as disabled, stupid, frustrated, lazy, empowered,* and *holding back*. These variables were then included in a CART analysis. For the most part, splits occurred in the decision tree that resulted in predictions for an overall negative or very negative experience of dyslexia, resulting in non-clinically significant findings. Of clinical relevance, for both early and late-assessed individuals, not having a comorbidity increased their likelihood of having an overall positive or neutral experience of their dyslexia. Additionally, for the early assessed group, feeling empowered (rated as neither or agree) and not feeling stupid (rated as neither or disagree) resulted in a higher likelihood of having an overall positive or neutral experience of their dyslexia. As for our initial hypotheses, individuals in the late assessed and self-identifying groups, who have an overall negative experience of their dyslexia were more likely to agree to the statement about *perceived laziness* compared to their early assessed peers. This pattern in responses was not replicated for the variable *stupid*, which did not result in heterogeneous responses across age of diagnosis but did vary with overall experience. In line with our hypothesis, the investigated variables are echoed in three of our generated themes from the Reflective Thematic Analysis; the internalizing effects of dyslexia, the perceived experience of dyslexia and the perceived perception of others. Here, participants wrote about feeling stupid and referred to secondary struggles with mental health as a result of their dyslexia. Participants documented the perceptions of peers, parents, teachers and others as lazy and slow and reported on their daily struggles with reading.

Not to be ignored, factors not investigated in this study are the secondary effects associated with receiving, or not receiving a diagnosis of dyslexia, at a given age. While this study explored the relationship between overall experience of having dyslexia and age of diagnosis, it did not consider the emotional, social or environmental effect of having a diagnosis

or not and the age at which that individual received this diagnosis. Looking at the results from the qualitative analysis, it is evident receiving or not receiving a diagnosis of dyslexia impacts individuals in multiple ways. Future research may wish to further investigate these effects, their impact on the individual emotionally, socially, environmentally and other.

One limitation of the current study is the nature of the sample, which was recruited both online and in person through voluntary participation. Recruitment efforts focused on targeted advertisements distributed to accessibility centres at universities across Canada and the United States, as well as to advocacy organizations and associations serving individuals with dyslexia and other learning disabilities. As a result, the sample is likely skewed toward individuals in higher education who are relatively high functioning and who may have already developed effective compensatory strategies for managing their dyslexia. This potentially limits the generalizability of our findings to the broader dyslexic population, particularly those who have not accessed postsecondary education or who face more severe barriers in academic or daily functioning.

This exploratory research initiative highlights potential protective and risk factors for individuals with dyslexia in developing a negative experience of their dyslexia. Given the exploratory nature of this research initiative, this paper intended to provide readers with a detailed account of the experience of, and secondary effects associated with, having dyslexia using both qualitative and quantitative data. Further research, including statistical modelling, with a larger sample size is required to test any hypothesis more explicitly. That said, the clinical relevance and implications of our findings are sizable given the breadth of questions and topics investigated.

Tables and Figures

Table 1
Demographics

	Age of Diagnosis			
	Early Assessed	Late Assessed	Self-Identifying	Total
	n=71	n=25	n=21	n=117
Age*	26.14	30.56	32.90	28.30
Gender				
# of Cis Male	15	14	6	35
# of Cis female	51	9	12	72
# of Other	5	2	3	10
Sex				
Male	15	13	6	34
Female	56	12	15	83
Dyslexia Adult Checklist*	55.96	57.8	56.67	56.48
Checklists Count above 40	68	24	20	112

Note. *Indicates that a mean was calculated for that row.

Table 2

Demographics: Part 2

	Age of Diagnosis							
	Early Assessed n=71		Late Assessed n=25		Self-Identifying n=21		Total n=117	
	n	%	n	%	n	%	n	%
Individuals with a Comorbidity	43	61	15	60	11	52	69	59
1 Comorbidity	25	35	7	28	6	29	38	32
2 Comorbidity	4	6	5	20	2	10	11	9
3 or more Comorbidity	14	20	3	12	3	14	20	17
Learning Disability								
In Math	3	4	1	4	0	0	4	3
In Writing	6	8	2	8	0	0	8	7
Other	4	6	2	8	5	24	11	9
ADHD/ADD	23	32	7	28	5	24	35	30
Anxiety (GAD, OCD, Social Anxiety)	16	23	5	20	3	14	24	21
Depression	11	15	4	16	2	10	17	15
Bipolar Type I or II	1	1	1	4	0	0	2	2
Autism Spectrum Disorder	3	4	2	8	1	5	6	5
Personality Disorder	3	4	0	0	1	5	4	3
PTSD	3	4	1	4	0	0	4	3
Other Mental Health Disorder	1	1	0	0	2	10	3	3
Other Physical Disability	2	3	2	8	0	0	4	3

Table 3

Descriptive Analysis

	Experience											
	Early Assessed <17				Late Assessed ≥18				Self-Identifying			
	Average n=71	Negative n=53	Neutral n=9	Positive n=9	Average n=25	Negative n=16	Neutral n=5	Positive n=4	Average n=21	Negative n=19	Neutral n=0	Positive n=2
Perceived Reading Difficulty (mean)	5.34	5.34	5.56	5.11	5.08	5.75	4.2	3.5	5.19	5.26		4.5
Comorbidities	61%	70%	33%	33%	60%	81%	40%	0%	52%	53%		50%
Family Dyslexia Diagnosis	77%	79%	56%	89%	64%	63%	80%	50%	67%	68%		50%
Self as Disabled	42%	49%	11%	33%	52%	56%	40%	50%	43%	47%		0%
Stupid*	3	2	3	4	3	2.5	5	3	2	2		4
Frustrated*	2	2	2	2	2	1	2	3.5	1	1		4.5
Exhausted*	2	2	2	2	2	2	3	3.5	2	2		4
Lazy*	3	3	3	4	3	2.5	3	2	2	2		2.5
Empowered*	4	4	3	2	4	4	3	2.5	4	4		4
Unique*	3	3	3	3	2	2	3	2.5	3	3		2
Dyslexia as Gift*	3	4	3	3	3	3	2	2	3	3		2
Differently Abled*	2	2	2	2	1	1.5	1	1	2	2		1.5
Work Harder*	1	1	1	1	1	1	1	2.5	1	1		2
Dyslexia Disappear*	2	2	3	2	2	2	3	3	1	1		3.5

Work Performance*	2	2	3	4	2	2	3	3.5	2	2	2.5
Felt Limited*	2	2	2	3	2	2	3	3.5	2	1	3.5
Holding Back*	3	2	4	4	2	2	2	3.5	2	2	2.5

Note. *Indicates that reported data denotes the Median, with a value of 1 indicating strongly agree and 5 strongly disagree.

Table 4

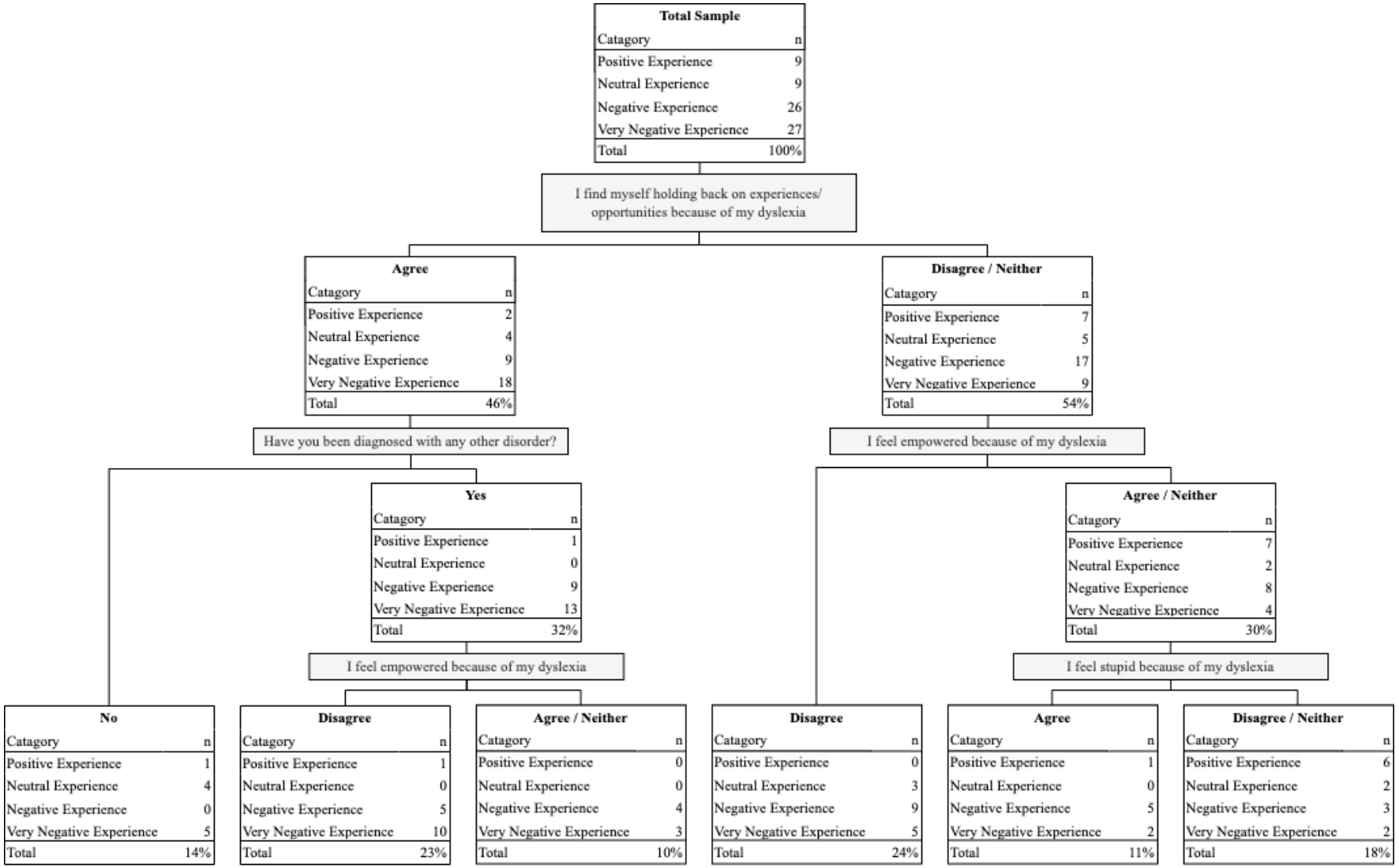
Questions/Statement Shorthand

Questions/ Statements	Rating Scale	Shorthand
What is your perceived severity of reading difficulties?*	1-10, 10 as severe	Perceived Reading Difficulty
Have you been diagnosed with any other disorder?*	Yes/No	Comorbidities
Do you have a family member that is diagnosed with dyslexia or is perceived to have dyslexia?*	Yes/No	Family Member with Dyslexia
Do you consider yourself disabled on a day-to-day basis because of your dyslexia?*	Yes/No	Perception of Self as Disabled
I feel STUPID because of my dyslexia*	Likers-Scale	Stupid
I feel FRUSTRATED because of my dyslexia*	Likers-Scale	Frustrated
I feel EXHAUSTED because of my dyslexia	Likers-Scale	Exhausted
I am told I am LAZY because of my dyslexia*	Likers-Scale	Perceived Laziness
I feel EMPOWERED because of my dyslexia*	Likers-Scale	Empowered
I feel UNIQUE because of my dyslexia	Likers-Scale	Unique
I want people to know that having dyslexia is a gift	Likers-Scale	Dyslexia as a Gift
Having dyslexia doesn't mean you are dumb, but rather smart in a different way	Likers-Scale	Differently Abled
I often feel like I need to work harder than my peers	Likers-Scale	Work Harder
If I could, I would take a pill that would make my dyslexia disappear	Likers-Scale	Dyslexia Disappear
On a daily basis, my dyslexia affects my work in a negative way	Likers-Scale	Work Performance
When choosing a career path, I felt limited because of my dyslexia	Likers-Scale	Felt Limited
I find myself holding back on experiences/ opportunities because of my dyslexia*	Likers-Scale	Holding Back

Note. Likert scales are rated Strongly Agree (1) – Strongly Disagree (5). * Denotes questions included in CART analysis.

Fig.1

Classification and Regression Tree (CART) analysis illustrating the relationship between predictor variables and the overall experience of dyslexia for the early assessed group (<17 years old).



Note. Nodes show the proportion of individuals within each category, highlighting significant predictors and their impact on the overall experience. For this and all subsequent CART analysis, the box at the top of the trees (Node 0) displays the dependent variable, the experience depending on when individuals were diagnosed with dyslexia. The boxes in grey show the predictors. The subsequent nodes, other than node 0, depict the participants' response to the predictor question in the heading. Each node displays the total number of participants in each category on the dependent variable and the percentage of the total sample represented in that node.

Fig.2

Classification and Regression Tree (CART) analysis illustrating the relationship between predictor variables and the overall experience of dyslexia for the Late Assessed Group (≥18 years old)

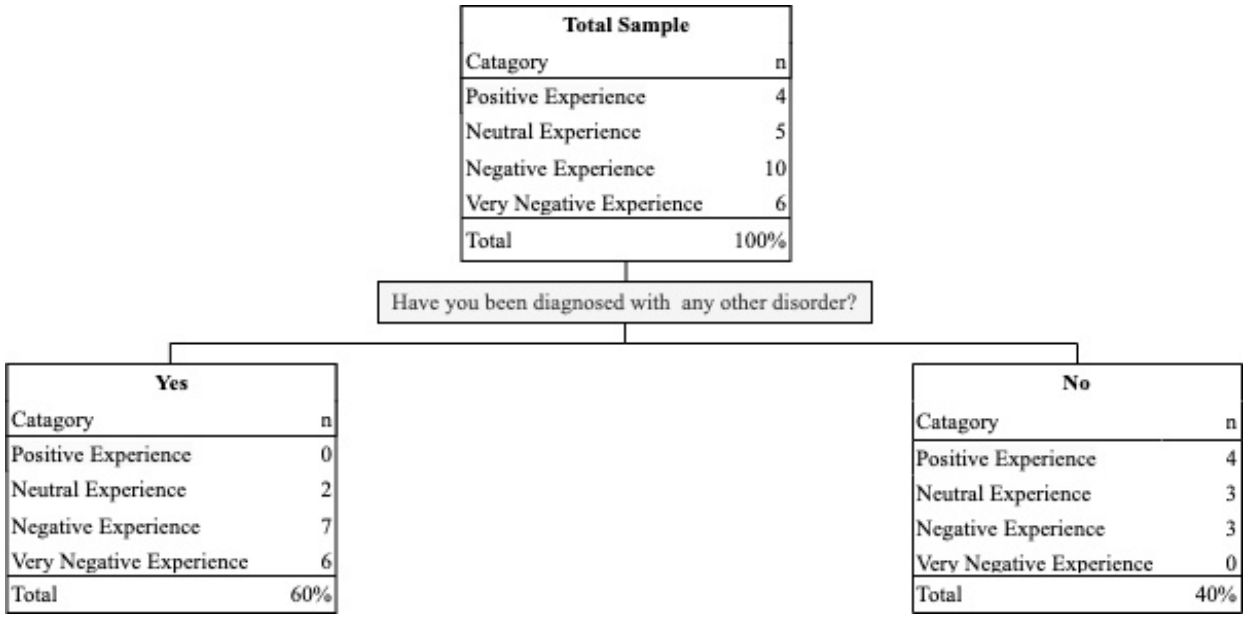
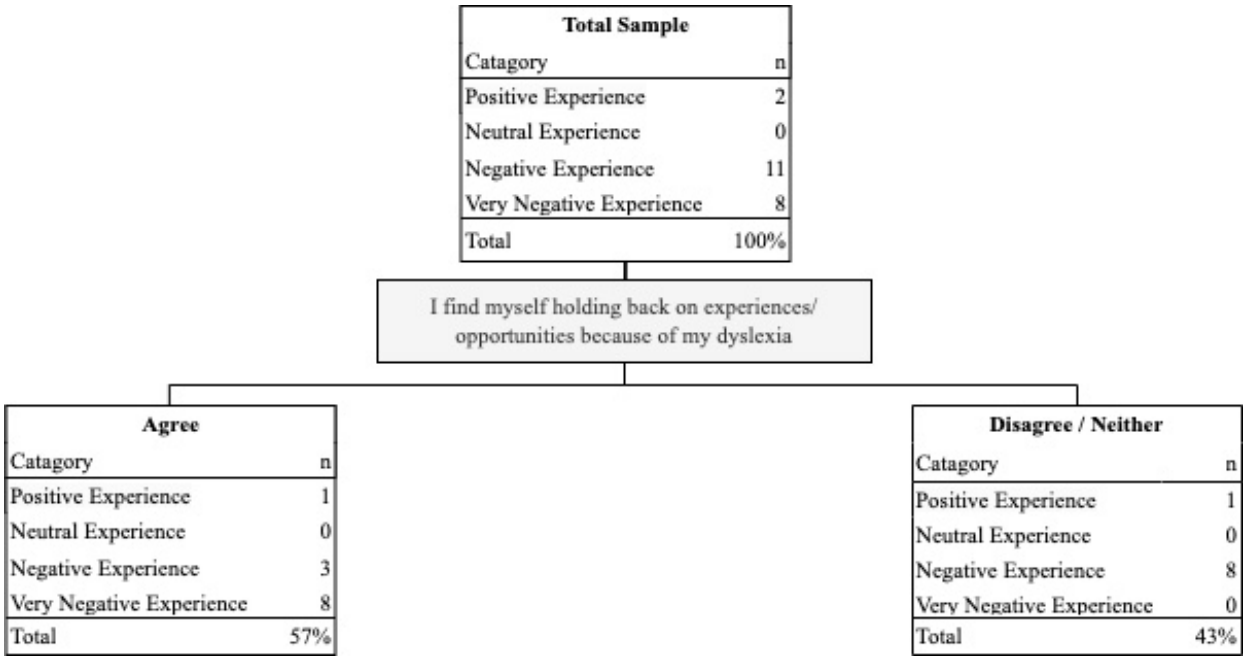


Fig.3

Classification and Regression Tree (CART) analysis illustrating the relationship between predictor variables and the overall experience of dyslexia for the Self-Identifying Group



CHAPTER 4:

STUDY 3

Visual Attention in Adults with Dyslexia: Using the gaze-contingent moving window paradigm

Note: Copy edited version of this study is current under review *Visual Cognition*

Abstract

The gaze-contingent moving window paradigm was established for measuring the perceptual span, defined as the number of orthographic units that can be processed in a single glance by the foveal and parafoveal vision. The aim of this study is to replicate the original case study by Rayner and colleagues (1989) in investigating the perceptual span of individuals with dyslexia. The original study included two experiments using the gaze-contingent moving window paradigm: a case study and subsequent analysis of two individuals with dyslexia. We mirrored the window sizes (to the right of fixation) from the original study and utilized the X mask condition, additionally, we used transparent statistical analysis, and standardized texts. We hypothesized that our sample of individuals with dyslexia would reach asymptote in reading speed when reading under a smaller window condition compared to our control sample. Results from our sample did not find a statistically significant interaction effect across groups and window size, although differences were observed based on visual inspection of plotted data, replicating the results from Rayner and colleagues (1989). Our results are consistent with other replications, finding evidence against a perceptual span deficit in dyslexia in lieu of a possible broader higher-level visual processing deficit.

Keywords: Dyslexia, Reading, Perceptual Span, Gaze-Contingent Moving Window.

Introduction

Researchers that study reading are often interested in testing and exploring the processing of visual orthographic information during an eye fixation. A fixation occurs when the readers eye movements pause, at which point information is acquired, with the duration of fixation having been linked to visual processing time (Rayner, 1998). Fixations are separated by both saccades (eye movements in the rightward direction in English) and regressions (eye movements in the leftward direction in English, when reading in a language whose sentences read from left to right; Franzen et al., 2021; Rayner, 1998). This exploration into the information processed during a fixation has led to the development of multiple overlapping concepts, such as the visual span, visual attention span and perceptual span. These concepts are each accompanied by psychophysiological paradigms designs to test nuance differences in fixation processing (see Frey & Bosse, 2018 for detailed explanation).

Of interest here is the perceptual span defined as the number of letters, or orthographic units, that can be processed in a single glance by the foveal and parafoveal vision (Frey & Bosse, 2018; McConkie & Rayner, 1975; Rayner, 2014). It was later defined as the limited region from which useful information is acquired (Rayner, 2014; Rayner et al., 2010). The perceptual span can be studied using the gaze-contingent moving window paradigm. In this paradigm, the amount of information available when reading is restricted based on a predetermined window size while the surrounding parts are masked, typically by X's. As the reader's gaze moves, the window position is adjusted on the screen using the eye position determined by a high-sample frequency (>500Hz) eye tracker. The perceptual span is then inferred based on the size of the window when the rate is equivalent to the reading rate when reading a full line of text (McConkie & Rayner, 1975; Rayner et al., 2010). This paradigm has face validity, in that participants read a sentence of text (Rayner, 2014). Generally, the accepted perceptual span for an average/ typical reader is asymmetric, with 3-4 characters to the left of fixation, and 14-15 characters to the right of fixation (Frey & Bosse, 2018; McConkie & Rayner, 1975; Rayner, 2014; Rayner et al., 1980).

Of importance to the current paper, the perceptual span can vary in size depending on the demand of cognitive task being conducted. The foveal-load hypothesis stipulates that the perceptual span decreases in size based on the difficulties of what is being processed (Henderson & Ferreira, 1990). Under this hypothesis, the size of the perceptual span is affected by reader

related (linguistic knowledge and age; Rayner, 1986) and text related (word and syntax difficulties; Frey & Bosse, 2018; Henderson & Ferreira, 1990) influences. Other researchers using the moving window paradigm have found that those learning to read (Häikiö et al., 2009; Rayner, 1986), dyslexic readers (Rayner et al., 1989), other neurodiverse individuals (i.e.; Schizophrenia; Whitford et al., 2023) and older readers (Rayner et al., 2009) have smaller perceptual spans compared to typical readers. In the current paper, we focus on dyslexic readers due to observed eye movement differences when compared to non-dyslexic readers (Franzen et al., 2021).

Dyslexia, as we conceptualize it, is multifactorial with no one core deficit (Kristjánsson & Sigurdardottir, 2023). Also referred to as a Specific Learning Disability in reading, dyslexia is categorized by difficulty in either reading, comprehension, spelling, and written expression, lasting over six months despite the provisions of targeted interventions (American Psychiatric Association, 2013). It is a developmental disorder that persists into adulthood, although it may be masked through the development of compensatory strategies or even manifest later in life when academic demands exceed the individual's capacity (American Psychiatric Association, 2013; Livingston et al., 2018). A visual attention deficit of dyslexia has been proposed as a possible explanation for the deficits experienced by individuals with dyslexia (Kristjánsson & Sigurdardottir, 2023). While the phonological deficit theory of dyslexia remains the dominant causal theory, researchers have questioned its causal nature and propose other possible explanations behind dyslexia (Gavril et al., 2021; Premeti et al., 2024; Stein, 2023). Rayner, Henderson and Pollatsek (1989) conducted a case study using the gaze-contingent moving window paradigm on a university professor who identified as having dyslexia. This study used a symmetrical window of 7, 15, 23, and 31 characters (viewing 3, 7, 11, and 15 characters to the right of fixation) and a no window as well as two mask conditions, X's and random letters. In the X conditions, they found that the professor read faster than the control group in the smallest window condition and his reading rate was fastest when only 7 characters to the right of fixation was visible. His reading rate decreased when reading with 11 and 15 visible characters to the right of fixation (Rayner et al., 1989). In the second experiment, two additional individuals with dyslexia were then tested, this time with number of words rather than characters forming the window size. The researchers concluded that these individuals with dyslexia reached asymptote in reading speed with a 2-word window size compared to the control group with a 3-word

window size. They reported this difference to be evidence for a potential subtype of individual with dyslexia who present with visual-spatial deficits and selective attentional deficits marked by a smaller perceptual span (Rayner et al., 1989).

Whitford and colleagues (2023) employed the gaze-contingent moving window paradigm using window sizes 2, 6, 10, and 14 characters to the right of fixation (and a fixed 4 characters leftward of fixation) on 19 individuals with dyslexia and 17 matched controls. They found a statistically significant effect of group and window size, as well as an interaction effect. Both groups had a perceptual span of ~14 characters to the right of fixation. However, they noted that overall reading fluency across window sizes was less impacted for individuals with dyslexia when reading at smaller window sizes compared to the control group (Whitford et al., 2023).

In a recent paper, Luke and colleagues (2024) investigated the causes of dyslexia, hypothesizing different outcomes on reading and visual search tasks using the perceptual span as evidence for underlying deficits. In their reading task, they used the gaze-contingent moving window paradigm with 16 letter characters to the left of fixations and 4, 8, 12, and 16 letters to the right of fixations and a no mask condition. Additionally, they used texts averaging 66.5 words presented on multiple lines from the Natural Stories corpus and the USA Today online archive. The mask used was created by randomly replacing letters with letters of a similar shape, creating nonsense letter strings (see Rayner Henderson & Pollatsek, 1989). Their sample of individuals with dyslexia read slower than the control group on all conditions. They found that the dyslexia group was less affected than the control group when reading in the 4 window condition and was not statistically significant from the no window condition in the 8 window condition, concluding that their sample of individuals with dyslexia has a perceptual span between 4 and 8 characters to the right of fixation, compared to the control group who had a perceptual span of 8 to 12 characters. These results were echoed in the analysis looking at fixation duration and saccade amplitude. One issue with this paper was the lack of texts controlled for length, cognitive content, which may produce differences in reading speed and eye movements (Franzen et al., 2021)

The aim of this study is to replicate the original research study (Rayner et al., 1989) investigating the perceptual span of individuals with dyslexia, using the moving window paradigm with X's as a mask, asymmetric window sizes of 3, 7, 11 and 15 visible characters to the right of fixation, use texts standardized for linguistic content and reading speed, a large

sample of individuals with dyslexia, and both null hypothesis significance testing and Bayesian statistics (Rayner et al., 1989). We hypothesize that our sample of individuals with dyslexia will have a smaller perceptual span compared to our control group. However, we expect the magnitude of this difference to be smaller than the effect outlined by Rayner and colleagues (1989), given that they did not report effect sizes or confidence intervals. Additionally, given the erratic nature of eye movements in this population, we hypothesis that our sample of individuals with dyslexia will make more eye movements and fixate longer when reading compared to the control group (Franzen et al., 2021).

Method

All aspects of this research were conducted in compliance with the regulations outlined by The Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans, as well as The Official Policies of first author's affiliated University, including the Policy for the Ethical Review of Research Involving Human Participants. Informed consent was obtained from the participants after an explanation of the study was given to them. The research protocol was approved by the University's Human Rights Ethics Research Committee (certificate: 30009781).

Participants

The study consisted of 35 adults with dyslexia and 33 adults without dyslexia. The dyslexia group self-identified as having dyslexia. Participants were therefore not required to present proof of a formal diagnosis. All control participants scored below 40 on the Dyslexia Adult Checklist (see below). Participants in both groups were required to be above the age of 18 and speak English fluently. Both groups were recruited through Concordia's Psychology Participant Pool for undergraduate students to receive extra credit. The dyslexia group was also recruited through various means including social media advertisements, flyers, and a list of previous participants from past research studies. All participants received $30 or two credits for their time. Data were collected in Montreal, Canada in the Concordia Vision Lab as part of a multi-experiment study.

Initial test sample was comprised of 78 participants, 43 controls and 35 individuals with dyslexia. A total of five control participants were excluded from analysis as they self-identified as having dyslexia and three scored above 40 in the adult dyslexia checklist. An additional two controls were removed due to poor eye tracking calibration. See Table 1 and 2 for participants demographics (see OSF repository for language demographics).

A priori analysis was conducted using G*Power3.1. Using a Fixed effects ANOVA, an effect size of 0.64 and an alpha of 0.05, 2 groups and 5 conditions, and it was found that a total sample size of 51 is needed to detect a group difference, should a difference of that magnitude exist. A minimum effect size of interest of 0.64 was used in the calculation based on a η_p^2 value of 0.29 reported by Rayner, Slattery and Belanger (2010).

Stimuli and Apparatus

Stimuli were presented on the Eyelink 1000 SR Research (Eyelink 1000, SR Research, Ottawa, Ontario). Participants were tested individually in a standardized environment. The Minnesota Read sentences (MN read) were used as the stimulus for both experimental paradigms. Each sentence is comprised of 60 characters including spaces and are written at the second and third grade level (Mansfield et al., 2019). MNREAD sentences are made up of 10-15 words per sentence. For our purposes, we used sentences from MNREAD extended sentence corpus, pulling equally from templates 1 through 14, counterbalanced (Mansfield et al., 2019; see data file in OSF repository). All trials were presented in a fixed width font to control for the size of the region of interest.

Stimuli were presented and data collected using an iMac (2011 2700 i7, 16GB RAM) with an external monitor to present the stimuli. Participants viewed stimuli on a linearized video monitor (View Sonic G225fb 2100 CRT, 1024 × 768-pixel resolution, 100-Hz refresh rate). A chin rest was used to stabilize head position at a distance of 70 cm from the screen. Eye position was acquired remotely using a video-based eye movement monitor (Eyelink 1000, SR Research, Ottawa, Ontario) using a binocular setup with the sampling rate set to 1000Hz. Calibration used a standard series of 9 dots across the screen, with participants needing an accuracy of <0.5° on average, with no point exceeding 1.3°.

A gaze contingent moving window paradigm was constructed in Experiment Builder (ver. 2.5.1, SR Research, Ottawa, Ontario), following the procedure laid out by Rayner (2014; also see McConkie & Rayner, 1975). Participants were presented with one sentence at a time with 3, 7, 11 and 15 visible characters to the right of fixation as well as a no window condition. Here, window sizes were masked using X's. In all conditions, there was a constant of 4 characters to the left of fixation, apart from the no window condition. A total of 122 trials were created for the purpose of this study, including 2 test trials. Each participant completed a total of 61 trials, including 1 practice trial. Trials where counterbalance so that each participant

completed the same condition 14 times, except for the no window condition, based on results from pilot testing. Participants were able to take a break after viewing the first 31 trials, at which point they underwent the calibration process once more. Attention questions were asked for 30% of trials, in which participants where asked if they saw a target word in the prior sentence. They used the keyboard to indicate *yes* or *no* by pressing 1 or 2 respectively.

Measures

Two subsets of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 2008), symbol search and coding, were used as measures of processing speed. The WAIS has an inter-scorer agreement coefficient that ranges from 0.98–0.99, and an intra-class correlation ranging from 0.91–0.97. Its internal consistency coefficient on the processing speed index tasks ranges from 0.87–0.98 (Canivez, 2010). Correlations between scores on tests that measure similar constructs were in the 0.80 range on criterion-related validity measures (Schraw, 2010).

Phonological processing and manipulation were measured using two subtests of the York Adult Assessment Battery-Revised (YAA-R; Warmington et al., 2013), spoonerisms and rapid automatized naming (RAN; digit and object subtests) tasks. To our knowledge, at the time of publication, there are no reliability coefficients derived for this tool.

A questionnaire was administered to participants that included demographic questions, the Adult Dyslexia Checklist (Smythe & Everatt, 2001) and the ADHD self-report scale symptom checklist (ASRS-vI.I; Kessler et al., 2005). Previous research has found the Adult Dyslexia Checklist to be valid (Cronbach's α=0.86), and reliable (sensitivity=91.5%, specificity=80%) using a cutoff score of 40 (Stark et al., 2025). In their cardinal manuscript, Kessler and colleagues (2005) found the six-question ASRS screener to have a sensitivity of 68.7% and specificity of 99.5% with a total classification accuracy of 97.9%.

Procedure

Tasks were counterbalanced to avoid order effects. After providing consent, participants began by completing the gaze contingent moving window or a second eye tracking tasks. In the gaze contingent moving window task participants were calibrated on the EyeLink 1000. Participants were given a break halfway through the task, after which calibration was repeated. A fixation point was presented halfway down the screen, on the left-hand side, where the beginning of each sentence would be presented. Participants were to fixate on this point and press the spacebar, at which point the stimuli (i.e., sentence) would appear. Attention questions were asked

for a set number of trials with the aim of incentivizing participants to read each sentence for comprehension. Participants responded to the questions by pressing one for “yes” or two for “no”. A total of 61 trials were presented.

Participants also completed WAIS tasks and the YAA-R tasks in a counterbalanced order, between eye tracking tasks. All participants first completed the symbol search task, followed by the coding task when administering the WAIS tasks. Similarly, participants first complete the RAN task, followed by the spoonerisms task for the YAA-R. Participants completed the study by filling out the questionnaire. In total, the study lasted approximately an hour and a half.

Eye-movement Data Processing

Fixations and saccades were recorded at a sample rate of 1,000 Hz and stored for offline analysis with Data Viewer (version 3.1.97, SR Research, 2017, Ottawa, Ontario) and R (R Core Team, 2021). We set the minimum fixation duration threshold to 10 ms, and the minimum saccade amplitude to 0.1°. We excluded 20 ms before and after a blink and any beyond the bounds of the stimulus display and before the start of the trial. These analysis parameters help to remove outliers caused by random eye movements unrelated to reading. All fixations were drift corrected by the drift value obtained at the start of each trial. A trail threshold of 5 fixations was established, in that trails which less then 5 fixations were excluded from the analysis. The initial offline analysis was conducted in DataViewer where a trial report was exported.

Statistical Analysis

All data was analysed using Bayes factors as well as effect size measures. In doing so, we were able to identify the strength of evidence for the null hypotheses and research hypothesis, while also using traditional null hypothesis significance testing. Data and additional tables and figures are available from the project's OSF repository.

A total of 19 trials (i.e., sentences) were excluded in the final eye movement analysis across all participants ($n_{control} = 33$, $n_{dyslexia} = 35$). Final trial count was 4182 trials. The data was inspected, there were no missing values, and sample cases were taken independently of one another. Given the wide range and severity of symptoms seen in dyslexia, no univariate outliers were removed from the analysis. Both visual inspection of Q-Q plots and Levene’s test of equality of variances indicate a violation of homogeneity of variance. Shapiro-Wilk tests of normality as well as skewness and kurtosis values calculated for each independent variable per

group, suggesting a deviation from normality (see table in OSF repository). Partial Eta squared effect size was therefore calculated as it is a less biased measure of effect size. Bayes factors were also computed to interpret the relative strength of the null hypothesis as compared to the alternative hypothesis (Dienes, 2011), using the JASP default Cauchy prior width of 0.7, as other values only have minimal impact on the results (van den Bergh et al., 2020). A post hoc bootstrapped comparisons using a Bonferroni correction was used to further identify differences in windows sizes across groups.

A total of five 2X5 independent sample multifactorial ANOVAs were conducted for reading speed, fixation duration, fixation and saccade count and saccade amplitude, comparing results across groups, individuals with dyslexia and control, across the five window sizes. Reading speed was measured in words per minute (wpm) and used as an estimate of perceptual span (McConkie & Rayner, 1975; Whitford et al., 2023). For descriptive statistics see Table 3.

Results

Reading Speed

A two-way ANOVA was used to examine the effect of groups and window size on reading speed measured in wpm. We found a statistically significant main effects for both group and window size with small effect sizes ($\eta_p^2 = 0.04$, $\eta_p^2 = 0.06$ respectively). This suggests that there is a statistically significant difference in reading speed between individuals with and without dyslexia irrespective of window size, and a statistically significant difference in reading speed between window sizes irrespective of group. An interaction effect between group and window size on reading speed was found, despite its trivial effect size ($\eta_p^2 = 0.004$; see Table 4). Post Hoc comparisons using a bootstrapped Bonferroni correction showed that the control group read more wpm across all window sizes compared to the dyslexia group (see Table 5).

Further exploring the interaction, relative to the no window condition, individuals with dyslexia's reading rates were statistically significant in only the 3-character condition (138 vs. 163 wpm; $t = -3.01$, $d = -0.285$ [-0.593, 0.024], $p = 0.039$). A similar pattern was found for the control group, in that the only statistically significant difference found was of the 3- character condition (163 vs. 207 wpm; $t = -5.05$, $d = -0.495$ [-0.816, -0.174], $p < 0.001$). A visual presentation of the perceptual span is presented in Figure 1 and 2.

We plotted our research finding using a means-based line graph with window size on the X-axis and reading rate in WPM on the Y-axis, mirroring the original research figures within

McConkie and Rayner (1975) and Rayner, Murphy, Henderson and Pollatsek (1987). With the aim of further understanding our research findings and reflecting current best practices of presenting individual data points (Ho et al., 2019), we also generated a Cumming estimation plot with raw data plotted on the upper axes; each mean difference is plotted on the lower axes as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars (Moving beyond P values, 2019). As data were bootstrapped, the effect size measures are expected to be slightly different from the first analysis due to sampling variability. This way of presenting our findings provides further transparency into the distribution of our data, allowing for greater interpretation of findings.

We observed that compared to controls, the dyslexia group's reading rate was less impacted (compared to the no window condition) by the 3-character (25 vs. 44 wpm), and 15-character (11 vs. 23 wpm) window conditions. Conversely, the control group was less impacted by the 7-character (6 vs. 4wpm), 11-character (23 vs. 21wpm) window conditions.

Eye Movements

There were statistically significant main effects for both group and window size with small to moderate effect sizes on all four independent variables: fixation duration, fixation count, saccade amplitude and saccade count. No statistically significant interaction effects were found between group and window size (see Table 4). Visual inspection of the data and the results of Post Hoc comparisons using a bootstrapped Bonferroni correction showed that individuals with dyslexia made more fixations compared to the control group across all window sizes as indicated by small to median effect sizes, however no statistically significant differences were found during the no window condition (d=-0.34). As for the duration of these fixations, a statistically significant difference between groups were found for the 3-window size condition (d=-0.25), in that individuals with dyslexia made statistically significantly more fixations compared to controls when reading in the smallest window condition. Additionally, individuals with dyslexia made statistically significantly more saccades in the 7- (d=-0.27) and 15- (d=-0.33) window size conditions and longer saccade amplitude when reading in the 15- (d=0.29) window size condition compared to the control group (see Table 5).

Discussion

To our knowledge, three studies have investigated the perceptual span of individuals with dyslexia using the gaze-contingent moving window paradigm, outlined above, with the most recent study investigating this topic concurrently with our own investigations. This study aimed to replicate the original case study by Rayner, Henderson and Pollatsek (1989) with a larger sample size, transparent statistical analysis and standardized texts. Here, we mirrored the window sizes (to the right of fixation) from the original study and utilized the X mask condition.

Through visual inspection of the Cumming Estimation Plot (Figure 2) as well as measures of skewness, it is apparent that the distribution of both groups are non-normally distributed. This is to be expected given the nature of reading speed data (Brysbaert, 2019; Franzen et al., 2021). Furthermore, beyond the previous ANOVAs which use the mean as central tendency and require normally distributed data, there is no adequate method that allows for between group comparisons across multiple conditions without the introduction of multiple comparisons, adding additional statistical limitation. This high degree of skewness and distribution differences between groups could account for the lack of statistically significant differences between window sizes across conditions, as well as the substantive evidence for the null hypothesis, per the bayes factor.

On average, our sample of control individuals experienced its highest reading rate when reading in the 15-window condition (230wpm). That said, the differences between the 11- and 15-window conditions (228 vs. 230wpm) are not statistically significant. While the difference between the 15- and no window condition (207 vs. 230wpm) are also not statistically significant, and our control readers did not reach an asymptote in mean reading speed as reported in the original study by Rayner, Henderson and Pollatsek (1989), our sample did experience a greater reading rate with increased window size, marked by a perceptual span of 15-characters to the right of fixation. It should be noted that our control sample's reading rate in the no-window condition is within the average reading range for adults reading non-fiction (175–300 wpm) and just below the average reading rate of 238 wpm(vs. 230 wpm), which speaks to the generalizability of our findings (Brysbaert, 2019).

As for individuals with dyslexia, Rayner, Henderson and Pollatsek (1989) observed that their subject with dyslexia reach an apex in mean reading rate when reading with a window size of 15 characters, 7 characters to the right of fixation. Conversely, their control sample

experienced increased reading rates at the larger window sizes, with confidence intervals and effect sizes not provided. Simply looking at mean reading rates, our sample of individuals with dyslexia experienced an increased mean reading rate when reading in the 11-character window size (*m* = 186 wpm), while our control group's reading rate reached its peak with a 15-character window size (*m* = 230 wpm), with both samples decreasing in the no window condition. In both experiments, individuals with dyslexia experience a deteriorating performance with increased window sizes. In the second experiment with word-windows, Rayner, Henderson and Pollatsek (1989) introduced a comparison with two other individuals with dyslexia. They found that these individuals with dyslexia reached asymptote at a two-word window size compared to the control at a 3-word window size. Conversely, the subject from the second study experienced an apex in reading rate at in the 2-word condition and deterioration in performance in the 3-word and no window conditions (Rayner et al., 1989). In our case, both our control and dyslexia samples experienced an apex in reading rate with a decreased reading rate with increased available parafoveal information. Our observed pattern stands in contrast with this original result. Rayner (2014) touches on this point, explaining that for some readers asymptote is not reached and that reading may be faster in the 15-letter condition compare to a no window condition (see Veldre & Andrews, 2014). Another hypothesis is that the use of the Xs at larger window size allows for more accurate and better targeted eye movements (Luke et al., 2024; Rayner et al., 1989).

The most recent investigation into the perceptual span in individuals with dyslexia by Luke and colleagues (2024) reported equivocal evidence for a smaller perceptual span in individuals with dyslexia. Of note, Luke and colleagues' (2024) study differs fundamentally from the present study in a few ways. Firstly, they opted to use a window size of 16 characters to the left of fixation, compared to the generally accepted 4 characters used in this study. Additionally, Luke and colleagues (2024) used a random letter mask of non-sense words compared to the X's used in the present study. In the original study, differences were not observed when using the random letter, in that there was no difference in reading performance across window size in the random letter condition for the individual with dyslexia (Rayner et al., 1989). Rayner and colleagues (1989) explain that the random letter condition appeared to interfere with word identification and that the X condition provided readers with a clearer demarcation, allowing for better-targeted eye movements in the rightward direction. The lack of demarcation when using random letters as a mask could explain the statistically significant difference in saccade

amplitude and fixation duration witnessed by Luke and colleagues (2024) across window sizes, compared to the findings seen here.

When comparing eye movement differences, Rayner, Henderson and Pollatsek (1989) reported means across window sizes for their individuals with dyslexia and control sample. No other statistics were reported. Mean differences were calculated for comparison purposes, although interpretations should be made with caution. Looking at forward fixation count, the mean difference between Rayner Henderson and Pollatsek's (1989) control group and their sample of individuals with dyslexia range from -0.01 (3 window condition) to -1.4 (15 window condition). Conversely, the mean differences in our sample range from -3.01 (3 window condition) to -4.62 (15 window condition), both differences being statistically significant. In the 15-character condition our sample's average reading speed was 174 wpm and 163 wpm in the no window condition. Our results are comparable with the reported finding from Franzen and colleagues (2021) who reported an average reading rate of 171 wpm (SD=38.37) for their sample of individuals with dyslexia.

As for fixation duration, Rayner, Henderson and Pollatsek's (1989) individuals with dyslexia had a shorter fixation duration, compared to control, when reading in the 5- and 7-window condition, and a longer fixation duration when reading in the 11- and 15- window size conditions. Conversely, our sample of individuals with dyslexia had, on average, longer fixations across all conditions compared to our control group. These differences in eye movements, taken together with reading speed comparisons, within and between the experiments, gives way to inconsistencies. One possible explanation for this, can be that the individual with dyslexia used in this original case study is not representative of *all* individuals with dyslexia. Further, Kristjánsson and Sigurdardottir (2023) describe dyslexia as multifactorial, with many underlying and contributing causes which differ across individuals and with a spectrum of severity. For this reason, dyslexia researchers should not use a case study format (Kristjánsson & Sigurdardottir, 2023).

A second study employing the gaze-contingence moving window paradigm, found both dyslexia and control groups to have a perceptual span of ~14 characters to the right of fixation. Similar to our findings, they found both window size and group effects as well as and interaction effect for reading rate. They noted that individuals with dyslexia experienced slower reading rates compared to the control group irrespective of window size, except when reading in the

smallest window condition. Whitford and colleagues (2023) explain that in their sample, overall reading fluency across window sizes (compared to the no window condition) was less impacted for individuals with dyslexia when reading at smaller window sizes compared to the control group. This was the case on the 2- (51 vs. 84 wpm), 6- (16 vs. 30 wpm) and 10-character conditions (8 vs. 23 wpm) but not the 14-character condition. Comparatively, we found our dyslexia group's reading rate to be less impacted by the 3-character (25 vs. 44 wpm), and 15-character (11 vs. 23 wpm) window conditions while our control group was less impacted by the 7-character (6 vs. 4 wpm) and 11-character (23 vs. 21wpm) window conditions. Lastly, Whitford and colleagues (2023) reported statistically significant differences in reading rates on the 2-, 6- and 10-characters conditions for both their dyslexia and control groups, concluding that both groups' perceptual spans were ~14 characters rightward of fixation, as reading rates were not reduced at that window size. Conversely, we only found statistically significant differences for the 3- character conditions, for both our dyslexia and control groups.

As for eye movements, Whitford and colleagues (2023) reported eye movement differences between their control and dyslexia group for their no-window condition only. They found statistically significant differences between groups on forward saccade length, number of fixations and number of regressions. They did not find statistically significant differences between groups in on forward fixation duration, concluding that their sample of individuals with dyslexia displayed robust oculomotor markers during normal reading (Whitford et al., 2023). In our sample, we found statistically significant main effects of group for fixations and saccades count as well as greater fixation duration and saccades amplitude, compared to our control group, while controlling for window size. That said, further investigation into these effects via post hoc comparisons (Table 5) and visual inspection of the data (Figure 2), indicate no statistically significant differences between groups in the no window condition. Our findings stand in contrast with past investigations into the eye movement differences in individuals with dyslexia (Franzen et al., 2021), who observed difference on longer standardized texts (IReST). It therefore would be interesting for future researchers to use progressively longer texts with the gaze contingent window paradigm, to see how the length of text impacts dyslexic readers.

Research studies on this topic lends evidence against a smaller perceptual span for individuals with dyslexia (Luke et al., 2024; Whitford et al., 2023). Rather, it is possible that individuals with dyslexia may experience a broader higher level visual processing deficit, in that

they are less able to take advantage of parafoveal information that is otherwise available to them (Luke et al., 2024). Should this be the case, such a deficit could possibly result in a smaller perceptual span as evidenced in the original findings by Rayner and colleagues (1989) as well as in the primary analysis by Luke and colleagues (2024), but not result in an overall trend as indicated by the otherwise null results. Knowledge of the perceptual span of individual with dyslexia can serve to further substantiate claims for a visual attention deficit in individuals with dyslexia. Findings of a smaller perceptual span reflect the increase in cognitive strain and visual fatigue faced by individuals with dyslexia. Formulizing this difference in the perceptual span could be seen as evidence equating to performance deficits in school and the workplace. Additionally, the findings from the proposed research study will help in the development of (early) intervention activities which are known to improve perceptual span, thus improving reading speed and comprehension.

In sum, the stated aim of this study was to replicate the original experiment by Rayner and colleagues (1989) in investigating the perceptual span of individuals with dyslexia. Looking at Figure 1, one can conclude differences in perceptual span between our control and dyslexia group, whereby individuals with dyslexia's perceptual span would be 11-characters and the control group 15-characters to the right of fixation. That said, we did not find statistically significant evidence to back up these claims, using both traditional null hypothesis significance testing and Bayesian statistics. The lack of statistical evidence could be, at least in part, accounted for by the distribution of our results. Further plotting of our findings (see Figure 2) indicate that the eye movements are non-normally distributed, findings that are consistent with previous research (Brysbaert, 2019; Franzen et al., 2021). Future research into the perceptual span of individuals with dyslexia should assess and contrast this method with other measures of visual attention (Frey & Bosse, 2018; Kristjánsson & Sigurdardottir, 2023), as well as vary the length of the text used (Franzen et al., 2021). Additionally, research exploring a higher-level visual processing deficit is needed to better understand how individuals with dyslexia are processing parafoveal information.

Tables and Figures

Table 1.

Sample Demographics

	Dyslexia	Control
	n=35	n=34
Age*	25.37	23.68
Gender		
# of Cis Male	12	9
# of Cis Female	21	24
# of Other	2	0
Sex		
# of Male	12	9
# of Female	23	24
Number of spoken languages*	2.37	2.71
Level of Education*	2.63	2.73
Age of diagnosis*	13.76	
Self-reported comorbidity (% yes)	60%	18%
Dyslexia Adult Checklist*	52.03(10.29)	31.76(3.20)
# of participants above cut-off		
ASRS-vI.I*	3.71(1.58)	1.88(1.60)
# of participants above cut-off	21	5
Spoonerisms	5.90(4.20)	3.72(1.89)
Rapid Automatized Naming (words per second)		
Digit	2.41(0.60)	2.95(0.62)
Object	1.63(0.28)	1.85(0.30)
Processing Speed		
Symbol Search	10.83	11.09
Coding	10.31	11.62

Note. *Indicates that a mean was calculated for that row; Processing Speed (Symbol Search and Coding subtests of the WAIS-IV) are measured in standardized scores based on age. Values in brackets indicate the standard deviation. For level of education, question inquired about highest level of education completed coded as; 1=Primary/Elementary, 2=Secondary/High School, 3=College/University/Undergraduate, 4=Graduate Degree.

Table 2.

Sample Demographics: Part 2

	Dyslexia n=35		Control n=34	
	n	%	n	%
Individuals with a Comorbidity	21	60	6	18
1 Comorbidity	12	34	2	6
2 Comorbidity	5	14	3	9
3 Comorbidity	4	11	1	3
Learning Disability				
In Math	1	3	0	0
In Writing	7	20	0	0
Other	1	3	0	0
ADHD/ADD	15	43	2	6
Anxiety	5	14	4	12
Depression	2	6	3	9
Bipolar Type I or II	1	3	0	0
Autism Spectrum Disorder	1	3	0	0
Personality Disorder	1	3	1	3
PTSD	0	0	1	3

Table 3.

Descriptive Table

Window Size	N	WPM		Fixation Count		Fixation Duration		Saccade Count		Saccade Amplitude	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control											
3	475	163.13	70.03	17.89	9.84	235.69	38.44	19.49	12.70	2.97	0.91
7	475	210.89	96.93	14.96	7.06	215.22	38.39	15.96	8.70	3.54	1.09
11	472	227.92	105.79	15.17	14.68	212.28	40.02	16.49	23.00	3.69	0.99
15	473	230.15	114.29	14.01	7.62	212.31	48.56	15.11	9.97	3.79	1.08
No Window	133	206.95	88.08	13.26	5.89	195.36	29.85	15.15	9.14	4.42	1.19
Dyslexia											
3	501	137.69	59.40	20.90	11.32	245.29	40.90	22.01	12.41	2.94	1.09
7	503	168.66	77.51	18.88	10.94	222.44	32.71	19.76	12.47	3.36	1.11
11	504	185.70	90.59	18.59	12.95	219.95	34.35	19.36	15.21	3.49	1.04
15	502	174.01	87.56	18.66	12.50	221.32	32.79	19.74	14.95	3.47	1.06
No Window	144	162.90	70.96	17.00	9.04	208.78	28.31	18.80	11.30	4.19	1.37

Table 4.

2x5 Independent Samples ANOVA

	Sum of Squares	df	Mean Square	F	p	η^2_p	BF_{10}
WPM							
Group	$1.430\times10^{+6}$	1	$1.430\times10^{+6}$	182.365	< .001	0.042	5.875×10^{-47}
Window Size	$1.919\times10^{+6}$	4	479676.792	61.186	< .001	0.055	6.421×10^{-48}
Group ✻ Window Size	115788.648	4	28947.162	3.692	0.005	0.004	0.354
Residuals	$3.271\times10^{+7}$	4172	7839.598				
Fixation Count							
Group	6791.969	4	1697.992	14.127	< .001	0.013	1.902×10^{-8}
Window Size	11391.651	1	11391.651	94.773	< .001	0.022	2.306×10^{-25}
Group ✻ Window Size	360.724	4	90.181	0.75	0.558	7.188×10^{-4}	0.001
Residuals	501469.837	4172	120.199				
Average Fixation Duration							
Group	71315.887	1	71315.887	49.553	< .001	0.012	8.422×10^{-70}
Window Size	512666.521	4	128166.63	89.055	< .001	0.079	4.269×10^{-11}
Group ✻ Window Size	2551.149	4	637.787	0.443	0.777	4.247×10^{-4}	6.982×10^{-4}
Residuals	$6.004\times10^{+6}$	4172	1439.186				
Saccade Count							
Group	9885.362	1	9885.362	50.238	< .001	0.012	1.734×10^{-4}
Window Size	7381.605	4	1845.401	9.378	< .001	0.009	5.671×10^{-13}
Group ✻ Window Size	664.397	4	166.099	0.844	0.497	8.087×10^{-4}	0.002
Residuals	820927.374	4172	196.771				
Average Saccade Amplitude							
Group	30.038	1	30.038	26.517	< .001	0.006	9.281×10^{-84}
Window Size	488.329	4	122.082	107.775	< .001	0.094	4.044×10^{-6}
Group ✻ Window Size	9.431	4	2.358	2.081	0.081	0.002	0.017
Residuals	4725.826	4172	1.133				

Note. Type III Sum of Squares

Table 5.

Bootstrapped Post Hoc Comparisons – Window Size * Group

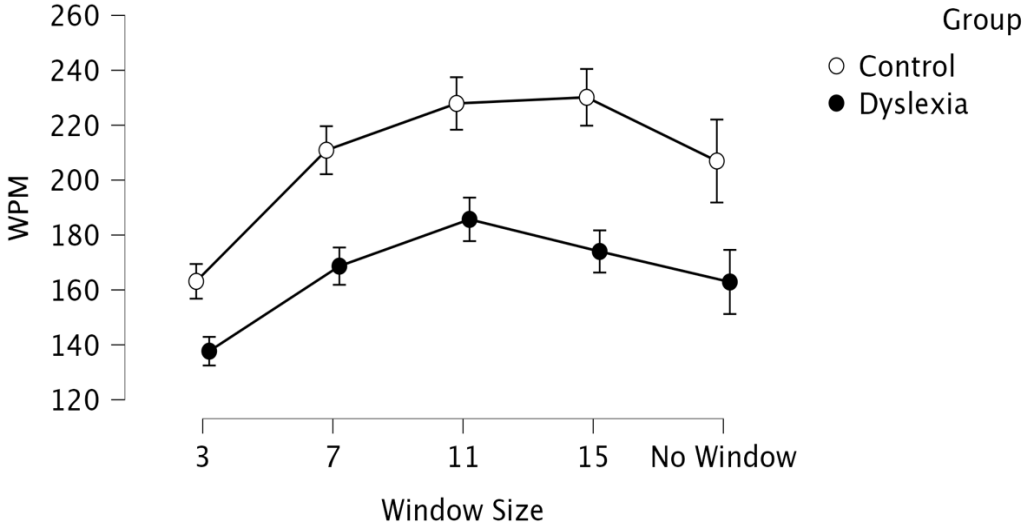
Window Size	Mean Difference	SE	bias	t	Cohen's d	Lower	Upper	p_{bonf}
Fixation Count								
3	-3.008	0.688	0.012	-4.298	-0.28	-0.484	-0.066	< .001
7	-3.951	0.587	-0.023	-5.587	-0.36	-0.567	-0.148	< .001
11	-3.463	0.9	-0.011	-4.872	-0.31	-0.521	-0.103	< .001
15	-4.621	0.653	0.006	-6.617	-0.42	-0.634	-0.214	< .001
No Window	-3.741	0.886	-0.023	-2.84	-0.34	-0.734	0.051	0.204
Fixation Duration								
3	-9.668	2.485	0.014	-3.953	-0.25	-0.462	-0.044	0.004
7	-7.242	2.273	-0.037	-2.975	-0.19	-0.399	0.019	0.133
11	-7.644	2.346	-0.04	-3.157	-0.20	-0.411	0.007	0.072
15	-9.031	2.672	0.105	-3.706	-0.24	-0.447	-0.028	0.01
No Window	-13.249	3.406	0.056	-2.94	-0.35	-0.746	0.039	0.149
Saccade Count								
3	-2.567	0.8	-0.034	-2.809	-0.18	-0.389	0.029	0.225
7	-3.743	0.679	0.016	-4.224	-0.27	-0.479	-0.061	0.001
11	-3.058	1.209	-0.074	-3.194	-0.21	-0.414	0.005	0.064
15	-4.591	0.791	0.032	-5.157	-0.33	-0.54	-0.121	< .001
No Window	-3.657	1.281	-0.041	-2.163	-0.26	-0.653	0.132	1
Saccade Amplitude								
3	0.04	0.067	8.365×10^{-4}	0.572	0.04	-0.172	0.246	1
7	0.179	0.068	0.003	2.593	0.17	-0.043	0.375	0.43
11	0.201	0.066	-94.78	2.961	0.19	-0.019	0.399	0.139
15	0.312	0.068	-0.001	4.589	0.29	0.085	0.503	< .001
No Window	0.243	0.16	0.004	1.817	0.22	-0.174	0.611	1
WPM								
3	25.595	4.084	0.002	4.486	0.29	0.078	0.496	< .001
7	42.309	5.531	0.154	7.454	0.48	0.267	0.686	< .001
11	42.061	6.313	-0.209	7.445	0.48	0.267	0.687	< .001
15	56.163	6.547	0.317	9.895	0.63	0.424	0.844	< .001
No Window	43.363	9.735	-0.051	4.137	0.50	0.105	0.89	0.002

Note. Bias corrected accelerated. Bootstrapping based on 1000 successful replicates. Mean Difference estimate is based on the median of the bootstrap distribution. P-value and confidence intervals adjusted for comparing a family

of 10 estimates (confidence intervals corrected using the tukey method). Some confidence intervals could not be computed. Possibly too few bootstrap replicates. Defined significance at the <0.05.

Figure 1.

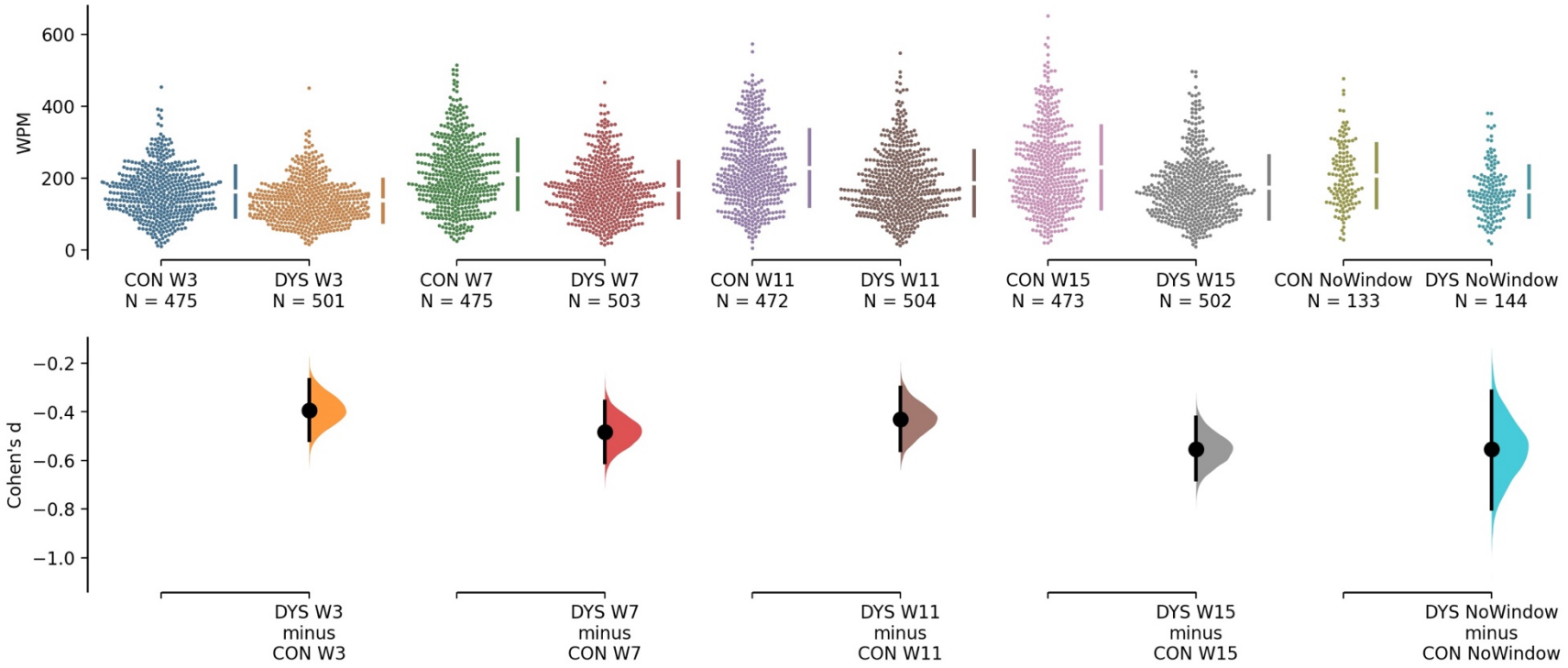
Means Reading Speed Across Window Sizes by Group



Note. Error bars about means are 95% confidence intervals.

Figure 2.

Cumming Estimation Plot of Reading Speed Across Window Sizes by Group



Note. The Cohen's d for 5 comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each mean difference is plotted on the lower axes as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars. CON=Control group. DYS=Dyslexia group. W=Window Size.

CHAPTER 5:

STUDY 4

Investigating spatial and sequential letter reversals in adults with dyslexia: a psychophysiological approach using the oddball paradigm

Note: Copy edited version of this study is current under review in *Dyslexia*

Abstract

Flipping a letter in space, such as *b* and *d*, termed spatial reversals and sequential reversals, changing the sequence of letters in a word such as *weird* and *wried,* are frequently reported by individuals with dyslexia, as well as those without. In this study, we hypothesized that adults with dyslexia, compared to controls, would make more errors and take longer to recognize letter/word manipulations that implement spatial and sequential reversals. We used an oddball paradigm with six conditions: three conditions use spatial reversals in single-letter stimuli and three conditions investigated sequential reversals in five-letter arrays of words and non-words. A signal detection analysis was conducted for accuracy of responses, across conditions for individuals with and without dyslexia. Two-tailed permutation t-tests were conducted to investigate group differences on reaction time data accompanied by plotted bootstrapped shift functions. We observed differences in the strategies used between our sample of individuals with and without dyslexia. Additionally, group differences were found for accuracy on tasks investigating sequential reversals but not spatial reversals where the control participants outperformed our sample of individuals with dyslexia. The impact of context-based cues and the potential role of cognitive-linguistic and visual crowding effects are considered when interpreting the results.

Keywords: Adult Dyslexia, Oddball, Letter Reversals, Sequential Reversals, Spatial Reversals

Introduction

A diagnosis of a learning difficulty tends to be associated with a simplified symptom. These simplified associations often persist in popular culture, regardless of their scientific accuracy. In the case of dyslexia, many laypeople consider letter flipping or reversals to be its defining symptom, with letter reversals referring to the spatial reorientation of letters. In the Latin alphabet, letter reversals can occur in the left/right orientation (i.e., 'b' and 'd') or in the up/down orientation (i.e., 'b' and 'p'; Berent & Platt, 2021; Daniel et al., 2024; Mindell, 1978). Scientifically speaking, difficulties associated with dyslexia have been linked to a variety of factors including but not limited to; visual perception, phonemic awareness, attention and working memory, morphological processing, and text comprehension (American Psychiatric Association, 2013; Kristjánsson & Sigurdardottir, 2023; Lyon et al., 2003; Odegard et al., 2024). Berent and Platt (2021) attribute this quick and dirty association between dyslexia and letter reversals by lay people to their understanding of dyslexia as innate, hereditary and residing in the body, in this case, the visual system. Causal myths and misconceptions, as well as simplification about dyslexia symptomatology, underestimate the complexities of human behaviour, cognition and the role of genotype (Macdonald et al., 2017). Now rejected as a causal explanation of dyslexia, Orton (1925 as cited by Macdonald et al., 2017) first theorized dyslexia as being caused by *strephosymbolia* or *twisted symbols*, noting that the children he was working with tended to reverse letter characters (spatial letter reversals: i.e., 'b' and 'd') and write letters in the wrong order (sequential letter reversals, i.e., 'skate' and 'stake'; Helland, 2022). Patrons of the phonological deficit as the primary causal theory of dyslexia highlight letter reversals as commonplace in literacy acquisition in both individuals with dyslexia and typical reading children alike (Macdonald et al., 2017). Macdonald and colleagues (2017) briefly note that persistent letter reversals are a consequence of poor reading that may be linked to cognitive impairments, but they are not a causal factor in the development of reading problems. They acknowledged that letter reversals can be a symptom for some individuals with dyslexia. Having an over-simplified and single-factor heuristic of complex issues such as a dyslexia diagnosis can yield significant consequences for children and adults alike who receive or do not receive a dyslexia diagnosis (Stark & Johnson, 2025). Researchers rejecting the causal role of letter reversals have noted the harmful consequences of this myth stating that parents and teachers may delay referral for diagnosis in children who do not present with letter flipping (Macdonald et al.,

2017). Additionally, people who attribute letter reversals to dyslexia, and furthermore the visual system may turn to non-evidence-based practices that may further delay effective interventions (Berent & Platt, 2021; Macdonald et al., 2017).

Causal or not, the reversal of letters has been reported as a hallmark symptom of dyslexia since its inception, despite letter reversals also being common among individuals without dyslexia (Helland, 2022). Some researchers believe that the perception of letter flipping could help further our understanding of dyslexia. For example, Treiman and colleagues (2014) investigated letter reversals of left versus right-facing letter forms in the Latin alphabet in 5- and 6-year-old children. They believed that letter reversals were the product of letter characteristics and not a characteristic of the individual, in that through statistical learning we learn from an early age that letters in the Latin alphabet are more likely to be right facing (Treiman et al., 2014). Under this theory, children who reverse left-facing letters would show signs of good statistical learning ability. While they did find statistically significant evidence for increased letter reversal errors when writing left versus right-facing letters, they did not find evidence linking statistical learning ability (increase left to right reversals) to later reading ability. Furthermore, the rate of letter reversals was not indicative of later reading skills, and therefore not predictive of a later dyslexia diagnosis. These findings depict an inherent learning of statistical probability in young children who later develop reading difficulties as well as typical readers (Treiman et al., 2014).

Another proposed hypothesis for sequencing errors in children with dyslexia is that of developmental delay whereby children with dyslexia have immature part-whole integration and general reading abilities, performing similarly to younger typical readers and worse compared to age-matched controls on tasks using anagrams (Mindell, 1978). In line with these findings, Marinus and colleagues (2018) looked at the types of errors in letter position tasks in children of various ages and adults. They found that letter position errors are common in reading development and decrease in frequency into adulthood. Interestingly, while letter position errors were most common across age ranges, children in grade 1 were most likely to make other types of errors, speaking to a change in reading strategy, moving away from serial decoding with increased age. In tasks exploring letter orientation errors, 10-year-olds with dyslexia made a greater number of errors compared to age-matched controls on tasks of recognition and production (Terepocki et al., 2002). They proposed three explanations for their results citing (1)

an indirect deficit in magnocellular processing via poorly specified mental representations of letters, (2) a weakness in phonological processing, although not tested, resulting in letter reversals as secondary consequences of prolonged reading difficulties, and (3) over-reliance on visual processes, rather than a deficit in visual processing ability, as indicative of increased left-right reversals errors in the dyslexia group and no group differences on other tasks using unfamiliar letter forms and letter rotations.

As noted above, the presence of letter reversals is evident in children with and without dyslexia as part of literacy development, raising the question of whether letter reversals are indeed characteristic of dyslexia or whether they characterize children learning to read, thus being the result of an immature perceptual processing system. This fact is commonly provided as counterevidence for a causal sequential processing hypothesis of dyslexia (Macdonald et al., 2017; Mindell, 1978). That said, the perception of letter reversals remains persistent into adulthood for a subset of individuals with dyslexia, further driving this short-hand association (Peter, et al., 2021a). By studying reversals in adults with dyslexia, who have plateaued in word reading skills compared to children whose reading abilities remain variable, we are better able to explore these reversals (Peter, et al., 2021a).

Peter and colleagues (2021a & 2021b) conducted companion studies looking at sequential and spatial reversals in written word recognition (Peter, et al., 2021a) and written word production (Peter, Albert, & Gray, 2021b) in adults with and without dyslexia. Using a word pair task, Peter and colleagues (2021a) manipulated word pairs to include spatial and sequential letter reversals. Individuals with dyslexia displayed decreased accuracy in the sequential rearrangement and left/right reversal conditions and no differences were observed in the up-down and visual similarity conditions. From these findings, researchers conclude there is an association between sequential and spatial letter reversals that persist into adulthood. As for reaction time, results differed by group but not by condition, indicative of a group characteristic and processing speed deficit, and not specific to the study's experimental condition. Additionally, a subset (n=3) of their sample of individuals with dyslexia who produced letter reversals in the left/right plane on a rapid letter naming task, had decreased accuracy on both the left/right and sequential rearrangement conditions. They proposed an underlying deficit in the sequential processing of letters and letter elements in a subset of individuals with severe dyslexia (Peter, et

al., 2021a). Here, the authors did note their small sample size (n=44) and use of a single letter task in detecting left-right reversal errors as possible limitations in their study.

In a similar study, Peter and colleagues (2021b) investigated spatial and sequence reversals in written word production. In line with their previous findings in written word recognition, they found their sample of adults with dyslexia to make more sequential errors, and a correlation (rho=0.47) was found for accuracy between word recognition and production tasks. Interestingly, the same three participants with dyslexia displayed difficulty in left/right reversals when spelling words (Peter, Albert, & Gray, 2021b). Of note, some of the participants with dyslexia did not display errors in spatial or sequential reversals in both production and recognition tasks. These findings provide further evidence for a deficit theory in sequential preprocessing, but only in a subset of individuals with dyslexia.

A possible contributing factor affecting letter reversals is visual crowding (for review, see Levi, 2008). Visual crowding is broadly defined as an impairment in recognition of a target as a consequence of nearby distractors, also known as flankers, in the periphery (Bouma, 1970). Previous researchers have noted a decreased performance of individuals with dyslexia on orthographic tasks when using crowding paradigms with flankers close to the target (Bouma & Legein, 1977; Martelli et al., 2009). Moreover, the visual crowding effect has a greater impact when stimuli are presented in the periphery and when the presence of the stimuli is timebound (Martelli et al., 2009). While the current paper does not directly investigate visual crowding, crowding was considered in the design of this study and is discussed as a possible contributing factor in letter reversals.

This study aims to further investigate both spatial and sequential letter reversals in adults with dyslexia. By employing the oddball paradigm, we aim to examine how individuals with dyslexia detect and respond to visually presented spatial and sequential letter reversals, compared to typical readers. We hypothesize that across all conditions, compared to our control group, our sample of individuals with dyslexia will be less accurate and display an increased reaction time in identifying and reacting to both spatial and sequential reversal oddball stimuli. We further hypothesize that these differences will be greater in the sequential compared to the spatial conditions due to visual crowding effects that have been reported previously within individuals with dyslexia (Martelli et al., 2009).

Method

The research conducted in this study adhered to the regulations established by both the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans and the Official Policies of Concordia University. Ethical approval was received from the Concordia University Human Research Ethics Committee (HREC Certificate: #30009781). Informed consent was obtained from all participants after being informed of the nature of the study.

Participants

Our sample of individuals with dyslexia was recruited in person. Individuals with dyslexia were mainly recruited via the Concordia Vision Lab's database of individuals with dyslexia in addition to social media advertisements and printed flyers. Individuals with dyslexia were required to self-identify as having dyslexia and proof of diagnosis by a licenced professional was not required. Typical readers were recruited through the Department of Psychology Participant Pool. All control participants were required to score below 40 on the Dyslexia Adult Checklist. Participants who did not meet this criterion were not included in the final sample. All participants (dyslexia and control) were recruited as part of a multi-experiment study and received $30 or two credits for their time.

Following recruitment, the initial sample consisted of 86 participants, with the final sample consisting of 79 participants (Dyslexia=35, Control=44; see Table 1). Participants were excluded for incorrectly completing the oddball paradigm task (n = 2), control participants scoring above 40 on the dyslexia adult checklist (n=3), or presence of missing not-at-random data (n=2).

For participants in the dyslexia group, self-identification was confirmed through a positive response to the question, "Do you self-identify as having dyslexia?" Self-identification of dyslexia has been found to be a valid measure of reading difficulties in previous research (Jones, Asbjørnsen, Manger, & Eikeland, 2011; Nalavany, Logan, & Carawan, 2018). Although a formal diagnosis was not required to be eligible to participate, participants were asked if they had been formally diagnosed by a professional. In response, all 35 participants reported that they had received a diagnosis. See Table 1 for a description of demographic characteristics (See OSF repository for language demographics).

An *a priori* power analysis, conducted using G*Power 3.1 (Erdfelder, Faul, & Buchner, 1996), tested the difference between two independent means. Using a one-tailed independent

samples t-test, a minimal effect size of interest (d = .80) based on Stark, Franzen and Johnson (2022), an alpha of .05, and a minimal desired power of .95, a minimum sample size of 35 participants per group is required to detect a group difference, should a difference exist. (Faul et al., 2007).

Stimuli and Apparatus

The oddball paradigm was created using PsychoPy Builder (Version 2021.2.3) and deployed using Pavlovia (https://pavlovia.org). Participant responses were recorded and stored by Pavlovia. All data were downloaded and coded by the first author to ensure anonymity.

Behavioural measures of accuracy and response time were calculated for each of the six conditions, consisting of 1- and 5-letter conditions. Spatial letter reversals were investigated in the three single-letter conditions with the letter *b* presented as the distractor. Target stimuli included *left-right* (distractor: b, target: d), *up-down* (distractor: b, target: p), and *left-right/up-down* (distractor: b, target: q) reversal conditions. Sequential letter reversals were investigated in the 5-letter conditions, consisting of *random letters* (distractor: skfht, target: shfkt), *word-nonword* (distractor: weird, target: wried), and *word-word* (distractor: stake, target: skate) conditions (see Table 2). Here, the placement of the second and fourth letters in the five-letter distractor stimuli was switched to generate the target stimuli. The random letter condition included lowercase ascender letters (k, h, f, t) that had not been utilized in previous conditions, except for the letter *s*. Six condition blocks were created consisting of 40 trials each, 240 trials total, in which 70% (28 trials) of trials displayed the distractors stimuli and 30% (12 trials) depicted the target stimuli. The six conditions trial blocks were counterbalanced and the trials within them were presented randomly. Prior to commencing the experimental conditions, all participants underwent a training (with feedback) block using *X* distractor and *O* target stimuli to allow them to learn the oddball paradigm.

At the beginning of each condition, participants were presented with written instructions stating the distractor for that condition with the instructions to press the spacebar if they did not see the distractor. Subjects were not exposed to the target stimuli prior to commencing the condition block. The condition block was started once a participant pressed the spacebar. At which point a fixation cross was presented in the center of the screen for 100 milliseconds followed by the presentation of a distractor or target stimulus in the middle of the screen for 800 milliseconds and an intertrial interval was one second. Once a condition block began, it

continued until it was completed, regardless of participant responses. All stimuli were presented on a grey background with white Open Sans font equivalent to Times New Roman.

Measures

A questionnaire was administered to participants that included demographic questions, the Adult Dyslexia Checklist (Smythe & Everatt, 2001) and the ADHD self-report scale symptom checklist (ASRS-vI.I; Kessler et al., 2005). The Dyslexia Adult Checklist (Smythe & Everatt, 2001) is a symptom checklist for adult dyslexia comprised of 15 questions used to assess aspects of literacy, language and organization. Items require the respondent to rate symptoms of dyslexia on a 4-point Likert-type scale (rarely, occasionally, often, most of the time, and easy, challenging, difficult, very difficult). Previous research has found the Adult Dyslexia Checklist to be valid (Cronbach's α=0.86), and reliable (sensitivity=91.5%, specificity=80%) using a cutoff score of 40 (Stark et al., 2025). The ASRS-vI.I was administered to all participants given the high comorbidity rate between individuals with dyslexia and ADHD, and its possible impact on our research findings given the nature of the oddball task. Kessler and colleagues (2005) found the six-question ASRS screener to have a sensitivity of 68.7% and specificity of 99.5% with a total classification accuracy of 97.9%.

Procedure

Both control and individuals with dyslexia were recruited as part of a larger research initiative. These participants filled out the questionnaire and completed the oddball task on Pavlovia. Participation lasted approximately 2 hours.

Analysis

Accuracy and response time were calculated for each condition, for each participant. Accuracy was calculated as the proportion of correct responses (correct rejection and correct hits) relative to the total number of trials in that condition. Response time was computed as the average overall reaction time, correct and incorrect. A preliminary analysis not presented here showed no differences in reaction times on correct compared to incorrect trials. Averaged participant conditions were removed from analysis when the average accuracy for that condition was equal to or below 30%. In total, 15 participant conditions were removed, resulting in 459 total averaged conditions. A signal detection analysis, with accompanied *d'* and *criterion C*, was conducted for accuracy of responses, across conditions for both groups. Signal detection analysis

was used as it accounts for more nuances in understanding decision-making and depicts the trade-off between "false alarms" and "misses," which accuracy alone does not capture.

For the reaction time data, we used the collapsed mean responses per participant across conditions. Estimation Statistics (Ho et al., 2019) were used to analyze unpaired mean differences. Given the nature of the data and unequal group sizes, a total of 16 two-tailed permutation t-tests were conducted, across the six conditions, between groups, for accuracy and reaction time. We opted to use permutation t-tests and bootstrapping instead of traditional t-tests to reduce the risk of type 1 errors. Permutation t-tests assume the exchangeability of sample pairs under the null, however, our sample is made up of individuals with and without dyslexia, so we cannot assume random assignment of groups. By not meeting this assumption, we cannot make causal inferences based on our findings (Howell, 2015). 5000 bootstrap samples were taken to calculate the 95% confidence interval around the mean difference, which were bias-corrected and accelerated. P-values can be interpreted as the probability of observing the effect size (or greater), assuming the null hypothesis of zero difference is true. This test was employed as it is not affected by imbalanced cell counts, as in this case where target-present trials only account for 30% of the trials. Given the expected non-normal nature of reaction time data and the biased nature of measures of central tendency in reaction time data, we additionally opted to plot our data using a bootstrapped shift function (Rousselet & Wilcox, 2019). This analysis is well suited for skewed reaction time data (Rousselet & Wilcox, 2019) and demonstrates the difference between the two groups' reaction times at the decile points of each distribution.

Results

All non-identifiable data and additional tables are available in the project's OSF repository.

For the results of the signal detection analysis, we found that individuals with dyslexia were less accurate or performed equivalently to the control group in identifying the target stimuli when it was present. Conversely, the dyslexia group had a higher or equivalent correct rejection rate compared to the control group on all conditions (see Table 3). These patterns of responses depict a difference in strategy between groups indicated by the response bias measure *C* (see Fig. 1). Despite the difference in strategies used, the overall performance accuracy on the task, did not differ between groups except for the *up-down* condition, whereby the dyslexia group outperformed the control group as indicated by a larger *d'* ($d'_{dys} = 4.57$, $d'_{con} = 3.68$; Fig 1).

Permutation t-tests of mean differences were conducted for each condition between groups for accuracy and reaction time, displayed in Cumming estimation plots (Fig 2, & 3). For accuracy, differences in mean between groups were observed on tasks involving sequential reversals but not spatial (Table 4). No between-group mean differences were observed across conditions for reaction time (Table 4). When looking at the reaction times, the results from our Cumming estimation plots and graphically presented raw data, show differences between the two groups across the reaction time distributions, with the largest differences being observed at the tails of the distributions (Fig 3). The greatest of these between-group differences occurred at the tail end of the sequential reversal conditions, notably the random letter and word-nonword conditions. These analyses depict differences between groups that are, otherwise, undetectable when strictly looking at the differences between the mean central tendency of the distributions (see supplemental materials and OSF repository).

Discussion

Using an oddball paradigm, we investigated spatial reversals in single-item conditions and sequential reversals using five-letter arrays in adults with and without dyslexia. We observed between-group differences in accuracy for sequential reversals, but not spatial reversals, with the greatest difference occurring in the random letter condition. Further investigation revealed a difference in strategy used between groups, despite the lack of discrimination differences measured using *d'*. Broadly, no statistically significant differences were observed for reaction time across groups or conditions using traditional analysis of means, but differences were observed when using the shift function to look at the decile locations of each distribution.

Accuracy

As a standard score, a larger *d'* indicates increased sensitivity in the ability to detect the difference between the target and distractor, while a *d'* of zero indicates chance level performance. Figure 1 depicts *d'* across conditions for each group. Here, we see that both groups discriminated between the target and distractor stimuli with high accuracy and above-chance performance across all conditions. Additionally, we observe similar sensitivity between groups on all conditions, except for the *up-down* condition, where the dyslexia group outperformed the control group. Between-group differences emerge when looking at the strategy used. Here, the dyslexia group would appear to adopt a conservative strategy, with a high correct rejection rate accompanied by a higher miss rate, cooperated by the response bias measure *C*. This means that

the dyslexia group were less likely to press the spacebar, irrespective of which stimuli were present in the trial. Here, individuals with dyslexia adopted a more conservative response strategy in certain tasks to reduce the likelihood of errors and minimize the consequences of making mistakes. This stands in contrast to the control group who used a liberal strategy, pressing the space bar more often as indicated by a higher hit rate and high false alarm rate as well as positive *criterion C* values (Fig. 1; Table 3). This difference in strategy is especially prevalent in conditions looking at sequential reversals, reflected in the mean group differences observed in Fig 2 and by the response bias measure *C* in the bottom part of Fig 1.

This difference in strategy between the groups could suggest that at a group level, individuals with dyslexia placed a higher value on not being wrong. By contrast, this interpretation suggests that our control sample placed greater importance on hitting the target at the expense of making more mistakes. At a larger population-level sample size, this pattern may reflect broader social implications in that individuals with dyslexia may be prioritizing error avoidance, limiting negative judgement and placing greater importance on being correct over fast.

Previous researchers have proposed a serial order processing deficit for individuals with dyslexia, finding that individuals with dyslexia recall items with the same accuracy as typical readers. However, the order in which they recall the item, both verbally and non-verbally, was affected (Hachmann et al., 2014). Furthermore, sequential reversals have been found in languages other than English such as Hebrew and vary based on the stimuli, occurring least frequently in words that cannot be rearranged to form a novel word (i.e., lunch–lcnuh), and most frequently in words in which the letters can be rearranged to form a novel word (i.e., stake – skate; Friedmann & Gvion, 2001; Friedmann & Gvion, 2005; Friedmann & Rahamim, 2007). Similarly, our sample of individuals with dyslexia had a lower hit rate (83%) and higher false alarm rate (3%) in the *word-word* condition compared to the *word-nonword* condition (93% and 1% respectively. That is, our sample, made more errors in the *word-word* condition compared to the *word-nonword*, speaking to the lexical and/or familiarity effects of words. This tells us that there is a familiarity effect for words in dyslexia, in that participants with dyslexia have near-perfect performance on the *word-nonword* condition. However, individuals with dyslexia had a decreased performance when distinguishing between two words, showing a lack of distinction between real words. This could be the result of a letter position effect (see below).

We observed that performance accuracy for both groups was most affected by the random letter condition (see Table 4; Hit_{dys}=79%, Hit_{con}=90%). The use of random letter strings or non-words is commonplace in psychophysiological experiments as letter strings remove lexical meaning (Frey & Bosse, 2018; Gavril et al., 2021; Henderson & Henderson, 1975). Additionally, the use of random letter strings removes the familiarity effects and top-down influences of words (Frey & Bosse, 2018; Henderson & Henderson, 1975). Previous researchers have noted an increased accuracy and reaction time in identifying the presence of words compared to non-words that can explain the decreased accuracy of our groups (Henderson & Henderson, 1975). Although not investigated here, it has been proposed that the decreased accuracy observed in the dyslexia sample may be the result of less effective decoding skills (Kwok & Ellis, 2014).

In a study comparing sequential and left/right reversals in a word comparison task in adults with and without dyslexia, Peter and colleagues (2021a) found the dyslexia group to be less accurate compared to the control group in trials of sequential reversals and in the *left-right* reversals. Additionally, they did not find group differences in accuracy in a comparison *up-down* condition. These findings, in part, are consistent with the findings from our study. Here, we found statistically significant group differences for all three of our sequential reversal conditions, *word-word*, *word-nonword*, and *random letter* conditions, consisting of five letters. However, we did not find group differences in our spatial reversal conditions, which consisted of single-letter manipulations. This stands in contrast to Peter and colleagues' (2021a) experiment where all conditions used either mono- or disyllabic words with 3 to 7 letters. It is therefore possible that the use of single letter stimuli may have led to a ceiling effect in our study, as indicated by the near-perfect hit (96-99%) and correct rejection rates (94%-99%) seen in both groups. While these results speak to a possible deficit in serial order sequencing, the ceiling effect witnessed in the spatial reversal conditions does not allow for further interpretations to be made.

One possible explanation behind the observed differences between our groups in sequential reversals is visual crowding. Crowding is the visual phenomenon of introducing distractors, known as flankers, around a target reducing accuracy of recognition (Bertoni et al., 2019; Bouma, 1970; Strasburger, 2020). In all three of the sequential reversal conditions, we used five-letter arrays which have the added effect of introducing crowding. Additionally, the presentation of our stimuli was timebound, at 800 milliseconds, which may have resulted in

increasing crowding effects which can be amplified under time-limited exposure to stimuli (Martelli et al., 2009). Research investigating crowding in individuals with dyslexia has found causal links between excessive crowding and children with dyslexia (Bertoni et al., 2019) and has been linked to decreased reading rate in dyslexia to crowding effects (Martelli et al., 2009). It has been hypothesized that crowding effects in dyslexia may explain positional uncertainty in focused attention when reading (Kristjánsson & Sigurdardottir, 2023).

Investigations of the visual crowding effect typically manipulate spacing at the letter, word and line level to alleviate crowding effects. Increased letter, word, and line spacing has been found to increase reading accuracy and speed in a subset of children and adults with dyslexia by decreasing the effects of crowding (Bertoni et al., 2019; Joo et al., 2018; Moores et al., 2015; Zorzi et al., 2012). Additionally, some proposed interventions for dyslexia include the manipulation of letter spacing to alleviate symptoms of dyslexia (Joseph & Powell, 2022; Stark et al., 2022; Zorzi et al., 2012). Future research investigations of this type could use these findings to increase and decrease crowding effects by varying the inter-intra-word spacing of different conditions.

In this study, we opted to switch letter position two and four, to introduce positional uncertainty. Previous research has found that letters in the first and central position are most accurately identified in a forced choice target search paradigm using five character strings (Mindell, 1978; Tydgat & Grainger, 2009). This effect is the result of acuity, presuming that the individual is fixating on the center letter in the word, and crowding. By manipulating letters in the second and fourth letter position, we introduce flankers on each side of the target letters to increase the difficulty of the task (Snell et al., 2022). That said, different proposed models exist to explain the identification of letters necessary for reading. While Tydgat and Grainger (2009) adhere to a simultaneous model, others posit that letters are processed sequentially (Whitney, 2001). Future research studies should investigate the role of letter position in letter reversals, testing both simultaneous and sequential models of letter processing.

Beyond crowding, the five-letter conditions introduced visual and cognitive complexity in testing the participants' ability to visually encode longer strings of information under increased cognitive demand. Inherently, longer strings require parallel or serial encoding, which may tax working memory and orthographic decoding resources to a greater extent than single-letter stimuli. As such, observed differences across conditions may reflect not only perceptual

constraints (e.g., crowding) but also broader linguistic processing and memory challenges seen in individuals with dyslexia. Taken together, these observed performance differences in five-letter conditions may therefore result from an interaction between low-level visual-perceptual factors and higher-order memory and cognitive-linguistic factors. Future work might seek to disentangle these factors by systematically varying lexicality, string length, serial order, and type of reversal.

Reaction Time

The oddball task was evaluated by investigating both accuracy and reaction time. An important note is that reaction time data is non-normally distributed and therefore using measures of central tendency can prove insufficient in detecting possible group differences (Rousselet & Wilcox, 2019). While we did not find differences between our groups on reaction times, across conditions, we do note differences in the tail ends of the distributions pointing to possible differences in a subset of the population warranting further investigation (see OSF). Similarly, in contrast to our a priori hypothesis, visual inspection of the cummings plot indicated no differences in reaction times between spatial and sequential conditions. These findings contrast with previous research which demonstrates that response times are greater in multi-letter arrays in comparison to single-letter stimuli (Liberman et al., 1971).

Limitations

Of note, this study uses self-identification for group formation which could affect the replicability and generalizability of findings. Here, our sample of individuals with dyslexia self-reported having received a formal diagnosis of dyslexia. Similarly, comorbidities were not accounted for in this study and group matching was not performed. Future research initiatives may wish to confirm diagnosis by asking for psychoeducational reports or by way of assessment as part of the research study, in addition to further controlling for inherent group differences. Another possible limitation of the current research is that of the letter position effect in the sequential letter version conditions. In their study, Snell, Grainger and Meeter (2022) speak to the possibility of participants developing attention bias to parts of the letter strings. While this is a possibility in our research paradigm, we opted to not directly state the task's target but rather told participants the distractor with the instructions to not hit the space bar when they see the noted distractor. By doing so, we intended for participants to identify the target on their own by scanning the entirety of the stimuli. Future research could look to expand on sequence reversals in an oddball paradigm, accounting for letter position effects (see Snell et al., 2022). The present

study investigated solely behavioural measures of reaction time and accuracy, future studies may wish to expand research initiatives to include eye tracking and EEG, specifically the investigations into N200 and P300 (see Rüsseler et al., 2003). Lastly, there is a need for further investigations into the effect of crowding in adult dyslexia as it pertains to spatial and sequential letter reversals.

This study investigated spatial reversals, the reversals of letters in space such as *b* and *d*, as well as sequential reversals, the reversals of letters within five letter arrays of non-words and words such as *weird* and *wried,* in adults with and without dyslexia. No between-group differences were found for reaction time across the six conditions, although differences were observed for accuracy on tasks investigating sequential reversals, with the control group outperforming our sample of individuals with dyslexia. We conclude that context-based cues, cognitive-linguistic and visual crowding effects may have an impact on performance accuracy in trials of sequential reversals. Future studies should further explore the role of visual crowding in both spatial and sequential letter reversals in adults with dyslexia.

Table 1.

Sample Demographics

	Dyslexia	Control
	n=35	n=44
Age*	25.37	24.50
Gender		
# of Cis Male	11	9
# of Cis Female	23	35
# of Other	1	0
Sex		
# of Male	11	10
# of Female	24	34
Age of diagnosis*	13.79 (9.13)	
Level of Education*	2.69	2.78
Self-reported comorbidity (%yes)	60%	20%
Dyslexia Adult Checklist*	52.31(9.80)	32.27(3.88)
# of participants above cut-off	33	0
ASRS-vI.I*	3.60(1.50)	2.02(1.68)
# of participants above cut-off	20	11

Note. *Indicates that a mean was calculated for that row. Values in brackets indicate the standard deviation. For level of education, question inquired about highest level of education completed coded as; 1=Primary/Elementary, 2=Secondary/High School, 3=College/University/Undergraduate, 4=Graduate Degree.

Table 2

Overview of Visual Oddball Paradigm Conditions

Conditions	Distractor	Target
Feedback Condition	x	o
Left-Right	b	d
Up-Down	b	p
Left-Right / Up-Down	b	q
Random Letter	skfht	shfkt
Word-Nonword	weird	wried
Word-Word	stake	skate

Note. This table depicts the stimuli used in each of the 6 conditions in this study.

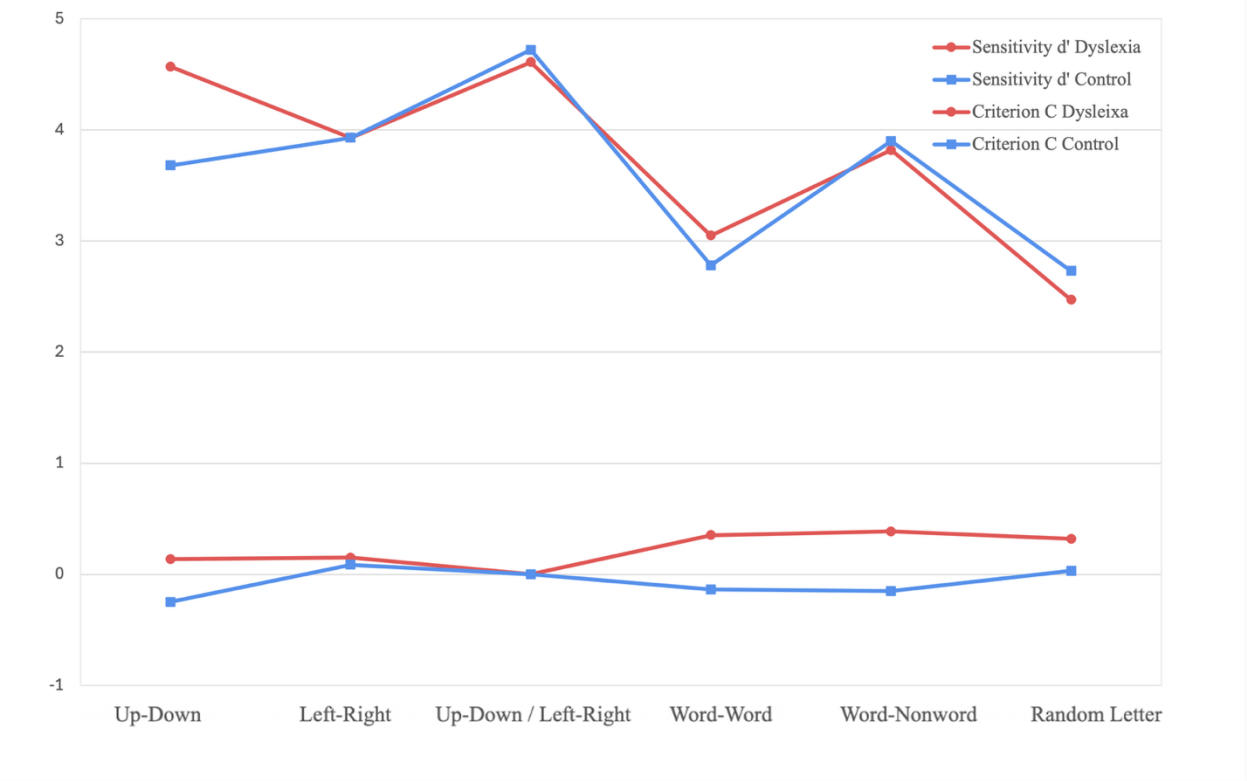
Table. 3

Signal Detection Table for Accuracy across Groups and Conditions

		Response			
		Dyslexia		Control	
		Yes	No	Yes	No
Stimulus		Up-Down			
	Present	0.91	0.09	0.98	0.02
	Absent	0.01	0.99	0.06	0.94
		Left-Right			
	Present	0.96	0.04	0.97	0.03
	Absent	0.02	0.98	0.02	0.98
		Up-Down / Left-Right			
	Present	0.99	0.01	0.97	0.03
	Absent	0.01	0.99	0.02	0.98
		Word-Word			
	Present	0.83	0.17	0.94	0.06
	Absent	0.03	0.97	0.10	0.90
		Word-Nonword			
	Present	0.93	0.07	0.98	0.02
	Absent	0.01	0.99	0.04	0.96
		Random Letter			
	Present	0.79	0.21	0.90	0.10
	Absent	0.06	0.94	0.08	0.92

Fig 1.

d' and Criterion C for Accuracy across Conditions



Note. The darker line represents the dyslexia group; the lighter line represents the control group. The conditions are presented on the x-axis.

Table 4.

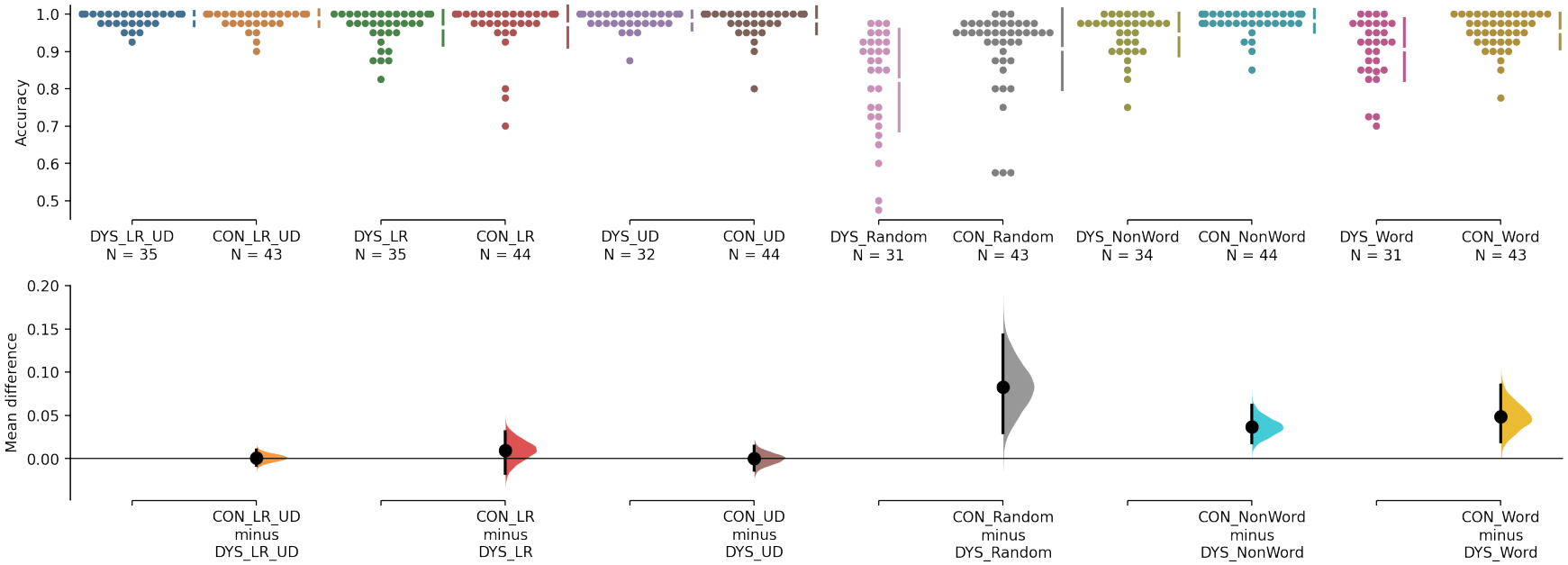
*Permutation T-Tests of Mean Differences – Condition * Group*

Condition	$n_{control}$	$n_{dyslexia}$	Mean Difference	Lower	Upper	*p* value (permutation)
Accuracy						
Up-Down/Left-Right	35	43	0.001	-0.008	0.010	0.805
Left-Right	35	44	0.010	-0.017	0.031	0.445
Up-Down	32	44	0.000	-0.014	0.014	0.971
Random Letter	31	43	0.083	0.030	0.143	0.004*
Word-Nonword	34	44	0.037	0.018	0.062	<0.001*
Word-Word	31	43	0.049	0.020	0.085	0.001*
Reaction Time - Total						
Up-Down/Left-Right	35	44	-0.007	-0.032	0.015	0.568
Left-Right	35	44	-0.007	-0.036	0.019	0.632
Up-Down	33	43	0.022	-0.015	0.064	0.278
Random Letter	35	44	-0.005	-0.033	0.022	0.730
Word-Nonword	35	44	-0.016	-0.044	0.012	0.278
Word-Word	35	44	-0.021	-0.068	0.016	0.314

* $p < .05$

Fig 2.

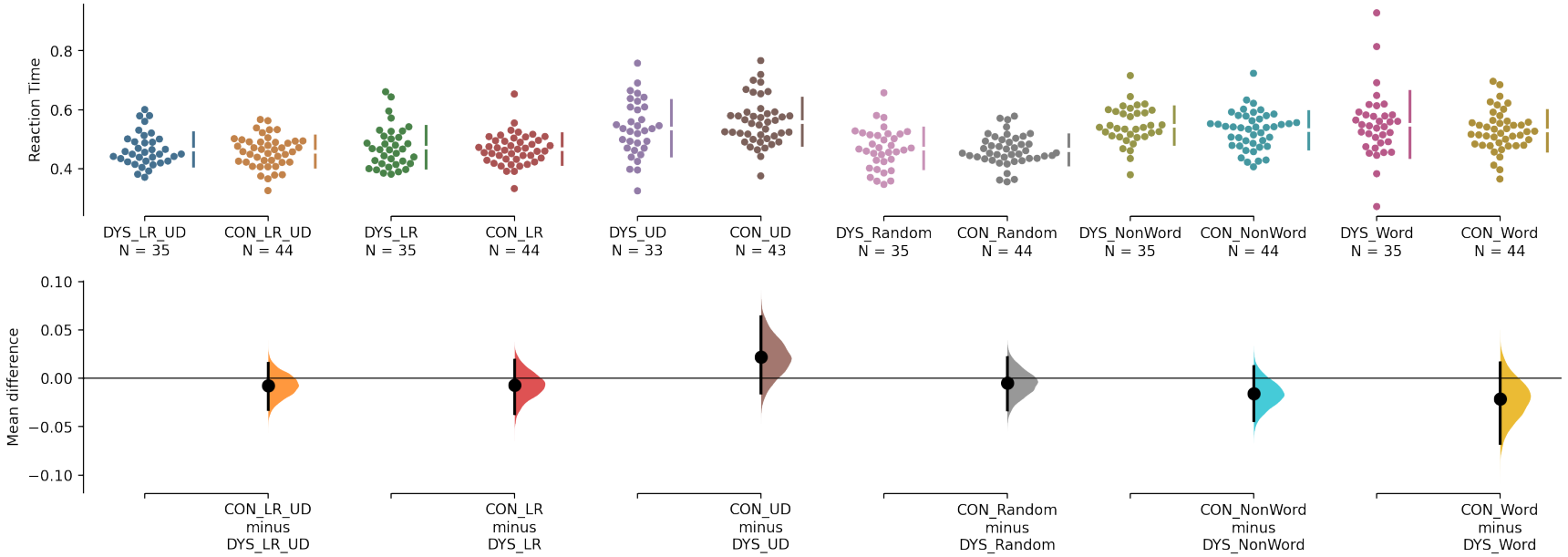
Cumming Estimation Plots of Mean Differences for Accuracy



Note. The accuracy and difference between individuals with dyslexia and controls across the 6 conditions are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each mean difference is plotted on the lower axes as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars.

Fig 3.

Cumming Estimation Plots of Mean Differences for Reaction Times



Note. The reaction times and difference between individuals with dyslexia and controls across the 6 conditions are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each mean difference is plotted on the lower axes as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bar.

CHAPTER 6
GENERAL DISCUSSION

The overall aim of this thesis was to better understand the perceptual experience of adult dyslexia. It examined three broad domains within the field of dyslexia namely screening, individual experience and the visual attention hypothesis. This was accomplished by way of four studies. Chapter 2 validated the Dyslexia Adult Checklist in a sample of adults with and without dyslexia using both univariate and multivariate statistical approaches. The questions within the Dyslexia Adult Checklist target frequently reported symptoms associated with Dyslexia. However, until now the checklist had never been investigated in terms of its validity of detecting Dyslexia. Chapter 3 used a mixed-method approach to explore how the occurrence and timing of a dyslexia diagnosis influence individuals' experiences, rated as positive, neutral or negative. Using a variety of statistical approaches, I explored the experience of, and secondary effects associated with, having dyslexia using both qualitative and quantitative data. Chapter 4 looked at the perceptual span of adults with dyslexia, using a naturalistic reading paradigm. This study is a replication study using the gaze-contingent moving window paradigm, by using a sample size that was calculated to detect the effect size of interest. Lastly, Chapter 5 explored bottom-up influences of visual processing occurring in letter flipping in adults with dyslexia. Using the oddball paradigm this paper investigated behavioural responses in spatial and sequential letter reversals in single- and multi-letter arrays.

Taken together, these manuscripts add to the research field on adult dyslexia. Each paper aims to answer a research question that remained unanswered. In so far that these unanswered questions have now been answered, new questions arise in their place. The last chapter of this thesis asks these new questions. Here, we propose new research questions in furthering these domains of research exploring adult dyslexia.

Study 1 (Chapter 2)

The Dyslexia Adult Checklist, created by Smythe and Everatt (2001), is a 15-item screening tool for adult dyslexia. The checklist is freely available online in PDF version and is marketed on the British Dyslexia Association website as a tool for self-exploration and understanding. That said, to our knowledge, prior to our research study, there were no publicly available statistical reports outlining the reliability or validity of this screening tool. Study 1 in this thesis aimed to validate the Dyslexia Adult Checklist in its current form, exploring the tool's

effectiveness as a 15-item measure. The items in this tool consider both literary and non-literary sources of deficits, suggesting an adherence to a multi-deficit model of dyslexia. Of interest to my greater thesis topic, many of these questions reflect a perceptual deficit, for example “Do you confuse visually similar words such as cat and cot?” and “Do you lose your place or miss out lines when reading?” Future research into the checklist may wish to explore the effectiveness of the checklist when removing highly corrected items. Based on our sample of adults with dyslexia, we found an average inter-item correlation of 0.35. Conducting further item analyses may allow for the condensing of the questionnaire by removing highly correlated items. A Rasch Analysis can help determine items that are most effective in identifying adults with dyslexia (Boone, 2016).

The ideal screening tool for identifying risk factors is free of charge, easily accessible, self-administered and psychometrically valid and reliable (Smythe, 2010). In its current form, based on the suggested new user guidelines in Study 1, the Dyslexia Adult Checklist meets these criteria. That said, the lack of publicly available information on test construction leaves users questioning the rationale behind its construction and item formation. Future researchers may therefore wish to build upon the Dyslexia Adult Checklist, creating new evidence-based items that take into consideration factors structure and the addition of more rigorous psychometric testing. Suggested factors may include items investigating possible underlying deficits of dyslexia, such as phonological difficulties and visual symptoms, the shared experiences of and compensatory strategies used by adults with dyslexia, or the creation of factors and items mirroring DSM-5 criteria for diagnosis of dyslexia (American Psychiatric Association, 2013; Lyon et al., 2003). Additionally, researchers may wish to alter the scoring system of the questionnaires, removing or altering the weights of questions as well as the use of 5 vs. 4-point likers scale.

Study 2 (Chapter 3)

Shared experiences and compensatory strategies are, in part, investigated in Study 2 of this thesis. This paper is, to our knowledge, the first of its kind to investigate the experiences of adults with dyslexia using both quantitative and qualitative research. As such, the explorative nature of this study positions it as a jumping point for further investigations as well as more targeted research questions. Most specifically, targeted research investigating the experience of dyslexia in relation to other comorbidities. Of particular interest given the result of this study is

to further investigate the question "I find myself holding back on experiences/ opportunities because of my dyslexia." This question speaks to the impact of having dyslexia on the individual and their sense of self-worth consequently. Also unique to this study is the use of qualitative analysis in a large (n=93) sample study. In better understanding experiences, research initiatives attempting to understand the experience of adults with dyslexia would benefit from large-scale, more directive, open-ended questioning.

In this study, the variable of interest was the timing and occurrence of a dyslexia diagnosis. In the DSM-5, criteria for diagnosis, time of diagnosis, symptoms and factors for diagnosis are of acute interest (American Psychiatric Association, 2013). However, based on the results from this study, it is apparent that the timing and occurrence of a dyslexia diagnosis may play less of a role in how a person experiences their diagnosis than what might otherwise have been expected. In so far that dyslexia is lifelong, future research may wish to focus on identifying factors towards the development of a positive or neutral experience. In addition, researchers may wish to further understand the factors that predict a later negative experience, to foster environments for success. Lastly, future research may wish to study the experience of individuals using a longitudinal model, starting in late elementary and high school into adulthood.

Study 3 (Chapter 4) & Study 4 (Chapter 5)

Visual processing paradigms are one way we explored the visual attention hypothesis associated with dyslexia. This hypothesis posits that dyslexia is caused by deficits in perception, more specifically visual attention and ocular motor control, both investigated as possible areas for deficit (Kristjánsson & Sigurdardottir, 2023). Still being explored in the dyslexia literature is the concept of visual crowding. Crowding, also referred to as lateral masking or surround suppression, is a phenomenon in visual perception whereby recognition of targets is impaired as a result of surrounding distractors, referred to as flankers (Strasburger, 2020). While commonly talked about as a phenomenon occurring in the peripheral vision, reading research has noted crowding effects in the fovea. Strasburger (2020), stresses the discrepancy in defining terms in the literature, noting a distinction between the foveal area spanning 5 degrees of eccentricity and the location with which the observer is fixating, the foveola at 1.4 degrees, or the foveal bouquet with a diameter of only 8 to 16 arcminutes. With crowding occurring in the fovea and periphery, researchers studying dyslexia have turned to crowding to further explore reading-related deficits.

One proposed explanation for these findings was the crowding effect. As outlined in the discussion of Study 4, crowding effects were considered in the construction of this study. Most notably, the sequential letter reversal conditions were made up of five letters, with reversals occurring at the second and fourth letter positions to maximize crowding. The stated aim of this manipulation was to increase the difficulty of the task. Future research of this type is needed to better tease apart our findings. By increasing the difficulty of the task by introducing greater crowding effects, we would hypothesize larger group differences, eliminating the ceiling effects observed in this study. Additionally, the exploration of EEG data in such an initiative may serve as further evidence.

While not explicitly discussed in Study 3, crowding effects may potentially affect the results of gaze-contingent moving window paradigms. Study 3 aimed to replicate the original experiment by Rayner and colleagues (1989), who pioneered the gaze-contingent moving window paradigm, exploring the perceptual span of individuals with dyslexia. Rayer and colleagues (1989) did so using a case study design, followed by a replication with two individuals dyslexia. Mirroring tthe window sizes (to the right of fixation) and using an X mask conditions from the original study, this study added to the literature with a larger statistical power informed sample size, transparent statistical analysis and standardized texts. Inconsistent with previous findings which concluded a smaller perceptual span for adults with dyslexia compared to typical readers, we did not find statistically significant group differences in the size of the perceptual span (Luke et al., 2024; Whitford et al., 2023). Not accounted for in these studies are crowding effects. In this paradigm, windows are created using Xs or random letters, both of which induce crowding effects. To our knowledge, the moving window paradigm has not been completed with the absence of characters to enforce window size. The absence of stimuli in creating various window sizes would have the added benefit of studying peripheral preview while not inducing additional crowding from the window itself.

Study 4 of this thesis expended on the oddball paradigm to explore the bottom-up influences of visual processing occurring in letter flipping in adults with dyslexia. Here we found that individuals with dyslexia made increased errors compared to the control sample when identifying sequential letter reversals. Letter arrays were made up of five letters, consisting of *random letters* (distractor: skfht, target: shfkt), *word-nonword* (distractor: weird, target: wried), and *word-word* (distractor: stake, target: skate) conditions. Conversely, no group differences

were found on conditions exploring spatial reversals; *left-right* (distractor: b, target: d), *up-down* (distractor: b, target: p), and *left-right/up-down* (distractor: b, target: q) reversal conditions.

The investigation into crowding as a possible mechanism behind dyslexia is not novel. Previous researchers have found that by increasing letter spacing, and inter-word spacing, reading rates increase, especially in individuals with dyslexia (Chiu & Drieghe, 2023; Perea et al., 2012; Zorzi et al., 2012). That said, differences in study designs, sample construction and levels of measures have led to mixed findings and subsequent questions (Bellocchi, 2013). Here, Bellocchi (2013) highlights the heterogeneous nature of dyslexia whereby not all individuals with dyslexia display deficits in visual-spatial perceptual, nor phonological deficits, and its high comorbidity with other deficits with attention and executive functioning (Menghini et al., 2010). Additionally, when studying crowding effects in dyslexia, researchers use a variety of stimuli, linguistic and non-linguistic as well as word-non-word comparisons, both within and between studies; the range of these studies therefore limits cross-study comparisons (Bellocchi, 2013; Spinelli et al., 2002). Lastly, researchers have attempted to extend crowding effects in individuals with dyslexia cross-linguistically, with the aim of generalizing findings, furthering the evidence-based for a crowding deficit hypothesis (Ziegler & Goswami, 2005). Other considerations when studying crowding paradigms are the use of single letter arrays versus more naturalistic research paradigms (Perea et al., 2012; Slattery & Rayner, 2013) as well as the age and reading level of the dyslexia sample (Cassim et al., 2014; Martelli et al., 2009).

While there is considerable evidence pointing towards the improvement of reading in individuals with dyslexia as a result of increased letters between within and between words, the processes involved in readers have limited conclusions. That is, there is a need for more crowding-based studying using naturalistic paradigms with concurrent with eye tracking (Bellocchi, 2013). Such a study was proposed by Perea and colleagues (2012) as a future direction, however to our knowledge was never completed. Perea and colleagues (2016) did however examine inter-letter spacing in text reading using eye tracking in typical readers only, finding shorter fixation durations when reading text with increased letter spacing. That said, no differences were observed between conditions on total reading time and text comprehension, concluding no facilitative role from additional inter-letter spacing for typical readers. Similarly, Slattery and Rayner (2013) and Paterson and Jordan (2010) investigated inter- and intra-word spacing in typical readers. Here, Patterson and Jordan (2010) found a disruption in saccadic

programming with increased between-letter spacing. That is, in typical reading, we expect fixations to occur to the left of the center of the word. By increasing the letter spacing within the words, Patterson and Jordan (2010) noted differences in saccadic programming where the fixations occurred nearer the beginning of the word. They explain that the addition of within-word spacing made word boundaries less clear, which may account for the saccadic shift. Additionally, this effect was even greater when clear word boundaries were lacking by increasing between-word spacing as well.

Building on my previous research looking at eye movement differences in text reading between typical readers with and without dyslexia (Franzen et al., 2021), as well as the research presented in this thesis, a compilation of research studies could be created to better investigate this question regarding crowding and dyslexia. More specifically, such a research collective would require using eye tracking technology, standardized texts, homogenous samples of individuals with and without dyslexia and be completed using various languages, in child and adults alike. Other research directions could include the use of AI technology and assistive technologies in improving the reading experience of individuals with dyslexia. Researchers in Japan tested recall, reading comprehension efficiency, and user experience in dyslexic participants using LARF (Let AI Read First) technology (Zhao et al., 2025). An AI-tool, LARF annotates *important* information in texts with highlighting, bolding, underlining, and other marks with the aim of enhancing reading abilities. Zhao and colleagues (2025) found LARF effective in improving reading performance. Not studied here, is the perceptual differences available to LARF users such as font size and color or differences in tools used for enhancing readability such as highlighting, bolding, and underlining. While this studied compared LARF to a control group who read the text like normal and other annotative technologies (bionic reading), it did not compare its efficacy to current reading interventions such as text-to-speech. Other research initiatives may investigate the interplay between annotative AI-tools and text-to speech, their effectiveness as unique tools, and the performance of dyslexic readers when these tools are used concurrently.

The collection of studies making up this dissertation depict a cohesive and multidimensional story of adult dyslexia, beginning with identification, expanding to include lived experience, then delving into the underlying perceptual mechanism of reading. Findings from these studies can be seen as complimentary, with the subjective experience of feeling

different mirror by objective differences in the perception of adults with dyslexia, reinforcing the idea that the emotional toll of dyslexia is not imagined, but rather is grounded in measurable cognitive differences. Taken together, these studies further support a multi-deficit model of dyslexia and underscore the importance of integrating lived experience into the study and understanding of adult dyslexia.

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