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Language, Reading, and Resting-state Oscillatory Power in ADHD, DLD, and Comorbid ADHD/DLD

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Abstract

High rates of comorbidity in attention-deficit/hyperactivity disorder (ADHD) and developmental language disorder (DLD) have motivated interest in utilizing psycholinguistic and physiological metrics to distinguish between these conditions. However, past studies have focused on one disorder and overlooked the significant overlap in symptoms between ADHD and DLD. Consequently, less is known about how these assessments can distinguish between "pure" (no comorbidities) cases of either disorder or comorbidities. This thesis aims to elucidate the basis of these overlapping disorders by examining language, reading, and resting-state oscillatory power differences and assessing their potential in distinguishing ADHD and/or DLD. Chapter 2 presents a scoping review of research on language abilities in ADHD and DLD. It revealed that children with ADHD had better morphosyntax/grammar, general/core language, receptive, and expressive language than those with DLD. However, there were variations in assessments of phonological processing, syntax, narrative language, and vocabulary. On the other hand, performance on semantic, pragmatics, and figurative language assessments were similar between groups. Standardization across studies is highlighted as crucial to consolidate inconsistencies and gain a clear understanding of the distinct language difficulties associated with each disorder. Chapter 3 builds on the findings of Chapter 2 by investigating whether the presence of a comorbid language disorder exacerbates language and reading difficulties in ADHD. Additionally, this chapter explores the ability of psycholinguistic assessments to distinguish between groups: ADHD (combined or inattentive subtype), DLD, and comorbid ADHD + DLD. Measures of reading efficiency could distinguish between the two types of ADHD, but not between other groups. Interestingly, scores on the standard language screener were no worse for children with ADHD + DLD than children with DLD only. These findings offer valuable insights into differential diagnosis and the identification of comorbidity In Chapter 4, resting-state electroencephalography (EEG) was used to examine oscillatory power differences in ADHD, comorbid ADHD + DLD, and control groups. It also examined whether groups could be distinguished based on their oscillatory power patterns. While EEG power spectra differences were observed between pure and comorbid ADHD + DLD, resting-state EEG was unable to accurately distinguish any of the groups with high accuracy, suggesting limited reliability as a diagnostic tool. Chapter 5 summarizes the findings of this thesis in relation to the shared cognitive deficits in ADHD and DLD and pathways contributing to comorbidity.

Key Words

Attention-deficit/hyperactivity disorder, developmental language disorder, language, reading, comorbidity, scoping review, resting state electroencephalography

Lay Summary

Distinguishing between attention-deficit/hyperactivity disorder (ADHD) and developmental language disorder (DLD) can be challenging due to their frequent co-occurrence and the overlap in their symptoms. Previous studies have explored language and physiological measures to distinguish these disorders but often neglect the significant symptom overlap. This thesis aims to shed light on the shared characteristics of these disorders and evaluate the potential of psycholinguistic assessments and resting-state electroencephalography (EEG) in distinguishing children with ADHD, DLD, and co-occurring ADHD + DLD.

The first study provides an overview of research on language abilities in ADHD and DLD. Children with ADHD exhibited better language skills than those with DLD, particularly in areas such as grammar, general language, receptive language, and expressive language. However, the findings varied across studies, and semantic and figurative language performance was similar between the two groups. Standardization across studies is emphasized to achieve a clearer understanding of the distinct language difficulties associated with ADHD and DLD.

The next two studies of this thesis expanded on the findings from the first study by comparing the different language, reading, and resting-state brain activity patterns of children and adolescents with ADHD, DLD, and co-occurring ADHD + DLD. These studies also investigate whether performance on language and reading assessments and resting-state brain activity can distinguish between these groups. The results showed that standard language and reading measures can help distinguish between ADHD and DLD, and different subtypes of ADHD. Further, that children and adolescents with co-occurring ADHD + DLD exhibit distinct resting-state brain patterns compared to those with ADHD-only.

Overall, the findings of this thesis demonstrate that there are similarities and differences in the language, reading, and resting-state brain patterns between children with ADHD and those with co-occurring ADHD + DLD, which can aid in distinguishing between the two groups. These findings contribute to our understanding of the behavioural and biological factors underlying ADHD, DLD and their co-occurrence.

Co-Authorship Statement

The first two chapters of this dissertation are under review for publication in scientific journals. The presented data are based on a series of collaborative research projects; however, all analyses were performed, and manuscripts were written by Kaitlyn M.A Parks with feedback from Marc F. Joanisse.

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List of Abbreviations

Abbreviation	Meaning
ADHD	Attention-deficit/hyperactivity Disorder
ADHD-1	Attention-deficit/hyperactivity Disorder- Inattentive Subtype
ADHD-C	Attention-deficit/hyperactivity Disorder- Combined Subtype
DLD	Developmental Language Disorder
ADHD + DLD	Attention-deficit/hyperactivity + Developmental Language Disorder
TD	Typically Developing
ASD	Autism Spectrum Disorder
ODD	Oppositional Defiant Disorder
DSM	Diagnostic and Statistical Manual of Mental Disorders
EEG	Electroencephalography
FR	Frontal Region
CR	Central Region
LT	Left Temporal
RT	Right Temporal
PR	Parietal Region
OR	Occipital Region
rs-fMRI	Resting State Functional Magnetic Resonance Imaging
CTOPP	Comprehensive Test of Phonological Processing
WJPB-R	Woodcock-Johnson Psycho-Educational Battery Revised
K-TEA	Kaufman Test of Educational Achievement
WRAT-R	Wide Range Achievement Test-Revised
PPVT-R	Peabody Picture Vocabulary Test-Revised
EVT	Expressive Vocabulary Test
TLC-EE	Test of Language Competence Expanded Edition
CELF	Clinical Evaluation of Language Fundamentals
GFTA	Goldman Fristoe Test of Articulation
SWAN	ADHD Symptoms and Normal Behavior Scale
CBCL	Child Behavior Checklist
TOWRE	Test of Word Reading Efficiency
PDE	Phonemic Decoding Efficiency
SWE	Sight Word Efficiency
NWR	Nonword Repetition
WISC	Weschler Intelligence Scale
VSI	Visual Spatial Index
IQ	Intelligence Quotient
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
HBN	Healthy Brain Network
Hz	Hertz
β	Standardized Coefficient
B	Unstandardized Coefficient
95%	95% Confidence Interval

ANOVA	Analysis of Variance
ANCOVA	Analysis of Covariance
F	F distribution value
ROC	Receiver Operating Characteristic
AUC	Area Under the Curve
BCa	Bias-corrected Accelerated Bootstrap Interval
χ^2	Chi Square Distribution
R^2	Coefficient of Determination
ηp2	Partial Eta Squared
d	Cohen’s d
IU	Index of Union
LOOCV	Leave One Out Cross Validation
FDA	Food and Drug Administration
EPV	Event per Variable
SE	Standard Error
Exp (B)	Odds Ratio
RMSE	Root Mean Square Error
PCA	Principal Component Analysis

Chapter 1：Introduction

Academic and social success depend heavily on a child's ability to understand and use language. Most children will learn language with little effort and no formal parental teaching. For these children, listening to their parents and engaging in frequent social interactions is sufficient for learning language. For some, however, learning language is not as effortless. Developmental language disorder (DLD) is a common childhood disorder that impacts multiple areas of language processing (Bishop et al., 2017) including production, comprehension, and phonology. DLD commonly co-occurs with attention-deficit/hyperactivity disorder (ADHD), which is characterized by developmentally inappropriate degrees of inattention and/or hyperactivity-impulsivity (5th ed.; DSM–5; American Psychiatric Association [APA], 2013). This high rate of comorbidity (between 20-50%; Bruce et al., 2006; Hagberg et al., 2010; Sciberras et al., 2014) is surprising given that the two disorders concern domains of cognition generally thought to be distinct; moreover, evidence suggests that many children have one diagnosis but not the other, supporting the view that these are etiologically distinct disorders rather than a distinct complex syndrome.

Research exploring comorbid symptomology in ADHD and DLD has shown that these children experience overlapping difficulties with language, social functioning (Bishop et al., 2017; Geurts & Embrechts, 2008; Kim & Kaiser, 2000; Korrel et al., 2017; Leonard, 2014; McGregor et al., 2020), peer victimization (Guerts & Embrechts, 2008; Kim & Kaiser, 2000; Redmond, 2011), and academic functioning (Arnold et al., 2020) that can persist into adulthood (Conti-Ramsden et al., 2018). Regardless of a comorbid language diagnosis, the distinct components of ADHD can uniquely impact language and social outcomes, with inattentive symptoms, but not hyperactive-impulsive symptoms, being linked to greater social difficulties (Parks et al., 2020) and hyperactive-impulsive, but not inattentive symptoms being linked to greater language difficulties (Guerts & Embrechts, 2008). While individuals with ADHD struggle across multiple language domains, research has repeatedly shown that when compared to those with DLD, these difficulties are much more nuanced (Oram Cardy et al., 2010; Redmond & Ash, 2014; Redmond et al., 2011).

Researchers have been interested in comparing the linguistic characteristics of ADHD and DLD due to the overlap in their symptoms. They have also explored the effectiveness of behavioural assessments in distinguishing between these diagnostic groups and whether these assessments can serve as reliable diagnostic markers. Additionally, there is promising research utilizing physiological metrics such as electroencephalography (EEG) to distinguish between diagnostic groups. Specifically, studies have found evidence of atypical resting-state EEG patterns (spontaneous neuronal activity independent of stimulation) in ADHD compared to typically developing (TD) children.

Indeed, behavioural and resting-state metrics hold tremendous promise in advancing our understanding of how these two disorders intersect, and how they are etiologically distinct. However, current research seeking to differentiate ADHD and DLD from controls has only compared “pure” samples of DLD (without co-occurring ADHD) or ADHD (without co-occurring DLD). Whether findings are robust enough to extend to comorbid samples remains unclear. My research seeks to provide an overview of language abilities in ADHD and DLD as well as address previous shortcomings by examining the utility of behavioural and resting-state EEG metrics in the context of diagnostic comorbidity. In this chapter, I will describe the shared cognitive deficits observed in both ADHD and DLD, highlighting how these shared deficits may contribute to the comorbidity between the two disorders. The use of behavioural and resting-state EEG metrics to distinguish ADHD, DLD, and comorbid samples is also discussed. Additionally, the chapter briefly highlights the existing research gaps regarding diagnostic utility in this field.

1.1 Shared Cognitive Deficits in ADHD and DLD

By definition, ADHD is marked by impairments in attention and/or hyperactivity-impulsivity, and DLD is marked by impairments in language. However, there is evidence to suggest that difficulties in both disorders are not restricted to these core impairments and can encompass domain-general cognitive deficits related to executive function as well (Brown, 2009; Laasonen et al., 2018; Leonard et al., 2007; Willcutt et al., 2005). Executive functioning is a top-down cognitive process that refers to a set of higher-order skills including inhibition (response inhibition, interference control), working memory updating, and set shifting (Miyake et al., 2000). Several cognitive factors have been put forth to explain the deficits found in ADHD and DLD, and similar underlying systems have been suggested to explain symptoms in both disorders. For example, deficits in interference control (the ability to ignore irrelevant stimuli) have been reported in DLD (Blom & Boerma, 2020; Finneran et al., 2009; Pauls & Arichbald, 2016) and ADHD (Mullane et al., 2009; Barkley, 1997), but behaviorally these difficulties can manifest in unique ways in each disorder. Other non-linguistic difficulties in DLD include general processing speed and short-term memory (Archibald, 2017; Leonard et al., 2007). These deficits have also been observed in ADHD (Dovis et al., 2013; Kibby et al., 2019).

Jonsdottir and colleagues (2006) investigated whether comorbid language impairment in ADHD would impact working memory processes and found that the presence of language impairments contributed to verbal, but not nonverbal working memory deficits. Findings from Cohen et al. (2000) corroborate and extend these findings by showing that working memory assessments (both verbal and nonverbal) are more closely related to DLD than ADHD.

In addition to interference control, processing speed, and short-term memory, other attentional processes are compromised in ADHD and DLD. Attention is related to executive function (Johnston & Dark, 1986) and is essential for proper language learning (Evans & Saffran, 2009). For instance, attention can help learners filter out and identify important versus unimportant linguistic information within a constant stream of input. The process of filtering out irrelevant information often occurs implicitly, without the learner's awareness (van Moorselaar et al., 2020) but attention can also be effortful. The ability to attend to a stimulus over an extended period of time (sustained attention) and selectively process stimuli while ignoring irrelevant information for a short time (selective attention) are both thought to be impaired in DLD (Finneran et al., 2009; Kapa & Plante, 2015; Kapa et al., 2017; Smolak et al., 2020; Spaulding et al., 2008) and ADHD (Barkley, 1997; Shalev & Tsal, 2003). Even children with DLD who have not been diagnosed with ADHD have difficulties sustaining their attention (Blom & Boerma, 2020; Ebert & Kohnert, 2011; Finneran et al., 2009; Spaulding et al., 2008). Given the connection between language and attention, it is apparent why children with difficulties in one area are more prone to difficulties in the other.

In summary, children with ADHD and DLD both have underlying deficits in their ability to process information. These overlapping cognitive deficits include working memory, executive functioning, attention and focus, and language processing. Attention deficits have been suggested as one of the underlying causes of DLD. Overlapping deficits in sustained and selective attention in ADHD and DLD coupled with high rates of comorbidity between the disorders further support this notion.

1.2 Electrophysiological Findings in Language

Since resting-state oscillatory activity at specific frequencies reflects the brain's underlying processing (Mantini et al., 2007), it is not surprising that a growing body of literature has examined connections between resting-state EEG and higher order functions like language. For example, resting-state theta band EEG activity has been linked to TD children's language proficiency (Lum et al., 2022) and sentence comprehension skills (Batiaansen et al., 2005; Beese et al., 2017; Hald et al., 2006). Such findings also are relatively specific: other research examining connections between theta activity and language in TD children found no relationship between theta power and vocabulary (Cantiani et al., 2019) or expressive language abilities (Maguire & Schneider, 2019). Expressive and receptive language skills have also been reliably associated with gamma activity in TD children (Benasich et al., 2008; Brito et al., 2016; Cantiani et al., 2019; Gou et al., 2011). Gou et al. (2011) examined whether gamma oscillations could predict language and cognitive outcomes in infants and young children and found that gamma activity significantly predicted phonological working memory (measured using a non-word repetition task) at 4 and 5 years of age. The authors conclude that higher gamma activity during certain developmental periods may index better working memory capacity. Important relationships have also been documented between alpha activity and language skills in TD children. Kwok et al. (2019) found relationships between spontaneous alpha oscillations and oral language skills in 4- to 6-year-old TD children, where children with higher alpha activity had poorer language skills. However, after controlling for age and non-verbal IQ, these relationships were no longer significant.

Research using EEG oscillations to explore language impairment, particularly in the context of DLD, is scarce. However, there are some notable findings in this area. Children with DLD have been found to exhibit abnormal EEG activity compared to TD children (Billard et al., 2010) and increased theta activity has been associated with the presence of language impairment (Wolthuis et al., 2022). Additionally, one study identified abnormal spectral power in a small sample of children with DLD compared to TD children but did not find an association between EEG patterns and later language development (Billard et al., 2010). Other studies have reported increased epileptiform EEG discharges in children with language impairments (Mehta et al., 2015; Nenadovic et al., 2014). Notably, associations have been observed between resting-state alpha activity in EEG and reading ability in children with written language disorders (Babiloni et al., 2012; Clarke et al., 2002; Duffy et al., 1980; Colon et al., 1979; Skylar et al., 1972). Furthermore, reduced functional connectivity has been found in the language-related brain networks of individuals with DLD (Badcock et al., 2012; De Guibert et al., 2011; Hugdah et al., 2004), suggesting disruptions related to the synchronization of neural activity during language processing.

Overall, the existing literature suggests potential connections between resting-state EEG patterns and language skills in children with written language disorders and typical development. However, there is a lack of research examining resting-state EEG patterns in language disorders and how comorbid ADHD may impact these patterns. Further investigation is needed to better understand the relationship between resting-state EEG and language impairments, particularly in the context of comorbid ADHD.

1.3 Electrophysiological Findings in ADHD

1.3.1 Psychophysiological Models of ADHD

Although many models have been proposed to explain the unique brain states of individuals with ADHD, there are three that have received the most attention (Saad et al., 2015). The models include the *maturation lag* model (Kinsbourne, 1973), *developmental deviation* model (John et al., 1987), and the *cortical hypoarousal* model (Satterfield & Dawson, 1971).

The maturation lag model proposes that behavioural symptoms indicative of pathology in ADHD are reflective of a relative delay in cortical development (Kinsbourne, 1973). This lag in ADHD is thought to affect various aspects of the central nervous system, and accordingly, their symptom severity. More specifically, Kinsbourne (1973) argued that compared to healthy brains, those with delayed maturation achieve attentional switching skills at a slower rate. Several resting-state EEG studies have found evidence congruent with the maturational lag model, showing that brain activity at rest is similar between children with ADHD and their younger TD peers (El-Sayed et al., 2003; Mann et al., 1992; Rubia et al., 2000). Moreover, findings from Satterfield et al. (1973) support this model by demonstrating increased slow-wave EEG (theta) in ADHD that is consistent with delayed cortical maturation. In general, resting-state EEG research has shown that children with ADHD typically demonstrate more slow-wave activity (theta) and less high-frequency activity (alpha, beta) than controls (see Clarke et al., 2020 and Newson & Thiagarajan, 2019 for reviews). These distinct resting state patterns in ADHD have been interpreted as reflecting delayed maturation.

In contrast, the developmental deviation model suggests that behavioural symptoms in ADHD are not the result of delayed maturation, but instead represent a deviation from typical development. As such, their brain patterns are not like that of typical children at any age (John et al., 1987). Several resting-state EEG studies provide compelling evidence in support of the developmental deviation model (Clarke et al., 2002; Chabot et al., 1996; Dickstein et al., 2006; Hobbs et al., 2007; Zametkin et al., 1993).

The cortical hypoarousal model proposed by Satterfield and Dawson (1971) suggests that core symptoms associated with ADHD are the result of an under aroused nervous system. In this model, hypoarousal in ADHD (or low central nervous system arousal) is reflected as an increase in slow-wave EEG activity (Clarke et al., 2020). Behaviourally, hypoarousal can manifest as a lack of vigilance, focus, and attentional resources. Researchers have proposed that hyperactive and impulsive behaviours in ADHD can act as autoregulatory strategies that can enhance arousal and stimulation so they can remain vigilant (Geissler et al., 2014). Researchers have coined this tendency to stabilize brain arousal as ‘vigilance regulation’ and propose it to be another way to explain arousal dysregulation in ADHD (Geissler et al., 2014). Importantly, the focus on hypoarousal in these models provides information about the functional aspects of the underlying pathology in ADHD. Because it can help researchers and clinicians understand connections between etiology and behavioural systems in ADHD, these models may be more useful than previous ones in terms of clinical utility.

In summary, pre-existing psychophysiological models of ADHD have helped shape early interpretations of brain alterations in this population. In the maturation lag model, alterations in ADHD are described as being similar to typical behaviour in younger, unaffected children. In the developmental deviation and cortical hypoarousal models, alterations in ADHD are described independent of normal populations and a greater emphasis on the underlying pathology of ADHD is considered.

1.3.2 Resting-state EEG Patterns in ADHD

There is a rich history of data demonstrating atypical resting-state EEG spectra in ADHD relative to controls (Barry et al., 2003; Koehler et al., 2009; Satterfield et al., 1972). One of the most robust findings in ADHD and resting-state EEG research is increased theta and decreased beta activity in ADHD relative to controls, also referred to as "theta-to-beta" ratio. The theta/beta ratio was previously believed to represent arousal (Lubar, 1991), but more recent findings suggest it is a marker of cognitive processing capacity (Clarke et al., 2019; Picken et al., 2020). Elevated theta/beta is such a common characteristic of ADHD that it was approved by the Food and Drug Administration (FDA) in the United States to inform ADHD diagnosis (Loo & Arns, 2015). The availability of this objective tool could help reduce diagnostic error and compliment current gold standard clinical assessments. However, more recent work has found that the theta/beta ratio is present in other psychiatric disorders such as schizophrenia, OCD, and internet addiction (Newson & Thiagarajan, 2019), suggesting that this ratio may be a marker for a similar set of symptoms across related disorders rather than specific to ADHD. Additional research is needed to uncover how the theta/beta ratio can be used in the context of diagnostic comorbidity.

This emerging literature provides valuable insight regarding the brain-behaviour connections in ADHD. Although studies examining resting-state EEG in ADHD have used various methods to classify diagnostic groups and quantify EEG, findings have been comparable across studies (See Clarke et al., 2020). In general, most studies report elevated slow-wave activity in ADHD, reflected in relative theta power. These findings tend to remain consistent in eyes-open and eyes-closed conditions. Reduced relative alpha and relative beta (but not absolute alpha and beta) in ADHD compared to controls has also been observed across most studies. Findings regarding delta power have been much more variable, but a fair number of studies have reported increased relative and absolute delta in ADHD. Much less is known about how additive language difficulties in ADHD would impact the EEG profiles and the diagnostic utility of resting-state EEG.

1.4 Utility of Behavioural Metrics

Behavioural measures of ADHD that assess impulsive responding, sustained attention, and vigilance may have limitations in clinical settings because these deficits are not exclusive to ADHD (Ricco et al., 2001). Relying solely on these measures in clinical settings could lead to over-identification of ADHD or under-identification of DLD. Indeed, previous research has demonstrated high false positive rates (81%) when using executive function assessments (The Gordon Diagnostic System; Gordon, 1995) to distinguish ADHD from those with comorbid language disorders (Rielly et al., 1999). Standard language tasks used to identify language disorders can also be challenging for children with ADHD even when comorbid language difficulties are not apparent (Oram Cardy et al., 1999). These findings suggest that tasks used to identify language disorders may require cognitive processes, such as inhibition, working memory, and executive function, that children with ADHD often struggle with.

To circumvent these issues, researchers have explored other efficient methods for identifying ADHD and DLD and decades of research have provided evidence that nonword repetition and sentence recall are robust clinical markers of language impairment (Archibald & Joanisse, 2009; Falcaro et al., 2008; Redmond et al., 2011) across ages (Conti-Ramsden, 2003; Conti-Ramsden & Hesketh, 2003; Oetting & Cleveland, 2006; Poll et al., 2010) and languages (Guasti et al., 2021; Taha et al., 2021; Vang Christensen, 2019; Wang et al., 2022). Although less studied, research has found that along with assessments of nonword repetition and sentence recall, tense marking and narrative discourse measures are among the best at distinguishing ADHD and DLD (Redmond et al., 2011). However, much less is known about how these assessments function in unique subtypes (inattentive versus combined subtypes of ADHD) or in the context of comorbidity. Furthermore, despite marked reading deficits in DLD (Catts et al., 2005) and ADHD (Brimo et al., 2020; Peterson & Pennington, 2015), no studies to date have explored the capacity of word and nonword reading measures in distinguishing the two disorders. Going forward, the application of these assessments in children and adolescents with unique subtypes and comorbidities must be considered before the utility of these metrics can be fully trusted.

1.5 Utility of Resting-state EEG Metrics

Advances in neuroimaging technologies have led to significant growth in our understanding of the neural correlates of ADHD and related disorders. Studies utilizing resting-state functional magnetic resonance imaging (rs-fMRI) have found promising functional neural correlates of schizophrenia (Kottaram et al., 2018), autism spectrum disorder (ASD; Abraham et al., 2017), and Parkinson's disease (Skidmore et al., 2013). Other work has found reliable alterations in resting-state EEG power frequency in Alzheimer's disease (Ju et al., 2017), ASD (Shepard et al., 2018), schizophrenia (Luo et al., 2020), and most notably, ADHD (Furlong et al., 2021). These alterations are believed to reflect neurophysiological differences associated with the diagnostic symptoms of a particular disorder. Relative to other neuroimaging techniques, resting-state EEG is less invasive, inexpensive, and requires low cognitive demands. For these reasons, the resting-state EEG approach to measuring power spectra is suitable in younger subjects with developmental disorders.

1.6 Relevant Issues in Diagnostic Utility Research

Most resting-state EEG studies focus on one clinical disorder at a time. As a result, much is less is known about the neurophysiological profiles of children with comorbid diagnoses or whether signature resting-state EEG markers, such as increased theta, can differentiate pure and comorbid groups. Although limited, findings from studies investigating the utility of resting-state EEG in ADHD and comorbid disorders (e.g., autism spectrum disorder, reading disability, conduct disorder) point to qualitatively distinct EEG profiles reflected in reductions in power across frequency bands in comorbid groups compared to controls (Bink et al., 2015; Bellato et al., 2020; Buyck & Wiersema, 2014; Clarke et al., 2002; Park et al., 2017; Shephard et al., 2018). These findings highlight the importance of including comorbidities in future investigations so that comparisons across patient groups can be made and research findings are generalizable to broader ADHD and DLD populations.

Notably, a major challenge for researchers when administering diagnostic assessments is not whether a child has a diagnosis, but which diagnostic category best suits their symptomology. Making these distinctions can be especially difficult in disorders that rarely present without comorbid difficulties, like ADHD and DLD. The use of studies with only pure cases of ADHD and DLD to draw conclusions about the diagnostic value of behavioural and resting-state EEG metrics, such as the FDA-approved theta/beta ratio in ADHD, is common. However, pure samples are rare and only represent a small portion of the population. This is problematic as research findings from such studies may not be applicable to the broader population. An additional concern is that elevated levels of theta/beta have been found in other psychiatric conditions (Newson & Thiagarajan, 2019), indicating that this marker is not specific to ADHD. This lack of specificity raises questions about the reliability of using the theta/beta ratio as a sole diagnostic marker for ADHD, as well as its potential to extend to DLD and yield false-positive results.

1.7 Objectives and Overview

The central objective of this thesis is to elucidate the basis of the overlapping disorders of ADHD and DLD, including why they might co-occur. Previous research on diagnostic utility has compared children with either ADHD or DLD to TD controls. However, both disorders exhibit high heterogeneity and a complex range of overlapping behaviours. To address this, the current thesis utilizes behavioural and EEG approaches to explore how children and adolescents with ADHD and/or DLD and subtypes of ADHD can be more effectively distinguished and characterized.

Chapter 2 provides a comprehensive scoping review of studies examining a wide range of language abilities in ADHD and DLD. Research in this area continues to grow, and yet the findings remain inconsistent. Review findings are summarized based on notable similarities and differences between groups. The need for standardization across studies regarding diagnostic criteria and assessment protocols are discussed.

Chapter 3 builds upon the findings from chapter 2 by examining the impact of comorbid language disorder in children with ADHD, and how it may worsen language and reading difficulties. Previous research has identified various assessments, including language measures, nonword repetition, tense marking, narrative discourse, and sentence recall (Redmond et al., 2011) as effective in distinguishing between ADHD and DLD children. Chapter 3 expands on this research by examining whether additional language and reading assessments can accurately classify children with ADHD and/or DLD, as well as different subtypes of ADHD (combined or inattentive subtype). This experiment aims to deepen our understanding of how the co-occurrence of these two conditions influences language and reading, as well as the overlapping presentation of symptoms. Furthermore, this research seeks to contribute to the scarce area of research on how psycholinguistic assessments can effectively distinguish comorbid samples.

Relying solely on behavioural measures for clinical diagnosis can introduce biases, both from the patients and the researchers involved. Clinical interviews, for instance, can be influenced by a parent's subjective perception of what is considered normal behaviour in their child. Parents may also have their own biases that motivate them to actively seek out a particular diagnosis for their child. Diagnoses are often based on these interviews and assessments that rely on subjective ratings. To address these limitations, Chapter 4 compares oscillatory power during resting-state EEG recordings between pure ADHD, comorbid ADHD + DLD, and TD groups. The aim is to explore the potential utility of more objective measures in distinguishing ADHD, comorbid ADHD + DLD, and TD children and adolescents. The chapter also considers the impact of age and diagnosis on oscillatory power. This approach seeks to provide a more comprehensive assessment of the distinct characteristics and brain patterns within these clinical populations, minimizing the influence of subjective biases.

The findings presented in this thesis have important implications for understanding the behavioural and biological pathways involved in ADHD, DLD, and their comorbidity. They can contribute to a deeper understanding of the behavioural and neurophysiological profiles of children and adolescents with pure and comorbid diagnoses, shedding light on which cognitive systems may be affected. Furthermore, these findings can assist researchers and clinicians in making informed decisions about the validity of language, reading, and resting-state EEG metrics in diagnosing ADHD and DLD. Overall, this thesis can offer valuable insights into these highly comorbid disorders and their overlap, offering potential directions for future research and clinical practice.

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Chapter 2 : Language Abilities in ADHD and DLD: A Scoping Review

2.1 Introduction

The ability to comprehend and use language plays a vital role in a child's academic and social success. While most children effortlessly acquire language through interactions with their parents and social experiences, some encounter challenges in this process. These children who struggle to grasp essential language concepts in their early years face an increased risk of difficulties in academic, social, and emotional development (Clegg et al., 2005; Bretherton et al., 2014). Language difficulties can persist beyond the school years, negatively affecting occupational performance, economic success (Johnson et al., 2010; Law et al., 2009), and quality of life (Eadie et al., 2018; Lensing et al., 2015; Wehmeier et al., 2010). Extensive research has been conducted to understand the development of fundamental language skills and to identify specific areas where children with language difficulties may face obstacles during critical stages of language acquisition.

Language learning difficulties can be associated with various clinical conditions or diagnoses, impacting various aspects of language such as phonology, morphology, syntax (language form), semantics (content), and pragmatics (the social use of language). Some children who struggle with language acquisition may also have co-occurring conditions like hearing loss, developmental disabilities, or neurological impairments, which impede their ability to learn language in a typical environment. For instance, a child with a hearing impairment may face challenges in language learning due to the inability to rely on auditory input. On the other hand, some children may exhibit typical development in most areas but struggle specifically with language and speech. In such cases, language difficulties can arise without an underlying clinical or cognitive deficiency. Additionally, certain children with pre-existing diagnoses may experience language difficulties despite language not being a core feature or symptom of their existing condition.

Persistent problems in language development in the absence of any known perceptual, cognitive, or clinical disorder has been variously termed specific language impairment (SLI), language delay, language disorder, and language-learning difficulty. More recent consensus suggests the term developmental language disorder (DLD) best captures this admittedly heterogeneous category (Bishop et al., 2017). Children with DLD are among those who experience language difficulties in the absence of any underlying biomedical conditions (e.g., brain injury, cerebral palsy, neurodegenerative diseases). This condition affects approximately 7-8% of school-aged children (Johnson et al., 1999; Norbury et al., 2016; Tomblin et al., 1997) and can impact various degrees of language processing including production, comprehension (Bishop et al., 2017; Leonard, 2014; McGregor et al., 2020), phonology (Archibald & Joanisse, 2009), morphosyntax (Arosio et al., 2016), expressive grammar (Yarian et al., 2021), and pragmatics (Arosio et al., 2017; Leonard, 2014). Some early predictors of DLD between the second and third year of life include limited expressive vocabulary, poor comprehension, absence of word combinations, and absence of gestures (Sansavini et al., 2021). These language difficulties put children with DLD at greater risk for negative peer and social interactions.

Attention-deficit/hyperactivity disorder (ADHD) is a psychiatric/behavioural disorder characterized by developmentally inappropriate degrees of inattention and/or hyperactivity-impulsivity (5th ed.; DSM–5; American Psychiatric Association [APA], 2013). While previous estimates suggested ADHD rates of 3-7% (Polanczyk & Jenson, 2008), recent research indicates a higher prevalence, with 15.5% of school-aged children meeting the diagnostic criteria (Rowland et al., 2015). Children with ADHD, like those with DLD, are at a greater risk for negative peer relations and school outcomes. Teacher and caregiver reports indicate that children with ADHD are more likely than their TD peers to wander off topic during conversations, blurt out answers, have difficulty remembering verbal instructions, and not wait their turn in conversation (Guerts & Embrechts, 2008; Kim & Kaiser, 2000). These challenges are particularly significant during early preschool years when children learn how to focus their attention on teachers, engage with peers, and follow classroom instructions appropriately.

While language difficulties are not a diagnostic requirement for ADHD, numerous studies have highlighted their prevalence in individuals with ADHD. These difficulties encompass comprehension (Korrel et al., 2017), production (Kim & Kaiser, 2000), and the social use of language relative to TD peers (Geurts & Embrechts, 2008; Green, Johnson, & Bretherton, 2014; Korrel et al., 2017; Purvis & Tannock, 1997; Staikova et al.,2013). Around 40-50% of children with ADHD exhibit co-occurring speech and/or language impairments (Bruce et al., 2006; Cohen et al., 1993; Hagberg et al., 2010; Oram Cardy et al., 1999; Sciberras et al., 2014), and 20-30% of those with language impairments also have ADHD (Beitchman, Hood, Rochon, & Peterson, 1989; Tannock & Schachar, 1996). Some researchers suggest that the concomitant language difficulties associated with ADHD are the result of poor information processing that can compromise environments that support language learning (Love & Thompson, 1988).

This pronounced overlap in symptomology can make it especially difficult to differentiate them, which can result in increased risk of misdiagnosis or misclassification.

Studies comparing language abilities in ADHD and DLD have yielded mixed results, with some finding reduced syntactic (Helland et al., 2014), and phonological processing abilities in DLD relative to ADHD (Redmond et al., 2011a), and others not (Everatt et al., 2008; Javorsky, 1996; Luo & Timlet, 2008). Similarly, variations exist in the findings concerning narrative language ability and vocabulary between the two conditions (Fillppatou & Livaniou, 2005; Luo & Timlet, 2008; Redmond et al., 2011a, 2011b; Williams, 2000). These discrepant findings may stem from a lack of standardization across studies regarding eligibility, measurement tools, assessment protocols, criteria for ADHD and DLD, and/or unmeasured comorbidities.

Symptoms of ADHD and DLD can be observed in children as young as three years old (Barkley, 1989). However, much of the research conducted on these conditions has focused on school-aged children. This emphasis on older children is due to several reasons. First, as children progress thorough primary school, they face greater demands that require increased attention, focus, and longer periods of inactivity (Agapitou & Andreou, 2008). With increased demands, the impact of poor language skills may become more noticeable, making it easier to recognize the extent to which these children deviate from their TD peers. Second, identifying language disorders in preschoolers can be challenging due to the significant variability in children's communicative patterns and language development during this stage (Sansavini et al., 2021). The wide variability makes it difficult to differentiate between language delay and language disorder. Additionally, there is a lack of developmentally appropriate assessments for preschoolers with ADHD (Byrne et al., 1998), making it challenging to diagnose or refer for diagnosis at this age. Researchers propose that assessments of linguistic difficulties should extend beyond language, and include non-linguistic abilities, such as working memory, expressive prosody, executive skills, and sound discrimination (Sansavini et al., 2021). Sustained attention assessments may also be useful markers of language difficulties, considering the connection between language and attention in both DLD (Smolak et al., 2020) and ADHD (Bellani et al., 2011). Including non-linguistic abilities in assessments could lead to improvements in risk assessments for preschoolers with language difficulties, enabling more precise and early diagnoses.

The purpose of this scoping review is to provide a comprehensive summary of language performance in children with ADHD and DLD. Scoping reviews represent a comprehensive approach to synthesize the available evidence available on a topic on which there does not already appear to be a broad consensus. By identifying similarities and differences in language abilities between these two prevalent disorders, the review seeks to deepen our understanding of the overlapping and distinct language features present in ADHD and DLD. The findings of this review have the potential to shed light on why these two disorders often co-occur and could have important implications for improving services, treatment effectiveness, and risk assessments for these children.

A scoping review aims to comprehensively identify all the relevant literature on a topic and can be useful in clarifying key concepts, identifying the types of evidence available, and/or examining how research is conducted on a topic (JBI, 2020; Pham et al., 2014). Unlike systematic reviews however, the aim is not to critically appraise individual studies, address the effectiveness of study designs or interventions, or answer focused research questions. Rather, they serve as an initial step to future research where a complete picture is currently lacking, and toward systematic reviews that can examine topics more narrowly and answer specific research questions. A comprehensive review of the research examining language ability in ADHD and DLD is needed to consolidate many of the inconsistent findings in the literature. A scoping review is the ideal way forward in motivating future work in this domain.

2.2 Methods

To understand the shared and unique language characteristics in ADHD and DLD, a scoping review was conducted based on the methods prescribed in the Joanna Briggs Manual for Evidence Synthesis (JBI, 2020), and was formatted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRIMSA-ScR; Tricco et al., 2018). The current review methods involve the following five stages: (a) identify the research question, (b) identifying relevant studies, (e) study selection, (d) charting the data; and (e) summarizing and reporting results. The objectives and methods of this review were pre-registered to the Open Science Foundation website (https://osf.io/5jrgy/). Please see Figure 2.1 for an illustration of the scoping review process.

Articulate the Research Question

- Form question based on the literature review and prior research knowledge
- Perform preliminary search to identify volume of literature/keywords

Identify Relevant Studies

- Development of inclusion/exclusion criteria
- Create review protocol and upload to Open Science Framework
- Search two electronic databases (done collaboratively with a trained librarian)

Study Selection

1. Title and abstract screening
    - Apply pre-defined inclusion/exclusion criteria
    - Reliability trial of ten articles (meetings to further establish reliability)
    - Review of inclusion/exclusion criteria
2. Full-text review
    - Review of research question and inclusion/exclusion criteria
    - Reliability trial of ten articles (meetings to further establish reliability)
3. Reference list screening
    - Review of inclusion/exclusion criteria
    - Reliability trial of ten articles
    - Clarification meetings as needed

Charting the Data

- Development of the data charting form in Covidence
- Data extraction (reviewed and coded twice)

Collating, Summarizing, and Reporting the Results

- Kappa inter-rater agreement
- Quantitative presentation of findings (performance on language measure)
- Qualitative/thematic analysis of findings

Figure 2.1. Flow diagram of the scoping review process adapted from Cunningham et al. (2017).

2.2.1 Identifying the Research Question

The aim of the present review was to summarize and disseminate research findings on language abilities in children with ADHD and DLD. Specifically, it was of interest to answer the following questions: (a) how do children with ADHD perform relative to children with DLD on various language assessments, and (b) in what areas of language do they have overlapping and distinct difficulties?

2.2.3 Identifying Relevant Studies

A preliminary search was conducted to determine the volume of literature available on the topic and given this amount of literature, whether a scoping review was appropriate. The preliminary search also served to determine relevant search terms and keywords that should be used during the final search. This preliminary search identified few articles, suggesting, a scoping review was the most appropriate approach to summarizing available evidence. Further, given that few studies were identified, the decision was made to avoid applying any publication date or participant age restrictions during the final search.

Following the preliminary search, a second search was performed and applied to the databases PsycINFO (OVID), ERIC, Scopus, and Medline (OVID) on February 12th, 2021. Broad search terms were used to gather a list of articles relevant to the topic. The search terms included “developmental language disorder” OR “specific language impairment” OR “language difficulties" OR “primary language impairment” OR “language disorder” OR “language disability” AND “attention deficit hyperactivity disorder” OR “attention deficit disorder with hyperactivity” OR “attention deficit hyperactive disorder” OR “attention deficit disorder” OR “hyperkinesis” OR “hyperkinetic disorder” AND “language” OR “vocabulary” OR “verbal communication” OR “oral communication” OR “psycholinguistics” OR “pragmatics” OR “comprehension” OR “grammar” OR “phonology” OR “syntax” OR “semantics” OR “morphology” OR “linguistics” OR “verbal ability” OR “verbal fluency”. All terms were selected based on those used in previous studies identified during the preliminary search and no limits were applied in any of the four databases. This search yielded a total of 2,283 studies, 316 of which were duplicates. All studies included in the final review must have met the following inclusion criteria: Empirical studies published in a peer-reviewed journal and written in English. Participants were required to have non-comorbid ADHD and DLD that was confirmed by either a clinical professional and/or through a standardized assessment. Specifically, it was required that each study determined that participants with DLD did not also have ADHD or vice versa. Related to this point, children with DLD were required to have clear deficits in areas related to receptive/expressive, grammar, and phonology. Studies were required to include at least one behavioural measure of language ability. Such measures could include, but were not limited to assessments of receptive, expressive, phonological, syntactic, semantic, and/or pragmatic language abilities. All studies must have reported original, empirical findings. Studies meeting the following exclusion criteria were not included in the review: Studies that assessed only comorbid samples including but not limited to, Dyslexia and/or autism spectrum disorder. Dissertations, reviews, case studies, books, and studies examining only spelling, reading, and/or writing abilities were also excluded. A full assessment of the complex issues around comorbidity of ADHD with DLD was beyond the scope of this review. Our aim was to limit the review to studies focusing on ADHD or DLD (without comorbid reading and/or developmental disorders) to allow a clear characterization of the language difficulties specifically associated with ADHD and DLD symptoms, rather than those that may reflect multiplicative or additive effects of two or more distinct disorders.

2.2.4 Study Selection

The screening program Covidence (*Covidence*, 2021) was used to thoroughly screen and extract relevant data throughout the scoping review process. After removing duplicate articles, two researchers (KP and CM) were trained on the inclusion and exclusion criteria prior to starting the review process, and then independently screened and reviewed the titles and abstracts of each article. An initial reliability run was performed by both reviewers on a small number of articles to evaluate their proportion of agreement and determine whether additional training on the inclusion and exclusion criteria was necessary. The reliability run consisted of reviewing the titles and abstracts of ten articles independently. Any discrepancies that occurred during this process were discussed. Following this, the reviewers proceeded with independently reviewing the titles and abstracts for the full sample of articles. They then discussed which articles should be included in the review and completed the full-text review for these items. Articles that were not available through the Western University Library were requested through Racer Interlibrary Loan (n = 11). All articles excluded during the full-text screening process along with reasons for exclusion can be found in the appendix. Any discrepancies that occurred during the screening process were resolved through discussion and the involvement of a third reviewer, who was also a researcher in Psychology (LB).

In addition, reference lists of the selected articles and review articles returned by the search were used to identify additional review articles that matched the inclusion criteria. The cited articles were screened in the same manner as described above with an additional reviewer (KH), starting with the titles and abstracts, and moving onto the full-text stage. No new articles were identified via this method, yielding a total of 18 studies for inclusion in this review. Figure 2.2 illustrates the scoping review process, including reasons that articles were excluded at each screening stage.

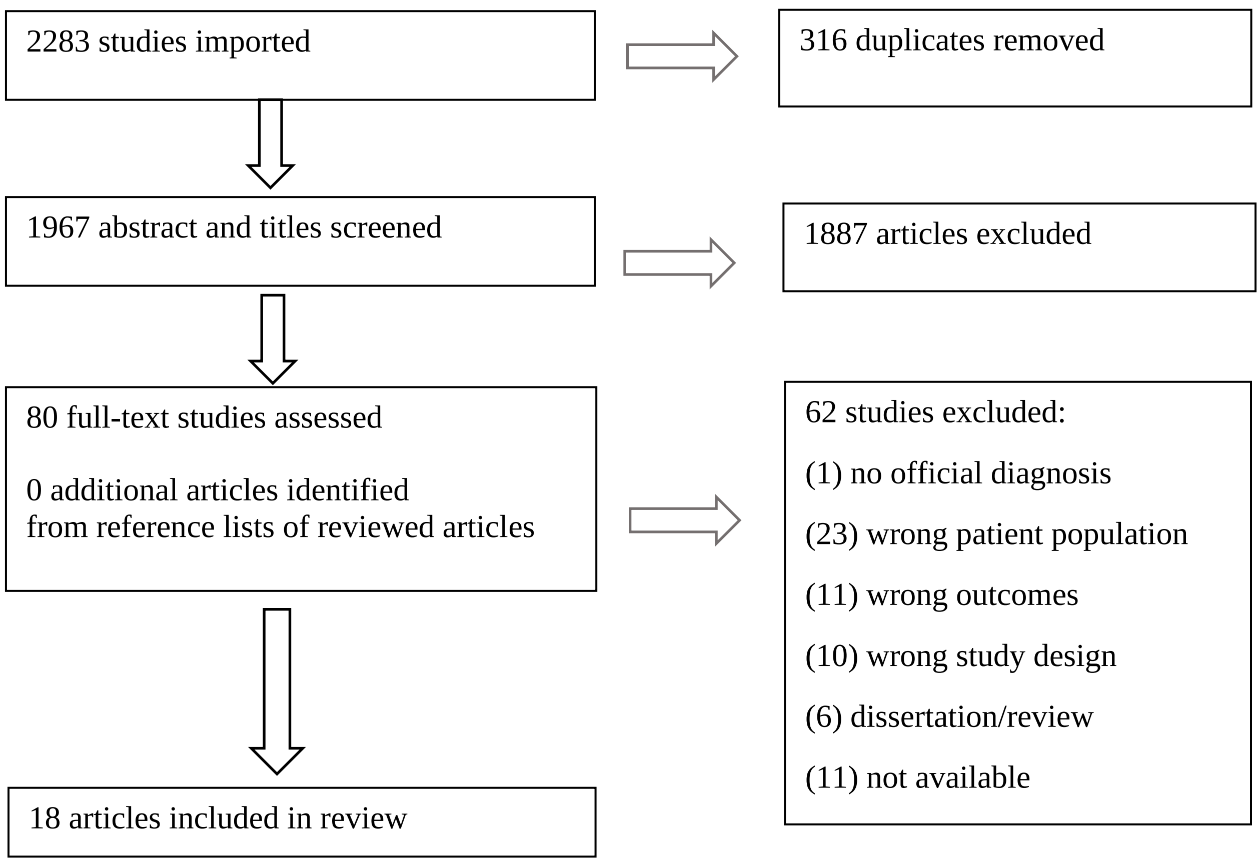

Figure 2.2. PRISMA flowchart illustrating the process for the selection of included articles.

2.2.5 Charting the Data

Following the screening phases, each article was scanned and charted individually in Covidence by a trained reviewer (KP) using the following headings: general information, methods, results, and conclusions. For general information, the following data was charted: author(s) and year of publication. Methods included the following information: study aim(s), mean age, and sample size for ADHD and DLD groups separately, total sample size, age range, gender, confirmation of ADHD and DLD diagnosis (task/measure used), language task used, and language abilities examined. Results included the following information: ADHD versus DLD performance on language tasks, type of statistic (analysis of variance/t-test). Finally, conclusions included the following information: summary of performance and findings, and other relevant details. Following this, each article was reviewed a second time by the same reviewer to ensure all relevant details were charted correctly. Studies that met the inclusion criteria were carefully examined to determine whether the group comparisons on language abilities were based only on the assessments used to diagnose or confirm DLD status. If children with DLD were required to score lower on these assessments to qualify for DLD membership, then the question of whether children with DLD displayed inferior performance compared to children with ADHD on these assessments had effectively been resolved (See Appendix for methods used for evaluating language for group inclusion). It is crucial to note that these articles (n = 2) were retained in our current review because there is little research on this topic, they aligned with our inclusion criteria, and may offer insights into the comparative performance of these children on language measures.

2.2.6 Summarizing and Reporting the Results

After extracting the data, the number of studies assessing each type of language ability were calculated. Qualitative results for each study were also summarized.

2.3 Results

Quantitative and qualitative findings were reported for the present review. Descriptive characteristics for each study, including sample size and mean ages for each group are outlined in Table 2.1. Performance summaries comparing ADHD to DLD children are outlined in Table 2.2 and language task(s) and language domain(s) assessed in each study are outlined in Table 2.3. In addition, qualitative summaries are provided based on the language domain. After carefully examining each article, seven domains of language were identified: language form, language content, language use, general language ability, expressive language ability, receptive language, narrative language, and vocabulary. All three reviewers categorized each individual article based on the language abilities assessed before consensus was made. Domains were entirely guided based on the language abilities examined in each study. For example, studies that examined phonological abilities in ADHD and DLD were placed under the language form domain.

The kappa statistic was used to determine interrater reliability between the two reviewers during the title and abstract and full-text screening stages. For the title and abstract screening stage, interrater reliability was substantial (κ = .73). For the full-text review stage, interrater reliability was strong (κ =.88), suggesting that there was considerable agreement between the reviewers in applying the inclusion and exclusion criteria. Reliability was improved from the title and abstract screening to the full-text screening stage by meeting to discuss any uncertainties throughout the screening process and involving a third reviewer who was trained on the inclusion and exclusion criteria.

Table 2.1. Demographic characteristics for each individual article (N = 18).

Author(s)	*n* (ADHD)	ADHD Gender	*n* (DLD)	DLD Gender	Mean age (ADHD)	Mean age (DLD)	Stimulant Medication During Assessment
Everatt et al. (2008)	12	8 males, 4 females	13	9 males, 4 females	11.50	11.62	--
Filippatou & Livaniou (2005)	32	28 males, 4 females	49	35 males, 14 females	8.90	8.60	No
Helland et al. (2014)	21	17 males, 4 females	19	17 males, 2 females	10.10	8.70	--
Hutchinson et al. (2012)	16	12 males, 4 females	18	12 males, 6 females	7.36	7.76	No
Javorsky (1996)	26	15 males, 11 females	14	6 males, 8 females	12.30	14.10	Yes
Löytömäki et al. (2020)	17	14 males, 3 females	13	9 males, 4 females	8.06	7.62	Yes
Luo &Timler (2008)	6	4 males, 2 females	5	3 males, 2 females	10.90	10.10	--
McInnes et al. (2003)	21	21 males	19	19 males	10.90	10.60	No
Oram Cardy et al. (2010)	14	10 males, 4 females	14	11 males, 3 females	9.00	9.60	No
Redmond & Ash (2014) † same participants as Redmond (2011a, 2011b)	20	15 males, 5 females	20	12 males, 8 females	7.85	7.85	No
Redmond et al. (2011a) †	20	15 males, 5 females	20	12 males, 8 females	7.85	7.85	No
Redmond (2011b) † same participants as Redmond et al. (2011a)	20	15 males, 5 females	20	12 males, 8 females	7.85	7.85	No

Redmond (2005) †	10	9 males, 1 female	10	7 males, 3 females	6.91	6.58	Yes
Redmond (2004) † same participants as Redmond (2005)	10	9 males, 1 female	10	7 males, 3 females	6.91	6.58	Yes
Short et al. (2020)	26	85% males	24	83% males	5.55	5.79	--
Stanford & Delage (2020)	20	13 males, 7 females	20	12 males, 8 females	8.10	8.60	Yes
Weyandt & Willis (1994)	36	36 males	34	18 males, 13 females	9.01	8.55	--
Williams et al. (2000)	10	5 males, 5 females	10	5 males, 5 females	6.00	6.00	--

Note. † Indicates that the same group of participants were examined across studies. -- indicates information was not provided by authors.

2.3.1 Language Form

Language form was examined by several studies in the review and included phonology (sound patterns; Everatt et al., 2008; Javorsky, 1996), phonological processing (Hutchinson et al., 2012; Redmond et al., 2011a) syntax (word order; Javorsky, 1996; Helland et al., 2014), and morphosyntax/grammar (language structure; Redmond et al., 2011a, Redmond, 2011b, Stanford & Delage, 2020). Among the studies that examined these language forms, performance varied according to the type of form examined, and contradictory findings emerged for syntactic abilities. Overall, children with ADHD had better morphosyntactic/grammatical abilities (Redmond et al., 2011a, Redmond, 2011b, Stanford & Delage, 2020). Phonological abilities were comparable in ADHD and DLD (Everatt et al., 2008; Javorsky, 1996) when measured using vocabulary and achievement tests, but significantly worse in DLD compared to ADHD when measured using a nonword repetition task (Hutchinson et al., 2012; Redmond et al., 2011a). Among the two studies that examined syntactic skills, one found that compared to children with ADHD, those with DLD scored lower (Helland et al, 2014) while another found ADHD and DLD performance to be comparable (Javorsky et al., 1996).

Everatt et al. (2008) examined whether a series of language, reading, and cognitive measures could distinguish children between 11 to 13 years of age with DLD, ADHD, and other special educational needs from their TD peers. Phonological awareness was measured using a segmentation task where children were required to segment sentences such as “say boat without /b/’’. Children with ADHD and DLD did not significantly differ on phonological awareness and the remaining individual measures were not accurate in differentiating the special educational needs children from their TD peers.

Hutchinson et al. (2012) examined whether examined phonological short-term memory abilities in ADHD and DLD between 6 and 9 years of age using a non-word repetition task. On this task, children hear an unfamiliar nonword and are expected to repeat it as quickly as possible. The authors found that children with language impairments made significantly more phonological errors than children with ADHD. Javorsky and colleagues (1996) also compared the phonological and syntactic abilities of children and youth with ADHD and DLD between 6 to 17 years of age. Composite phonology and syntax scores were created by administering several subtests or subscales from the Woodcock-Johnson Psycho-Educational Battery-Revised (WJPB-R; Woodcock & Johnson, 1989), Kaufman Test of Educational Achievement (K-TEA; Brief Form; Kaufman & Kaufman, 1989), Wide Range Achievement Test-Revised (WRAT-R; Jastak & Wilkinson, 1984); Peabody Picture Vocabulary Test-Revised (PPVT-R; Dunn & Dunn, 1981), and Test of Language Competence-Expanded Edition (TLC-EE; Wiig & Secord, 1988) that tapped into spelling ability (phonology), dictation, writing samples, proofing, usage, and punctuation-capitalization (syntax). Although children and youth with ADHD performed significantly better on dictation and spelling subtests, they did not differ from the DLD group on the composite phonology and syntax scores. Helland et al. (2014) used the children's communication checklist (CCC-2; Bishop, 2003) to measure syntactic abilities and found that relative to children with DLD, children with ADHD have better overall syntactic abilities.

Additionally, Stanford and Delage (2020) compared the morphosyntax profiles of children with ADHD and DLD using two computer-based assessments. First, the child was presented with an image and encouraged to describe the image using appropriate sentence structure. The child's ability to produce several morphosyntactic forms was then evaluated, including passives, future tense, past tense, plural verb conjugations, irregular plural nouns, and contracted articles. The second morphosyntax task was intended to elicit third-person nominative and accusative pronouns and required children to respond to a question about an image on a screen. As expected, compared to children with ADHD, those with DLD scored lower on both morphosyntax tasks. Similarly, Redmond et al. (2011a) and Redmond (2011b) found that children with ADHD not only outperformed those with DLD on assessments of grammar but performed comparable to TD peers. Together, these findings suggest that morphological/grammatic abilities are superior in ADHD and syntactic and phonological difficulties might be more heavily impacted by the diagnostic criteria used to define groups and the task selected to measure these abilities.

Contradictory findings emerged among the two studies that examined syntactic abilities (Javorsky, 1996; Helland et al., 2014) and this could be the result of using different diagnostic criteria and standardized assessments. Javorsky (1996) was published earlier and therefore, an earlier version of the Diagnostic and Statistical Manual of Mental Disorders (3rd edition, revised) (DSM- III-R; American Psychiatric Association, 1987) was used to establish diagnostic status, at a time when inattention was the predominant focus of the diagnosis rather than both inattention and hyperactivity-impulsivity. Further, Javorsky (1996) described language learning disabilities as subtle difficulties in expressive and receptive language, as well as behavioural difficulties related to oppositionality, aggression, and withdrawal. Including children in the language disordered group with behavioural difficulties that often overlap with symptoms of

ADHD, such as oppositionality (Biederman, 2005), may explain why comparable syntactic abilities were found between the two groups.

However, comparable performance between ADHD and DLD children does not necessarily indicate that children with ADHD are not experiencing difficulties in the specified language areas. Phonological processing involves recognizing, manipulating, and segmenting parts of words and sentences which can place high attentional demands on a child with ADHD. In fact, many of the studies summarized above found that children with ADHD scored lower on these measures than their TD counterparts (Everatt et al., 2008; Hutchinson et al., 2012; Stanford & Delage, 2020).

2.3.2 Language Content

Children who demonstrate strong language content can understand meaning in different types of words, phrases, and narratives. They are also better able to categorize different words, generate analogies, and make repeated associations. Only two studies compared the semantic abilities of children with ADHD and DLD (Helland et al., 2014; Javorsky, 1996), and both found no significant differences. Specifically, children with ADHD and DLD both had weaker semantic abilities compared to TD peers, yet these abilities were comparably weak among the two groups.

Although both studies found evidence of weak semantic abilities in ADHD and DLD, they varied on their methods of assessment, the way their diagnostic groups were defined, as mentioned above, and the age ranges examined. As a result, findings could be reflective of methodological differences rather than true semantic weaknesses in ADHD and DLD. Helland et al. (2014) used the CCC-2 to measure semantic abilities in children between 6 and 12 years of age. The CCC-2 consists of 70-items that are broken up into ten subscales and measure speech, syntax, semantics, as well as other subscales relating to the use of language. The semantics subscale assesses how many times the child mixes up words of similar meaning. Javorsky (1996) measured semantic abilities in children and youth between 6 to 17 years of age using various assessments. The authors performed a factor analysis to determine how well several independent assessments loaded onto three language clusters: syntax, phonology, and semantics. The PPVT-R, WJPB-R listening comprehension, and K-TEA reading were best at loading onto the semantic language cluster. The listening comprehension subtest of the WJPB-R measures the ability to provide one-word responses to cloze passages verbally. The reading subtest of the K-TEA is a measure of basic decoding and comprehension skills of short passages. Although both subtests tap into reading ability, they also rely on the ability to recognize and apply words based on their meaning.

Despite the differences between studies, the respective authors arrived at the same conclusion. Together, they found that children and adolescents with ADHD and language disorders both struggle with aspects of semantic language. Another explanation for why children with ADHD and DLD performed similarly on semantic language tasks could be due to shared deficits in cognitive processes involved in these tasks. Semantic processing relies on working memory, attention, and executive functions, which are known to be impaired in both ADHD and DLD (Brown, 2009; Laasonen et al., 2018; Leonard et al., 2007; Willcutt et al., 2005). These deficits may impact their ability to effectively access and retrieve work meanings during semantic processing. Although an important contribution to the present review, the results from these two studies should be interpreted with caution. Additional studies are needed to confirm whether these findings are replicable and determine whether firm conclusions can be drawn about overlapping semantic difficulties in these two populations.

2.3.4 Language Use

Pragmatic language refers to the appropriate use of language in social contexts and social interactions. Pragmatic language is typically divided into three domains: discourse, communicative intention, and presupposition (Fujiki & Brinton, 2009; Geurts et al., 2008; Landa, 2005). Discourse includes how to initiate, maintain, and end conversations, communicative intention involves how to request or inform, and presupposition involves assumptions about the speaker and the context. Children with pragmatic difficulties may struggle to pick on up verbal and nonverbal cues, convey information through nonverbal means such as facial expression, gesture, or prosody, or violate the rules of conversational exchange (Adams et al., 2006; Camarata & Gibson, 1999; Fujiki & Brinton, 2009; Gilmour et al., 2004; Merrison & Merrison, 2005; Ruser et al., 2007; Ryder et al.,2008). Another area of pragmatics includes figurative language, or non-literal language, such as metaphors, idioms, hyperbole, indirect requests, and clichés. Figurative language refers to linguistic expressions that cannot be interpreted directly from the meaning of their constituents (Vulchanova et al., 2015). The listener must retrieve meaning by going beyond the literal interpretation of the speaker and instead focus on the intended meaning. Figurative language expressions can vary in transparency, structure, and length. Thus, unlike literal language, figurative language requires greater processing by relying on the combination of linguistic and contextual cues (Vulchanova et al., 2015).

A large amount of research examining children’s language abilities has focused on language form and content, while less has focused on language use, especially in developmental disorders. To our knowledge, only one review has summarized figurative language processing in ADHD and DLD, with an emphasis on intervention strategies (Chahboun et al., 2021). In line with this, only two studies compared the pragmatic language abilities of children with ADHD and language disorders/disabilities (Javorsky, 1996; Helland et al., 2014) and both found that children and adolescents had equivalent abilities in this area of language. Helland et al. (2014) assessed the social use of language in children using the CCC-2 (Bishop, 2003) and the following subscales were examined: inappropriate initiation (asks questions even though already knowing the answer), stereotyped language (uses favorite phrases in inappropriate contexts), use of context (appreciates humor expressed by irony), nonverbal communication (looks at the person they are talking to), social relations (hurts or upsets other children unintentionally), and interests (shows interests in things or activities most people would find unusual such as washing machines or traffic lights). No significant differences were found between the two groups on any of the subscales, apart from the interest subscale. On the interest subscale, there were no significant differences between the DLD and TD group however, scores of children with ADHD indicated that they experienced greater difficulties than the DLD group and the TD group. Specifically, children with ADHD showed more interests in things or activities that others may find unusual. Overall, children with ADHD and DLD displayed equivalent pragmatic difficulties and differed significantly from their TD peers on subscales measuring inappropriate initiation, stereotyped language, use of context, nonverbal communication, and social relations.

Although not the primary focus of the study, Javorsky (1996) examined figurative language abilities in children and adolescents using the Test of Language Competence

(TLC; Wiig & Secord, 1988). In this task, participants were required to interpret ambiguous language from pictures and auditory stimuli. The authors examined these abilities in children and adolescents with ADHD, language learning disabilities (LDD), ADHD/LDD, and neither ADHD nor LDD (neither). No significant differences in figurative language were observed among the four groups. An important consideration here is that although participants in the neither group did not meet the criteria for ADHD or LDD, they were receiving either inpatient or partial hospitalization for psychiatric conditions such as affective disorder (i.e., dysthymia and major depressive disorder) and disruptive disorder (i.e., oppositional defiant disorder and conduct disorder). These participants were therefore being treated for additional psychiatric disorders and would not fit the criteria as a TD control group. It remains unclear how these additional symptoms impacted performance on the figurative language task, and how ADHD and LDD performance would differ from those with TD. Previous research has found that pragmatic skills of patients with other psychiatric conditions, such as depression, have been found to be poorer than controls (e.g., Zurlo & Ruggiero, 2021). Other research has found that preschoolers with ODD demonstrate significantly more impaired pragmatic language abilities than children without disruptive behaviour disorders (Gremillion & Martel, 2014). Additionally, compared to TD controls, children with DLD (Bühler et al., 2018) and ADHD (Staikova et al., 2013) have difficulties in figurative language. The inclusion of a TD group would have allowed for more direct conclusions about how figurative language abilities in ADHD and LLD deviate from that of TD children and adolescents.

A large amount of research in DLD has focused on impairments in language structure and content, but the above findings suggest that children with language disorders also experience significant pragmatic difficulties that are comparable to that of children with ADHD. Overall, these findings indicate that children with ADHD and DLD have similar pragmatic language profiles. Together, these findings suggest that children would benefit from therapeutic interventions that focus on improving these aspects of language, in addition to language structure and content.

2.3.5 General Language

Five studies examined language performance overall, without looking more closely at any specific areas of ability. Each of these found evidence of diminished overall language ability in children with DLD compared to those with ADHD (Lou & Timler, 2008; Redmond & Ash, 2014; Redmond et al., 2011a; Redmond, 2011b; Short et al., 2020). Within these studies, general language ability was often measured by using a core language score that assessed sentence comprehension, word structure, grammatical and semantic abilities, and short-term memory. Lou and Timler (2008) examined narrative organization in children with ADHD, DLD, and TD between 8 to 11 years of age while accounting for language abilities. Core language skills were examined using the Clinical Evaluation of Language Fundamentals (CELF-4; Semel et al, 2004) and children with DLD had significantly lower core language scores than the ADHD group. However, the two groups performed just as well as each other and their TD peers at organizing story information. These findings suggest that children with DLD have lower overall language abilities but are comparable to ADHD and TD children at organizing story ideas. These findings should however be interpreted with caution given that only six children with ADHD and five with DLD were included in the final sample.

Similarly, Redmond et al. (2011a), Redmond (2011b) and Redmond & Ash (2014) found that compared to children with ADHD, children with DLD had significantly lower overall language abilities. Although not the primary focus of their study, Short et al. (2020) also examined overall language ability in children with ADHD and DLD between the ages of 4 and 7 years. The authors were interested in whether difficulties in play emerge because of developmental disabilities and whether perceptions of play are impacted by differences in language and behaviour. Children were videotaped while engaging in free play and raters were presented with videos of children playing where language was either audible, or not. The presence of language altered play ratings for children with ADHD and DLD, but not TD. When language was audible, raters scored children with DLD more poorly on play than their TD peers. When language was not audible for children with ADHD, raters perceived their play to be more disorganized compared to when language was audible. Thus, when language was not available to support their play, children with DLD were perceived to play better, but children with ADHD were perceived to play worse. When language was audible, children with ADHD looked the same as their TD peers. In the study by Short et al. (2020), language competence was measured using a parent-report language assessment known as the Adaptive Language Inventory (ALI; Feagans & Farran, 1979) which yielded a total score and significant differences between the ADHD and DLD groups emerged. Parents rated their children with DLD as having significantly more difficulties in overall language than parents of children with ADHD. Taken together, these findings suggest that compared to children with ADHD, those with DLD have greater overall language difficulties. These difficulties were evident on both standardized and parent-report assessments.

2.3.6 Expressive Language

In the current review, expressive language refers to spoken language production. Numerous studies have provided evidence to suggest that children with ADHD have better spoken language abilities than children with DLD (Helland et al., 2014;Hutchinson et al., 2012; Löytömäki et al., 2020; McInnes et al., 2003; Oram Cardy et al., 2010; Redmond, 2004; Redmond, 2005; Weyandt & Willis, 1994). Differences between ADHD and DLD children have been found in expressive language (Hutchinson et al., 2012; Löytömäki et al., 2020; McInnes et al., 2003; Oram Cardy et al., 2010; Weyandt & Willis, 1994) language production (Short et al., 2020), speech (Helland et al, 2014), spoken language (Redmond, 2004; Redmond, 2005) and oral language (Javorsky, 1996). Interestingly, one of these studies found differences in language production between ADHD and DLD children when a parent-report measure was used, but not on a standardized measure of expressive language (Short et al., 2020).

Fewer studies have found that children with ADHD and DLD have comparable spoken language abilities (Javorsky, 1996; Short et al., 2020). Javorsky (1996) examined oral expression in children and adolescents with ADHD and DLD between the ages of 6 and 17 using the TLC (Wiig & Secord, 1988). As previously mentioned, their language disordered sample included children and adolescents with behavioural difficulties that have been shown to overlap with ADHD. This study was also the only one to examine spoken language in older adolescents. The remaining studies included children under the age of 12. These methodological differences may explain why spoken language was comparable in the ADHD and DLD groups, as speech skills may be more developed in adolescents compared to younger children.

Short et al. (2020) examined the language production abilities of children between the ages of 4 and 7 years using both a parent-report and standardized language assessment; interestingly, significant differences emerged between the two assessment types. Parents rated their children with DLD as having significantly more difficulties in language production than parents of children with ADHD but there were no significant differences between the two groups on the standardized measure of expressive language. There are several explanations for why greater difficulties were observed on the parent-report assessment, but not the standardized language measure. Parents of children with DLD may be overestimating their child's language difficulties. This bias may be especially true if a diagnosis of DLD has been confirmed and services and treatments are already in use. Further, most children in the study were preschoolers and variability in children's communicative patterns at this time can make identification of a language impairment difficult. As such, the standardized language assessment may not have been sensitive enough to distinguish children with language difficulties from those with ADHD.

2.3.7 Receptive Language

Among the studies that have examined receptive language in ADHD and DLD, findings have been mixed. Most studies have found that children with ADHD have superior language comprehension abilities compared to children with DLD (Filippatou & Livaniou, 2005; Hutchinson et al., 2012; McInnes et al., 2003; Oram Cardy et al., 2010; Weyandt, 1994), while only two have found performance between groups to be comparable (Everatt et al., 2008; Javorsky, 1996).

Hutchinson et al. (2012) examined whether distinct linguistic profiles exist for children with ADHD and DLD between 6 and 9 years of age. As expected, children with ADHD had better receptive language abilities than children with DLD. Filippatou and Livaniou (2005), McInnes et al. (2003), and Weyandt and Willis (1994) also examined whether several linguistic tasks could accurately classify children with ADHD and DLD. Filippatou and Livaniou (2005) were specifically interested in whether the Weschler Intelligence Scale for Children (WISC- III; Weschler, 1992) could accurately identify children and adolescents with ADHD, DLD, and learning disabilities between the ages of 3 and 17. Overall, children and adolescents with DLD scored significantly lower on all subtests, including those assessing language comprehension while those with ADHD scored lower on coding and information subtests. The vocabulary and similarities subtests were the best predictors for distinguishing children with language disorders from those with ADHD and learning disabilities. However, no subtests could accurately identify children with ADHD and learning disabilities. Thus, the WISC- III is a useful tool in comparing the cognitive and language profiles of children with already established diagnoses but is not appropriate alone for differential diagnosis. In contrast, Weyandt and Willis (1994) found that vocabulary tasks could accurately classify children with ADHD and DLD. Children between the ages of 6 and 12 completed two vocabulary tasks and overall, children with DLD scored lower on tasks measuring receptive language. Further, discriminate function analysis revealed that 77% of the cases of children with ADHD and DLD were correctly classified, revealing that assessments of vocabulary can accurately discriminate ADHD from DLD.

Compared to children with ADHD, McInnes et al. (2003) and Oram Cardy et al. (2010) found evidence of impaired receptive language in children with DLD. Oram Cardy et al. (2010) also examined processing dysfunctions in DLD, ADHD, and TD children and found that children with ADHD demonstrated slower processing speed than children with DLD or TD. It is suggested that slower reaction times on speeded tasks could be indicative of altered attention, decreased arousal, or impaired/delayed timing in ADHD rather than slowed processing speed. Under this interpretation, tasks measuring speed of processing may reflect the interference of other processes that are core impairments in ADHD.

Fewer studies have found evidence to suggest that language comprehension abilities are comparable in children with ADHD and DLD (Everatt et al., 2008; Short et al., 2020). Everatt et al. (2008) used the British Picture Vocabulary Scale (BPVS; Dunn et al., 1982) to assess receptive vocabulary in children with ADHD and DLD aged between 11 and 13. In this task, the child was required to select the picture that best matched the verbal phrase spoken by an experimenter. No significant differences were found between children with ADHD and DLD on the receptive vocabulary measure. Similarly, Short et al. (2020) found that children with ADHD and DLD between the ages of 4 and 7 years had similar language comprehension performance on a parent-report and standardized language assessment of receptive language ability.

2.3.8 Narrative Language

Narrative language is an important part of expressive and receptive language that involves the ability to recall, interpret, and produce stories and events, organize, and structure narrations of stories. Narrative measures tap into several elements essential in narrative discourse including the ability to remember critical story information, use appropriate sentence structure, and establish ties across sentences. Only three studies have directly compared the narrative language skills of children with ADHD and DLD (Luo & Timler, 2008; Redmond et al., 2011a; Redmond et al., 2011b) and findings have been mixed. Two studies using the same participants found evidence for reduced oral narration and comprehension in DLD compared to ADHD (Redmond et al., 2011a, 2011b. The other study found no significant differences between groups in their development of story elements or ability to organize and structure narrations of stories (Luo & Timlet, 2008).

2.3.9 Vocabulary

Two studies that examined vocabulary were identified and both used the WISC-III vocabulary subtest (Weschler, 1992). The WISC-III is a coarse measure of vocabulary and not the gold standard compared to the Peabody Picture Vocabulary Test (PPVT) or its expressive counterpart the EVT. Thus, the use of the WISC-III in the two studies opens the possibility of finer grained findings if a more extensive vocabulary test were used. Between the two studies, contradictory findings emerged with respect to ADHD and DLD-group performance (Fillppatou & Livaniou, 2005; Williams, 2000). One study found children with ADHD had better vocabulary abilities than children with DLD (Fillppatou & Livaniou, 2005) and the other found no differences in vocabulary between groups (Williams, 2000). However, for both studies, the primary focus was not to assess vocabulary abilities. Rather, these studies focused on the discriminative ability of the WISC- III and whether there are cognitive impairments consistent with frontal-dysfunction in children with ADHD and DLD. Fillppatou and Livaniou (2005) aimed to examine the discriminative ability of the WISC- III in classifying children and adolescents with ADHD and DLD and found evidence for greater vocabulary difficulties in those with DLD. Conversely, Williams (2000), who aimed to examine the neuropsychological profiles of 6-year-old children with ADHD and DLD, found that there were no significant differences in vocabulary between the ADHD and DLD groups. Importantly, the sample size of the compared groups was small (n = 10), and the ADHD group only included children who had the hyperactive subtype of ADHD. Like studies assessing semantic language, additional work is needed to determine whether vocabulary abilities in ADHD and DLD are comparable or distinct.

Table 2.2. Summary of studies comparing ADHD to DLD individuals on language tasks (*n* = 18).

Author(s)	Language Task(s) *Subtests/Subscales*	Language Abilities(s) Assessed	Performance Summaries
Everatt et al. (2008)	British Picture Vocabulary Scale, Phonological Segmentation Task.	Receptive vocabulary and phonological awareness.	No significant differences in receptive language or phonological awareness.
Filippatou & Livaniou (2005)	Wechsler Intelligence Scale-III – *vocabulary and comprehension subtests.*	Vocabulary and comprehension.	The ADHD group had better vocabulary and comprehension than the DLD group.
Helland et al. (2014)	Children's Communication Checklist -2.	Speech, syntax, semantics, coherence, inappropriate initiation, stereotyped language, use of context, nonverbal communication, social relations, interests.	The ADHD group had better speech and syntax than the DLD group. No significant differences in semantics, coherence, inappropriate initiation, stereotyped language, use of context, nonverbal communication, or social relations. The ADHD group had greater interests in things or activities most would find unusual.
Hutchinson et al. (2012)	Clinical Evaluation of Language Fundamentals-4 – *receptive and expressive language index scores.* The Children's Test of Nonword Repetition.	Receptive and expressive language, phonological working memory, and speech perception.	The ADHD group had better receptive, expressive, and phonological abilities than the DLD group.

Javorsky (1996)	Test of Language Competence (TLC) – *Composite, Oral expression, Figurative language subtests.*, Peabody Picture Vocabulary Test-Revised (PPVT-R), Woodcock-Johnson Psycho-Educational Battery-Revised (WJBP-R) –*word identification, writing samples, proofing, usage, punctuation-capitalization, passage comprehension, dictation, and spelling subtests,* Kaufman Tests of Educational Achievement (K-TEA)– *reading and spelling subtests*, Kaufman Brief Intelligence Test (K-BIT) – *vocabulary subtest,* Wide Range Achievement Test-Revised (WRAT-R) – *spelling subtest*, Lindamood Test of Auditory Conceptualization.	Oral, figurative [TLC], receptive language [PPVT], semantics [PPVT-R, WJBP-R, K-TEA], syntax [WJPEB-R], phonology [WJPEB-R, K-TEA, WRAT-R, Linda-mood TAC], vocabulary [K-BIT]	No significant differences in oral, figurative, receptive language, semantics, syntax, phonology, or vocabulary.
Löytömäki et al. (2020)	Boston Naming Test.	Expressive language.	The ADHD group had better expressive language than the DLD group.
Luo &Timler (2008)	Clinical Evaluation of Language Fundamentals-4. The Test of Narrative Language.	Core language. Narrative language.	The ADHD group had better core language than the DLD group. No differences in narrative language.
McInnes et al. (2003)	Peabody Picture Vocabulary Test- III, Expressive Vocabulary Test, Clinical Evaluation of Language Fundamentals-3 – *receptive and expressive language index scores*.	Receptive and expressive language.	The ADHD group had better receptive and expressive language than the DLD group.
Oram Cardy et al. (2010)	Clinical Evaluation of Language Fundamentals-3. – *receptive and expressive language index scores*.	Receptive and expressive language.	As expected, based on inclusion criteria, the ADHD group had better receptive and expressive language scores than the DLD group.

Redmond & Ash (2014) * same participants as Redmond (2011a, 2011b)	Clinical Evaluation of Language Fundamentals-4 Screening Test.	Language screening test.	As expected, based on inclusion criteria, the ADHD group had better overall language scores than the DLD group.
Redmond et al. (2011a) *	Clinical Evaluation of Language Fundamentals-4 Screening Test, Test of Early Grammatical Impairment. Nonword Repetition. Test of Narrative Language.	Language screening test [CELF-4], grammatical abilities for present-tense and past-tense verbs [TEGI]. phonological processing [NWR], narrative language.	The ADHD group had a better overall language, grammatical, phonological processing, oral narration, and comprehension abilities than the DLD group.
Redmond (2011b) *	Clinical Evaluation of Language Fundamentals-4 Screening Test, Test of Early Grammatical Impairment. Test of Narrative Language.	Language screening test [CELF-4], grammatical abilities for present-tense and past-tense verbs [TEGI], narrative language.	The ADHD group had a better overall language, grammatical, oral narration, and comprehension abilities than the DLD group.
Redmond (2005) * same participants as Redmond (2004)	Test of Language Development Primary-3.	Spoken language.	ADHD had better spoken language than the DLD group.
Redmond (2004) *	Test of Language Development Primary-3.	Spoken language.	ADHD had better spoken language than the DLD group.
Short et al. (2020)	Adaptive Language Inventory [parent-report], Clinical Evaluation of Language Fundamental Preschool-2, Clinical Evaluation of Language Fundamentals-3.	Comprehension, production, and total language [ADI]. Receptive and expressive language [CELF-2, CELF-3].	No difference in comprehension, receptive, expressive language. The ADHD group had better production and total language than the DLD group
Stanford & Delage (2020)	Bilan Informatisé de Langage Oral.	Morphosyntax.	ADHD had better morphosyntax than the DLD group.

Weyandt & Willis (1994)	Peabody Picture Vocabulary Test, Boston Naming Test.	Receptive and expressive language.	The ADHD group had better receptive and expressive language than the DLD group.
Williams et al. (2000)	Wechsler Intelligence Scale-III – *vocabulary subtest.*	Vocabulary.	No difference in vocabulary between groups.

Table 2.3. Summary of language tasks and language domains assessed in each study (*n* = 18).

Language Domain	Language Measure(s)	Studies
Language Form		
Phonological Processing	Woodcock-Johnson Psycho-Educational Battery-Revised, Kaufman Tests of Educational Achievement, Wide Range Achievement Test-Revised, Lindamood Test of Auditory Conceptualization, Nonword Repetition Task, Children's Test of Nonword Repetition.	Everatt et al. (2008); Javorsky (1996), Redmond et al. (2011a); Hutchinson et al., (2012)
Syntax	Children's Communication Checklist-2, Woodcock-Johnson Psycho-Educational Battery-Revised.	Helland et al. (2014); Javorsky (1996)
Morphosyntax/Grammar	Bilan Informatisé de Langage Oral, Test of Grammatical Impairement	Redmond et al. (2011a); Redmond (2011b); Stanford & Delage (2020)
Language Content		
Semantics	Peabody Picture Vocabulary Test-Revised, Children's Communication Checklist-2, Woodcock-Johnson Psycho-Educational Battery-Revised, Kaufman Tests of Educational Achievement.	Helland et al. (2014); Javorsky (1996)
Language Use		
General Communication	Children's Communication Checklist-2	Helland et al. (2014)
Coherence	Children's Communication Checklist-2	Helland et al. (2014)
Nonverbal Communication	Children's Communication Checklist-2	Helland et al. (2014)
Use of Context	Children's Communication Checklist-2	Helland et al. (2014)
Non-literal Language	Test of Language Competence	Javorsky (1996)
General Language Ability		
Core Language	Clinical Evaluation of Language Fundamentals-4	Luo & Timler (2008)

Verbal Response to Stimuli	Clinical Evaluation of Language Fundamentals-4 Screening Test	Redmond &Ash (2014); Redmond et al. (2011a), Redmond (2011b)
Total Language	Adaptative Language Inventory	Short et al. (2020)
Expressive Language		
Expressive Language	Clinical Evaluation of Language Fundamentals-4, Boston Naming Test, Expressive Vocabulary Test, Clinical Evaluation of Language Fundamentals-3, Clinical Evaluation of Language Fundamentals-Preschool 2, Adaptative Language Inventory	Hutchinson et al. (2012); Löytömäki et al. (2020); McInnes et al. (2003); Oram Cardy et al. (2010); Short (2020); Weyandt (1994)
Oral Language	Test of Language Competence, Clinical Evaluation of Language Fundamentals-Preschool 2, Adaptative Language Inventory	Javorsky (1996)
Spoken Language	Test of Language Development Primary-3	Redmond (2005); Redmond (2004)
Production	Adaptive Language Inventory, Clinical Evaluation of Language Fundamentals-Preschool 2	Short et al. (2020)
Speech	Children's Communication Checklist-2	Helland et al. (2014)
Receptive Language		
Receptive Language	British Picture Vocabulary Scale, Clinical Evaluation of Language Fundamentals-4, Clinical Evaluation of Language Fundamentals-3, Clinical Evaluation of Language Fundamentals-Preschool 2, Peabody Picture Vocabulary Test, Adaptative Language Inventory	Everatt et al. (2008); Hutchinson et al. (2012); Javorsky (1996); McInnes et al. (2003); Oram Cardy et al. (2010); Short et al. (2020); Weyandt & Willis (1994)
Comprehension	Wechsler Intelligence Scale-III, Adaptative Language Inventory, Clinical Evaluation of Language Fundamentals-Preschool 2	Filippatou & Livaniou (2005) ; Short et al. (2020)
Narrative Language		

Narrative Organization	The Test of Narrative Language.	Redmond et al. (2011a, 2011b) ; Luo & Timler (2008)
Vocabulary		
Word knowledge	Wechsler Intelligence Scale-III	Filippatou & Livaniou (2005); Williams et al. (2000)

2.4 Discussion

The current review examined studies of language ability in children and adolescents with ADHD and DLD to better understand their shared and unique language characteristics. The findings indicate that children with ADHD exhibit better morphosyntactic/grammatical abilities, overall language abilities, receptive and expressive language, compared to children with DLD. However, semantic, phonological, figurative, and pragmatic language abilities were comparable between the two groups. There was variation in performance on assessments of phonological processing, syntax, narrative language, and vocabulary. Children with ADHD also experienced challenges in certain language domains, however these difficulties were often less pronounced than those reported in children with DLD. The findings are discussed by highlighting similarities, differences, contradictory findings, and age-related trends that emerged from the reviewed studies.

2.4.1 Similarities and Differences

The current state of the literature suggests that children and adolescents with ADHD and DLD have comparable semantic and pragmatic abilities (both in the social use and figurative use of language). These findings are consistent with previous research that has compared the language performance of individuals with ADHD or DLD to TD individuals. However, it is important to note that there are limited studies directly comparing language abilities between ADHD and DLD across multiple language domains. Therefore, when discussing similarities and differences, comparisons will be made relative to TD children and adolescents.

Research consistently indicates that children with DLD consistently exhibit difficulties in semantics (Brackenbury & Pye, 2005; Sheng & McGregor; 2010). They produce fewer semantic responses and make more errors on assessments of semantic language (see Brackenbury & Pye, 2005 for review) than TD children. Earlier studies have demonstrated semantic challenges in DLD at the phrase, sentence, and text levels (Bishop, 1997; Bishop & Adams, 1992; Norbury, 2004). Recent research has linked poor semantic abilities in DLD to expressive vocabulary difficulties and word-finding issues (Sheng & McGregor; 2010). Additionally, deficits in new word acquisition, storage and organization of known words, and lexical access/retrieval have been identified as contributing factors to poor semantic processing in children with DLD (Brackenbury & Pye, 2005).

Consistent with the current findings, previous work comparing the pragmatics of children and adolescents with ADHD and DLD has demonstrated difficulties in both groups (Bishop & Baird, 2001; Green et al., 2014; Staikova et al., 2015) and in DLD separately (Adams & Lloyd, 2005; Bishop & Norbury, 2002; Botting, 2003; Geurts & Embrechts, 2008; Narayanan et al., 2021). Children with ADHD exhibit challenges in conversational report and engage in more stereotyped conversations compared to TD children (Bishop & Baird, 2001). Children with DLD also struggle in these domains and may experience pragmatic language disorders independent of their existing language disorder (Adams & Lloyd, 2005; Bishop & Norbury, 2002; Botting, 2003). Distinguishing between pragmatic-related difficulties and generalized linguistic difficulties in DLD is crucial (Narayanan et al., 2021). Studies have highlighted how children with DLD struggle with turn-taking, unusual use of language, and have difficulties understanding context in pragmatically demanding situations (Narayanan et al., 2021). Children with comorbid ADHD + DLD may face pragmatic difficulties that reflect both conditions (Green et al., 2014), such as difficulties using language accurately according to the context (Adams et al., 2009; Green et al., 2014; Perkins, 2010) and disruptions in turn-taking and speech organization (Green et al., 2014). The combined presence of ADHD and DLD symptoms can have a unique impact on pragmatic language abilities compared to having either disorder alone. Although the symptoms of ADHD and DLD contribute differently to pragmatic language difficulties, both groups demonstrate challenges in this language domain. It is important to consider the high attentional demands experienced by children with ADHD when examining their performance on language tasks. They may expend more cognitive resources to achieve comparable performance to children with DLD, which can have negative consequences not evident on the tasks themselves.

Most studies reviewed found significant differences in language abilities between children with ADHD and DLD. Children with ADHD demonstrated superior morphosyntactic/grammatical abilities, overall language abilities, receptive and expressive language, compared to children with DLD. Additionally, many studies reported that children with ADHD had better spoken (n = 8) and language comprehension (n = 5) abilities compared to those with DLD. It is important to note that difficulties in language production and/or comprehension are core features of DLD, so it is expected that children with this condition would exhibit greater challenges in these areas of language compared to other groups.

In summary, children, and adolescents with ADHD and DLD show similarities in phonological and semantic language abilities, as well as in their social language use. However, significant differences were observed across most language domains, favoring children with ADHD. Specifically, children with ADHD had better morphosyntactic/grammatical abilities, general language abilities, spoken language, language comprehension, and expressive language compared to children with DLD.

2.4.2 Contradictory Findings

The findings from numerous studies examining language abilities in children with ADHD and DLD present contradictory results. Some studies found comparable phonological abilities in these groups (Everatt et al., 2008; Javorsky, 1996) while others reported worse phonological abilities in DLD compared to ADHD (Hutchinson et al., 2012; Redmond et al., 2011a). Similarly, there were conflicting findings regarding syntactic abilities (Javorsky, 1996; Helland et al., 2014), vocabulary (Fillppatou & Livaniou, 2005; Williams, 2000), and narrative language ability (Luo & Timlet, 2008; Redmond et al., 2011a, 2011b). In terms of language comprehension and spoken language, some studies found superior abilities in ADHD, while others found no significant differences between groups (Everatt et al., 2008; Javorsky, 1996; Helland et al., 2014). Among the studies that found no significant differences in spoken language, one included a language disordered group with behavioural difficulties like those reported in ADHD (Javorsky, 1996) and the other found contradictory findings within their study by using two different measures of spoken language (Short et al., 2020). Recall that significant differences in language production emerged on the parent report, but not the standardized assessment of expressive language. Short et al. (2020) reported that children in the DLD group did not differ significantly from either of the developmentally delayed groups on the parent-report measure of language production. However, when group difference analyses were conducted by the primary and tertiary author of the current review, the opposite was found to be true. Parents of children with DLD rated their children as having significantly more language production difficulties (t (48) = -2.46, p = 0.017) compared to parents of children with ADHD.

In summary, additional research is needed to further investigate and compare the syntactic, narrative, and vocabulary skills of children and adolescents with ADHD and DLD. Only two studies in the current review examined syntactic skills, three narrative skills (two of which included the same participants), and two vocabulary skills. The contradictory findings make it challenging to draw definitive conclusions. More studies examined language production and comprehension in ADHD and DLD and only two in each language domain found no significant differences. Noteworthy shortcomings exist within the studies that reported no significant differences between groups in language production, and therefore, these findings should be interpreted with caution.

2.4.3 Age Trends in Language

In the current review, it was decided not to restrict studies based on the age of participants for two main reasons. First, there were a limited number of articles available that specifically assessed and compared language abilities in ADHD and DLD. Second, by including participants of all age ranges, the review aimed to provide a comprehensive overview of language abilities in these groups from early childhood to adolescence. The age range of participants in the reviewed studies varied, with the youngest participant being 3 years old (Filippatou & Livaniou, 2005) and the oldest being 17 years old (Javorsky, 1996). Most participants were between the ages of 7 and 10 years.

The review included two studies examining younger children with an average age of five and six years, respectively (Short et al., 2020; Williams et al., 2000). These studies found no significant differences between children with ADHD and DLD in comprehension, receptive language, expressive language, (Short et al., 2020) and vocabulary (Williams et al., 2020) on standardized assessments. However, studies focusing on older children were more likely to identify significant differences across various language dimensions. This could be attributed to the increased manifestation of symptoms in each disorder as children enter primary school and face more demanding environment. Nevertheless, findings from the reviewed studies suggest that around the age of seven, distinctions in language patterns between ADHD and DLD become more quantifiably different.

In the early years, there is substantial overlap in language profiles between children with ADHD and TD (El Sady et al., 2013), as well as between children with DLD and TD (Paul et al., 2008). However, as children grow older, there is a noticeable shift where those with DLD experience difficulties in structural language (Bishop & Snowling, 2004; Catts et al., 2002; Ramus et al., 2013) and those with ADHD struggle more with the pragmatic components of language (Bignell & Cain, 2007; Bishop & Baird, 2001; Geurts & Embrechts, 2008; Mueller & Tomblin, 2012). These findings imply that with age, children’s language challenges become more quantifiable and tend to coincide with the reported difficulties characteristic of their conditions. One interpretation for this divergence proposed by Hawkins et al. (2016) is that executive function difficulties linked to ADHD give rise to behavioural and social communication difficulties associated with the disorder. Conversely, alternative domain-general cognitive difficulties associated with DLD such as impaired procedural learning (Nicolson & Fawcett, 2007; Ullman, 2004), processing speed, and/or short-term memory (Archibald, 2017; Leonard et al., 2007) impact structural language skills. These cognitive functions that underpin the social and structural components of language may be tested more when children enter the school-age years and environmental demands increase. The evidence suggesting that children can have pragmatic language difficulties without structural language impairments (Bishop, 2014; Conti-Ramsden et al., 1997; Hawkins et al., 2016) supports the idea that these two dimensions of language originate from distinct sources.

To date, no longitudinal studies have investigated whether the observed age trends in language difficulties in ADHD and DLD continue into adulthood or if differences become less pronounced. The current review did not include studies with adult participants, so definitive conclusions cannot be drawn without further research. Early research using outdated diagnostic criteria for ADHD found no significant differences in various language domains between adolescents with ADHD and DLD (Javorsky, 1996). However, more recent studies have shown that adults with ADHD experience increased social difficulties (Sacchetti et al., 2017), and are acutely aware of these challenges (Friedman et al., 2013). As children with DLD grow older, some demonstrate a resolving pattern of social communication difficulties (Reilly et al, 2010), although a significant portion continue to experience persistent structural language difficulties into adolescence (Conti-Ramsden et al., 2000). At the group level, adults with DLD tend to score lower on standardized assessments of language compared to TD individuals (Conti-Ramsden et al., 2018). However, at the individual level, there is considerable variation in performance, with some individuals lagging while others perform within the normal range. Further research is needed to understand the long-term trajectories of language difficulties in ADHD and DLD as individuals transition into adulthood.

The above research suggests that pragmatic language impairments are common in ADHD, while structural language difficulties are more prevalent in DLD. However, a large body of research lends support to the notion that language development in DLD (Conti-Ramsden et al., 2018; Conti-Ramsden et al., 2019) and ADHD is highly heterogenous (Luo et al., 2019) and no single explanation can account for all aspects of DLD or ADHD. Specifically, pragmatic communication problems are evident in DLD (Bishop & Norbury, 2002) and difficulties in structural language are present in ADHD (Green et al., 2014). Studies have also found that delays in speech during early development (9-18 months) are significant predictors of ADHD later in life (Gurevitz et al., 2014). These findings emphasize the need for further research directly comparing the language skills of children with ADHD and DLD to gain a deeper understanding of their shared and distinct characteristics.

2.4.4 Limitations

There are several limitations concerning the methodology of the current review. First, the review did not include grey literature such as dissertations and unpublished studies. As such, there may be some concerns regarding publication bias and presenting a full view of the available evidence on this topic. These decisions were guided by little grey literature on this topic being found, as well prior work showing that excluding this type of literature improves replicability and the inclusion of it seldom impacts review findings

(Hartling et al., 2017; Vickers & Smith, 2000). Second, only articles written in English were included, which may have resulted in relevant literature being excluded as well as presented a biased view of the literature. However, during our search, no non-English articles were identified or excluded based on this criterion. Further, reviews focusing on topics that differ significantly from the current one such as complementary and/or alternative medicine is more heavily impacted by the exclusion of non-English articles (Pham et al., 2005). Third, definitions of DLD in the studies reviewed included children with the receptive/expressive grammar/phonology subtype(s) and therefore, findings do not extend to children who have difficulties outside of our protocol (e.g., pragmatic language impairments, reading disabilities). Finally, some of the included studies specifically precluded DLD-level scores from the ADHD groups, which guarantees better performance in the ADHD group on the tasks of interest. For instance, studies that did not allow for comorbidity among ADHD and DLD groups could introduce bias, potentially making ADHD appear less similar to DLD than it actually is. To improve the accuracy of study findings, additional research is needed that takes into account the overlap in ADHD and DLD symptoms when evaluating performance across a variety of tasks.

One barrier worth noting here relates to the number of articles that were not obtainable through Racer interlibrary loan (*n* = 11). After several failed attempts to retrieve the potentially relevant articles, the decision was made to exclude them from our review (See supplemental material for list of articles).

2.4.5 Implications for Further Research

The current review findings prompt further inquiries for future research. The literature as it stands lacks comprehensive examinations of sex and gender factors, despite clear disparities in ADHD and DLD. While there are some biases and girls are often underdiagnosed, historically ADHD has been thought to be a male dominated disorder. Similarly, language delay and DLD are sometimes reported as more prevalent in males than in females (Chilosi et al., 2021). Accordingly, samples in the review reflected these trends, with studies reporting more males than females in both affected and control groups. In fact, some reviewed studies only included male participants with ADHD (McInnes et al., 2003; Weyandt & Willis, 1994) and DLD (McInnes, 2003) and only one had an equal distribution of males and females (Williams et al., 2000). Since the publication of these studies, progress has been made in not only identifying but improving our understanding of female ADHD. Even though a large portion of parents and educators still overestimate ADHD in boys and underrate ADHD in girls (Mowlem et al., 2019), emerging research shows that prevalence rates are almost comparable between the two genders (Davidovitch et al., 2021). The existence of gender differences in DLD have also been challenged with researchers proposing that the increased male prevalence could reflect a selection bias. Unlike females, males with DLD often have increased behavioural difficulties (Beitchman et al., 1996; Chilosi et al., 2021), which may increase their likelihood of being referred for clinical services. Despite this, a recent review analyzing evidence from epidemiological, twin, aggregation, and sex chromosome studies found evidence to support a higher prevalence of DLD in males, with them having almost three times the risk for language delay compared to females (Chilosi et al., 2021). Future research should consider how ADHD and DLD can present differently in males and females, whether there are gender related differences in language and task performance, as well as ensure diagnostic tools reflect these differences.

Another potential avenue for future work is to examine whether the subtypes of DLD and/or distinct components of ADHD differentially impact language. Previous work has demonstrated that the three subtypes of ADHD (predominantly combined, predominantly inattention, and predominantly hyperactive-impulsive) differentially impact aspects of academic achievement (Pham, 2016) and phonological skills in younger children (Dally, 2006). One study included in the current review that only examined children with attention difficulties found no significant differences in phonological awareness between children with ADHD and language disorders (Everatt et al., 2008). It is therefore worth investigating how the distinct subtypes of ADHD contribute to phonological awareness as well as other language forms (syntax, semantics, grammar). Furthermore, DLD can be limited to certain domains including phonology, morphosyntax, and vocabulary (Bishop et al., 2017). Research has found that some children with DLD demonstrate primarily expressive and/or receptive difficulties, while others display primarily phonological difficulties (Rodriguez et al., 2017). Recent work has found that children with the primary expressive subtype of DLD experience greater problems with verbal fluency as well as both verbal and spatial working memory (Rodriguez et al., 2017). It is likely that these children will demonstrate greater language difficulties related to their respective subtypes, however, further investigations into how they perform on other language assessments (both verbal and nonverbal) is needed. Further, within these subtypes, gender differences exist with a larger proportion of males experiencing isolated phonological disorder, persistent expressive disorder, and receptive expressive disorder compared to females (Chilosi et al., 2021). Future work should therefore investigate how the different subtypes of ADHD and DLD impact various forms of verbal and nonverbal language, including the potential impact of gender on this relationship.

Relatedly, future studies should review the literature looking at the language profiles of children with comorbid ADHD + DLD. As previously mentioned, our aim was to limit the review to studies focusing on pure samples of ADHD or DLD to allow a clear characterization of the language difficulties specifically associated with ADHD and DLD symptoms. With that said, estimates of the overlap between speech and language disorders and ADHD can vary from as low as 8% to as high as 90%, depending on the source and type of sample (Brown, 2009). Some children with ADHD may meet the clinical threshold to receive an additional diagnosis of DLD, while others may not. It is important to acknowledge that reported rates of ADHD and DLD can differ based on referral sources, assessment protocols, and criteria for language impairments. The current review findings might have been influenced by unmeasured comorbidities or participants with ADHD or DLD who had subclinical attention or language challenges.

Future systematic or meta-analytic reviews may directly compare and examine the severity of language difficulties in these conditions across studies. These reviews could also compare measures with different psychometric properties to determine whether differences are partly due to measurement weakness or reflect the presence of overlapping deficits. This examination is however, beyond the scope of the current review, which is meant to provide an overview of the available literature rather than address specific questions regarding the appropriateness or effectiveness of language measures. More importantly, a minimum of 10 studies per construct or language domain are recommended for accurate calculations in meta-analytic reviews (Borenstein et al., 2021) and therefore, additional research will be needed before such a structured review is possible. High rates of comorbidity and heterogeneity in ADHD and DLD coupled with differences in diagnostic criteria among studies may complicate things further. For a systematic or meta-analytic review to be possible, similar criteria must be used to diagnose both disorders and similar constructs must be used to measure language ability. Otherwise, comparisons of performance across studies are not as reliable.

From a practice standpoint, our review findings suggest that different profiles of language require different treatment approaches. For example, figurative language weaknesses experienced by both groups may benefit from behavioural interventions targeting structural language, vocabulary, theory of mind, and executive function, all of which are thought to underlie successful figurative language (Chahboun et al., 2021). Focusing on these aspects of language to improve nonliteral language may then consequently lead to improvements in vocabulary and structural language for children with DLD. Given that children with ADHD and DLD experience overlapping difficulties, it may also be useful to consider group therapy approaches. Group therapy can help with the development of appropriate social and interpersonal skills, as well as cooperative learning (Matić et al., 2018). Future studies should therefore consider the efficacy of treatment approaches for different language profiles, particularly among children with ADHD, DLD, and other related disorders.

2.4.6 Conclusions

A failure to learn and use language properly can have significant consequences on academic, social, and emotional development (Bretherton et al., 2014; Clegg et al., 2005). These difficulties can persist into adulthood, affecting various aspects of life and employment (Eadie et al., 2018; Johnson et al., 2010; Law et al., 2009; Lensing et al., 2015; Wehmeier et al., 2010). To mitigate the impact of these difficulties, it is crucial to investigate the language abilities of children with ADHD and DLD and identify areas where they may share difficulties.

The evidence presented in this review suggests that children with DLD experience greater language difficulties compared to those with ADHD, but with some important caveats. Children with ADHD and DLD have comparable performance on tasks assessing semantics, pragmatics, and figurative language. This is noteworthy because some studies specifically preclude DLD when identifying ADHD, making it unlikely that comorbid symptoms can account for the observed similarities in performance across these tasks. The review highlights the lack of consistency on how researchers define their participants, which might contribute to equivocal findings. There is an increased need for standardization regarding eligibility, diagnostic criteria, and the measurement tools used across studies to resolve inconsistencies. The differences in findings across studies might be more reflective of what the language tasks are testing rather than shared and distinct impairments across groups. Despite the limitations related to the paucity of studies and inconsistencies in identifying and defining the two disorders, this review represents a crucial step in improving our understanding of the language profiles of these two conditions. By identifying the specific language abilities that are intact or affected in each disorder, professionals can tailor interventions and support strategies to address the unique needs of these children.

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Chapter 3 : Language and Reading in ADHD and Comorbid ADHD + DLD

3.1 Introduction

One key issue for researchers when administering diagnostic assessments is not whether a child has typical or atypical development, but which designation the child falls under. Making these distinctions can be especially difficult in children with attention-deficit/hyperactivity disorder (ADHD) and developmental language disorder (DLD) because elevated levels of inattention in ADHD could disrupt the way these children respond on language assessments in a way that is like DLD. The significant social and academic difficulties resulting from poor language skills have led researchers to investigate which measures are most effective at identifying language impairments (Conti-Ramsden, 2003; Poll et al., 2010; Redmond et al., 2011). Previous research has predominately focused on DLD, with some comparing the linguistic characteristics of ADHD and DLD (Parigger et al., 2012; Redmond et al., 2011; Redmond et al., 2019; Stanford & Delage, 2020, Stanford & Delage, 2023). Given that language deficits are prevalent in both disorders, it is unsurprising that assessments of language function can serve as reliable diagnostic markers. Children with DLD exhibit clear deficits in areas such as verbal comprehension (Bishop et al., 2017; Korkman & Hakkinenrihu, 1994), grammar (Fonteneau & van der Lely, 2008; Hsu & Bishop, 2010), and the ability to make accurate vocabulary associations (see Leonard, 2014 for a review).

While children with ADHD also struggle in these language domains, their difficulties are often less pronounced than those seen in children with DLD (Oram Cardy et al., 2010). This distinction in language profiles makes it easier to differentiate between the two groups. In addition to comprehensive language assessments, research spanning several decades has shown that nonword and sentence repetition tasks can be particularly valuable indicators of language impairment. Several key studies have found associations between performance on these tasks and genotype/phenotype correspondence in DLD (Falcaro et al., 2008; Monaco, 2007; Redmond et al., 2011; Rice et al., 2009). Nonword and sentence repetition tasks have consistently proven to be reliable clinical markers of language impairment (Archibald & Joanisse, 2009) across various age groups, including young adults (Poll et al., 2010) and young children (Conti-Ramsden, 2003; Conti-Ramsden & Hesketh, 2003; Oetting & Cleveland, 2006; Redmond et al., 2011). Moreover, these tasks have demonstrated their effectiveness in different language contexts, including English (Redmond et al., 2011), Danish (Vang Christensen, 2019), Arabic (Taha et al., 2021), Italian (Guasti et al., 2021), and Mandarin-speaking children (Wang et al., 2022).

Word and nonword reading abilities might also serve as important markers of DLD. However, compared to nonword repetition and general language skills, less research has focused on using reading measures as clinical markers for DLD. Most studies examining reading efficiency have primarily investigated children and young adults with dyslexia, a disorder characterized by marked difficulties in decoding, word reading, and spelling (APA, 2013). Dyslexia is estimated to affect between 3 to 20% of the population (Rutter et al., 2004; Shaywitz, 1996; Spencer et al., 2014), although prevalence rates can vary depending on diagnostic criteria.

Interestingly, both children with ADHD (Brimo et al., 2020; Gillberg, 2010; Kaplan et al., 2001; Peterson & Pennington, 2015) and DLD (Catts et al., 2005) also frequently experience co-occurring reading difficulties. Comorbidity rates are significant, with 25-

40% of children with ADHD (Boada et al., 2012) and 50% of those with DLD presenting with reading difficulties (Adlof & Hogan, 2018). Notably, research has indicated that reading problems in individuals with ADHD are more associated with the inattention components of the disorder rather than the hyperactive-impulsive aspects (Germanò, et al., 2010; Mascheretti et al., 2017). Previous work has further shown that teacher ratings of behavioural inattention have a direct effect on sight word reading (Martinussen et al., 2014). Further research is needed to better understand how the specific components of ADHD can differentially impact reading outcomes. Investigating the unique reading challenges faced by children with primarily inattentive symptoms in ADHD compared to other subtypes will enhance our understanding of how these specific subtypes impact reading outcomes. This research will contribute to the development of targeted interventions for addressing reading difficulties in children with ADHD, tailoring approaches based on the needs associated with different ADHD subtypes.

Failing to consider how assessments can differentiate between comorbid samples and pure samples limits the generalizability of findings to the larger population, where comorbidity rates are high. There is a significant overlap in symptomology between children with ADHD and DLD, underscoring the need to identify the best methods for distinguishing between these conditions. Accurate diagnosis is crucial in ADHD and DLD, as children often face under-identification (McGregor, 2020) or excessive referrals for evaluations (Gascon et al., 2022). The outcome of diagnostic assessments can be life-altering; they impact the kind of services children will and will not receive. Therefore, exploring the effectiveness of specific assessments in differentiating between ADHD and

DLD can inform future protocols, leading to improved treatments and services for these children.

The objectives of this study were to first investigate if the presence of a comorbid language disorder in individuals with ADHD exacerbates language and reading difficulties and second, determine whether psycholinguistic measures can aid in distinguishing between ADHD and/or DLD. To achieve these goals, we analyzed data from a large-scale open dataset to assess the discriminative abilities of language assessments, nonword repetition, phonemic decoding efficiency, and sight word efficiency. We focused on distinguishing cases of DLD, ADHD (combined and inattentive subtypes), and comorbid ADHD + DLD in children and adolescents aged 6-16 years. Additionally, we aimed to identify the most effective combination of these measures for accurately identifying cases of DLD.

3.2 Method

3.2.1 Participants

All participants were enrolled in the Healthy Brain Network (HBN) database (Alexander et al., 2017). The HBN, launched by The Child and Mind Institute, is an open database that contains data from approximately 10,000 New York area children and young adults across various measures. Participants were recruited using a community referral recruitment model. Advertisements were distributed to families who had concerns about psychiatric symptoms in their child. Participation was therefore based on perceived clinical concern, resulting in a high proportion of individuals affected by psychiatric illness in the HBN sample. All participants received a base battery intended to screen for different disorders, and some individuals scoring poorly on screeners were referred for a more in-depth testing. Those results were then used to make formal diagnoses by clinicians where appropriate, and those formed the basis of the diagnostic categories used in the present study. Participants received a battery of assessments that took approximately 12 hours to complete however, only those relevant to the current study will be described in detail and included in subsequent analyses. Participants were instructed to stop using their stimulant medication for the duration of the testing period.

Participants included children and adolescents between 6-16 years of age (*Mean age* = 9.73, *SD* = 2.56; 75.7 % male) who were diagnosed with at least one subtype of ADHD and/or DLD. This included the ADHD combined subtype (ADHD-C; *n* = 148), ADHD inattentive subtype (ADHD-I; *n* = 192), DLD (*n* = 39), comorbid ADHD-C + DLD (ADHD-C + DLD; *n* = 28), and comorbid ADHD-I + DLD (ADHD-I + DLD; *n* = 34). The HBN dataset also included participants with confirmed diagnoses of ADHD hyperactive-impulsive subtype and comorbid ADHD hyperactive-impulsive subtype + DLD (*n* = 17) however, these participants did not have complete data on the tasks needed for the current study and were therefore excluded. Additionally, children who did not have complete demographic information (*n* = 179) and those who were identified as having ‘other specified ADHD’ or ‘other specified ADHD + language disorder’ were also excluded from the analyses. See Table 3.1 for demographic information for each diagnostic category.

Table 3.1. Demographic information for each diagnostic group (N = 441).

Diagnosis	***n***	**Mean Age *(SD)***	**Min-Max**
ADHD-C	148	9.21 *(2.29)*	6.00-15.30
ADHD-I	192	10.40 *(2.61)*	6.01-16.00
DLD	39	8.51 *(2.34)*	6.03-15.70
ADHD-C + DLD	28	8.91 *(2.43)*	6.01-14.10
ADHD-I + DLD	34	10.1 *(2.66)*	6.32-15.90

Note. Age is in years. ADHD-C = Attention-deficit/hyperactivity disorder combined subtype; ADHD-I = Attention-deficit/hyperactivity disorder inattentive subtype; DLD = Developmental language disorder.

3.2.2 Ethics Considerations

The original HBN study was approved by the Chesapeake Institutional Review Board (https://www. chesapeakeirb.com/). Prior to conducting the research, written informed consent was obtained from participants ages 18 or older. For participants younger than 18, written consent was obtained from their legal guardians and written assent obtained from the participant. Further details on recruitment, eligibility, and diagnostic procedures, can be found in Alexander et al. (2017).

3.2.3 Determining Diagnostic Status

For all HBN participants, licensed and trained clinicians provided a final diagnosis after a battery of diagnostic tests were administered. The clinical staff consisted of psychologists, social workers, and psychiatrists. Responses on all tasks were scored by the administering clinician followed by a trained research assistant. To determine ADHD status, clinicians and trained research assistants administered the following tasks:

Conners ADHD Rating Scales Self-Report (Conners'), Strengths and Weaknesses of ADHD Symptoms and Normal Behavior Scale (SWAN), Quotient ADHD System. To determine language impaired status, the following tasks were administered: The Clinical Evaluation of Language Fundamentals (CELF-5) Screener (CELFST; Semel et al., 2013), the Goldman Fristoe Test of Articulation (GFTA; Goldman, 2015) 'Sounds and Words' subtest, the Comprehensive Test of Phonological Processing, Second Edition (CTOPP-2; Wagner et al., 2013), and the Test of Word Reading Efficiency, Second Edition (TOWRE-2; Torgesen et al., 2012). Additionally, participants who failed the CELF-5 Screener and/or performed poorly on GFTA subtests were offered additional language evaluations performed by a licensed speech and language pathologist. This assessment included the full CELF-5 assessment (Wiig et al., 2003), Expressive Vocabulary Test (EVT; Williams, 2007), the Peabody Picture Vocabulary Test (PPVT; Dunn & Dunn, 2007), the CELF-5 Metalinguistics (Wiig et al., 2003), and additional subtests of the GFTA.

The participants in the study were diagnosed with either ADHD combined (ADHD-C), ADHD inattentive (ADHD-I), and/or DLD. Although the sample sizes for the comorbid groups were smaller (ADHD-C + DLD n = 28; ADHD-I + DLD n = 34) than the remaining groups, it was important to maintain them as distinct diagnostic categories in line with the HBN evaluations. The primary focus of this paper was to distinguish between ADHD and comorbid ADHD + DLD, however, discriminations were also generated on the two types of ADHD to investigate how symptoms of each subtype can affect language and reading outcomes. Only participants with confirmed diagnoses and complete data on the relevant tasks were included in the final sample. Children who were identified as having speech sound disorder-only, dyslexia-only, and/or speech sound disorder + dyslexia, autism spectrum disorder, comorbid disorders (e.g., ADHD + autism spectrum disorder) were not included in the analyses.

3.2.4 Materials

Cognitive assessments. All participants completed The *Wechsler Intelligence Scale for Children* as a test of general intelligence (WISC-V; Wechsler, 2014). We elected to use the *Visual Spatial Index* (VSI) scores rather than Full Scale IQ (FSIQ) scores in subsequent analyses. The VSI provides an estimate of children's nonverbal reasoning and concept formation skills. It evaluates visual perception and organization, visual motor coordination, and the ability to synthesize abstract concepts and information. Since this subtest generates an IQ score that does not rely on verbal responding, it also provides an estimate of IQ that is not confounded by their language difficulties (DeThorne & Schaefer, 2004). This test provides norms from 6.0 to 17.0 years of age.

Psycholinguistic assessments. The *Clinical Evaluation of Language Fundamentals – Screening Test* (Semel et al., 2013) provides a brief but comprehensive assessment of language abilities and helps to evaluate whether a child needs further testing to identify a potential language disorder. The assessment includes the most discriminating items from the full CELF assessment and evaluates knowledge of grammatical morphemes, vocabulary associations, interpretation of spoken directions, and verbal sentence repetition.

The *Nonword Repetition* subtest of the *Comprehensive Test of Phonological Processing* (Wagner et al., 2013) was used to help evaluate children's phonological memory abilities as a prerequisite to reading fluency. The nonword repetition subtest measures the ability to repeat nonwords of increasing length and was included here given its sensitivity to both reading and language difficulties in children.

The *Test of Word Reading Efficiency* (Torgesen et al., 2012) provides an assessment of single-word and nonword reading fluency. The *Sight word Efficiency* (SWE) and *Phonemic Decoding Efficiency* (PDE) subtests were included in analyses and evaluated the number of real words (SWE) and nonwords (PDE) an individual can correctly name in 45 seconds.

3.2.5 Analyses

3.2.6 Comparing Language and Reading Performance

***Analysis of variance*.** Univariate analysis of variance (ANOVA) was conducted to determine the presence of group differences on the psycholinguistic measures (CELFST, NWR, SWE, and PDE). For CELFST, Levene's test indicated homogeneity of variance was violated, and therefore Welch's robust test of equality of means (asymptotically F distributed) was performed to determine group differences, and follow-up Games-Howell analysis was used to identify pairwise comparisons.

To evaluate the minimum sample size required to test these comparisons, an *a priori* power analysis was performed using G*Power version 3.1.9.7 (Faul et al., 2007). According to Cohen's (1988) guidelines, the study determined that a total sample of 200 participants (with approximately 40 participants per group) was needed to achieve 80% power to detect a medium effect size. The significance criterion for the ANOVA was set at $\alpha = .05$. The obtained sample size for the study was N = 441, which was considered adequate for testing the comparisons. However, the comorbid groups (*n* ADHD-I + DLD = 34; *n* ADHD-C + DLD = 28) had smaller sample sizes compared to the other groups. A power calculation determined the minimum effect size detectable with the smallest group (n = 28) would need to be at least medium-large sizes (d = 0.61). While comparisons involving these samples could yield valuable insights, it is important to consider the limitations imposed by smaller sample sizes when interpreting the results, especially in practical applications. Specifically, that smaller effect sizes would not be detectable.

3.2.7 Diagnostic Utility

Receiver operating curves. To examine how well the assessments could accurately distinguish diagnostic cases, receiver operating curves (ROC) were generated. The diagnostic power and optimal clinical cut-off values for each specific test are reported (Perkins & Schisterman, 2006; Sackett et al., 1991) for the following discriminations: ADHD-C versus ADHD-C + DLD, ADHD-C versus DLD, ADHD-I versus DLD, ADHD-C + DLD versus DLD, ADHD-C + DLD versus ADHD-I, ADHD-C versus ADHD-I, ADHD-C versus ADHD-I + DLD, ADHD-I versus ADHD-I + DLD, and ADHD-I + DLD versus DLD (See Figures 3.7-3.15 for all ROC curves). Given that sensitivity and specificity are valued equally in the current study, the index of union (IU) method (Unal, 2017) was used for selecting optimal cut-off points for diagnostic tests (See Table 3.3 for optimal cut-off points, sensitivity, specificity, positive likelihood ratio, and negative likelihood ratio). Following Simundic (2012), we interpreted AUC values between 0.9 and 1.0 as indicating excellent diagnostic accuracy, 0.8 - 0.9 as very good, between 0.7 - 0.8 as good, 0.6 - 0.7 as sufficient, 0.5 - 0.6 as bad, and <.05 not useful.

An additional power analysis was performed using MedCalc Statistical Software version 19.2.6 (MedCalc Software by Ostend, Belgium; https://www.medcalc.org; 2020) to evaluate the minimum sample size needed for the ROC analysis with a Type I error set at $\alpha = .05$ and Type II error set at $\beta = .80$. The analysis indicated that a minimum of 20 negative cases (no diagnosis) and 10 positive cases were needed to achieve these (total N = 30).

3.2.8 Predicting DLD Status

Binary logistic regression. A binary logistic regression was performed to determine whether nonverbal IQ, CELFST, SWE, PDE, and NWR could predict DLD status. Specifically, we aimed to compare cases of ADHD without DLD (combined and inattentive; $n = 340$) with cases of DLD (with or without ADHD; $n = 101$) to determine whether a specific combination of assessments (nonverbal IQ, CELFST, SWE, PDE, NWR) could better predict DLD status compared to individual assessments alone. Collinearity, which indicates multicollinearity in regression analysis, was tested, and all variables had variance inflation factors below 5.00, indicating low collinearity between predictors (James et al., 2017). To estimate the internal validity of the regression analysis findings, a bias-corrected accelerated (BCa) bootstrap method was applied. The BCa approach was selected because it provides more accurate estimation of 95% confidence intervals compared to the percentile approach (Efron, 1987; Efron & Tibshirani, 1993; Jung et al., 2019).

Cross validation methods help to estimate error bias, determine the best model fit, and ensure the model is not overfitting the data. To evaluate how well our logistic model would perform in practice and make more precise conclusions about the model predictions, we applied a leave-one-out (LOOCV) cross validation method to our data. In terms of evaluation metrics, the root mean square error (RMSE) is the most acceptable and measures the average difference between the predictions made by the model and the real observations. RMSE values between 0.2 and 0.5 indicate that the model can predict the data accurately.

For logistic regressions, sample size recommendations are less clear because odds ratios are scale dependent and there is no well-defined R^2. Thus, the minimum required sample size for our analysis was determined using rule-of-thumb guidelines (Bujan et al., 2018; Peduzzi et al., 1996) using an event per variable (EPV) formula. The ideal sample size is calculated using the following formula: ($n = 100 + 50i$) where i is equal to the number of predictors in the final model. For the current analysis, the EVP value is equal to 350 and our total sample size is 441 (ADHD $n = 340$; DLD $n = 101$). These findings suggest that our sample size is sufficient to perform our regression analysis.

3.3 Results

3.2.1 Comparing Performance Across Psycholinguistic Assessments

Group means and performance summaries for each cognitive and psycholinguistic assessment are presented in Table 3.2. There were significant group differences in nonverbal IQ, *F* (4, 397) = 7.09, *p* <.001. Pairwise comparisons revealed significant differences between ADHD-C and ADHD-C + DLD (*p* <.05), ADHD-C and DLD (*p* <.001), ADHD-I and DLD (*p* = <.05), as well as between ADHD-C and ADHD-I + DLD (*p* <.01). No other significant group differences were observed (Please see Figures 3.1-3.5 for plots illustrating the distribution of all assessments).

Language scores showed significant differences among groups, *F* (4, 85.90) = 45.49, *p* <.001. Pairwise comparisons indicated significant differences between ADHD-C and ADHD-C + DLD (*p* <.001), ADHD-C and DLD (*p* <.001), and ADHD-C and ADHD-I + DLD (*p* <.001). Moreover, significant differences were found between ADHD-I and ADHD-C + DLD (*p* <.001), ADHD-I and DLD (*p* <.001), and ADHD-I and ADHD-I + DLD (*p* <.001).

In the nonword repetition task, significant group differences were observed *F* (4, 391) = 7.28, *p* = <.002. Pairwise comparisons further revealed significant differences between ADHD-C versus DLD (*p* = <.001), ADHD-C versus ADHD-I + DLD (*p* = .005), ADHD-I versus DLD (*p* = .002), and ADHD-I versus ADHD-I + DLD (*p* = .010).

In terms of SWE, significant group differences in were observed, *F* (4, 377) = 10.70, *p* = <.001. Pairwise comparisons further indicated there were significant differences between ADHD-C and DLD (*p* =.002), ADHD-C and ADHD-C + DLD (*p* <.001), ADHD-C and ADHD-I (*p* = .011), and ADHD-C and ADHD-I + DLD (*p* <.001).

Additionally, significant differences were found between ADHD-C + DLD and ADHD-I (p = .019), as well as between ADHD-I and ADHD-I + DLD (p = .023).

In the analysis of PDE, significant differences were found between groups, F (4, 375) = 8.89, p = <.001. Further pairwise comparisons revealed that individuals with ADHD-C significantly differed from those with DLD (p =.005), ADHD-C + DLD (p <.001), and ADHD-I + DLD (p = .001). There were also significant differences between ADHD-C + DLD and ADHD-I (p <.001).

Distributions for each Assessment

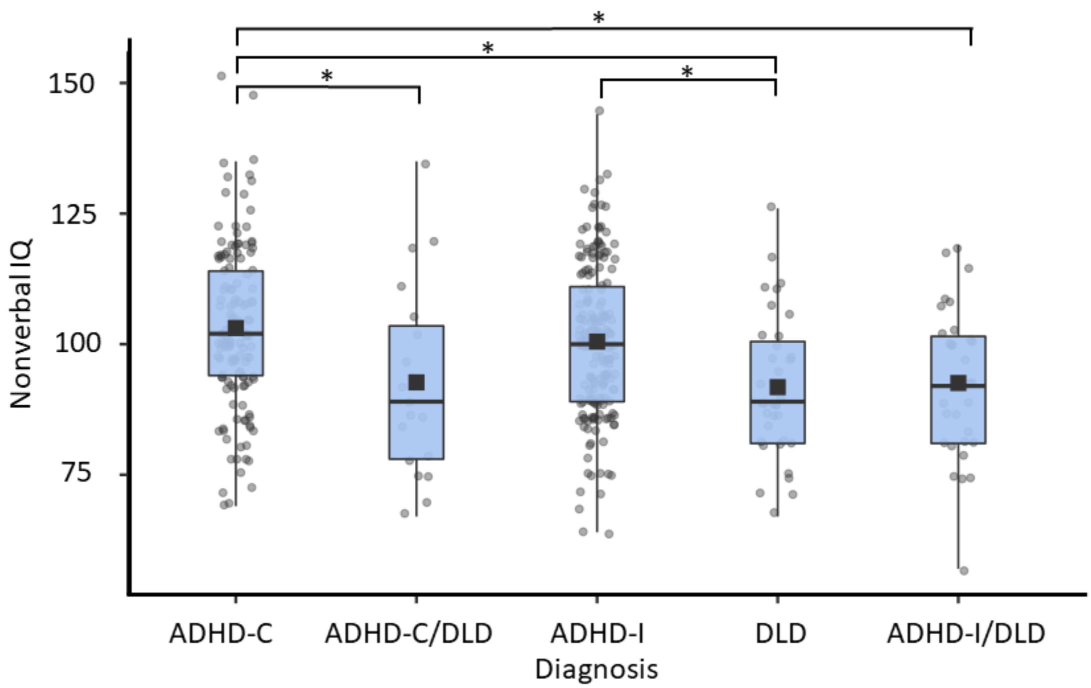

Figure 3.1. Box plots for Visual Spatial Index (VSI scores from The Wechsler Intelligence Scale (WISC-V). ADHD C = Attention-deficit/hyperactivity disorder combined type; ADHD I = ADHD inattentive type; DLD = Developmental language disorder.

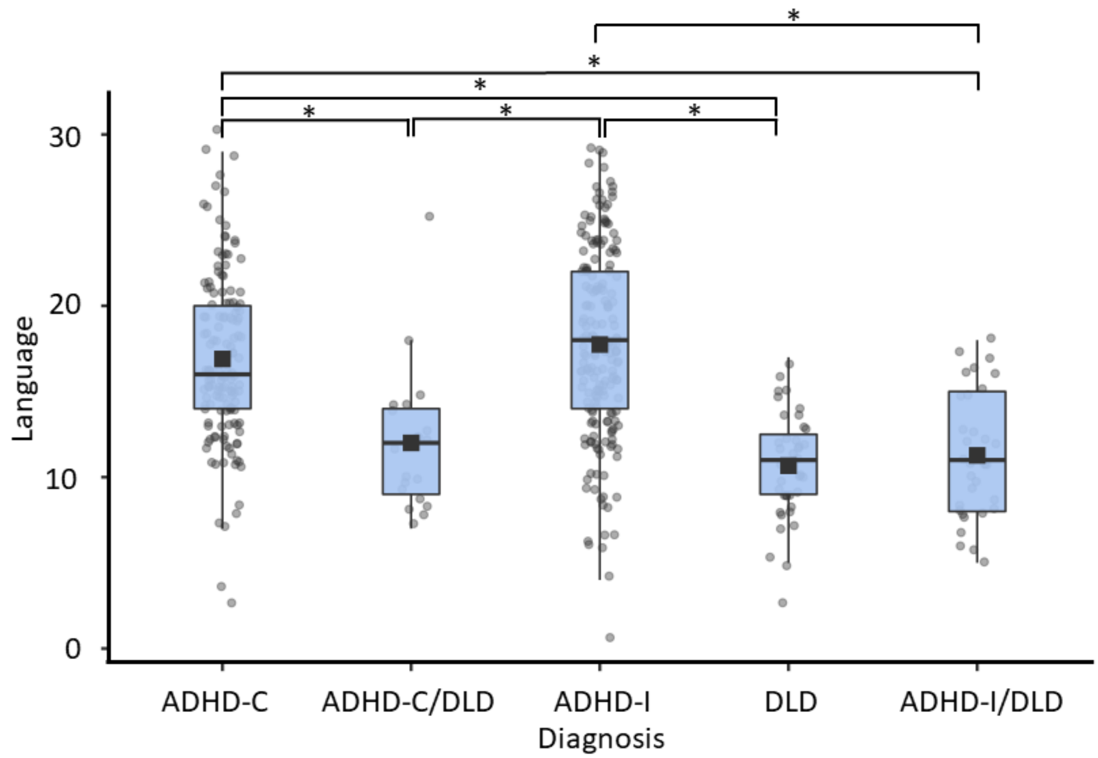

Figure 3.2. Box plots for Clinical Evaluation of Language Fundamentals – Screening Test (CELFST). ADHD C = Attention-deficit/hyperactivity disorder combined type; ADHD I = ADHD inattentive type; DLD = Developmental language disorder.

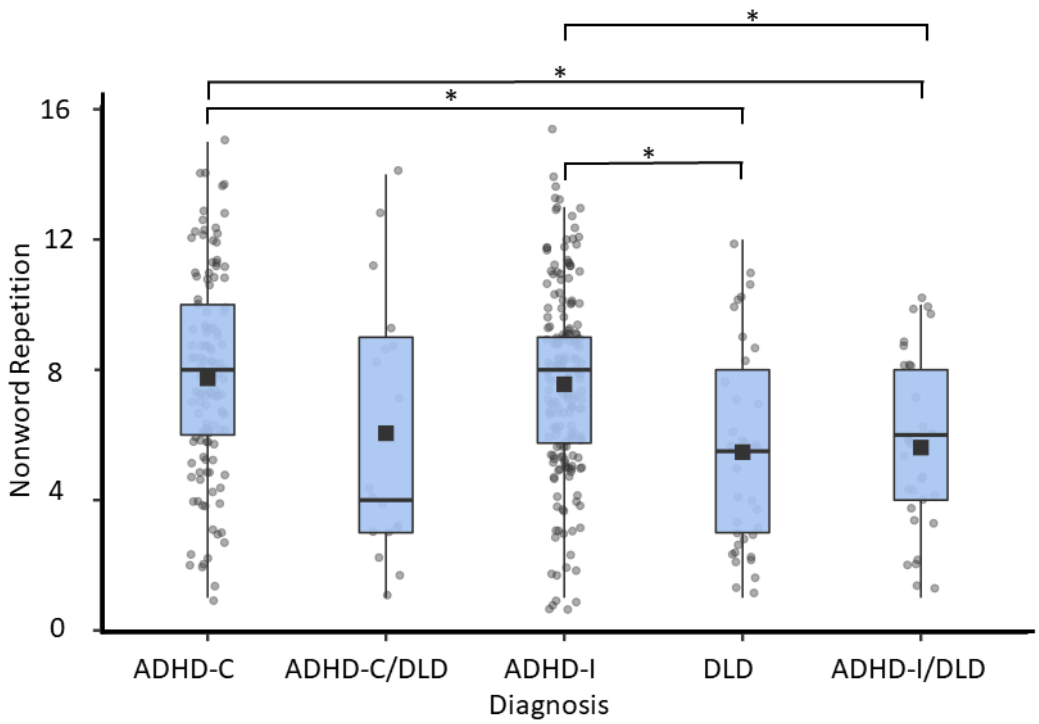

Figure 3.3. Box plots for Comprehensive Test of Phonological Processing (CTOPP) Nonword Repetition (NWR) subscale scores. ADHD C = Attention-deficit/hyperactivity disorder combined type; ADHD I = ADHD inattentive type; DLD = Developmental language disorder.

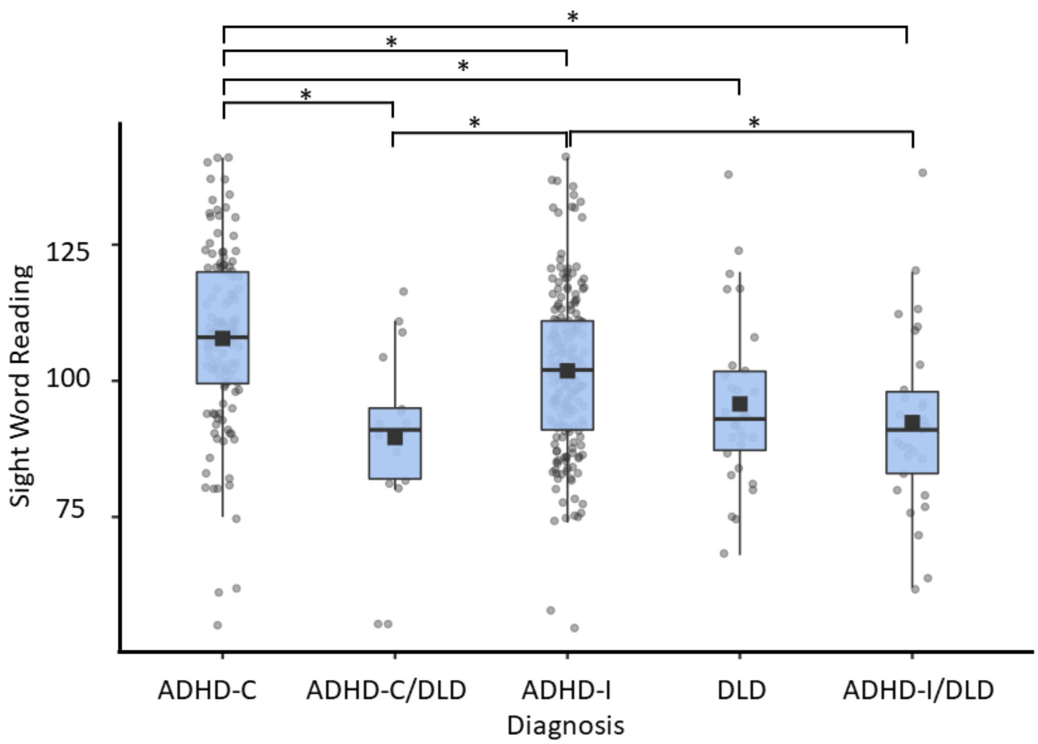

Figure 3.4. Box plots for Sight Word Efficiency (SWE) reading scores. ADHD C = Attention-deficit/hyperactivity disorder combined type; ADHD I = ADHD inattentive type; DLD = Developmental language disorder.

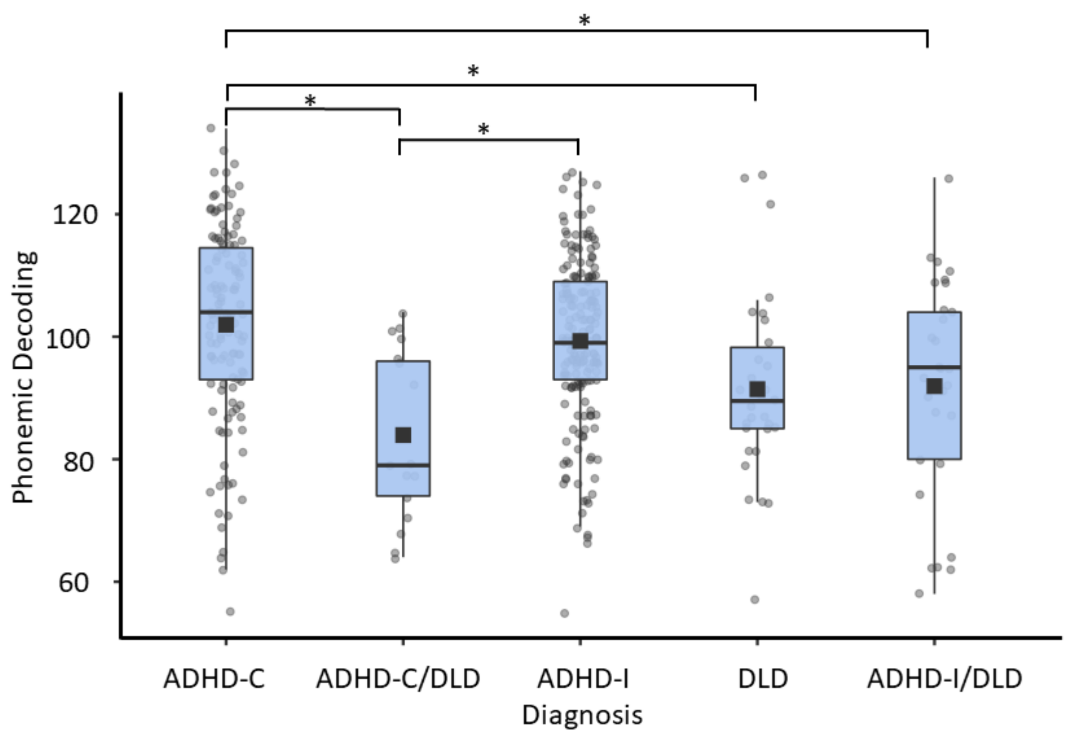

Figure 3.5. Box plots for Phonemic Decoding Efficiency (PDE) reading scores. ADHD C = Attention-deficit/hyperactivity disorder combined type; ADHD I = ADHD inattentive type; DLD = Developmental language disorder.

Table 3.2. Performance across all assessments by group.

Variable	ADHD-C (*n* = 147)	ADHD-I (*n* = 192)	ADHD-C + DLD (*n* =28)	ADHD-I + DLD (*n* = 34)	DLD (*n* = 39)	*df*	F
Nonverbal IQ	103 (15.70)	92.70 (18.60)	100.00 (14.40)	92.60 (14.50)	91.80 (13.60)	4, 397	7.09***
Language	16.90 (4.96)	12.0 (4.17)	17.70 (5.54)	11.30 (3.62)	10.70 (3.16)	4, 85.90	45.49***
Nonword Repetition	7.74 (3.09)	6.05 (3.91)	7.55 (2.93)	5.61 (2.76)	5.47 (3.23)	4, 391	7.28**
Phonemic Decoding	102.00 (16.10)	83.90 (13.80)	99.30 (13.50)	91.90 (18.00)	91.40 (15.40)	4, 375	8.89***
Sight Word Reading	108.00 (16.30)	89.60 (16.60)	102.00 (15.10)	95.80 (16.50)	85.90 (15.60)	4, 377	10.70***

Note. Nonverbal IQ = Wechsler Intelligence Scale Visual Spatial Index; Language = Clinical Evaluation of Language Fundamentals Screening Test. NWR = Comprehensive Test of Phonological Processing Nonword repetition subtest; Phonemic Decoding = Test of Word Reading Efficiency Phonemic decoding subtest; Sight Word Reading = Test of Word Reading Efficiency Sight word subtest. Means presented and standard deviations in brackets. *<.05, **<.01, ***<.001.

3.2.2 Summary

Children with ADHD-C and ADHD-I demonstrated better performance across various language domains compared to other diagnostic groups. However, there were no significant differences between ADHD-C and ADHD-I, except for the sight word efficiency task, where ADHD-C performed better. Both children with ADHD-C and ADHD-I showed better performance on the nonword repetition task compared to individuals with DLD and ADHD-I + DLD. However, children with comorbid ADHD-C + DLD did not perform worse than those with ADHD-C or ADHD-I. On the sight word efficiency task, children with ADHD-C had superior abilities compared to the other diagnostic groups, including ADHD-I. However, children with ADHD-I still outperformed the comorbid groups of ADHD-C + DLD and ADHD-I + DLD. Individuals with ADHD-C showed better phonemic skills compared to other diagnostic groups, except for ADHD-I, and children with ADHD-I outperformed the ADHD-I + DLD on this measure.

The collective results indicate that individuals with DLD (with or without ADHD) exhibited the most significant difficulties across the assessed measures. Those with DLD or comorbid ADHD + DLD (both combined and inattentive subtypes) had the lowest scores across tasks. The presence of comorbid ADHD + DLD did contribute to poorer scores on assessments, but this effect was not more pronounced than in cases of DLD alone. The combination of comorbid ADHD + DLD (combined or inattentive) did not appear to be associated with lower vocabulary, general language abilities, sight word efficiency, or phonemic decoding efficiency. When comparing children and adolescents with comorbid ADHD-C + DLD to those with comorbid ADHD-I + DLD, it was found that the latter performed worse on nonword repetition tasks. This finding suggests that the presence of a comorbid language disorder primarily affects nonword repetition abilities in children with the inattentive subtype of ADHD. Both combined and inattentive subtypes experience difficulties with attention. Compared to children with hyperactive-impulsive symptoms, children with inattentive symptoms also experience cognitive control and processing speed weaknesses (Goth-Owens et al., 2010). These elevated symptoms may have a differential impact on performance in tasks requiring high attentional demands, such as nonword repetition. The subtype of ADHD (combined or inattentive) did not show differential associations with other abilities, except for sight word efficiency. However, individuals with ADHD-I still outperformed both comorbid groups on this assessment. A follow up analysis repeated the above ANOVAs excluding test dependent outliers (*n* = 6), and all significant effects remained consistent.

3.2.3 Diagnostic Utility

ROC curves for the four assessments show that they were not all above the reference line or close to the edge of the upper-left quadrant. Further, the position of the curves changed depending on the discrimination (e.g., ADHD-C versus DLD). These findings indicate that not all assessments had excellent levels of diagnostic accuracy, and some assessments performed less well with certain discriminations. As expected, the CELFST was good at distinguishing the following comparisons: ADHD-C vs. DLD, ADHD-C vs. ADHD-C + DLD, ADHD-I vs. ADHD-C + DLD, ADHD-I vs. DLD, ADHD-I vs. ADHD-I + DLD, and ADHD-C vs. ADHD-I + DLD. The CTOPP nonword repetition was only sufficient at distinguishing ADHD-C from DLD and ADHD-C from ADHD-I + DLD. The TOWRE SWE was found to be good at distinguishing ADHD-C from DLD, ADHD-C from ADHD-C + DLD, ADHD-C from ADHD-I + DLD. Notably, it was the only measure sufficient in discriminating between the two types of ADHD. The TOWRE PDE was also good at distinguishing ADHD-C from DLD, ADHD-C from ADHD-C + DLD, and ADHD-I from ADHD-C + DLD. It was also the most sufficient at discriminating ADHD-C + DLD from DLD. Areas under the ROC curves ranged from a low of 0.43 (score for ADHD-C + DLD vs. DLD on the CELFST and CTOPP) to a high of 0.87 (score for ADHD-C vs. DLD and ADHD-I vs. DLD on the CELFST).

Overall, the ROC curves demonstrate that within our sample, the CELFST is the best at discriminating most groups of children but particularly those with ADHD-C from DLD (0.87) and ADHD-I from DLD (0.87). This finding is expected given that children with ADHD had to pass this screener to be classified as not having comorbid DLD. Moreover, the CELFST did not discriminate children and adolescents with ADHD-C from ADHD-I (0.45), and ADHD-C + DLD from DLD (0.43). Findings suggest that the TOWRE SWE was the most sufficient at discriminating between the two types of ADHD and the TOWRE PDE was the most sufficient at discriminating between ADHD-C + DLD and DLD (0.62). The remaining measures ranged from sufficient to not useful in discriminating the diagnostic groups.

The predictive value of each measure’s positive score (or score lower than the cut off) and negative score (or score higher than the cut off) is presented from the positive and negative likelihood ratios in Table 3. The larger the positive likelihood score and smaller the negative likelihood score, the more informative the measure. Under this interpretation, as expected, the CELFST was informative in discriminating between the most diagnostic groups (ADHD-C and DLD, ADHD-C and ADHD-C + DLD, ADHD-I and ADHD-C + DLD, and ADHD-I and DLD) compared to the remaining assessments which according to their respective likelihood ratios, were not informative in assigning clinical status. Importantly, positive likelihood ratios for all measures, including the CELFST were not near or above a recommended value of 10.00. These findings suggest that test scores on the CELFST below the optimal cut off point for each discrimination are indicative of “positive” rather than very positive of affected language status (Dollaghan, 2007; Redmond, 2011; Sackett et al., 1991). These findings further suggest that lower scores on the CELFST came from participants with DLD, rather than ADHD. On the CELFST, participants odds of having DLD compared to ADHD-I increased 5.54 times when they received a score below 15.00. In contrast, the positive likelihood ratio for the CELFST when the discrimination was between ADHD-C versus DLD was less predictive of DLD status, but still within the “moderately positive” range. The same was found for the CELFST when discriminations were between ADHD-I and ADHD-C + DLD. That is, their odds of having ADHD-C + DLD instead of ADHD-C or ADHD-I increased 4.60 and 4.80 times respectively, when they received a score below 15.00. In practical terms, these findings suggest that performance below the cut off scores for the above discriminations are suggestive, but insufficient to assign language impaired status to participants. For negative likelihood ratios, similar findings emerged. All negative ratios associated with informative positive ones on the CELFST were below 0.40, indicating that high scores were “negative” of affected status (Dollaghan, 2007; Redmond, 2011; Sackett et al., 1991). In other words, performance above the cut off values were again suggestive, but not sufficient to rule out DLD or ADHD-C + DLD status depending on the discrimination. Together, these findings indicate that, not surprisingly, inadequate performance on the CELFST is suggestive of DLD status but not sufficient to assign a formal language diagnosis. These findings are expected given that the CELFST is a screening test and is not psychometrically set up to diagnose children and adolescents.

In summary, as expected, the CELFST demonstrated high discriminatory ability in distinguishing between ADHD (combined or inattentive) and DLD in children and adolescents. It also performed well in distinguishing between comorbid diagnostic groups. These findings highlight the effectiveness of the CELFST in evaluating potential language difficulties. However, additional assessments should be administered following the CELFST to determine specific diagnostic categories and the impact of these categories on language performance. When comparing comorbid cases to ‘pure’ ADHD and DLD, the measures used in the study accurately identified and distinguished DLD and comorbid diagnoses without any decrease in performance. No single task showed superior discrimination between distinct categories, suggesting the importance of utilizing a combination of assessments. Clinical status, particularly DLD or comorbid ADHD-C + DLD, influenced performance in measures of general language ability, while tasks assessing nonword repetition and phonemic skills were less affected by clinical status. However, it should be noted that inadequate performance on a single assessment was not sufficient to determine clinical status. Further research is needed to validate the findings of the ROC analysis. Overall, these findings highlight the importance of using a comprehensive set of assessments to accurately determine diagnostic categories and understand how clinical status impacts language and reading performance.

Table 3.3. Diagnostic accuracy with psycholinguistic assessments.

Measure	Discrimination	Area under the curve [a]	Optimal cut-off	Sensitivity	Specificity	Positive likelihood ratio [b]	Negative likelihood ratio [c]
CELF *ST*	ADHD C vs. DLD	0.87	13.00	0.82	0.74	3.15	0.24
	ADHD C vs. ADHD C + DLD	0.81	15.00	0.69	0.85	4.60	0.36
	ADHD C vs. ADHD I	0.45	12.00	0.91	0.10	1.01	0.90
	ADHD I vs. ADHD C + DLD	0.81	15.00	0.72	0.85	4.80	0.33
	ADHD I vs. DLD	0.87	15.00	0.72	0.87	5.54	0.32
	ADHD C + DLD vs. DLD	0.43	11.00	0.51	0.45	0.93	1.09
	ADHD I vs. ADHD I + DLD	0.83	15.00	0.72	0.72	2.57	0.39
	ADHD I + DLD vs. DLD	0.47	9.00	0.78	0.30	1.11	0.73
	ADHD C vs. ADHD 1 + DLD	0.82	13.00	0.82	0.67	2.48	0.27
CTOPP *NWR*	ADHD C vs. DLD	0.69	7.00	0.66	0.67	2.00	0.51
	ADHD C vs. ADHD C + DLD	0.61	5.00	0.86	0.46	1.59	0.30
	ADHD C vs ADHD I	0.51	7.00	0.65	0.35	1.00	1.00
	ADHD I vs ADHD C + DLD	0.60	5.00	0.88	0.46	1.63	0.26
	ADHD I vs. DLD	0.68	7.00	0.65	0.67	1.97	0.52
	ADHD C + DLD vs DLD	0.43	5.00	0.53	0.46	0.98	1.02
	ADHD I vs. ADHD I + DLD	0.68	7.00	0.65	0.68	2.03	0.51
	ADHD I + DLD vs. DLD	0.48	10.00	0.17	0.87	1.31	0.95
	ADHD C vs. ADHD I + DLD	0.69	7.00	0.65	0.68	2.03	0.51

TOWRE *SWE*	ADHD C vs. DLD	0.73	100.00	0.75	0.70	2.50	0.36
	ADHD C vs. ADHD C + DLD	0.77	96.00	0.79	0.70	2.63	0.30
	ADHD C vs ADHD I	0.62	105.00	0.61	0.55	1.36	0.71
	ADHD I vs ADHD C + DLD	0.68	96.00	0.66	0.71	2.28	0.48
	ADHD I vs. DLD	0.63	96.00	0.66	0.60	1.65	0.57
	ADHD C + DLD vs DLD	0.55	94.00	0.50	0.58	1.19	0.86
	ADHD I vs. ADHD I + DLD	0.68	97.00	0.63	0.69	2.03	0.54
	ADHD I + DLD vs. DLD	0.57	90.00	0.70	0.48	1.35	0.63
	ADHD C vs. ADHD I + DLD	0.77	99.00	0.76	0.76	3.17	0.32
TOWRE *PDE*	ADHD C vs. DLD	0.71	93.00	0.76	0.63	2.04	0.38
	ADHD C vs. ADHD C + DLD	0.78	97.00	0.69	0.75	2.76	0.41
	ADHD C vs ADHD I	0.57	104.00	0.51	0.55	1.13	0.89
	ADHD I vs ADHD C + DLD	0.76	93.00	0.75	0.67	2.27	0.37
	ADHD I vs. DLD	0.69	94.00	0.72	0.67	2.18	0.42
	ADHD C + DLD vs DLD	0.62	85.00	0.77	0.58	1.83	0.40
	ADHD I vs. ADHD I + DLD	0.62	96.00	0.67	0.58	1.63	0.56
	ADHD I + DLD vs. DLD	0.44	81.00	0.83	0.28	1.15	0.61
	ADHD C vs. ADHD I + DLD	0.66	96.00	0.72	0.59	1.76	0.47

Note. ADHD C + DLD = Attention-deficit/hyperactivity disorder and Developmental language disorder; ADHD I = Attention-deficit/hyperactivity disorder Inattentive type; DLD = Developmental language disorder; ADHD C = Attention/deficit-hyperactivity combined type; CELFST = Clinical Evaluation of Language Fundamentals Screening Test; CTOPP = Comprehensive Test of Phonological Processing; TOWRE = Test of word reading efficiency.

a = Optimal cut-off based on Index of Union (IU), where sensitivity and specificity are the closest to the area under the ROC curve and the absolute value between sensitivity and specificity is minimal.

b = Positive likelihood ratio = Sensitivity/ (1 − Specificity): Values of 1 = neutral, 3 = moderately positive, ≥ 10 = very positive

c = Negative likelihood ratio = (1 − Sensitivity)/ Specificity: Values of 1 = neutral, ≤ 0.30 = moderately negative, ≤ 0.10 = extremely negative.

ROC Curves for Each Discrimination

ADHD Combined versus ADHD Combined + DLD

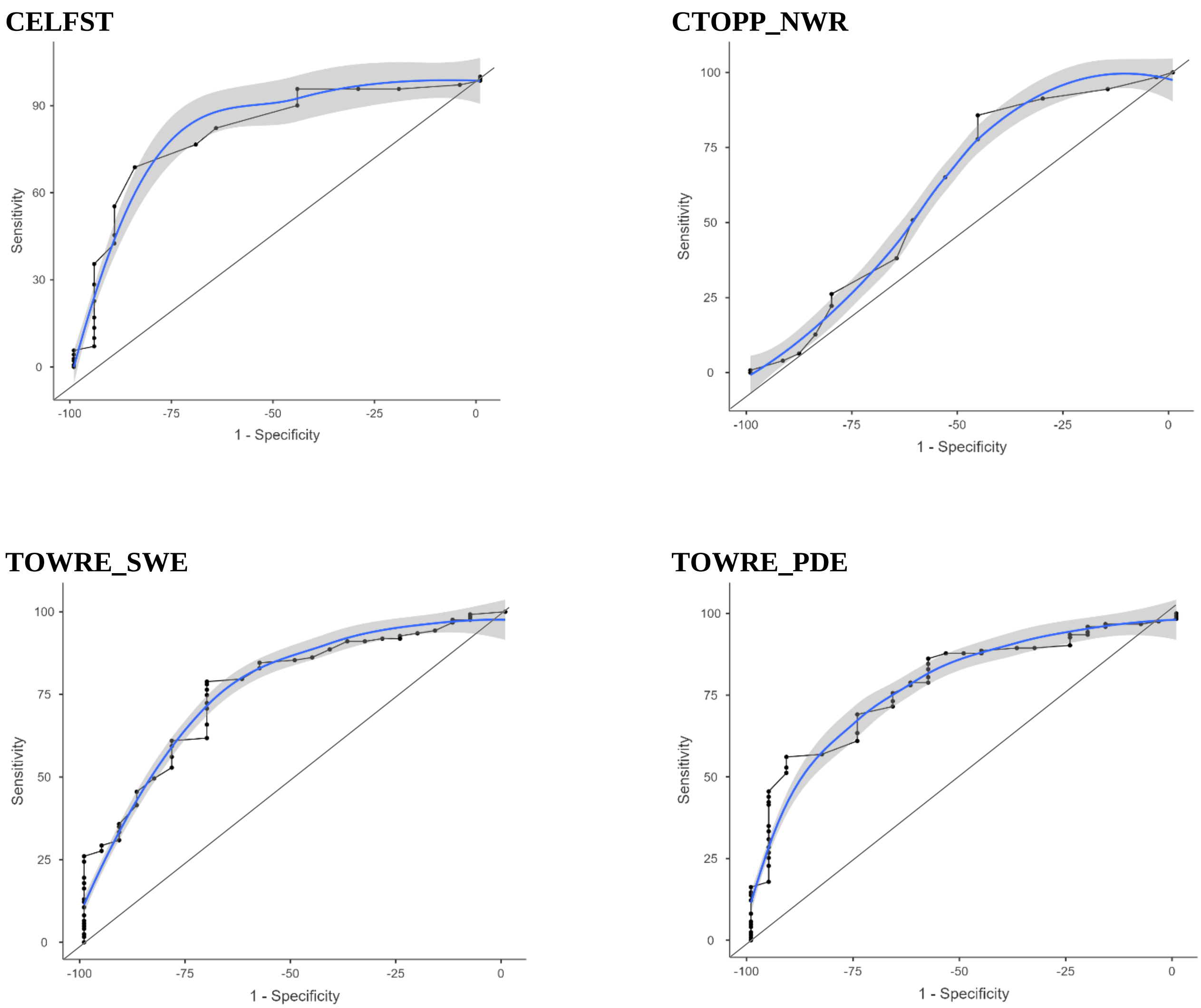

Figure 3.6. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD combined versus ADHD combined + DLD. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at "chance").

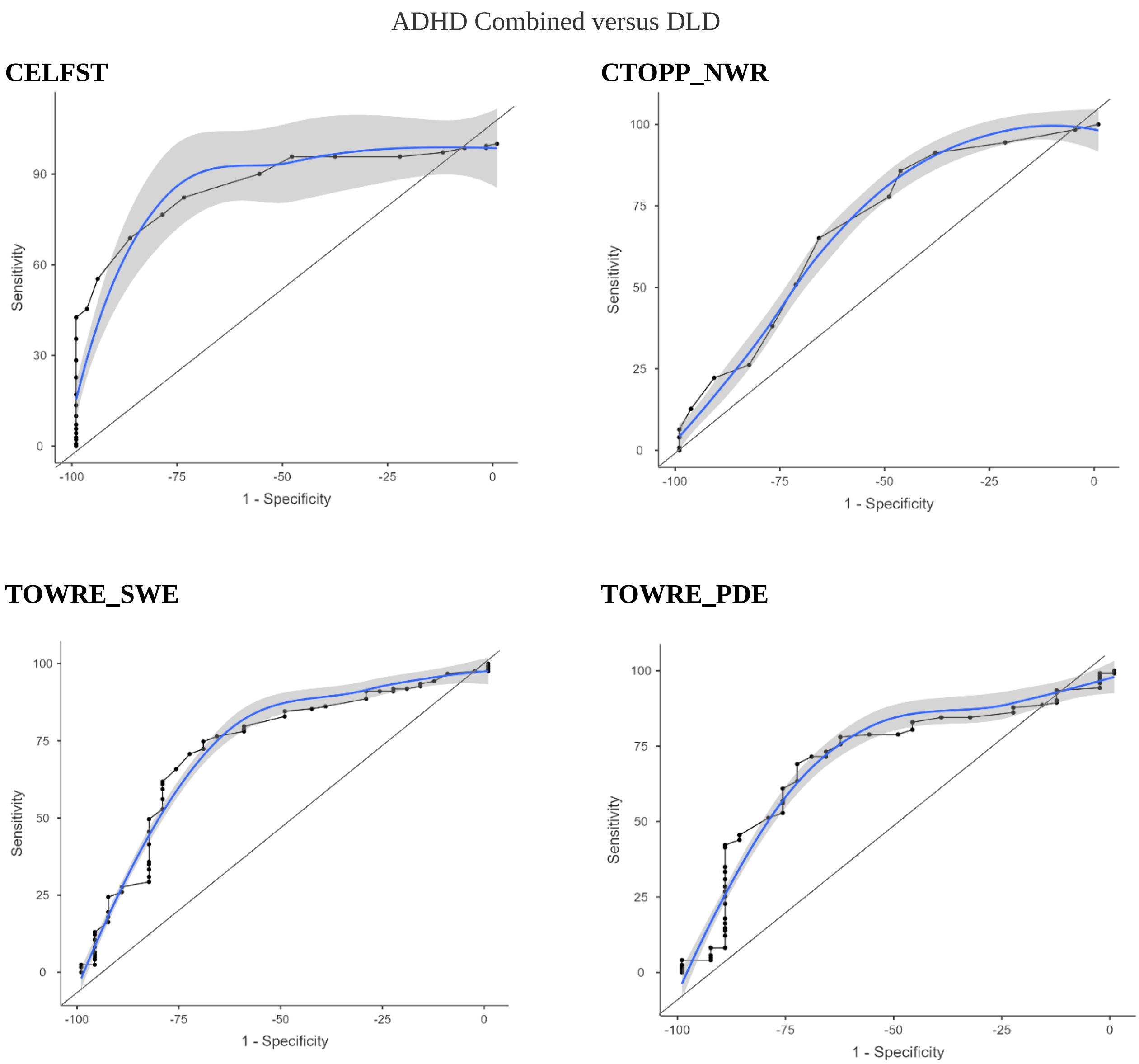

Figure 3.7. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD combined versus DLD groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at "chance").

ADHD Inattentive versus DLD

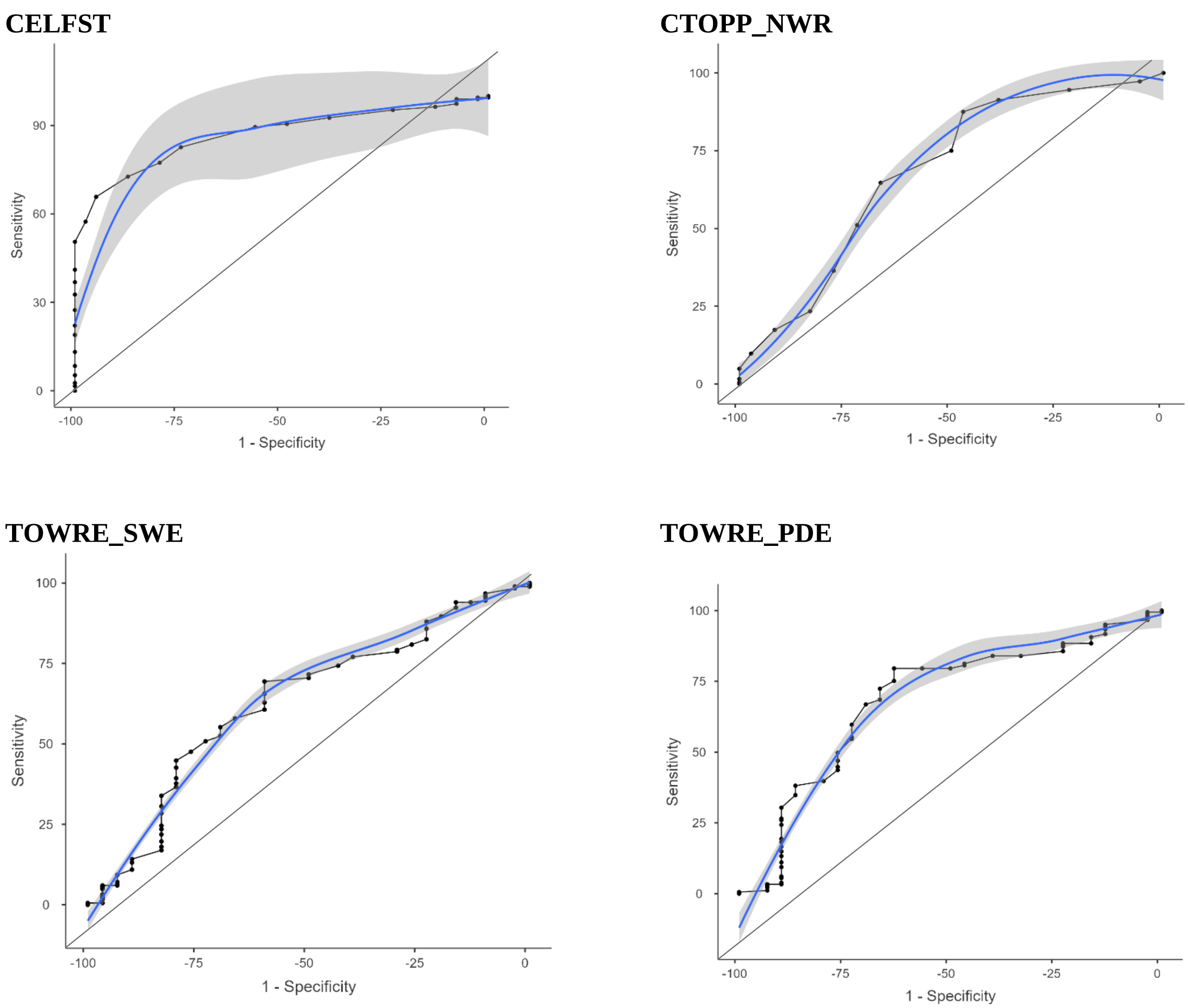

Figure 3.8. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD inattentive versus DLD groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at "chance").

ADHD Combined + DLD versus DLD

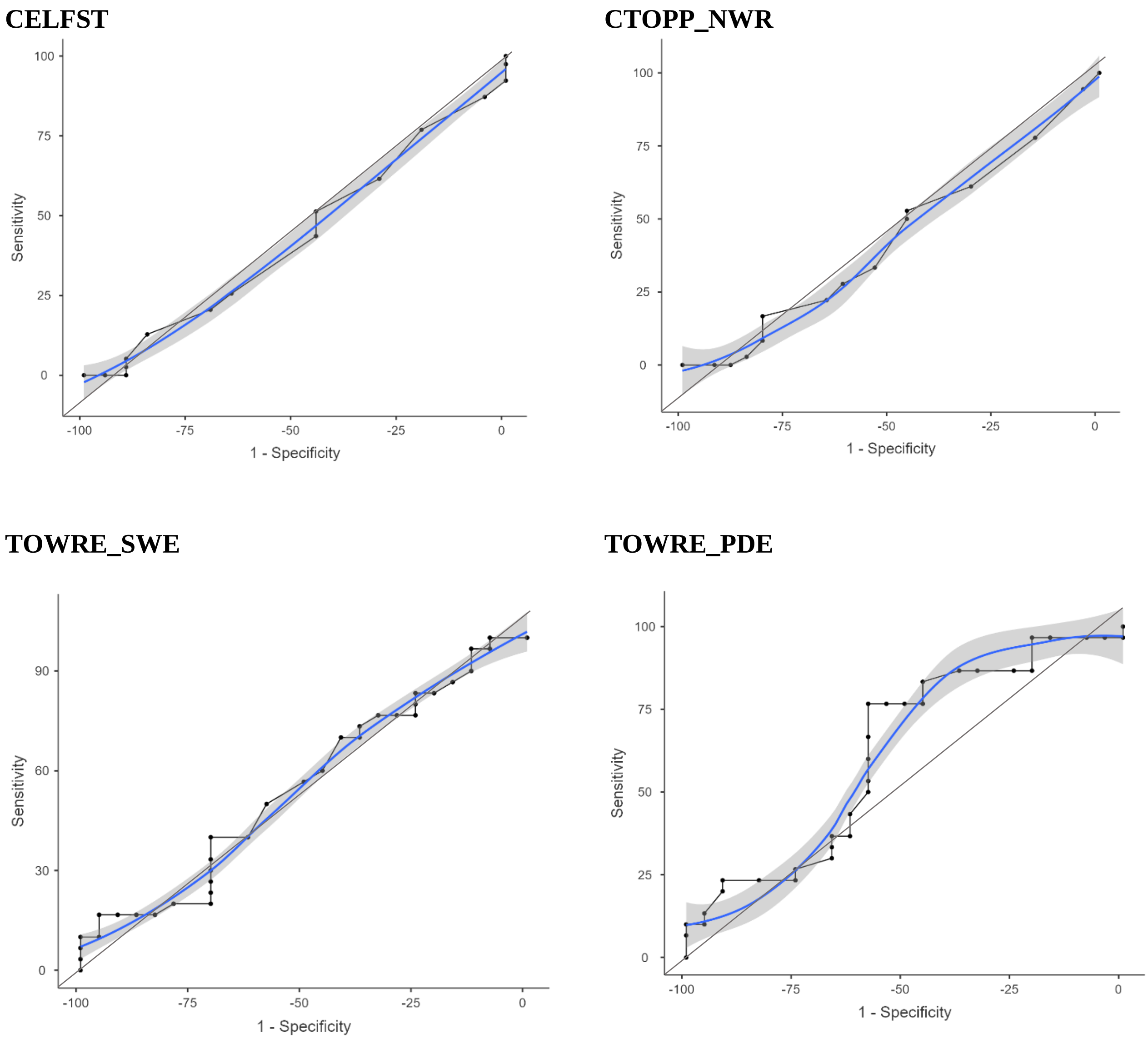

Figure 3.9. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD combined + DLD versus DLD groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at "chance").

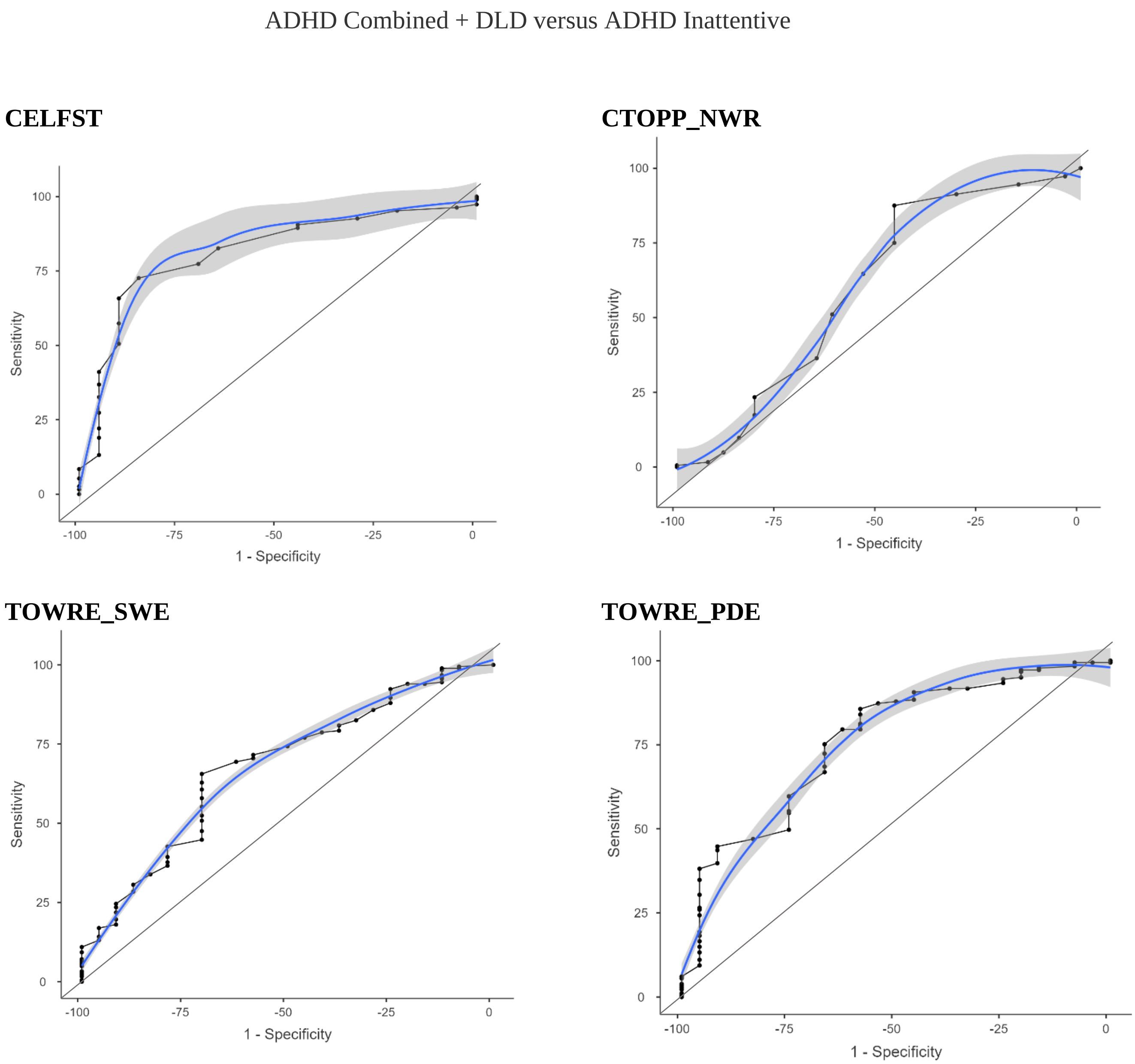

Figure 3.10. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD combined + DLD versus ADHD inattentive groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at "chance").

ADHD Combined versus ADHD Inattentive

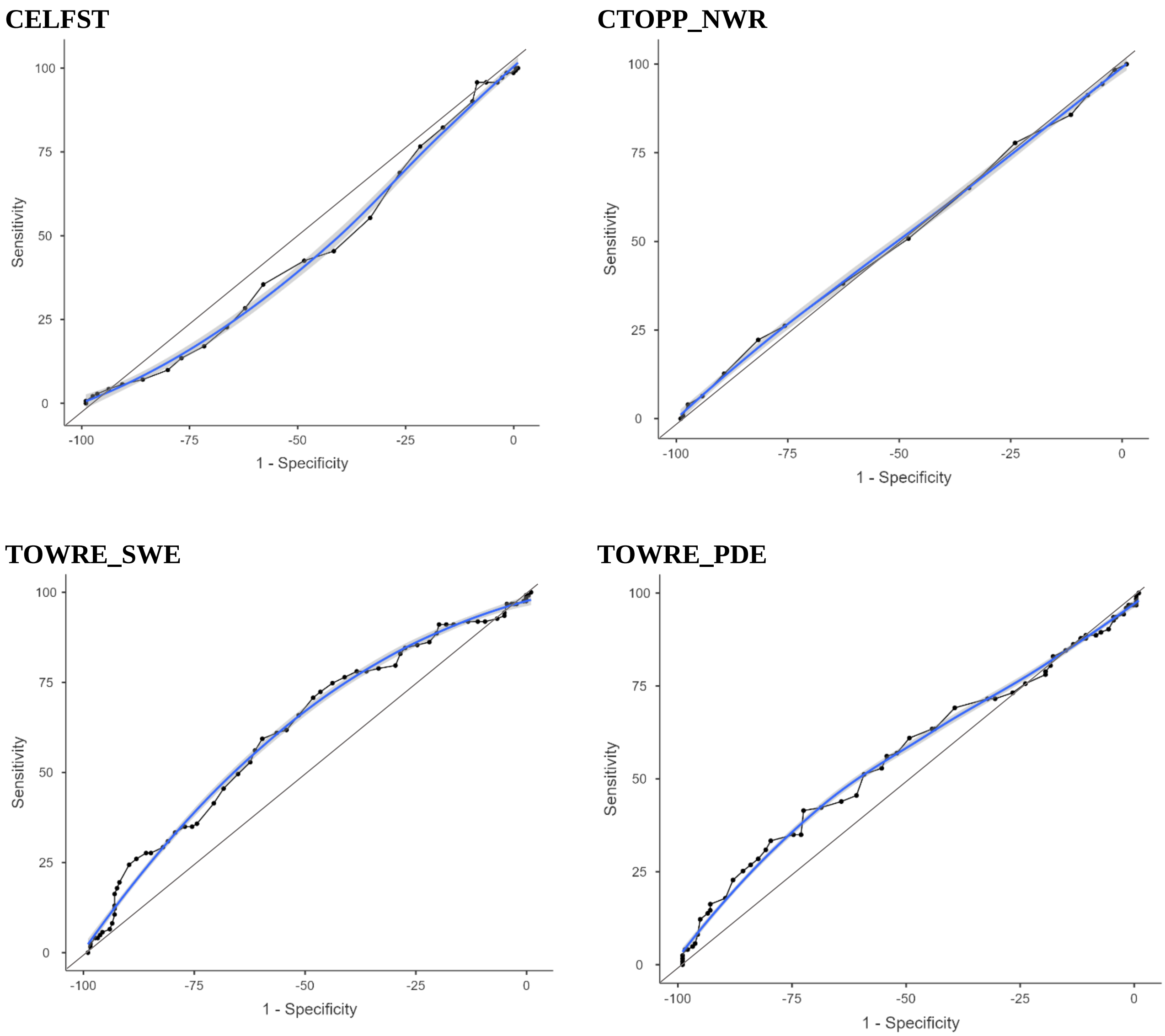

Figure 3.11. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD combined versus ADHD inattentive groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at “chance”).

ADHD Combined versus ADHD Inattentive + DLD

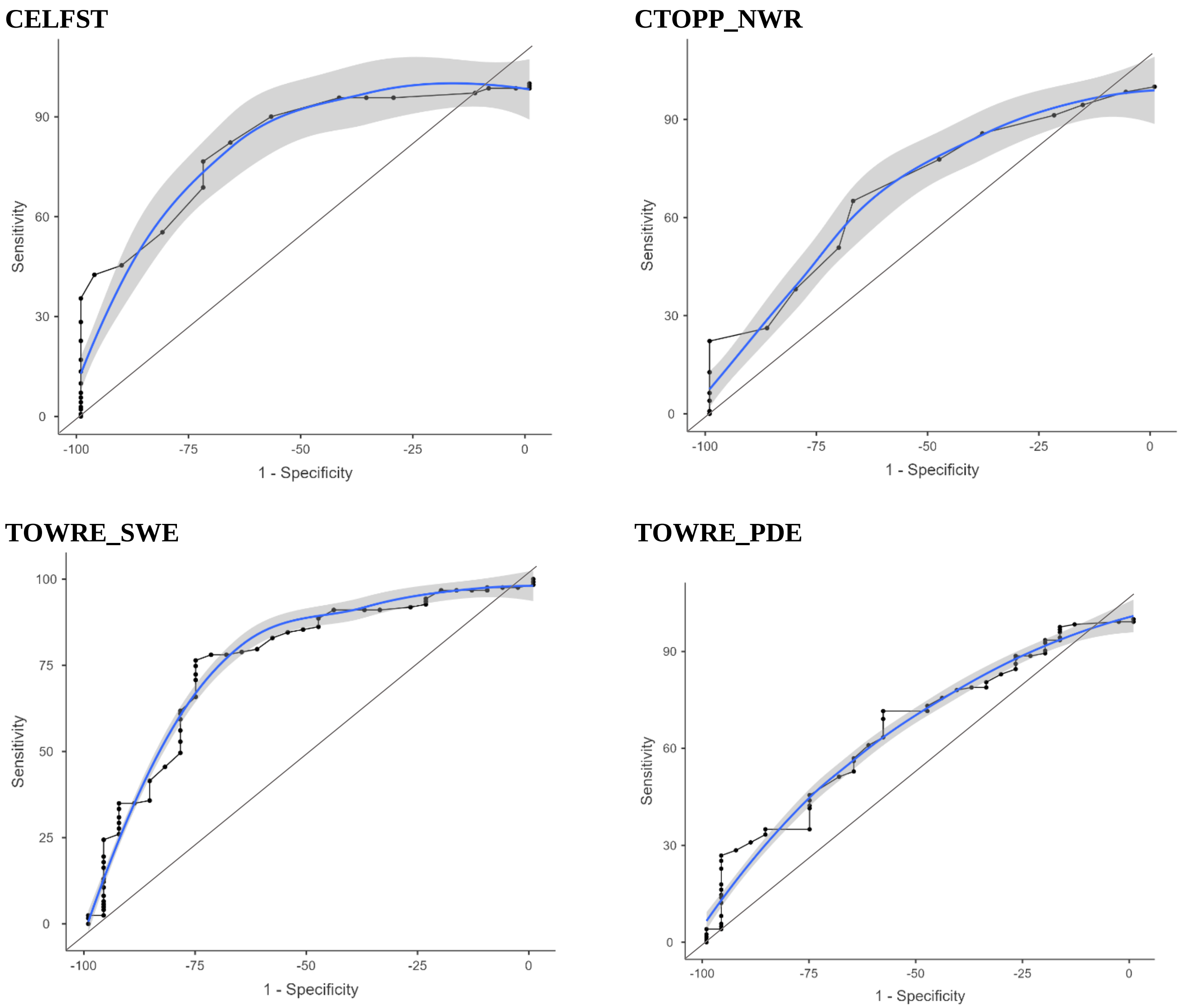

Figure 3.12. Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD combined versus ADHD inattentive + DLD groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at “chance”).

ADHD Inattentive versus ADHD Inattentive + DLD

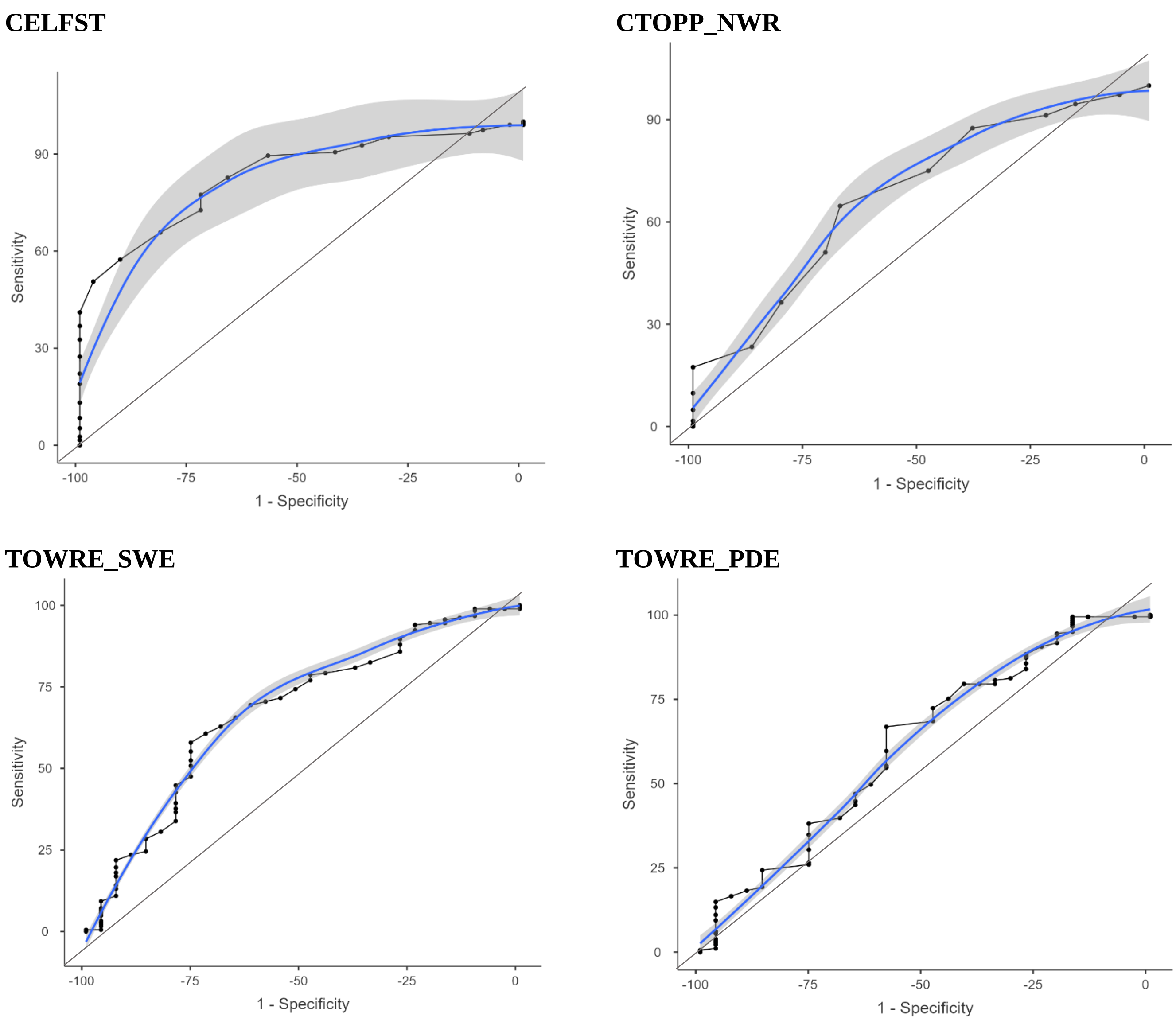

Figure 3.13.Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD inattentive versus ADHD inattentive + DLD groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at “chance”).

ADHD Inattentive + DLD versus DLD

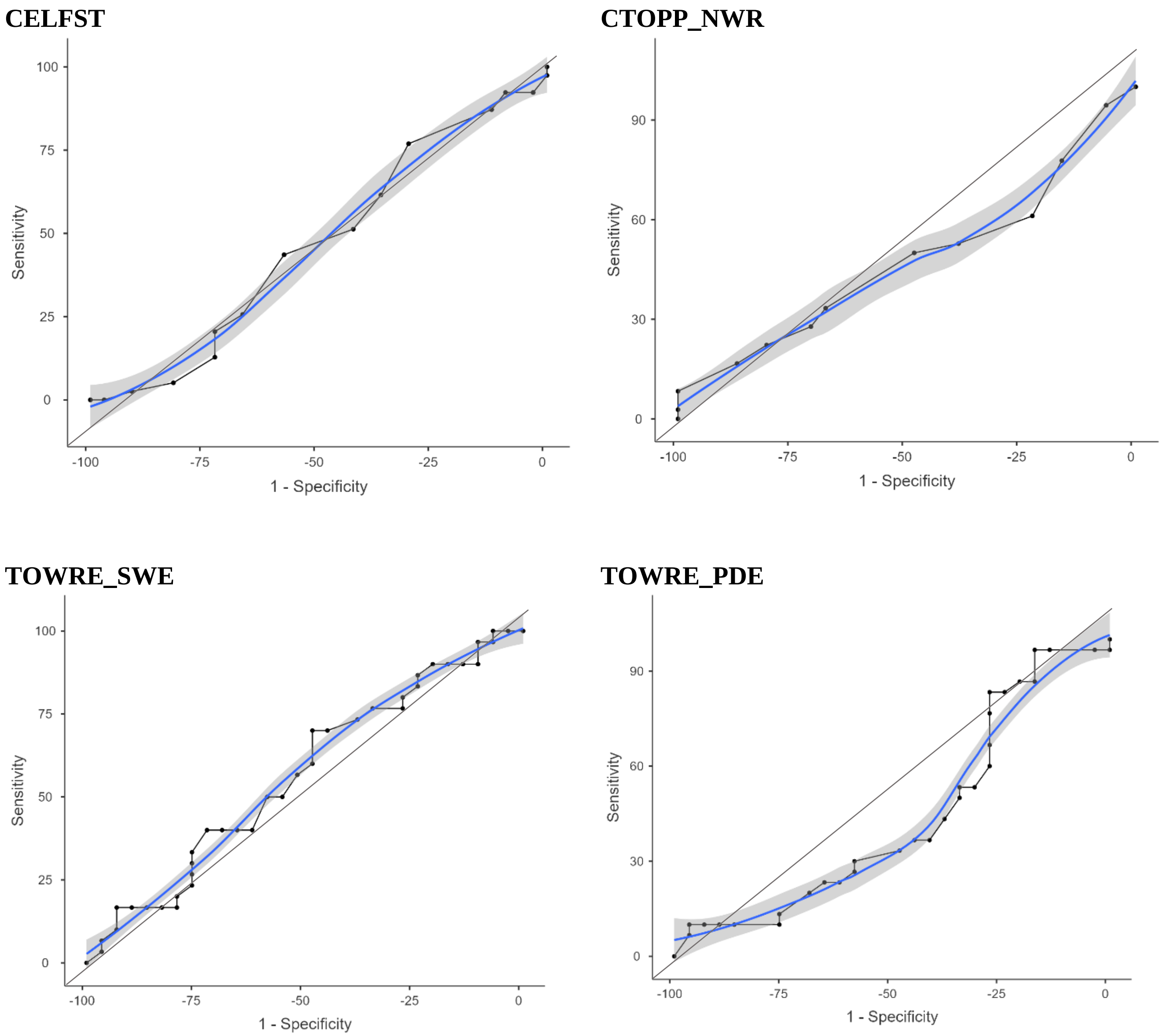

Figure 3.14.Receiver operating characteristics (ROC) curves associated with linguistic discrimination of ADHD inattentive + DLD versus DLD groups. 95 CI bound and standard error bars included (grey reference line indicates test accuracy at "chance").

3.2.4 Predicting DLD

In model 1 of the binary logistic regression, nonverbal IQ was entered, and the model was statistically significant $\chi^2(1) = 24.40$, $p<.001$ but only explained 6% of the variance in diagnosis (Nagelkerske R^2) and has 68% classification accuracy. Next, the CELFST was entered, and the model was statistically significant, $\chi^2(1) = 66.09$, $p<.001$, explained an additional 23% of the variance in diagnosis, and improved classification accuracy to 85%. Importantly, once the CELFST was added to the model, nonverbal IQ was no longer a significant predictor of diagnostic status. Adding SWE, PDE, and NWR in the subsequent models did not significantly improve the overall model, classification accuracy, or explain any addition variance (See Table 3.4 for regression statistics).

These findings indicate that the CELFST was the most efficient measure in predicting DLD status. Given that the CELFST was one of the assessments used to exclude children without potential language difficulties, these findings are not surprising. The cross-validation analysis indicated that the model was a good fit (RMSE .43).

Table 3.4. Binary regression models for the prediction of DLD vs. all other diagnoses.

					BCa 95% Confidence Interval	
Predictors	*B*	*SE*	Wald	Exp(*B*)	Lower Bound	Upper Bound
Model 1						
Nonverbal IQ	-0.046	0.011	**3.70***	0.968	0.065	0.026
Model 2						
Nonverbal IQ	-0.019	0.012	0.770	0.985	0.041	0.002
CELFST	-0.264	0.039	**16.30****	0.834	0.340	0.189
Model 3						
Nonverbal IQ	-0.015	0.011	0.653	0.985	0.006	0.011
CELFST	-0.237	0.041	**15.43****	0.834	0.157	0.041
TOWRE SWE	-0.011	0.014	0.003	0.999	0.017	0.014
TOWRE PDE	-0.004	0.014	1.723	0.979	0.025	0.014
CTOPP NWR	-0.041	0.054	0.024	0.990	0.066	0.055

Note. * $p < .05$, ** $p < .001$. *B* indicates unstandardized regression weights *SE* indicates standard error. Exp(*B*) odds ratio. BCa indicates bias-corrected accelerated bootstrap interval. Bootstrap confidence intervals are shown for each coefficient. All remaining values are asymptotic.

3.4 Discussion

The present study aimed to investigate whether the presence of a comorbid language disorder in ADHD impacts language and reading skills. The study also explored the efficacy of various psycholinguistic assessments in distinguishing between children and adolescents with ADHD, DLD, and comorbid ADHD + DLD. The analyses were guided by prior work examining the diagnostic utility of grammar, nonword repetition, sentence recall, and narrative language measures in ADHD and DLD (Redmond et al., 2011). While language and nonword repetition tasks have been shown to be robust clinical markers of DLD across ages and languages, much less is known about the capacity of reading efficiency measures to serve as clinical markers of DLD. Examining the capabilities of language and reading in distinguishing ADHD, DLD, and comorbid ADHD + DLD could lead to the adoption of these assessments in future protocols and further elucidate the overlapping difficulties experienced by these etiologically distinct disorders.

The current study demonstrated that the CELFST can accurately distinguish individuals with pure DLD from those with comorbid ADHD + DLD. This finding is significant because the CELFST is not a diagnostic measure of DLD, and not all children who fail the test receive a DLD diagnosis. The study also showed that reading efficiency measures are capable of distinguishing between subtypes of ADHD. However, despite these strengths, none of the groups could be clearly defined based solely on their reading or language abilities. Additional assessments are therefore necessary to accurately identify the presence of ADHD and/or DLD status.

The findings of the current study indicate that the coexistence of ADHD in children with DLD does not exacerbate language and reading difficulties. Moreover, the significant differences between children and adolescents with ADHD (combined and inattentive) were observed only in sight word efficiency, in favour of those with combined type. Cross-validation methods demonstrated that the model had good generalizability, suggesting that the results can be extended to other samples in predicting DLD status using the combination of tasks employed in the current study. Importantly, while reading efficiency measures, specifically sight word efficiency, proved to be the most effective in distinguishing between the two types of ADHD, the CELFST demonstrated the best overall performance in distinguishing between pure and comorbid cases of ADHD + DLD. The CELFST also emerged as the strongest predictor of diagnostic status, surpassing IQ, and vocabulary assessments.

Our findings diverge from previous studies showing high classification accuracy of DLD on nonword repetition tasks (Redmond et al., 2011). While the CELFST was found to be the best at distinguishing between ADHD and DLD, both reading efficiency subtests (SWE and PDE) performed well and were not far behind. In cases where the CELFST fell short in distinguishing between groups, such as in DLD versus comorbid ADHD-C + DLD, the SWE and PDE measures demonstrated good discriminatory abilities.

It is important for cut-off values to be replicated in other settings to determine the true accuracy of diagnostic tests (Redmond et al., 2011; Sackett & Haynes, 2002). As mentioned by Redmond (2011), optimal cut-off values can vary across studies and may be based on arbitrary criteria, such as “1.0 *SD* below the mean or below the 10th

percentile". Additionally, variability in estimates of comorbidity between ADHD and DLD symptoms can be attributed to differences in study design elements, such as age range, inclusionary and exclusionary criteria, and diagnostic criteria. Reports of co-occurrence between ADHD and DLD can range widely, from 8% to 90% in adults (Tannock & Schachar, 1996) and 4 % to 35% in children (Cantwell & Baker, 1987; Snowling et al., 2006). These variations highlight the importance of using reliable assessments in studying comorbidity. Currently, there is a lack of sufficient investigations comparing pure and comorbid samples of ADHD and DLD. The current study is the first to evaluate the diagnostic integrity of language and reading measures in children and adolescents who meet the criteria for both language impairment and ADHD. These investigations can assist researchers in interpreting co-occurring symptoms and determining which assessments can serve as valid clinical markers in similar groups of children. Although the CELFST alone is not sufficient to assign a diagnosis of language impairment, it contains some of the most discriminating items from the full CELF, which is frequently used as a benchmark or reference standard in language impairment assessments.

Contrary to previous research (Conti-Ramsden, 2003; Conti-Ramsden & Hesketh, 2003; Oetting & Cleveland, 2006; Poll et al., 2010; Redmond et al., 2011), the nonword repetition task used in the current study did not accurately distinguish between any of the groups. The discrepancy in findings could be attributed to several factors, particularly differences in task designs across studies. The most used nonword repetition task is an adaptation of Dollaghan and Campbell's (1998) task, known as the NWR. This task has been shown to distinguish children with DLD from their TD peers (Graf et al., 2007) and more recently, children with ADHD from those with DLD (Redmond et al., 2011). However, when combined with additional language assessments, the NWR task has demonstrated high diagnostic accuracy but low sensitivity rates that limit its clinical utility (50% range; Conti-Ramsden, 2003; Oetting & Cleveland, 2006). Another nonword repetition task used in younger children is the Children's Test of Nonword Repetition (CNRep; Garthercole & Baddeley, 1996). It shares similar features and scoring procedures with Dollaghan and Campbell's NWR task but presents 40 nonwords of varying syllable lengths. In the current study, the CTOPP-2 was used, which is almost identical to the previous assessments but includes 30 nonwords increasing in complexity. The CTOPP-2 has shown higher construct validity on both subtest and composite scores compared to the CNRep (Tennant, 2014). When paired with valid language assessments, the CTOPP-2 is considered a robust and reliable tool for identifying DLD in numerous studies (Leyfer et al., 2008; Loucas et al., 2016; Paradis, 2016). There are also differences in the way NWR tasks can be scored, which can impact their ability to distinguish groups (Archibald & Joanisse, 2009). For example, some researchers score these tasks by deducting points for phonemic errors using offline transcriptions. Other researchers score assessments online where correct responses depend on accurate recall at the item-level. Item-level scoring is argued to be more clinically practical because it minimizes training needs. The NWR used in the current study was scored at the item-level. Despite these task differences, the findings of the current study aligned with previous research, showing that children with DLD produced significantly more phonological errors compared to those with ADHD. These findings suggest that the deficits observed in DLD may not be dependent on the specific nonword repetition task used or the way it is scored.

The most interesting finding of the current study was that reading efficiency, rather than oral language, was the best discriminator between ADHD subtypes. The results from the group difference analyses supported this, revealing significant differences between children and adolescents with ADHD-I and ADHD-C in their ability to identify real words (TOWRE SWE), in favour of those with ADHD-C. However, there were no significant differences between the two groups in their ability to identify nonwords (TOWRE PDE). Inattention symptoms have been found to have a greater impact on sight word reading compared to hyperactive-impulsive symptoms (Martinussen et al., 2014). Nonetheless, children with ADHD-C also exhibit deficits in attention. An alternative, but related explanation is that children and adolescents with ADHD-C may benefit from the speeded nature of the sight word efficiency subtest due to their more impulsive style. Children with the predominately inattentive subtype also have greater processing speed weaknesses than children with hyperactive-impulsive symptoms (Goth-Owens et al., 2010) which may result in difficulties recalling words quickly. Children with the inattentive subtype may possess the knowledge of words but may not be as quick at identifying them during the task.

A more plausible explanation is that the ADHD-I group has higher levels of reading difficulties that do not reach clinical significance compared to the ADHD-C group. The current study excluded children with comorbid ADHD + reading disorders. Previous research has shown that inattention symptoms predict later reading achievement, even after controlling for core reading skills, hyperactivity, and reading levels (Dally et al., 2006; Miller et al., 2014; Rabiner & Coie, 2000). The findings of the current study suggest that inattention, even in the absence of a specific reading disorder, poses a risk to reading difficulties. These results highlight the importance of assessing whether children with ADHD exhibit reduced sight word and decoding skills, which are crucial for successful reading. They also underscore the important connections between impulsivity, attention, and reading.

To distinguish ADHD subtypes, performance on the SWE subtest of the TOWRE could be useful when combined with other well-validated assessments. Additionally, children and adolescents with ADHD-I may benefit from treatments focused on improving sight word reading. However, further research is needed to replicate these findings and enhance our understanding of ADHD subtypes and their relationship to reading efficiency.

The pattern of findings from the present study have several important implications. First, the presence of an additional diagnosis of ADHD in children with DLD does not compound language and reading difficulties further. Second, as expected, the CELFST distinguished children with DLD from those with ADHD, including most comorbid cases. However, there are exceptions when it comes to distinguishing between ADHD subtypes and comorbid ADHD-C + DLD from DLD. In these cases, the reading efficiency subtests show better performance. Therefore, the findings suggest that when distinguishing between ADHD and DLD, the use of both assessments (CELFST and TOWRE) will lead to more accurate outcomes. Additionally, it is important to consider individual challenges in language and reading within each diagnostic group, even when assessments can reliably distinguish between the groups.

3.4.1 Conclusions and Future Directions

Our findings have implications for both clinicians and researchers in terms of differential diagnosis and the identification of comorbidity. The results indicated that assessments of reading efficiency may be useful in distinguishing between different subtypes of ADHD. However, none of the groups could be clearly defined based solely on their reading or language abilities, highlighting the need for additional assessments to identify ADHD and/or DLD status.

Future research should focus on investigating which assessments are most effective in distinguishing between comorbid groups and different subtypes of ADHD and DLD, as well as other related disorders. The current findings suggest that assessments of reading efficiency may be a productive starting point. Furthermore, it is important to explore whether the same set of assessments can accurately predict DLD and/or ADHD in both younger and older children. While nonword repetition tasks have been established as robust markers of language impairment in young adults (Poll et al., 2010) and children (Conti-Ramsden, 2003; Conti-Ramsden & Hesketh, 2003; Oetting & Cleveland, 2006; Redmond et al., 2011), their applicability to ADHD and comorbid samples remains unclear and warrants further investigation.

In addition to behavioural assessments, future research should also explore the potential of physiological markers, like electroencephalography (EEG), in distinguishing between ADHD, DLD, and comorbid samples. Studies have shown atypical EEG patterns in children with ADHD (Satterfield et al., 1972; Koehler et al., 2009; Barry et al., 2003; Barry et al., 2010), and specific EEG patterns have been approved by the Food and Drug Administration (FDA) for informing ADHD diagnosis. There are also connections between specific EEG patterns and language proficiency (Beese et al., 2017; Hald et al., 2006; Lume et al., 2022). Therefore, further research is needed to explore the potential of objective physiological metrics in distinguishing between ADHD and comorbid ADHD + DLD. Investigating the utility of such metrics can provide valuable insights into the underlying biological markers and help improve the diagnostic accuracy of these conditions.

The current study has certain limitations that should be acknowledged. The sample used in the study did not include individuals with the hyperactive-impulsive subtype of ADHD, limiting the generalizability of the findings to the broader population of individuals with ADHD. Moreover, the high heterogeneity of the disorders examined and the small sample sizes in some comorbid subgroups may have reduced statistical power and generalizability. Future studies should aim to include larger samples to enhance the confidence in the reported findings. The current study did not include a non-clinical comparison group because the primary aim was to assess whether having both conditions worsened difficulties and contribute to the lack of studies performing cross-clinical comparisons. It is essential for future research to explore whether these findings can extend to other diagnostic groups with related difficulties. Given the frequent co-occurrence of ADHD, DLD, and reading disorders, it is crucial to examine whether the assessments used in the current study can effectively distinguish these populations. Further research is warranted to explore these aspects and broaden our understanding of these disorders.

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Chapter 4 : Resting State EEG Patterns in ADHD and Comorbid ADHD + DLD

4.1 Introduction

Individuals with attention-deficit/hyperactivity disorder (ADHD) demonstrate increased difficulties in inattention (inattentive subtype) and/or hyperactivity-impulsivity (hyperactive-impulsive subtype), or both (combined subtype). This disorder affects approximately 15% of school-aged children (Rowland et al., 2015). Another childhood disorder that commonly co-occurs with ADHD is developmental language disorder (DLD), affecting approximately 7-8% of school-aged children (Calder et al., 2022). Comorbid rates are between 20-50% (Bruce et al., 2006; Hagberg et al., 2010; Sciberras et al., 2014) and despite general agreement in prevalence rates for both disorders, there is evidence to suggest that rates are much more variable and can depend on factors such as age (Norbury et al., 2016), gender, race, and ethnicity (Polanczyk et al., 2014). The psychological and behavioural criteria used to diagnose ADHD and DLD must be able to account for this pronounced overlap.

Research examining comorbidity in ADHD and DLD has found overlapping language, social (McGregor et al., 2020), peer (Redmond, 2011), and academic difficulties (Arnold et al., 2020). This pronounced overlap in symptomology can make it especially difficult to differentiate them, which can result in increased risk of misdiagnosis or misclassification. Cognitive researchers have started to explore whether behavioural metrics can reliably distinguish children with ADHD and DLD from typically developing (TD) populations. These investigations have shown that assessments of tense marking, nonword repetition, narrative discourse, and sentence recall (Redmond et al., 2011) are among the best at distinguishing these disorders. However, the use of subjective assessments alone to inform clinical diagnoses can introduce a host of potential problems related to patient and researcher bias. As such, research has looked at the potential of an objective biomarker of ADHD, including resting-state electroencephalography (EEG) and found that these methods are reliable in distinguishing children with ADHD and other psychiatric disorders from controls (Furlong et al., 2021; see Newson & Thiagarajan, 2019 for a review).

Resting-state EEG records the spontaneous electrical activity in the brain primarily generated by the synchronized firing of neuron in the absence of any task or external stimuli. This synchronized firing is thought to reflect underlying neural processes and communication within the brain and can inform researchers about the brain’s intrinsic functional connectivity patterns (Mantini et al., 2007). Task-free approaches, such as resting-state EEG, offer distinct advantages when studying developmental groups. These approaches offer naturalistic conditions that can be easily replicated and applied to diverse developmental populations. By eliminating explicit cognitive demands, these approaches minimize interference from attention and task engagement fluctuations, which are especially pertinent in individuals with conditions like ADHD. This allows for a more accessible and reliable assessment of intrinsic brain activity in developmental populations.

Elevated levels of symptomology, such as inattention, can disrupt the way children respond on behavioural and/or clinical assessments. Resting-state EEG can help circumvent some of these issues. This technique has advantages when working with children, and even more so when children have limited attention spans because they can sit quietly and do not need to be trained on a task prior to recordings. It allows for the inclusion of children with lower verbal abilities, a group that is largely understudied due to the demands of many language and cognition tasks. Finally, biological indicators that do not rely as much on language acquisition may be beneficial for improving diagnosis early on when children are preverbal and help to reduce variability in prevalence rates.

Resting-state EEG analysis enables researchers to explore underlying cognitive processes, detect abnormalities in psychiatric conditions, and gain insights into the functional organization of the brain. Various techniques including coherence, phase synchronization, and spectral analysis can be applied to resting-state EEG data. In ADHD research, the most used EEG analysis is quantitative EEG, which involves power spectral analysis and the separation of EEG output into frequency bands. The resting-state EEG spectrum can be broken down into separate frequency bands, each purported to index distinct aspects of cognition: delta (<4), theta (4–7.5 Hz), alpha (7.5–12.5 Hz), beta (12.5–30 Hz), and gamma (30-40 Hz). For simplification purposes, these bands can be further broken down into two types of activity, each comprising the central frequency bands (Saad et al., 2018). The first is high voltage slow-wave activity (HVSA; delta and theta) and the second is low voltage fast-wave activity (LVFA; alpha, beta, gamma; Saad et al., 2018). Increased HVSA is an index of decreased arousal (Schomer & da Silva, 2012) whereas increased LVFA is an index of more activation or arousal (Balatoni & Detari, 2003; Castro-Alamancos, 2002; Steriade & McCarley, 1990).

Among the most prominent psychophysiological models that establish connections between etiology (causes) and behavioural systems in ADHD are the maturation lag (Kinsbourne, 1973), developmental deviation (John et al., 1987), and cortical hypoarousal models (Satterfield & Dawson, 1971).

According to the maturation lag model, children with ADHD experience a lag or delay in the development of certain aspects of the central nervous system compared to TD children, which in turn influences the severity of their symptoms. Compared to TD children, those with ADHD exhibit a slower development of attentional switching skills. Resting-state EEG studies have provided supporting evidence for this model by demonstrating that at rest, EEG activity is comparable between children with ADHD and their younger TD peers (El-Sayed et al., 2003; Mann et al., 1992; Rubia et al., 2000).

In contrast, the developmental deviation model proposes that behavioural symptoms in ADHD represent a deviation from typical development because the brain patterns in ADHD are not like those of TD children at any age (John et al., 1987). Several resting-state EEG studies have provided compelling evidence in support of the developmental deviation model (Clarke et al., 2002c; Chabot et al., 1996; Dickstein et al., 2006; Hobbs et al., 2007; Zametkin et al., 1993).

The cortical hypoarousal model suggests that the core symptoms of ADHD stem from an under arousal of the nervous system, referred to as hypoarousal (Satterfield & Dawson, 1971). This state of hypoarousal is reflected in slow-wave EEG activity, particularly in the theta (Clarke et al., 2020) and delta frequencies (Clarke et al., 2001). Hypoarousal can manifest behaviourally as a lack of focus, vigilance, and attention. These three models offer valuable insights into the functional aspects of ADHD and can help researchers and clinicians connect etiology to behavioural symptoms in children with ADHD.

There is substantial evidence to support the presence of atypical resting-state EEG spectra in individuals with ADHD compared to controls. One of the most consistent findings across this body of literature is increased theta power in ADHD (Barry et al., 2003; Barry et al., 2010; Clarke et al., 2020; Koehler et al., 2009; Newson & Thiagarajan, 2019; Satterfield et al., 1972). Additionally, some studies have reported reduced delta power in ADHD (Clarke et al., 2008; Dupuy et al., 2013) compared to controls. Findings for the beta frequency have been more variable, with some studies reporting decreased activity in ADHD compared to controls (Buyck & Wiersema, 2014; Clarke et al., 2006; Clarke et al., 2001) and others not (Janzen et al., 1995; Kuperman et al., 1996). Similar findings have emerged in the alpha frequency band (Clarke et al., 2006; Clarke et al., 2001; El-Sayd et al., 2002). Resting-state EEG patterns in ADHD show considerable variability across studies. However, one consistent finding is the presence of altered EEG patterns in individuals with ADHD compared to those without ADHD. The discrepancies in findings may be influenced by numerous factors, including age, EEG processing methods, criteria used to diagnose ADHD, and the presence of unmeasured comorbidities.

Existing research has provided considerable knowledge about the relationship between spontaneous oscillatory brain activity and language abilities in TD children. However, there is a gap in the literature regarding the investigation of resting-state EEG in children with language disorders. Moreover, there is limited understanding of how the presence of additional language difficulties in individuals with ADHD impacts EEG patterns and the utility of resting-state EEG. Studies investigating the relationship between resting-state EEG and language abilities in TD children have consistently found a connection between resting-state gamma EEG activity and both expressive and receptive language skills (Benasich et al., 2008; Brito et al., 2016; Cantiani et al., 2019;

Gou et al., 2011). Furthermore, additional research has identified associations between theta power and language proficiency (Lum et al., 2022), as well as theta power and sentence comprehension in TD children (Batiaansen et al., 2005; Beese et al., 2017; Hald et al., 2006). Limited research has been conducted on the clinical application of resting-state EEG in DLD. A single study by Billard et al. (2010) investigated the use of resting-state EEG longitudinally in a small sample of children with DLD and found no significant association between EEG patterns and later language development. Associations between spontaneous alpha power and reading ability has also been found in children with written language disorders (Babiloni et al., 2012; Clarke et al., 2002a; Colon et al., 1979; Duffy et al., 1980; Skylar et al., 1972), suggesting that alpha power may play a role in reading abilities. The existing literature emphasizes significant connections between resting-state EEG and language skills. It also sheds lights on the scarcity of research exploring resting-state EEG patterns in language disorders and comorbid disorders. Further research is needed to understand the specific resting-state EEG patterns and their clinical implications in language disorders and comorbid diagnoses.

Most of the studies that have explored resting-state EEG in developmental groups focus on one clinical disorder at a time. As a result, much less is known about whether signature resting-state EEG markers (increased theta, decreased beta) can differentiate comorbid groups. To date, fewer than ten studies have explored resting-state EEG in ADHD and comorbid disorders which include reading disability (Clarke et al., 2002a) oppositional defiant disorder (Clarke et al., 2002b), low intelligence (Clarke et al., 2006), autism spectrum disorder (ASD; Bink et al., 2015; Clarke et al., 2011; Shephard et al., 2018), conduct disorder (Buyck & Wiersema, 2014) internet gambling addiction (Park et al., 2017) and problematic internet use (Kim et al., 2017). All but two of these studies (Clarke et al., 2006; Buyck & Wiersema, 2014) point to qualitatively distinct EEG profiles reflected in reductions in power spectra across frequency bands in comorbid groups. If children and adolescents with comorbid conditions demonstrate significant overlap in resting-state bands, this would limit the utility of resting-state EEG in clinical settings. Going forward, the inclusion of children and adolescents with comorbidities must be considered so that comparisons across patient groups can be made and research findings are generalizable to broader ADHD and DLD populations.

One of the most robust findings in ADHD and EEG research is increased theta and decreased beta activity. Accordingly, researchers have used the “theta-to-beta” ratio as another way to explore brain activation in ADHD. The theta/beta ratio is thought to reflect cortical arousal and maturation delay and has been proposed as a better way to capture brain activation patterns in ADHD compared to focusing only on the slow-wave theta band power (Loo & Ann, 2015; Monastra et al., 2001). It was first proposed after findings that this ratio could discriminate unaffected children from those with attention-deficit disorder, learning disorders, and ADHD (Lubar, 1991). Since then, studies have confirmed the theta/beta ratio as a common characteristic of ADHD with sensitivity rates up to 86% and specificity up to 98% when compared to controls (Monastra et al., 1999). However, the theta/beta ratio has been found in other psychiatric disorders including schizophrenia, OCD, and internet addiction suggesting that this pattern may be characteristic of several conditions and not specific to ADHD. It is important to note that this ratio may also be age dependent and restricted to children given the lack of consistency in adults (Newson & Thiagarajan, 2019).

Despite age dependent findings and overlap in the theta/beta ratio across disorders, the Food and Drug Administration (FDA) approved the use of the theta/beta ratio to inform ADHD diagnosis in 2013. Given FDA approval, one might imagine the research findings are unequivocal, but several independent and review studies suggest the opposite (Arns et al., 2013; Loo & Barkley, 2005; Saad et al., 2018). In fact, just three years prior to the FDA approving this biomarker, several papers failed to find support for an increased theta/beta ratio in ADHD (Buyck & Wiersema, 2014; Koehler et al., 2009; Lansbergen et al., 2011; Liechti et al., 2013; Loo et al., 2013; Nazari et al., 2011; Ogrim et al., 2012; Sohn et al., 2010). A 2016 report from the American Association of Neurology suggests that the theta/beta ratio not be used as a stand-alone diagnostic tool or replace any standard clinical evaluation (Gloss et al., 2016). The report comments on how previous specificity rates are not consistent across groups and how an elevated level of false positives have emerged while using the theta/beta ratio. Thus, although this direction holds tremendous promise for better understanding disorders like ADHD and DLD, the clinical efficacy of the theta/beta ratio remains inconclusive. Further, while ample work has examined these EEG patterns in children and adults with ADHD, no research to date has examined the connections between resting-state EEG and DLD despite high comorbidity rates. A failure to consider how assessments could differentiate comorbid samples from pure samples reduces the generalizability of findings to the greater population where comorbid estimates are high.

4.1.2 The Present Study

Although the current literature shows the usefulness of resting-state EEG in distinguishing ADHD from other groups, the application of this method in children who also meet the criteria for a language disorder is not well understood. One aim of the present study was to confirm previous findings regarding distinct neural patterns in ADHD and investigate whether these patterns differ in individuals with comorbid ADHD + DLD. Specifically, the study examined oscillatory power during resting-state to determine if children with ADHD exhibit unique slow-wave (delta and theta) and fast-wave (alpha, beta, gamma) activation compared to control participants and children with comorbid ADHD + DLD. A second aim of the study was to extend previous investigations by exploring the utility of resting-state EEG and theta/beta power in distinguishing pure ADHD, TD, and comorbid ADHD + DLD groups. To account for developmental effects on resting-state EEG, a cross-sectional approach was further utilized, examining the impact of age and diagnosis on resting-state EEG power at various frequency bands. The current study addresses previous shortcomings by examining the utility of resting-state EEG in the context of diagnostic comorbidity.

4.2 Method

4.2.1 Participants

All participants were enrolled in the Healthy Brain Network (HBN) database and completed a battery of tests including standardized language and cognitive assessments, which took approximately 12 hours to complete. For a full description, please see Alexander et al. (2017); only those measures considered in the current study will be described in detail here. Participants included children and adolescents between 6-16 years of age (*Mean age* = 9.62, *SD* = 2.52; 34.8% female) with ADHD, comorbid ADHD + DLD and typical development. Participants were asked to discontinue their stimulant medication during testing. See Table 4.1 for demographic information for each diagnostic category.

4.2.2 Materials

Cognitive Assessments. All participants received *The Wechsler Intelligence Scale for Children* as a test of performance IQ (WISC-V; Wechsler, 2014) but only the *Visual Spatial Index* (VSI) scores were used in subsequent analyses as a measure of nonverbal IQ. Since this subtest generates a nonverbal IQ score that does not rely on verbal responding, it provides an estimate of IQ for children with DLD that is less confounded by their language difficulties (DeThorne & Schaefer, 2004).

ADHD Symptoms. The *Conners' Self Report Rating Scale* (C3RS; Conners, 2008) was used to assess ADHD symptoms for children and adolescents between 8-16 years of age. Two scales from the C3SR were used to examine the presence of behaviours associated with ADHD, the DSM-IV Inattentive scale, and the DSM-IV Hyperactive/Impulsive scale. Further, the *Child Behavior Checklist* (CBCL; Achenbach and Edelbrock, 1991) *Teacher Report Form* and *Parent Report Form* were used for all participants. On all assessments, higher scores are indicative of greater difficulties.

Table 4.1. Participant characteristics and comparisons across assessments (N = 429).

	ADHD (*n* = 148)	ADHD/DLD (*n* = 30)	Controls (*n* = 251)	Group Differences
Age (years)	9.21 (2.29)	8.78 (2.37)	9.94 (2.61)	F (2, 442) = 5.57, *p* = .004
Nonverbal IQ	101 (16.50)	92.80 (11.00)	97.10 (14.20)	F (2, 168) = 1.80, *p* = .169
CELF-Screener Total*	16.90 (4.95)	12.00 (3.89)	18.40 (5.63)	F (2, 72.87) = 27.64, *p* = <.001
C3SR				
DSM-IV inattentive	66.70 (12.90)	76.50 (11.50)	55.60 (12.20)	F (2, 255) = 35.92, *p* = <.001
DSM-IV hyperactive-impulsive	66.40 (11.10)	68.70 (13.80)	55.90 (12.40)	F (2, 255) = 25.71, *p* = <.001
CBCL				
Teacher Report Form	66.30 (10.50)	64.30 (6.63)	55.80 (6.78)	F (2, 127) = 23.44, *p* = <.001
Parent Report Form	56.20 (10.80)	51.20 (15.70)	53.90 (11.50)	F (2, 195) = 1.89, *p* = .154

*Welch's used for homogeneity violation. Considered 'at risk' when total score falls below criterion score for age on CELF Screener. The visual spatial index (VIS) score on the WISC-V has a (*M* = 10, *SD* = 3), C3SR, and CBCL T-scores are (*M* = 50, *SD* = 10).

4.2.3 Electroencephalography

High-density EEG data were recorded using a 128-channel EEG geodesic hydrocel system by Electrical Geodesics Inc. (EGI) in a sound-shielded room at a sampling rate of 500 Hz with a bandpass filter of 0.1 to 100 Hz. The recording reference was at Cz (vertex of the head) and for each participant, head circumference was measured, and an appropriately sized EEG net was selected. The impedance of each electrode was checked prior to recording to ensure good contact and was kept below 40 kOhm. Impedance was tested every 30 minutes of recording with saline added if necessary.

Resting State Paradigm. For each participant, five minutes of eyes-closed resting-state EEG data were obtained where they viewed a fixation cross on the center of a computer screen (see Alexander et al., 2017 for full details). Throughout the paradigm, participants were instructed to either open or close their eyes at various points. The voice of a female research assistant instructed them to “now open your eyes’ (rest with eyes open for 20 seconds) and “now close your eyes” (rest with eyes closed for 40 seconds). The paradigm was intended to measure endogenous brain activity during rest (Fox & Greicius, 2010).

4.2.4 Analyses and EEG processing

Analyses were guided by the review findings of Newson and Thiagarajan (2019) to maximize contact with the broader literature. This review highlights the lack of standardization across resting-state EEG studies and emphasizes this standardization with respect to frequency band selection, eyes closed versus eyes open conditions, and power spectrum computation. In the present study, we used the eyes closed condition to reduce variability in visual input and attention. We also used relative (power in one frequency band relative to the total power in one's EEG), instead of absolute EEG power (actual power in one's EEG; amplitude squared) to increase consistency and reduce variability related to head geometry and skull thickness (Hagemann et al., 2008).

The resting-state EEG was preprocessed using the MATLAB Fieldtrip toolbox (Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands). Pre-processing consisted of excluding the electrodes in the outermost circumferences (chin and neck) to create a standard 111 channel array (see Langer et al., 2017 for full pre-processing details). Any channel with a variance more than 3 standard deviations from the mean were identified as bad channels and interpolated. Noisy channels were identified through visual inspection and interpolated or replaced by zeros. All data were high-pass filtered at 0.1 Hz and notched filtered at 59-61 Hz with a Hamming windowed-sinc finite impulse response zero-phase filter. The filter order was 25% of the lower passband edge and ocular artifacts were removed by linearly regressing the EOG channels from the scalp EEG channels. A Principal Component analysis (PCA) algorithm was then used to remove sparse noise from the data. Finally, the entire dataset was visually inspected to discard whole block and/or paradigm recordings that remained nosy after manual noise removal methods.

The artifact-free resting-state EEG was then segmented into 2-second epochs. Each epoch was subjected to Fast Fourier Transform with a Hanning window taper, and then averaged across electrodes. Absolute spectral power was then calculated for each electrode in the delta (<4 Hz), theta (4–7.5 Hz), alpha (7.5–12.5 Hz), beta (12.5–30 Hz), and gamma (30–40 Hz) frequency bands. After absolute power was calculated, relative power was derived by taking the absolute spectral power in each frequency band and dividing it by overall power across the other frequencies (Bellato et al., 2020; Nishiyori et al., 2021) and the theta/beta ratio was calculated in accordance with previous research (Barry et al., 2004; Picken et al., 2019) by dividing relative theta power by relative beta power at each electrode site. For relative and theta/beta power, a more positive value would indicate greater spectral power where several neurons are oscillating at that power within the same phase.

For resting-state EEG in ADHD, effects haven been observed across temporal, parietal, and occipital brain regions (Clarke et al., 2020; Kamida et al., 2016; Newson & Thiagarajan, 2019), with the largest effects occurring maximal over frontal and central electrodes (Loo & Makeig, 2012; Clarke et al., 2020). For completeness, we examined if there were any significant differences across cluster locations within the diagnostic groups, selecting electrodes from all regions to avoid excluding potentially relevant effects. Electrode selection was based on prior work using the same 128-channel EEG system to examine resting state EEG in similar age groups (Kamida et al., 2016; Lui et al., 2021). Relative power, and the theta/beta ratio was obtained at each electrode site and averaged into six clusters: frontal region (Fp1, Fp2, F3, F4, F7, F8, Fz), central (C1, C2, C3, C4), left temporal region (T3-T7, T5-P7), right temporal region (T4-T8, T6-P8), parietal region (P1, P2, P3, P4, P5, P6, Pz), and occipital region (O1, Oz, O2). See Figure 4.1 for layout of electrodes used in each cluster.

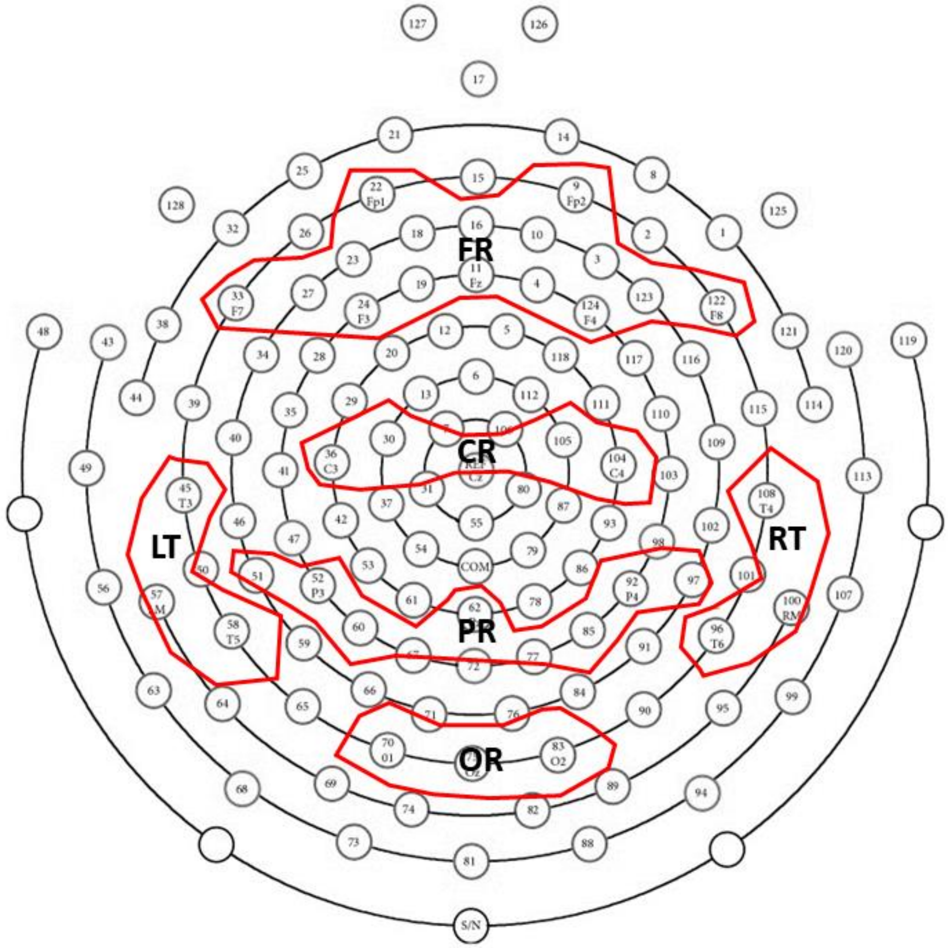

Figure 4.1. Layout of electrodes use in each cluster. Frontal Region (FR): E9, E11, E22, E24, E33, E122, E124; Central Region (CR): E30, E36, E104, E105; Left Temporal Region (LT): E45, E58; Right Temporal Region (RT): E96, E108; Parietal Region (PR): E51, E52, E60, E62; Occipital Region (OR): E70, E75, E83.

4.2.5 Comparing EEG Spectrum Power

Analysis of covariance. To compare power in each frequency band across diagnostic groups (ADHD, comorbid ADHD + DLD, controls), an analysis of covariance (ANCOVA) was performed with age entered as a covariate given the effect of age on EEG power (Kitsune et al. 2015; Michels et al. 2013). Following the methods of Shephard et al. (2018), a separate model was performed for each frequency band (alpha, beta, theta, delta, gamma) with electrode cluster (frontal, left temporal, right temporal, occipital, parietal) as a within- subjects' factor. Significant main effects and interactions between factors were further investigated using planned pairwise contrasts with Bonferroni correction applied to control for multiple comparisons. Mauchly's sphericity was used to determine whether the sphericity assumption was violated, and, in such cases, F-values were adjusted using a Greenhouse-Geisser correction. A post-hoc power analysis using G*Power version 3.1.9.7 (Faul et al., 2007) was performed using the smallest group sample size (n = 30 for each group; total N = 90). The analysis revealed that the study had sufficient statistical power to detect a medium-large effect (d =0.64) if all groups had n = 30.

Effects of age and diagnosis on EEG power. To examine the effects of age and diagnosis on resting-state EEG, a series of linear regression analyses were performed. Regression analyses were performed separately for each cluster and frequency band and included age, diagnosis, and their interaction. Another post-hoc power analysis was performed, focusing on the smallest group sample size and the results indicated that with two predictors (age and diagnosis), a large effect (d = .91) could be detected.

4.2.6 Diagnostic Utility

Binomial logistic regression with Classification Statistics. To examine the utility of resting-state EEG and theta/beta power in distinguishing pure, typical, and comorbid groups, a binomial regression was performed and sensitivity, specificity, and the area under the curve (AUC) were examined for ADHD versus comorbid ADHD + DLD, ADHD versus TD, and the combined ADHD groups (ADHD and comorbid ADHD + DLD) versus TD. The AUC demonstrates the benefit of using the test(s) or assessment(s) (resting-state EEG activity) where values approaching 1.00 indicate higher levels of classification and those closer to 0.5 indicate that a measure is not useful. A power analysis was performed to evaluate the minimum sample size needed for the ROC analysis with a Type I error set at $\alpha = .05$ and Type II error set at $\beta = .80$ and the results indicated that a total sample of 30 (10 positive cases, 20 negative cases) was needed to achieve these parameters.

4.3 Results

4.3.1 Comparing Frequency Band Activation

Significant main effects and interactions are discussed relative to each frequency band below. There were no significant differences across brain regions within the diagnostic groups. Our primary aim was to compare the strength of oscillatory power across ADHD, ADHD + DLD, and TD children and adolescents. Consequently, we emphasize findings related to group differences rather than differences found within the entire sample. Please see Table 4.2 for a summary of cluster differences across the entire sample. For the delta range, a significant main effect of cluster location on delta power F (1.94, 424.20) = 2.61, p <.05, $\eta p2$ =.012 was observed within the entire sample, with the effects greatest between frontal and occipital regions (p<.05, d = .226). There was also a significant main effect of diagnosis on relative delta power, F (2,219) = 3.60, p <.05, $\eta p2$ =.032, reflecting a significant decrease in delta power throughout all brain regions in ADHD + DLD relative to TD (p<.05), and ADHD + DLD relative to ADHD (p<.05).

Similar findings emerged for the theta range. A significant main effect of cluster location F (3.37, 562.45) = 4.10, p <.005, $\eta p2$ =.024 on theta power was observed, with the greatest effects found between frontal and occipital regions (p<.001, d = .610) within the entire sample. There was also a significant main effect of diagnosis on relative theta power, F (2,219) = 3.52, p <.05, ηp2 =.031, reflecting a significant increase in theta power throughout all brain regions in ADHD relative to TD (all p<.001). See figure 4.2 for relative power differences between groups in delta and theta bands.

For the alpha range, a significant main effect of cluster location F (1.90, 415.58) = 25.84, p <.001, ηp2 =.106 on alpha power was observed, with the greatest effects observed between the frontal and occipital electrode regions (p<.05, d = .659) within the entire sample.

Similar findings emerged for the beta range. A significant main effect of cluster location F (1.78,384.95) = 3.21, p <.05, ηp2 =.014 on beta power was observed, with the greatest effects found between frontal and occipital regions (p<.01, d = .230) within the entire sample.

In the theta/beta range, there was a significant main effect of cluster location F (1.90, 1095) = 25.31, p <.001, ηp2 =.104) on theta/beta power with the greatest effects found between frontal and parietal (p<.001, d = .587), and frontal and left temporal regions (p<.001, d = .530), within the entire sample. There were no significant main effects or interactions observed on gamma power.

Table 4.2. Cluster differences across entire sample.

Electrode Region	M *(SD)*	F	*df*	ηp2	*Post-hoc*
Delta *<4 Hz*		2.61*	1.94	0.012	Occipital > Frontal
Frontal	**2.03 (0.22)**				
Central	2.54 (0.20)				
Left Temporal	2.58 (0.38)				
Right Temporal	2.69 (0.19)				
Parietal	2.67 (0.16)				
Occipital	**3.30 (0.25)**				
Theta *4-7.5 Hz*		4.10**	3.37	0.024	Frontal > Occipital
Frontal	**0.282 (0.06)**				
Central	0.212 (0.13)				
Left Temporal	0.156 (0.05)				
Right Temporal	0.181 (0.06)				
Parietal	0.159 (0.07)				
Occipital	**0.134 (0.10)**				
Alpha *7.5-12.5 Hz*		25.84***	1.90	0.106	Frontal > Occipital
Frontal	**0.590 (0.11)**				
Central	0.223 (0.60)				
Left Temporal	0.218 (0.21)				
Right Temporal	0.212 (0.13)				
Parietal	0.219 (0.22)				
Occipital	**0.266 (0.44)**				
Beta *12.5-30 Hz*		3.21**	1.78	0.014	Occipital > Frontal
Frontal	**0.159 (0.20)**				
Central	0.271 (0.28)				
Left Temporal	0.290 (0.27)				
Right Temporal	0.298 (0.21)				
Parietal	0.287 (0.29)				
Occipital	**0.368 (0.38)**				
Theta/Beta Ratio		25.31***	1.90	0.104	Parietal, Left Temporal > Frontal
Frontal	**0.154 (0.20)**				
Central	0.168 (0.29)				
Left Temporal	**0.222 (0.27)**				
Right Temporal	0.177 (0.21)				
Parietal	**0.218 (0.21)**				
Occipital	0.184 (0.29)				

Note. *** <.001, **<.01, *<.05. Bolded values indicate significance.

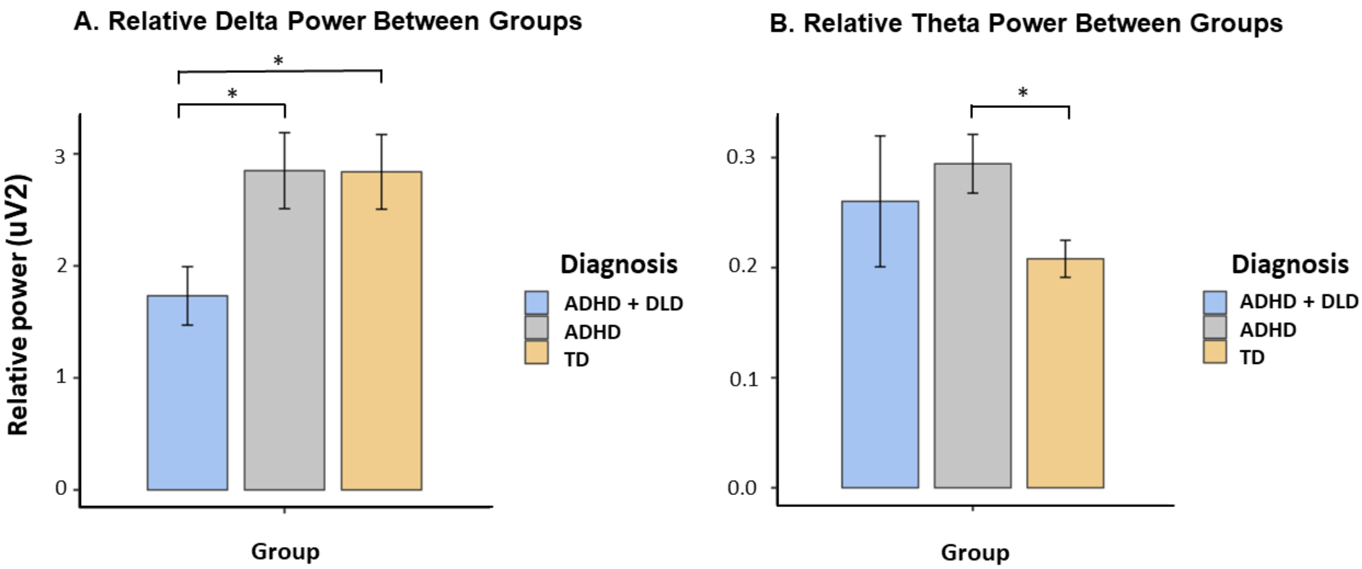

Figure 4.2. Group differences in relative power in delta (A) and theta (B) frequency bands. ADHD + DLD subjects are depicted in blue, ADHD in grey, and TD in yellow.

4.3.2 Age, Diagnosis, and Resting-state EEG Power

Regression analyses were conducted for each cluster and frequency band, including age, diagnosis, and their interactions. None of the regression models yielded significant interaction effects of age and diagnosis and main effects of diagnosis on frequency bands were identical to those observed in the group-differences analyses. Therefore, findings are discussed relative to the significant main effects of age on resting-state EEG frequencies.

Regardless of diagnosis, there was a general linear increase in relative fast-wave activity (alpha, beta, gamma), a decrease in relative slow-wave delta, and an increase in relative slow-wave theta with increasing age (Table 4.3). The increase in alpha power with age aligns with recent investigations showing an increase in alpha oscillations between 7 and 24 years of age in TD individuals (Cellier et al., 2021). The increase in resting-state theta activity with age is also consistent with prior ADHD research (Bresnahan et al., 1999; Saad et al., 2018). Findings relating to age changes in the remaining frequency bands (delta, beta, and gamma) are more variable across age in TD and ADHD populations.

In summary, the results indicate a general increase in relative resting-state power with age, except for delta power, which decreased with age. These results are mostly consistent with EEG patterns observed in TD children and adolescents as well as those with ADHD. The unexpected increase in theta oscillations across age suggests the possibility of delayed maturation. There is evidence to suggest that significant decreases in theta activity may not be noticeable until later adulthood (Klimesch et al., 1999). The current study examined adolescents up to 16 years of age, which may not be old enough to show this reported decline in theta activity. Other research suggests that in typical development, theta oscillations begin to decline in middle childhood (around 6 to 12 years) and alpha activity becomes more prominent (see Anderson & Perone, 2018 for a review). In TD children, decreases in delta and theta activity are thought to reflect the maturation of neural networks and improvements in executive function (Perone et al., 2018). Previous research has also linked alpha oscillations to cognitive functioning (Jenson et al., 2002) in typical development, suggesting that the observed increased in alpha oscillations with age may reflect neural maturation. The increase in alpha and decrease in delta oscillations observed in the current study are consistent with typical developmental models. However, these models do not fully account for the observed age-related findings, as theta activity did not decrease as expected from early childhood to adolescence.

Table 4.3. Regression analysis for resting-state EEG power and age.

Frequency Band	*B*	β	t	R^2	F (model)	β 95 % CI Lower Bound	Upper Bound
Theta/Beta Ratio	-.010	-.03	-0.15	.002	.021	-.0389	0.335
Alpha Power	.186	-.005	2.79	.039	**7.80****	.0020	.0097
Beta Power	.284	.009	4.43	.104	**19.61*****	.0005	.0014
Theta Power	.320	.016	5.00	.110	**25.01*****	.0094	.0218
Delta Power	-.352	-.023	-5.57	.135	**31.05*****	-.0305	-.0146
Gamma Power	.195	.002	2.95	.049	**8.71****	.0075	.0037

Note. *** <.001, **<.01. All frequency bands reflect relative power. *B* indicates unstandardized regression weights and β indicates the standardized regression weights. CI indicates confidence interval.

4.3.4 Logistic Regression with Classification Statistics

To determine how well resting-state EEG (relative power in each frequency band) and theta/beta power could correctly classify children and adolescents, the following discriminations were performed: ADHD versus ADHD + DLD, ADHD versus TD, and TD versus Diagnosed (ADHD and ADHD + DLD). Please see Tables 4.3-4.5 for classification statistics.

4.3.5 ADHD vs ADHD + DLD Discrimination

When comparing ADHD versus comorbid ADHD + DLD, alpha (p <.05) and beta (p <.05) were significant predictors of diagnosis. The model produced high sensitivity, but low specificity and was not considered useful (AUC = .69, sensitivity = .97, specificity = .13). It could correctly classify 97% of children with ADHD, but only 13% of those with comorbid ADHD + DLD. Adding theta/beta power into the equation minimally improved the overall model, as well as the ability to classify comorbid ADHD + DLD (AUC = .73, sensitivity = .95, specificity = .20).

4.3.6 ADHD vs TD Discrimination

When comparing ADHD versus TD, alpha, beta, and theta were all significant predictors of diagnostic status (all p <.05). The model produced high sensitivity, but low specificity and was not useful (AUC = .68, sensitivity = .86, specificity = .36). The model could correctly classify 86% of TD children and 36% of ADHD children. Identical to above, the addition of theta/beta only marginally improved the model and the ability to classify ADHD individuals (AUC = .72, sensitivity = .83, specificity = .45).

4.3.7 TD vs Diagnosed Discrimination

When comparing the TD versus Diagnosed groups, only theta power was a significant predictor of diagnosis ($p < .05$) however, identical to previous models, it was not useful in correctly classifying children and adolescents (AUC = .64, sensitivity = .49, specificity = .66). It could correctly classify 66% of TD children and 49% of those with a diagnosis. The inclusion of theta/beta power did not improve the overall usefulness of the model (AUC = .67, sensitivity = .52, specificity = .69).

In summary, relative alpha and beta power are important predictors in ADHD versus comorbid ADHD + DLD and ADHD versus TD discriminations and relative theta is important for ADHD versus TD and TD versus Diagnosed discriminations. Although promising, classification statistics indicated that none of the models were useful in correctly classifying the diagnostic groups. Collectively, findings suggest that there is not sufficient evidence to warrant the use of resting-state EEG or theta/beta power as diagnostic tools in ADHD or comorbid ADHD/DLD.

Table 4.4. Classification for ADHD versus ADHD + DLD Discrimination.

	Predicted		
Observed	ADHD	ADHD + DLD	% Correct
ADHD	(76) 35	(2) 4	97.40 (94.90)
ADHD + DLD	(26) 20	(4) 6	13.30 (20.00)

Note. Bracket values are classification statistics prior to the inclusion of theta/beta power.

Table 4.5. Classification for ADHD versus TD Discrimination.

	Predicted		
Observed	ADHD	TD	% Correct
ADHD	(28) 35	(50) 43	35.90 (44.90)
TD	(16) 20	(98) 94	86.00 (82.50)

Note. Bracket values are classification statistics prior to the inclusion of theta/beta power.

Table 4.6. Classification for TD versus Diagnosed (ADHD, ADHD + DLD).

	Predicted		
Observed	TD	Diagnosed	% Correct
TD	(75) 79	(39) 35	65.80 (69.30)
Diagnosed	(55) 52	(53) 56	49.10 (51.90)

Note. Bracket values are classification statistics prior to the inclusion of theta/beta power.

4.4 Discussion

The present study aimed to compare oscillatory power during resting-state EEG recordings in children and adolescents with pure ADHD and comorbid ADHD + DLD. The study also investigated age-related changes in resting-state EEG power in these groups. The effectiveness of resting-state EEG as a diagnostic tool was also examined. The results indicate distinct resting-state EEG profiles in children with pure ADHD and those with comorbid ADHD + DLD, which could be helpful in distinguishing between the two groups. Consistent with previous research, children with ADHD displayed increased theta power compared to TD children. Additionally, children with ADHD and co-occurring DLD exhibited reduced delta power in comparison to both ADHD-only and TD children. Our findings further demonstrate a general increase in alpha, theta, beta, and gamma activity with age as well as a general decrease in delta activity with age across the entire sample. However, when employing classification analyses, resting-state EEG alone was not able to accurately distinguish between any of the groups with high accuracy. Consequently, while there are discernible differences in EEG power spectra between pure and comorbid ADHD + DLD, the findings do not provide sufficient evidence to support the use of resting-state EEG as a reliable diagnostic tool for determining ADHD status. In summary, the study reveals significant differences in resting-state EEG patterns between pure and comorbid groups but suggests caution in relying solely on resting-state EEG for diagnostic purposes.

4.4.1 Group Differences in Resting-state EEG

Our findings are consistent with previous research showing increased theta power in individuals with ADHD. Elevated theta power is often considered an indicator of immature brain development (Kinsbourne, 1973), as it tends to decrease as the brain matures into adulthood (Saad et al., 2018). In our study, we found evidence of increased relative theta power in ADHD compared to control groups. The presence of theta power during resting-state EEG is a consistently reported finding in the ADHD literature with reductions in slow-wave activity (theta, delta) being linked to *hypo*arousal (Satterfield et al., 1972; Koehler et al., 2009; Barry et al., 2003). On the other hand, excessive theta power may be related to difficulties with focus and concentration (di Michele et al., 2005). We did not find significant differences in theta power between the two ADHD groups (comorbid ADHD + DLD and ADHD-only) in our study. This lack of difference may reflect overlapping difficulties with focus and engagement, making it difficult to distinguish them based on theta power.

Furthermore, we observed no significant differences in theta power between the comorbid ADHD + DLD group and the TD group. The presence of language impairments in individuals with comorbid ADHD + DLD may attenuate symptoms associated with theta power, such as hypoarousal. This could explain why theta activity in the comorbid group appears to align more closely with that of TD children and adolescents. While increased theta power in ADHD is a commonly reported finding, some studies have reported no significant differences in theta power between individuals with ADHD and control groups (Rommel et al., 2017). The inconsistencies in theta power findings across studies could be attributed to individual differences or unmeasured comorbidities in TD individuals. It is important to note, however, that although there were no statistically significant differences in theta power between the comorbid group and the TD group in the current study, this does not necessarily mean that the two groups do not differ.

Qualitatively, there appears to be an increase in theta power in the comorbid group compared to the TD controls, but the observed difference did not reach statistical significance.

In the current study, children, and adolescents with comorbid ADHD + DLD exhibited a distinct pattern of reduced delta power compared to those with ADHD-only and TD. The findings suggest that there is a specific alteration in delta wave activity in individuals with comorbid ADHD + DLD, highlighting the potential importance of delta oscillations in understanding and characterizing this group. Research findings regarding delta power in ADHD compared to TD individuals have been inconsistent. Some studies have reported an increased in delta power in boys with ADHD (Clarke et al., 2011), while others have found normal levels (Loo & Barkley, 2005). Partially in line with our findings, certain studies have observed reduced delta power in individuals with ADHD (Clarke et al., 2008; Dupuy et al., 2013) and in individuals with ADHD and comorbid ASD compared to controls (Shephard et al., 2018). Importantly, reductions in delta power were greater in children with ADHD (with or with ASD) than controls and children with ASD-only. There is also evidence to suggest reduced delta power in adolescents with ADHD and comorbid internet disorders (Park et al., 2017) relative to TD adolescents. These variable findings highlight the complexity of the relationship between delta power and ADHD.

While there is a relative scarcity of studies investigating delta wave activity in developmental disorders, existing research has highlighted the significance of delta oscillations during mental tasks (Harmony, 2013). Delta waves have been associated with various perceptual and cognitive operations (Kilmesh, 1999), and they play a role in reward mechanisms, cognitive processes related to attention (Knyazev, 2007) and inhibition (Kamarajan et al, 2004; Putman, 2001). Reduced delta power has been associated with difficulties in cortical inhibition, which refers to the brain's ability to supress irrelevant or distracting stimuli, leading to difficulties maintaining attention and cognitive control (Kamarajan et al, 2004; Putman, 2001). Although more research is needed to fully understand the relevance of delta wave activity in developmental disorders, these findings suggest that delta oscillations have implications for cognitive functioning and may be involved in core processes underlying ADHD and DLD. The function of delta power in relation to language and language disorders has been understudied. However, previous research has shown that increased delta power during wakefulness is associated with learning disabilities and ADHD (Papagiannopoulou & Lagopoulous, 2016; Shephard et al., 2018). Reduced delta power in the frontal regions has also been observed in young children who were later diagnosed with written language disorders (Schiavone et al., 2014), suggesting an association between delta power and language-related outcomes.

The reduced delta power observed in children and adolescents with comorbid ADHD + DLD in the current study can be explained within the context of brain-behaviour associations. In particular, reductions in delta power are believed to reflect hypoactivity, which aligns with impaired reinforcement and reward processing, core features of ADHD (Holroyd et al., 2008). This reduction in delta power in comorbid ADHD + DLD is consistent with models of hypoarousal, where individuals may exhibit lower levels of arousal or reduced cortical activation. It also aligns with the concept of vigilance regulation, where individuals with ADHD may rely on hyperactive and/or impulsive behaviours to increase arousal and sustain vigilance (Geissler et al., 2014). There is evidence linking lower levels of cortical arousal and core deficits in ADHD including difficulties maintaining attention and inhibiting distracting information (Kamarajan et al, 2004). Furthermore, associations between increased hyperactive and/or impulsive symptoms and challenges in arousal and attention regulation, which are linked to delta oscillations (Loo et al., 2009), have also been observed. In our sample, individuals with comorbid ADHD + DLD exhibited higher levels of inattention (as indicated by The Conners Rating Scale) compared to the ADHD group (p = .04). These higher rates of inattention in comorbid ADHD + DLD may reflect difficulties in regulating arousal and attention (Barkley, 1997). Delta oscillations are also connected to cognitive processes impaired in individuals with language disorders, including attention and executive functioning. It is plausible that the reduced delta power observed in individuals with comorbid ADHD + DLD contributes to the heightened ADHD symptoms observed in these individuals. The difficulties associated with comorbid language disorder may further compound these challenges.

It remains unknown whether reduced delta power specifically indicates language impairment, as reductions in delta power have also been observed in children with pure ADHD. Therefore, this pattern is likely not exclusively indicative of language difficulties. It is important to note that some studies have found elevated levels of delta activity in ADHD however, these have mainly focused on boys (Clarke et al., 2011; Hobbs et al., 2007) and adults/adolescents (Bresnahan et al. 1999; Kitsune et al. 2015). If replicated, the findings of the current study suggest that children and adolescents with comorbid ADHD + DLD could be distinguished from those with pure ADHD and TD individuals based on reductions in relative delta power.

In studies investigating resting-state EEG in ADHD, greater consistency has been observed in slow-wave oscillations (theta, delta) compared to high frequency or fast-wave oscillations (alpha, beta, gamma). The significance of findings in the higher frequency bands depends on the type of power analyzed (relative versus absolute). For instance, reductions in relative power, but not absolute power, have been observed in adults with ADHD in the same study (Bresnhan et al., 2006). Therefore, the lack of significant differences in relative alpha power between groups in the current study is not surprising. Additionally, age is a factor that influences the presence of significant effects in alpha and beta. Elevations in frontal alpha activity (Bresnahan & Barry, 2002; Hale et al., 2009; Koehler et al., 2009) and beta activity (Hale et al., 2010; Koehler et al., 2009) have been reported primarily in adults with ADHD. The current study took age into account, suggesting that age differences are unlikely to explain the lack of significant differences between groups in alpha and beta power. Similarly, no significant group differences were found in gamma power. Gamma activity is believed to be associated with learning, memory (Gruber et al., 2002; Miltner et al., 1999; Tallon-Baudry et al., 1998), attentional processes, and visual processing (Fernandez et al., 2021; Missonnier et al., 2010). Research suggests that beta and alpha activity are also associated with important cognitive functions such as attention, working memory, and concentration (Loo & Barkley, 2005). In the current study, the absence of significant differences between groups in the higher frequency bands (alpha, beta, gamma) could be attributed to their involvement in complex cognitive processes. There is greater individual variability in the cognitive processes thought to underlie high frequency oscillations, making it challenging to detect consistent EEG patterns across individuals. The ability to detect consistent resting-state patterns is especially difficult in developmental and comorbid groups like ADHD and DLD, which are characterized by high heterogeneity.

In summary, the current study did not find significant differences in alpha, beta, and gamma power. Slow-wave oscillations show more consistent findings, while fast-wave oscillations can be influenced by factors such as the type of power analyzed and age. Moreover, fast-wave oscillations underlie complex cognitive processes that are highly variable among individuals. The presence of comorbidity, cognitive profiles, and individual differences within these groups may add an additional layer of complexity.

Contrary to previous research, the current study did not find significant differences between cluster locations across any frequencies in our diagnostic groups. Previous studies in ADHD have reported greater theta activation, particularly in frontal-central regions of the brain, (Clarke et al., 2022; Hobbs et al., 2007), and greater delta activity in posterior regions (Clarke et al., 1998, 2011) in ADHD groups compared to TD groups. However, these findings were not replicated in the current study. Our findings partially algin with those of Clarke et al. (2019), which reported significantly elevated relative theta activity across the entire scalp in ADHD compared to controls. However, Clarke et al. (2019) also found maximal changes in theta and beta in the posterior regions, which differs from the current study. The lack of specificity in our findings could be explained by shared cognitive and underlying mechanisms between ADHD and DLD, as the study included both pure ADHD and comorbid ADHD groups. However, this explanation would not account for the lack of specificity in the TD group.

A more plausible explanation for the lack of topographical differences in the current study is the variability in EEG recording configurations, electrode selection, and frequency band definitions across different studies. A recent review highlighted significant variations in the types of reference electrodes used in EEG research, including the ears, mastoids, earlobes, and Cz (Newson & Thiagarajan, 2019). The lack of standardization in hardware and configurations can have a substantial impact on reported results. Moreover, there is considerable variability in the frequency range used to define specific frequency bands. For instance, the start and end points of the beta band can vary between studies, with variations ranging from 12 Hz to 15 Hz and endpoint variations between 20 Hz and 50 Hz. This inconsistency in frequency band definitions can contribute to discrepancies in findings. Furthermore, electrode selection is another area that exhibits high variability. In the current study, the electrode selection was based on prior research using the same 128-channel EEG system and focusing on resting-state activity in a similar age group (Kamida et al., 2016; Lui et al., 2021). However, there is limited consensus in the research community regarding which electrodes are most appropriate for each brain region (frontal, central, temporal, parietal, and occipital), particularly in the context of ADHD research.

Studies on resting-state EEG in ADHD have utilized different approaches to measure and compare EEG activity. However, the overall findings have been consistent across these studies. Most of the research indicates that relative to TD individuals, those with ADHD exhibit higher levels of slow-wave activity, specifically in the theta frequency range. This elevation in theta power in ADHD is observed across eyes-closed and eyes-open resting-state conditions. Additionally, compared to control groups, a majority of the studies have observed reduced levels of relative alpha and relative beta power in individuals with ADHD. The findings regarding delta power have been more variable, with some studies reporting increased relative and absolute delta power in ADHD, and others reporting reduced delta power in ADHD. In summary, the existing research suggests that individuals with ADHD commonly display elevated slow-wave activity in the form of increased theta power.

4.1.2 Age-Related Changes in Resting-State EEG

The regression results revealed a general increase in alpha, beta, gamma, and theta power and a general decrease in delta power with increasing age across the entire sample. These changes were not specific to any of the diagnostic groups studied and therefore, findings are discussed in relation to age-related changes in TD and ADHD populations. Our findings partially align with resting-state EEG patterns observed in TD children and adolescents over time, where delta and theta power decrease and alpha and beta power increase with age. In contrast, individuals with ADHD typically show increases in theta power with age, while beta power tends to normalize over time (Bresnahan et al., 1999; Saad et al., 2018). These age-related changes in resting-state EEG patterns correspond to the behavioural changes observed in individuals with ADHD, with impulsivity (associated with theta activity) tending to increase and hyperactivity (associated with beta activity) tending to decrease with age (Bresnahan et al., 1999).

In line with our findings, prior research has found evidence of increased alpha activity in ADHD (Beninger et al., 1984) and a decrease in delta activity in both ADHD and TD individuals (Bresnahan et al., 1999). Importantly, in both ADHD and TD, this decrease in delta continues from childhood into adolescents (6 to 17 years) but then decreases more rapidly in TD adults (20 to 42 years) than in ADHD adults. Moreover, general linear increases in relative beta power have been reported in children and adolescents with ADHD that fall within the age range studied here (Bresnahan et al., 1999).

In contrast to our findings and other studies, Giertuga et al. (2017) observed decreases in delta, theta, and beta frequency bands in both ADHD and TD children and adolescents between 9 and 16 years old. The authors also found a general decrease in absolute EEG power, with ADHD characterized by reduced theta activity. The findings from Giertuga et al. (2017) align with the deviant brain maturation model theory of ADHD since ADHD patterns were different from TD controls at any developmental stage. However, our current study, which included a similar age range, did not find similar associations. One explanation for these discrepancies is that authors included a high proportion (66%) of participants with comorbidities, such as oppositional defiant disorder, conduct disorder, and learning difficulties. This may have influenced their findings and make it difficult to directly compare their results with ours. The impact of these impairments on age-related effects in resting-state EEG remains uncertain due to the lack of research in this area. While the inclusion of participants with comorbid diagnoses improves generalizability, it also introduces additional complexities.

4.1.3 A New Psychophysiological Model of ADHD

In our study, we observed reduced delta power in the comorbid ADHD + DLD group compared to the TD and ADHD group, which is consistent with the cortical hypoarousal model of ADHD. We also found increased theta power in the ADHD group compared to the TD group. Elevated theta oscillations have been associated with brain immaturity or delayed cortical maturation (Matuura et al., 1993). Typically, theta oscillations decrease as children age, and persistent elevation of theta beyond childhood is considered a marker of immaturity. It is also possible that elevated theta acts as a compensatory mechanism in ADHD, allowing children to maintain alertness despite reduced cortical activation. Studies linking elevated theta to high cognitive effort and sustained attention in ADHD support this idea (Hermen et al., 2005).

The findings suggest that a new model should be proposed to account for the impact of comorbid symptoms on EEG patterns in individuals with ADHD, as well as across different age groups. Most of these brain-based models of ADHD have been revised or refuted to accommodate the diverse range of symptoms observed in ADHD. For example, recent research indicates that there is normal maturation in ADHD from childhood to adulthood (Clarke et al., 2019; Markovska-Simoska & Pop-Jordanova, 2017), and multiple dysfunctions within the central nervous system may underlie ADHD, extending beyond hypoarousal. In children and adolescents with comorbid ADHD + DLD, significant reductions in delta power were observed, indicating decreased cortical arousal. As a result, these individuals may rely on inattentive and/or impulsive behaviours to increase arousal. On the other hand, children and adolescents with ADHD exhibited significant increases in theta power, which can be seen as the brain's attempt to heighten attention and stay more alert. In both cases, changes in delta and theta power may reflect compensatory strategies, either in behaviour or in the brain, to achieve the goal of maintaining arousal and alertness. The development of additional models of ADHD should consider these unique compensatory strategies and the impact of comorbid symptoms on these strategies. These findings highlight the complex interplay between

EEG patterns, symptomatology, and compensatory mechanisms in individuals with ADHD and comorbid ADHD + DLD.

4.1.4 Classification Accuracy in Resting-state EEG

When examining the theta/beta ratio, we did not find significant group differences and none of the models could accurately classify diagnostic groups. These findings align with prior research that also failed to find significant group differences between individuals with ADHD and control subjects (Buyck & Wiersema, 2015; Loo et al., 2013). While some studies have reported high sensitivity and specificity rates for the theta/beta ratio in diagnosing ADHD, these results could not extend to identifying other comorbid disorders (Snyder et al., 2008). Additional studies have reported mixed findings, with sensitivity and specificity rates near or below 50% (Buyck & Wiersema, 2014; Coolidge et al., 2007; Liechti et al., 2013). Theta/beta power can also be mediated by factors such as the subtype of ADHD and the presence of comorbid psychiatric conditions (Loo et al., 2013). This finding is consistent with the understanding that the theta/beta ratio is not exclusive to ADHD and can be observed in other psychiatric disorders. Overall, the existing literature on the use of the theta/beta ratio in ADHD and comorbid samples lacks consistency and coherence. The current findings align with the broader body of research, indicating that there is currently insufficient evidence to support the use of the theta/beta ratio to inform diagnostic status in ADHD or comorbid conditions.

4.1.5 Implications for Future Research

Future work in this area should consider several important considerations to address the inconsistencies in the literature and improve our understanding of ADHD and DLD.

While the current study included age as a covariate to account for any maturational differences in resting-state EEG, alternative methods such as transitional frequency analysis (Klimesch, 1999) could provide a more individualized approach. Transitional frequency analysis considers the speed at which individuals transition between different brain states or processes, allowing for the determination of unique power bands for each individual (Saad et al., 2018). This method has the potential to overcome issues associated with arbitrary cut-off bands and could improve diagnostic accuracy for ADHD and DLD. These considerations are particularly relevant in disorders characterized by high heterogeneity, such as ADHD and DLD, where individual variations in EEG patterns are expected. However, further research is needed to fully explore the utility and implications of transitional frequency analysis as a diagnostic tool for these disorders.

Exploring EEG profiles in different subtypes and comorbid conditions of ADHD and/or DLD, such as co-occurring reading disorders, can provide valuable insights. Conducting longitudinal research could help researchers understand the age at which these conditions manifest distinct EEG profiles and how these profiles relate to behavioural symptoms and diagnostic evaluations. Our investigation of age-related effects on resting-state EEG in comorbid samples offers preliminary information about these longitudinal effects. These findings raise questions about the early predictive power of behavioural assessments and whether resting-state EEG becomes more informative at a specific stage of maturation. Further investigation is needed to gain a better understanding of the dynamics involved and to determine the optimal timing for utilizing resting-state EEG as a diagnostic tool. By examining the developmental trajectories and age-related changes in EEG profiles, researchers can enhance their understanding of ADHD and/or DLD and potentially improve diagnostic approaches for these conditions.

The use of resting-state EEG alone is limited in establishing reliable connections between brain activity and behaviour. To enhance our understanding of these associations, it is recommended to combine resting-state EEG with tasks involving high cognitive load. By incorporating such conditions, we can better discern whether individuals with ADHD are exerting cognitive effort during resting-state periods. It is possible that the observed increase in theta activity, commonly associated with ADHD in resting state tasks, may be a result of heightened mental effort similar to what is observed during high cognitive load conditions. Furthermore, future studies in ADHD and/or DLD research could benefit from adopting multimodal approaches, specifically combining resting-state EEG with resting-state functional magnetic resonance imaging (rs-fMRI). This integration of techniques allows for a more comprehensive exploration of both the structural and functional aspects of the ADHD and/or DLD brain, leading to a deeper understanding of the disorders and their underlying mechanisms.

4.1.6 Conclusions

This study is the first to explore resting-state EEG in individuals with ADHD and comorbid ADHD + DLD, aiming to identify common aspects of these disorders and evaluate the potential utility of resting-state brain activity in distinguishing between pure and comorbid cases. The findings reveal qualitative differences in resting-state brain activity between pure and comorbid ADHD + DLD groups, contributing to our understanding of the biological mechanisms underlying these disorders. However, the results suggest that resting-state EEG may have limited clinical utility as a standalone diagnostic tool due to significant overlap in resting-state EEG patterns among different clinical populations. Further research is needed to explore alternative approaches and improve the differentiation and diagnostic accuracy of resting-state EEG metrics in ADHD and comorbid ADHD + DLD.

While brain-based markers show promise, they should not be used as the sole diagnostic tool. Incorporating these measures into evaluations can contribute to advancing research toward physiological metrics, complementing subjective and behavioural assessments. It is essential to consider that a single univariate metric cannot diagnose the complex spectrum of behaviours observed in ADHD and/or DLD. Further investigation is required to understand how brain-based assessments can enhance our understanding of these disorders, while accounting for the multifaceted nature of these conditions.

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Chapter 5: General Discussion

The aim of this dissertation was to consolidate research on language abilities in attention-deficit/hyperactivity disorder (ADHD) and developmental language disorder (DLD) to enhance our understanding of the intersection and etiological distinctions between these two disorders. Additionally, much of previous research has focused on comparing "pure" samples of either ADHD or DLD without considering comorbid cases, leaving uncertainties about the generalizability of findings to comorbid samples. To overcome these limitations, my research consolidates findings from previous studies and examines language and reading abilities in both pure and comorbid ADHD + DLD samples. In addition, more objective measures were introduced to explore the differences between pure and comorbid ADHD + DLD and evaluate the utility of behavioural and resting-state encephalography (EEG) metrics in the context of diagnostic comorbidity. The present chapter will summarize findings from Chapters 2, 3, and 4, in relation to shared cognitive deficits in ADHD and DLD, and the pathways contributing to their comorbidity. The chapter discusses the implications of these findings and suggests directions for future research.

5.1 Relevant Findings

5.1.1 Shared language difficulties

Approximately 40-60% of children with ADHD also experience language impairments (Bruce et al., 2006; Hagberg et al., 2010; Sciberras et al., 2014). This is surprising considering that the two disorders are typically associated with distinct cognitive domains. Furthermore, research suggests that many children have either ADHD or DLD without the presence of the other, supporting the idea that these are separate disorders rather than a single complex syndrome. Although DLD is characterized by language impairments and ADHD is characterized by attention and/or hyperactivity-impulsivity impairments, evidence indicates that both disorders involve more than just these core deficits. Both ADHD and DLD can encompass broader cognitive difficulties related to executive functions (Kappa & Plante, 2015), working memory (Martinussen et al., 2005; Alderson et al., 2015), and domain-general cognitive deficits (Laasonen et al., 2018; Leonard et al., 2007). Moreover, slow processing speed and impaired rapid temporal processing has been proposed to underlie language impairments, but research has indicated children with ADHD have greater deficits in processing speed than children with language impairments, suggesting that these deficits are not unique to language disorders (Oram Cardy et al., 2010).

The findings of Chapter 2 highlight the greater language difficulties observed in children with DLD compared to children with ADHD. Specifically, children with DLD scored lower than children with ADHD on various language assessments, including those measuring morphosyntax/grammar, general language abilities, receptive, and expressive abilities, indicating more pronounced language impairments in DLD than ADHD. However, performance on semantic and figurative language tasks was comparable between the two groups, suggesting similarities in these specific language domains. Variations in performance were observed in tasks related to phonological processing, syntax, narrative language, and vocabulary, which may be influenced by sample differences. The findings further support the notion that DLD is characterized by deficits across multiple aspects of language, while overlapping cognitive impairments in both disorders may contribute to the similar performance observed in some tasks.

Across studies, the performance on assessments of semantic and figurative language was similar between children with ADHD and DLD. Semantic processing, which involves understanding word meanings and retrieving words, relies on cognitive skills such as attention, working memory, and executive functions (Allen et al., 2012). These cognitive processes are impaired in both ADHD and DLD, which may explain the lack of differences observed in semantic processing tasks. Similarly, understanding figurative language requires flexible thinking, making inferences, and integrating multiple meanings, all of which rely on attentional control, inhibitory control, working memory, and executive functions (Beaty et al., 2013). Overall, these shared cognitive deficits may contribute to the similar performance observed in semantic and figurative language tasks between children with ADHD and DLD.

The acquisition, comprehension, and production of morphosyntax/grammar in language rely on executive function processes as well (Stanford & Delage, 2020). These include inhibition, flexibility, processing speed, and working memory (Özkan et al., 2022). Additionally, the ability to recognize and apply grammatical patterns and rules, known as rule-learning, is crucial (Hsu & Bishop, 2011). Children with DLD exhibit core deficits in morphosyntax (Leonard, 2014) which could explain their poorer performance on these tasks compared to children with ADHD. Morphosyntax abilities in ADHD have been studied less than those in DLD, but some studies indicate that children with ADHD present with weaknesses in this area compared to typically developing (TD) children (Love & Thompson, 1988; Kim & Kaiser, 2000). Thus, there is evidence to suggest that children with ADHD also exhibit morphosyntactic weaknesses, but these are more nuanced than those observed in children with DLD. Moreover, research comparing executive function and morphosyntax skills in children with ADHD and DLD has found that although deficits in morphosyntax are present in ADHD, they are not characteristic of the disorder (Stanford & Delage, 2020). Although both groups may have impairments in the cognitive processes that contribute to successful morphosyntax/grammatic abilities, the inability to recognize and generalize grammatical rules may be a critical factor contributing to the poorer performance of children with DLD on morphosyntax/grammar tasks compared to children with ADHD.

The findings of Chapter 3 contribute to the existing literature by comparing language and reading abilities in ADHD and DLD, considering comorbid cases and different subtypes of ADHD. Consistent with the findings of Chapter 2, the study demonstrated that children with DLD exhibited significantly greater language and reading difficulties compared to children with ADHD. Importantly, the study also revealed that the presence of comorbid DLD in ADHD did not worsen difficulties in vocabulary, language, nonword repetition, sight word efficiency, or phonemic decoding. These tasks not only involve working memory but also rely on phonological processing, which is a core impairment in DLD (Claessen et al., 2013). The findings indicate that children with DLD, whether they had comorbid ADHD or not, performed significantly worse on language assessments compared to children with ADHD only.

It is noteworthy that children with predominately inattentive subtype of ADHD performed worse on the sight word reading task compared to those with the combined subtype, suggesting that unique symptoms of ADHD (inattentive-only versus inattentive/hyperactive-impulsive) may have a differential impact on performance in tasks requiring high attentional demands, such as sight word efficiency. One explanation for this finding is that children with hyperactive-impulsive symptoms were better at quickly processing information than children without these symptoms. Alternatively, research has demonstrated associations between inattentive symptoms and reading showing that children with the inattentive subtype of ADHD (without comorbid DLD) specifically have difficulties recognizing and reading familiar words automatically (Martinussen et al., 2014). The explanation for the differences in sight word reading efficiency between the and predominately groups is that the inattentive group has increased reading difficulties. This notion is supported by prior research showing that inattentive symptoms in ADHD predict later reading achievement (Dally et al., 2006; Miller et al., 2014; Rabiner & Coie, 2000). These findings emphasize the important connections between attention and reading skills. Overall, assessments of reading efficiency may be useful in distinguishing between ADHD subtypes. However, additional assessments may be necessary to accurately identify ADHD and/or DLD status, as none of the groups could be clearly defined based solely on language or reading abilities.

Together, the findings from Chapter 2 and 3 suggest similarities and differences in the language profiles of children and adolescents with ADHD and/or DLD. Although this could not be directly tested, comparable performance on some language tasks in ADHD and DLD may be the result of shared deficits related to executive function while differences in performance may be the result of unique deficits related to each disorder, such as rule-learning in DLD. However, it is important to note that similar performance on tasks between these groups does not necessarily indicate a shared deficit, as other factors may also contribute to their overlapping language difficulties. Both ADHD and DLD are highly heterogeneous disorders, which makes it challenging to identify consistent similarities or differences in language domains. The variability in symptoms, coupled with a lack of standardization across studies further complicates our understanding of these disorders. The findings from Chapter 2 and Chapter 3 highlight the complexity and multifaceted nature of ADHD and DLD, emphasizing the difficulties in establishing distinct boundaries and/or cut-offs for their diagnoses.

Standardized evaluations and norm-referenced tests are valuable tools for estimating and comparing language deficits in children with ADHD and DLD. However, they also have limitations. These tasks can impose demands on areas such as sustained attention, inhibition, and working memory, which are impaired in multiple disorders. Research has shown that children with ADHD may struggle with language assessments that require generating sentences using target words, as these tasks may place demands on memory (Oram Cardy et al., 1999). It is therefore possible that certain standardized language tasks may be challenging for children with ADHD, even without co-occurring language impairments.

The findings from Chapter 3 further highlight the potential of performance on the CELFST to distinguish between ADHD and DLD groups. However, the significant heterogeneity in these conditions makes it challenging to understand how the symptoms of each disorder, or a combination of symptoms, interact with performance. To address these complexities, Chapter 4 employed more objective measures, specifically resting-state EEG, to investigate differences in brain activity among individuals with ADHD, comorbid ADHD + DLD, and TD individuals.

5.1.2 Unique profiles of resting-state oscillatory power

Resting-state oscillations have been extensively studied in the context of ADHD (see Clarke et al., 2020 for a review) and their relationship to language abilities in TD children (Beese et al., 2017; Lum et al., 2022) has been established in previous research. Given this, there is interest in understanding the resting-state patterns in children with comorbid ADHD + DLD. Resting-state EEG metrics can enhance our understanding of the intersection and distinct etiology of ADHD and DLD. However, current research in this area has primarily focused on comparing "pure" samples of ADHD and related disorders to TD children. It remains unclear whether these findings can be generalized to individuals with comorbid ADHD + DLD. To address this gap, Chapter 4 compared oscillatory patterns during rest in children with ADHD, comorbid ADHD + DLD, and TD. The effectiveness of resting-state EEG metrics in distinguishing between ADHD and comorbid ADHD + DLD in children and adolescents was also examined.

The findings from Chapter 4 are in line with previous research, indicating that children with ADHD exhibit increased theta activity during rest compared to TD children. Elevated theta power is often associated with immature brain development (Kinsbourne, 1973) and tends to decrease as the brain matures into adulthood. While reductions in slow-wave activity, including theta and delta power, reflect *hypo*arousal (Satterfield & Dawson, 1971), increases in theta can indicate *hype*rarousal or overstimulation (di Michele et al., 2005). Interestingly, no significant differences in theta power were observed between the ADHD and comorbid ADHD + DLD groups.

Additionally, children with comorbid ADHD + DLD demonstrated a distinct pattern of reduced delta power compared to children with ADHD only and TD individuals. This unique pattern suggests a specific alternation in delta wave activity in individuals with comorbid ADHD + DLD, highlighting the potential significance of delta oscillations in understanding and characterizing this group. These findings are partially in line with other studies that have observed reduced delta power in individuals with ADHD (Clarke et al., 2008; Dupuy et al., 2013) and comorbid ADHD + autism spectrum disorder (ASD; Shephard et al., 2018). Reductions in slow-wave delta power are associated with hypoarousal, which aligns with impaired reinforcement and reward processing commonly seen in ADHD (Holroyd et al., 2008). The unique decrease in delta power observed in individuals with comorbid ADHD + DLD in the current study could be explained by the heightened ADHD symptoms also found in this group. In our sample, individuals with comorbid ADHD + DLD exhibited higher levels of inattention compared to the ADHD only group. These elevated levels of inattention in comorbid ADHD + DLD may stem from difficulties in regulating arousal (Barkley, 1997) which could be linked to reductions in slow-wave delta activity.

To summarize, children and adolescents with ADHD only exhibited increased theta power, which can be interpreted as the brain's effort to maintain attention and arousal. On the other hand, those with comorbid ADHD + DLD displayed reduced delta power and had increased inattentive symptoms compared to the ADHD only group. Children and adolescents with comorbid ADHD + DLD may therefore rely on inattentive and/or hyperactive behaviours to increase arousal levels when necessary. These changes in theta and delta power may represent compensatory strategies, either in behaviour or in the brain, aimed at achieving the goal of maintaining and regulating arousal.

The findings from Chapter 3 and Chapter 4 suggest interesting relationships between comorbid language disorder, language difficulties, and ADHD symptoms in children with comorbid ADHD + DLD. Chapter 3 revealed that a comorbid language disorder in ADHD does not exacerbate language or reading difficulties more than having DLD only. However, Chapter 4 demonstrated that comorbid ADHD + DLD does impact the presentation and severity of ADHD inattentive symptoms. Specifically, the presence of a comorbid language disorder in ADHD influenced the manifestations of inattentive symptoms and resting-state EEG patterns in a distinct manner compared to children with ADHD only. These findings highlight the importance of using multiple metrics to comprehensively assess the struggles experienced by children with pure and comorbid diagnoses. Behavioural assessments provide valuable insights, but when combined with resting-state EEG measures, a more comprehensive understanding of the connections between symptoms and the brain in ADHD and comorbid ADHD + DLD can be gained.

5.1.3 Age-related changes in resting state EEG

Age-related changes in resting-state EEG have been observed in both typical (Anderson et al., 2018) and atypical populations (Clarke et al.,2020), leading to the development of models that aim to explain these changes. In typical development, there is a proposed decline in slow-wave activity (delta, theta) as children grow older. However, in the context of ADHD, a delay in aspects of the central nervous system results in a lag in maturation, as suggested by the maturation lag model (Kinsbourne, 1973).

The findings presented in Chapter 4 showed a consistent pattern of increasing fast-wave activity (alpha, beta, gamma) and decreasing of slow-wave activity (delta) with age, regardless of diagnosis. Notably, theta activity, which is considered slow-wave activity, also increased with age. Typically, decreases in delta and theta with age reflect neural network maturation and improvements in executive function (Perone et al., 2018). Similarly, the connection between alpha oscillations and cognitive functioning (Jenson et al., 2002) suggests that increases in alpha oscillations with age may also reflect neural maturation.

In line with the findings from Chapter 4, previous research has found increases in alpha with age in TD individuals (Cellier et al., 2021) and increases in theta with age in individuals with ADHD (Bresnahan et al., 1999; Saad et al., 2018). However, Chapter 4 of this thesis reveals an increase in theta among all participants, suggesting a possible delay in brain maturation or immaturity. The timing of theta decline is variable in previous studies, with some suggesting it occurs in adulthood and others indicating a decline in middle childhood (Anderson & Peron, 2018).

While the increase in alpha and decrease in delta align with developmental models, it remains unclear whether the increase in theta found in our sample is consistent with any specific models. Further research investigating the developmental trajectories of brain wave activity into adulthood is therefore needed.

5.1.4 Diagnostic utility of behavioural and resting state EEG metrics

The overlap in symptoms between ADHD and DLD has motivated research on the effectiveness of behavioural assessments and physiological metrics, such as EEG, in distinguishing between these disorders and identifying reliable diagnostic markers. However, most of these studies have focused on investigating the profiles of children with individual clinical disorders rather than comorbid diagnoses.

The findings presented in Chapter 3 and Chapter 4 showed that language, reading, and resting-state EEG markers hold promise in distinguishing between ADHD and DLD, as well as comorbid cases. However, these markers should not be relied upon as standalone diagnostic tools. Findings from Chapter 3 showed that impaired sight word efficiency may suggest the inattentive subtype of ADHD. However, sight word reading and language ability on the screener were not sufficient to rule out other diagnoses. Similarly, resting-state oscillatory power and elevated theta/beta activity were not able to distinguish any of the diagnostic groups with high accuracy. These findings align with previous research, highlighting the inconsistencies in using resting-state oscillatory power and the theta/beta ratio as a clinical indicator of ADHD (Newson & Thiagarajan, 2019).

In summary, while there are noticeable differences in language, reading, and resting-state oscillatory power between ADHD, DLD, and comorbid ADHD + DLD, the findings do not provide sufficient evidence to support the use of these metrics as reliable tools for determining ADHD and/or DLD status. The research represents an important initial step in exploring the value of behavioural and physiological assessments for understanding ADHD, DLD, and comorbid ADHD + DLD. It is crucial to recognize that a single metric cannot effectively diagnose the complex range of behaviours observed in these disorders. Additional research and the integration of multiple assessment tools are needed to improve our understanding of these disorders and accurately identify individuals with comorbid presentations.

5.2 Directions for Future Research

The findings of this thesis provide valuable insights into the behavioural and neurophysiological characteristics of children and adolescents with pure and comorbid

ADHD + DLD. However, these findings also raise further questions that serve as motivation for future work in this field.

The findings from Chapters 2, 3, and 4 reveal the challenges in establishing clear boundaries between "pure" and comorbid cases of ADHD and/or DLD. These disorders are complex and multifaceted. While recognizing the overlap and using it to guide our understanding of these disorders is essential, there is a compelling case for developing measures that can accurately distinguish between them. The ability to accurately distinguish between disorders is crucial because standard interventions for ADHD and DLD can differ significantly, and tailored treatments are essential for optimal outcomes.

Interventions for children with ADHD often involve behavioural modifications to address symptoms of inattention and/or hyperactivity-impulsivity, and they may also receive stimulant medication. Children with DLD typically work with speech-language pathologists to improve their communication skills. Educational support and individualized education plans may be provided to both groups, but the specific course of treatment can vary. Future longitudinal studies could investigate how children with suspected ADHD and/or DLD respond to specific interventions and whether they lead to improved symptoms. If children with suspected language impairments respond better to treatments targeting language skills, it could confirm an accurate diagnosis. Similarly, improved response to interventions targeting both inattention and/or hyperactivity-impulsivity and language skills could help confirm a comorbid diagnosis. Additionally, exploring whether resting-state EEG can predict how individuals' respond to specific treatments, such as stimulant medication, could help facilitate individualized treatment plans based on brain patterns. These approaches could improve intervention effectiveness and diagnostic accuracy for these complex disorders.

The multifaceted nature of ADHD and DLD suggests that integrating various approaches to explore and distinguish these disorders would be beneficial. The findings of Chapter 4 suggest that there are unique resting-state EEG profiles in comorbid samples. Other research has demonstrated the utility of magnetic resonance imaging (MRI) in distinguishing other psychiatric conditions (Abraham et al., 2017; Kottaram et al., 2018). Combining neuroimaging techniques with behavioural measures may uncover associations between neurological markers and symptom severity in ADHD and DLD. Relying solely on one measure or limited combinations may not fully capture the complexity of these disorders. By integrating various approaches, a more comprehensive understanding of ADHD, DLD, and their comorbidity can be achieved.

In light of the complex overlap between ADHD and DLD, a reconceptualization of how we view these disorders may be necessary. It is important to continue to acknowledge the co-occurrence of these conditions and adapt interventions accordingly. Even in the absence of comorbidity, the significant heterogeneity of symptoms provides compelling evidence that a one-size-fits-all approach to treatment may not be effective. The findings from this thesis emphasize the need for personalized and targeted interventions to better address the unique challenges faced by individuals with ADHD and/or DLD.

The field of ADHD and DLD research requires increased validation and standardization. Inconsistencies in both behavioural and resting-state EEG studies hinder the identification of definitive patterns and markers of these disorders. The findings from

Chapter 2 highlight the lack of consistency in eligibility, diagnostic criteria, and assessment protocols used across studies. Similar limitations exist in resting-state EEG studies. The lack of standardization across studies limits our understanding of these disorders and progress in this area of research. To improve standardization, researchers must agree on diagnostic criteria, collaborate, and share datasets, conduct replication studies, and validate findings in larger sample sizes. Validating findings in larger sample sizes is crucial to enhance reliability and robustness of research outcomes, even if a topic has been previously explored. This thesis exemplified this approach by assessing the effectiveness of the widely used CELFST in distinguishing between children with ADHD and/or DLD.

Children with ADHD and DLD share underlying deficits in attention, working memory, and language processing, despite their distinct impairments in language, attention and/or hyperactivity-impulsivity, respectively. Each of the studies described in this thesis showed that children with DLD, with or without ADHD, exhibit unique behavioural and neurophysiological patterns. While DLD is characterized by greater language impairments overall, there was some overlap between ADHD and DLD reflected in certain language domains and resting-state frequencies, possibly due to shared cognitive deficits. These findings inform how behavioural and resting-state brain patterns relate to the core deficits specific to each disorder, enhancing our understanding of their comorbidity.

Together, the findings presented in this thesis provide valuable insights into the behavioural and biological pathways implicated in ADHD, DLD, and their comorbidity. They can enhance our understanding of the cognitive systems involved and their contributions to comorbidity. The findings also inform researchers and clinicians about the usefulness of behavioural and resting-state EEG metrics in diagnosing ADHD, DLD, comorbid ADHD + DLD, and related disorders. Ultimately, the studies presented here offer crucial directions for future research and clinical approaches, highlighting the overlap between these highly comorbid disorders.

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Appendix

Confirmation of DLD across studies for Chapter 2.

Author(s)	Methods for evaluating language for group inclusion	Inclusion measure was only language measure compared
Everatt et al. (2008)	All SLD children had an assessment either before or early in formal schooling that indicated slow language attainment, with the majority showing both receptive and expressive weaknesses.	No
Filippatou & Livaniou (2005)	The speech and language assessment entailed an interview with the parents regarding the child's language development, administration of the Children's Clinical Evaluation of Language Fundamentals-Revised (Semel et al., 1987), translated and adapted to the Greek language, and clinical observations of the child during the evaluation.	No
Helland et al. (2014)	No specification of test. A clinical diagnosis of SLI by a speech and language therapist, no mental retardation, Norwegian as their first language, no sensory neural hearing loss, speaking in sentences, and consistently completed CCC-2 as specified in the manual.	No
Hutchinson et al. (2012)	Achieved a score of at least 1.25 standard deviations below the mean of the CELF-4, Australian version and scored in the normal range on the WISC-IV nonverbal tasks. A diagnosis of ADHD was an exclusionary criterion.	No
Javorsky (1996)	Language learning disabilities (LLD) were determined using the Woodcock-Johnson Psycho- Educational Battery-Revised, Word Attack and Listening Comprehension subtests. A participant must have scored below a standard score of 85 on the WJPB-R Word Attack subtest and above a standard score of 85 on the WJPB-R Listening Comprehension subtest to receive an LLD diagnosis.	No
Löytömäki et al. (2020)	Some participants had the diagnostic label of SLI as they were diagnosed according to the ICD-10, which is still in use. Information needed to fulfil the inclusion criteria and detailed information about their child’s diagnosis and other issues was gathered from the parents using a questionnaire.	No

Luo &Timler (2008)	The child was receiving or had a history of receiving services for speech, language, or reading problems, the child obtained a standard score of 80 or above on the Test of Nonverbal Intelligence (TONI), and a standard score of 85 or lower on the CELF-4.	No
McInnes et al. (2003)	To be included in the DLD group. Children had to performance 1 SD below the mean on 2 of more of the Peabody Picture Vocabulary Test-III, Expressive Vocabulary Test, CELF-3 Receptive, or CELF-3 Expressive score, or 1.5 SD below the mean on at least one of these measures with evidence of receptive difficulties. Children with ADHD-only did not meet these criteria on the language measures. The study compared the groups on the individual test scores as well as experimental measures of listening comprehension.	No
Oram Cardy et al. (2010)	Children with SLI received a CELF-3 Receptive Language Score (RLS), Expressive Language Score (ELS), and Total Language Score (TLS) below 85. Children with ADHD and TD received CELF-3 RLS, ELS and TLS scores >85. This was the only language measure in the study upon which children with SLI and ADHD were compared.	Yes
Redmond & Ash (2014)	SLI children had all been identified as having language impairment by an independent SLP. Inclusion in the SLI group required performance below the appropriate cutoff score for their age on the Clinical Evaluation of Language Fundamentals–Fourth Edition Screening Test (CELFST-4: Semel et al., 2004). Children in the ADHD group did not have a concomitant diagnosis of language impairment and performed above the cutoff on the CELFST-4. This was the only language measure in the study upon which children with SLI and ADHD were compared.	Yes
Redmond et al. (2011a)	SLI children needed to be diagnosed as having a language impairment by an independent, certified SLP; (b) be receiving treatment for this language impairment during the time of the study; and (c) perform at or below the appropriate cutoff score for their age on the Clinical Evaluation of Language Fundamentals Screening Test—Fourth Edition (CELFST-4: Semel et al., 2004).	No
Redmond (2011b)	Same as above.	No
Redmond (2005)	SLI children needed a diagnosis of language impairment by a certified speech language pathologist and receipt of services at the time of the study; (b) a performance below 1 SD on at least two of the six core sub-tests from the Test of Language Development Primary-Third Edition (TOLD-P:3); and (c) no concomitant	No

	diagnosis of autism, PDD, or ADHD. ADHD children had no concomitant diagnosis of language impairment but TOLD-P:3 performance was not used to confirm this. The language measures compared in the study were one subtest of the TOLD-P:3 and an experimental language task	
Redmond (2004)	Same as above. The language measures compared in the study conversational measures from a language sample.	No
Short et al. (2020)	Children with DLD and ADHD had these formal diagnoses prior to study enrollment. The Adaptive Language Inventory (ALI; Feagans & Farran, 1979) total score was used to validate group membership but not for study inclusion/exclusion. The CELF-P2 and CELF-3 were additional language measures compared in the study.	No
Stanford & Delage (2020)	Participants in the DLD group had been officially diagnosed by a qualified speech-language therapist. Only children with DLD with documented deficits in morphosyntax were included and verified via correspondence with the SLTs directly involved in the children’s intervention services.	No
Weyandt & Willis (1994)	A diagnosis of receptive and expressive language disorder by the school's speech and language therapist, (b) average to above-average intelligence as assessed by the Raven's Coloured Progressive Matrices, and (c) enrollment in a regular education classroom with special education services for language therapy only.	No
Williams et al. (2000)	The Edinburgh Articulation Test for phonology, the Reynell Expressive Language Scale for expressive language; the Reynell Receptive Language Scale for receptive language; and the British Picture Vocabulary Scale for receptive vocabulary. Children whose scores decreased by at least 1 SD below the mean on at least one of these measures were designated as SLI for current selection purposes. All children selected had also failed on at least one measure of receptive language, expressive language, or phonology at age 39 months.	No

Articles and reasons for exclusion at the full-text screening stage for Chapter 2.

Author(s)	Reason for exclusion	Journal Name
Aziz (2017)	No official diagnosis	*International Journal of Language & Communication Disorders*
Baker (1992)	Not available	*Comprehensive Mental Health Care*
Beitchman (1987)	Wrong patient population	*Canadian Journal of Psychiatry*
Benner (2008)	Wrong patient population	*Education and Treatment of Children*
Berninger (2017)	Wrong patient population	*Journal of Learning Disabilities*
Cantwell (1991)	Review	*Journal of Learning Disabilities*
Cherkes-Julkowski (1998)	Wrong patient population	*Journal of Learning Disabilities*
Cohen (1993)	Wrong patient population	*Journal of the American Academy of Child & Adolescent Psychiatry*
Cohen (1998)	Wrong patient population	*Journal of Child Psychology & Psychiatry & Allied Disciplines*
Cohen (2000)	Wrong patient population	*Journal of Child Psychology & Psychiatry & Allied Disciplines*
Crespo-Eguilaz (2016)	Wrong patient population	*Revisita de Neurologia*
Crespo-Eguilaz (2009)	Not available	*Revisita de Neurologia*
D'Lncau (2000)	Dissertation	*Dissertation Abstracts International: Section B: The Sciences and Engineering*
Dalsggard (2020)	Wrong study design	*JAMA Psychiatry*

Davis (2017)	Wrong patient population	*Journal of Mental Health Research in Intellectual Disabilities*
DeHirsch (1975)	Not available	*Psychoanalytic Study of the Child*
Dyck (2011)	Wrong outcomes	*Research in Developmental Disabilities: A multidisciplinary Journal*
Eiges (2016)	Dissertation	*Dissertation Abstracts International: Section B: The Sciences and Engineering*
Geurts (2008)	Wrong study design	*Journal of Autism and Developmental Disorders*
Glennen (2005)	Wrong outcomes	*Seminars in Speech & Language*
Hart (2004)	Wrong study design	*Developmental Medicine & Child Neurology*
Hawkins (2016)	Wrong patient population	*Brain Sciences*
Humphries (1994)	Wrong patient population	*Journal of Developmental & Behavioral Pediatrics (1994)*
Hutzelmeyer-Nickles (2007)	Wrong patient population	*Praxis der Kinderpsychologie und Kinderpsychiatri*
Im (2007)	Wrong study design	*Yonsei Medical Journal*
Jafari (2019)	Wrong study design	*Psychology Research & Behavior Management*
Kadesjö (2004)	Wrong outcomes	*Eur. Child Adolesc. Psychiatry Suppl.*
Kibby (2004)	Wrong patient population	*Brain & Language*
Kitzes (2000)	Dissertation	*Dissertation Abstracts International: Section B: The Sciences and Engineering*
Korkman (2004)	Wrong outcomes	*Eur. Child Adolesc. Psychiatry Suppl.*

Korkman (1988)	Not available	*Psykologia*
Kruger (2001)	Wrong patient population	*Communication Disorders Quarterly*
LeDuigou (2010)	Wrong patient population	*Neuropsychiatr. Enfance Adolesc.*
Leung (2016)	Wrong outcomes	*Research in Developmental Disabilities*
Lindblad (2011)	Not available	*Research in Developmental Disabilities: A Multidisciplinary Journal*
Love (1988)	Wrong outcomes	*American Journal of Orthopsychiatry*
Mareva (2019)	Wrong patient population	*BMC Pediatrics*
McGrath (2008)	Not available	*Journal of Abnormal Child Psychology*
McInnes (2001)	Dissertation	*Dissertation Abstracts International Section A: Humanities and Social Sciences*
Nudel (2020)	Wrong study design	*Autism research: Official Journal of the International Society for Autism Research*
Ors (2005)	Wrong outcomes	*Cortex*
Palumbi (2018)	Wrong outcomes	*BMC Pediatrics*
Perna (2012)	Wrong patient population	*Applied Neuropsychology*
Petersen (2013)	Wrong study design	*Journal of Abnormal Psychology*
Pisella (2020)	Not available	*Developmental Medicine & Child Neurology*
Redmond (2020)	Wrong outcomes	*Journal of Speech Language & Hearing Research*

Redmond (2016)	Review	*Journal of Speech, Language & Hearing Research*
Redmond (2015)	Wrong patient population	*Language, Speech, and Hearing Services in Schools*
Sandler (1993)	Wrong patient population	*Perceptual & Motor Skills*
Sanger (1995)	Wrong patient population	*Journal of Childhood Communication*
Schuchardt (2017)	Not available	*Kindheit Entwickl*
Schuerholz (1995)	Wrong study design	*Journal of Learning Disabilities*
ShaunGohKok (2017)	Wrong patient population	*Journal of Abnormal Child Psychology*
Shimko (2019)	Wrong study design	*Journal of Communication Disorders*
Shmulsky (2007)	Not available	*Journal of Attention Disorders*
Sideridis (2013)	Wrong study design	*Journal of Learning Disabilities*
Snowling (2006)	Wrong patient population	*Journal of Child Psychology and Psychiatry*
Spratt (1998)	Not available	
Stolzenberg (1991)	Not available	
Trillingsgaard (2004)	Wrong patient population	*Eur. Child Adolesc. Psychiatry Suppl.*
Vig (1995)	Wrong outcomes	*Mental Retardation*
Willemsen-Swinkels (1998)	Wrong outcomes	*Journal of Autism and Developmental Disorders*

Curriculum Vitae
Kaitlyn Parks

Education

2023	Doctor of Philosophy: Psychology (Cognitive, Developmental, and Brain Sciences). University of Western Ontario
2019	Masters of Science: Psychology (Cognitive, Developmental, and Brain Sciences). University of Western Ontario
2016	Bachelor of Science (Honours): Psychology. Trent University

Research Publications

Peer-reviewed

1. **Parks, K.,** et al. (2021). The Task Matters: A Scoping Review on Reading Comprehension in ADHD. *Journal of Attention Disorders.*
2. **Parks, K.,** et al. (2020). Statistical learning and social communication: The mediating role of language. *Scientific Reports.*
3. **Parks, K.,** et al. (2020). Investigating the role of inattention and hyperactivity-impulsivity in language and social functioning using a dimensional approach. *Journal of Communication Disorders.*
4. Brierley, N., McDonnell, C., **Parks, K.,** … Stevenson, E (2020). Factor structure of repetitive behaviors across autism spectrum disorder and attention-deficit/hyperactivity disorder. J*ournal of Autism and Developmental Disorders*.
5. **Parks, K.,** Stevenson, R. (2018). Auditory and visual statistical learning are not related to ADHD symptomatology: Evidence from a research domain criteria (RDoC) approach. *Frontiers in Psychology*.

Under Review/Revisions

6. **Parks, K.,** et al. (under review). Language abilities in children and adolescents in ADHD and DLD: A scoping review. *Journal of Communication Disorders.*
7. **Parks, K.,** et al. (under review). Language and reading in ADHD and comorbid ADHD/DLD. *Journal of Child Psychology and Psychiatry Advances.*

8. Moreau, C., **Parks, K.,** et al. (under review) A systematic review and meta-analysis of multimedia learning: Multimodal input improves second language learning.

Preprints/In Prep

9. **Parks, K.,** et al. (2020, April 15). Sensory Processing in ASD and ADHD: A confirmatory factor analysis. Preprint arXiv:https://doi.org/10.31234/osf.io/myjbq

10. Brainin, L., **Parks, K.,** et al. (in prep.) A cognitive trajectory of reading disorder: A review of longitudinal follow-up studies.

Invited Talks

1. Statistical Learning Through Multiple Methods: Implications for Language and Social Functioning in Autism (May 2019). Vanderbilt University. Nashville, Tennessee.

2. Seminar Speaker for 'Ladies Coding Night', Equity, Diversity, and Inclusion Committee (February 2021). University of Western Ontario.

Knowledge Translation

1. **Parks, K.** (2022). How do patterns help children learn language and social skills? Blog on Learning and Development (BOLD).

2. **Parks, K.,** Stevenson, R. (2021). Treating Specific Symptoms of autism or ADHD can help children, even without a diagnosis. The Conversation Canada.

3. **Parks, K.** (2021). Moving Beyond Diagnostic Labels in ASD and ADHD Could Improve Access to Treatment. Inspiring Minds. Western University.

Oral Presentations

1. Rafat, Y., Mohammed, R., Valdivia, C., Abdeljawad, B., Edwards, A., **Parks, K.,** Dezfuly, N., Altoum, E., Stevenson, R. (May 2020). Audiovisual integration in Arabic-English bilingual adults and heritage speakers of Arabic living in Canada. Heritage Languages Around the World Conference. Lisbon, Portugal. (Conference cancelled).

2. **Parks, K.**, Schulz, S., Stevenson, R. (May 2019). Sensory Processing in ASD and ADHD: A Multi-Group Approach. Presented at Developmental Disabilities Academic Research Day. Western University, ON.

3. **Parks, K.** (May 2018). Statistical Learning and Social Communication: The Mediating Role of Language. Presented at 31st Annual Pediatric Research Day. Western University, ON.

4. **Parks, K.** (May 2018). Statistical Learning and Social Communication: The Mediating Role of Language. Presented at Developmental Disabilities Academic Research Day. Western University, ON.

5. **Parks, K.** (April 2017). Cryonics: The Possibility of Life After Death. Paper presented at Trent University Annual Philosophy Symposium. Peterborough, ON.

6. **Parks, K.** (March 2017). Language, Working Memory, and Figurative Language in Children with and without Language Problems. Trent University Annual 3 Minute Paper Competition. Peterborough, ON.

Conference Presentations

1. **Parks, K.,** Joanisse, M (March 2023). Can Psycholinguistic Assessments Differentiate Children and Adolescents with DLD from ADHD? SRCD – Society for Research in Child Development. Salt Lake City, Utah.

2. **Parks, K.,** Stevenson, R (May 2022). Statistical Learning in relation to ASD and ADHD traits: Further evidence for a spectrum of impairment. BCBL - interdisciplinary advances in statistical learning. San Sebastian, Spain.

3. **Parks, K.,** Anagnostou, E., Nicolson, R., Kelley, E., Georgiades, S., Crosbie, J., Schachar, R., Liu,X., Stevenson, R. (May 2020). Sensory Processing Behaviors Relate to Listening Comprehension and Oral Expression in ASD. The 2020 International Society for Autism Research. Seattle, Washington (Conference cancelled).

4. **Parks., K.,** et al. (March 2020). The Impact of Sensory Processing on Language Outcomes in Autism: Age Matters. Meeting on Language in Autism Conference. Durham, North Carolina (Conference cancelled).

5. **Parks, K.,** Stevenson, R. (Feb 2020). Does Multisensory Integration Enhance Statistical Learning? The 49th Annual Lake Ontario Visionary Establishment (LOVE) Conference. Niagara Falls, ON.

6. **Parks, K.,** et al. (May 2019). Sensory Processing in ASD and ADHD: A Multi Group Approach. Child Health Research Day. London, ON.

7. **Parks, K.,** et al. (May 2019). Using Sensory Processing Behaviors to Differentiate ASD and ADHD Diagnoses. The 2019 International Society for Autism Research. Montreal, Quebec.

8. Schulz, S. E., **Parks, K.,** … Stevenson, R. (May 2019). Sensory Processing as a Transdiagnostic Mechanism for Behavioural Outcomes in ASD and ADHD. The 2019 International Society for Autism Research. Montreal, Quebec.

9. **Parks, K.,** et al. (May 2019). Sensory Processing in ASD and ADHD: A Multi-Groups Approach. The 2019 International Society for Autism Research. Montreal, Quebec.

10. Sehl, C., **Parks, K.,** … Stevenson, R. (Feb 2019). A Temporal Community Structure Approach to Statistical Learning. The 48th Annual Lake Ontario Visionary Establishment (LOVE) Conference. Niagara Falls, ON.

11. **Parks, K.,** Griffith, L., Noonan, B. N., Stevenson, R. (May 2018). Statistical Learning and Autism-related Social Communication Difficulties. The 2018 International Society for Autism Research. Rotterdam, Netherlands.

12. **Parks, K.,** et al. (February 2018). The Impact of Statistical Learning on Autism-related Language and Social Communication Difficulties. The 47th Annual Lake Ontario Visionary Establishment (LOVE) Conference. Niagara Falls, ON.

Scholarships and Awards

2022-2023	Ontario Graduate Scholarship, University of Western Ontario, total value $15,000
2019 – 2022	Social Sciences and Humanities Research Council of Canada (SSHRC), University of Western Ontario, total value $105,000
2019- 2020	Ontario Graduate Scholarship, University of Western Ontario, total value $15,000
2019- 2020	Ralph S. Devereux Award, University of Western Ontario, total value $1,800
2019 - 2020	Clinical and Mental Health Poster Award, Child Health Research Day, London Health Sciences Centre, London, Ontario
2018 - 2019	Autism Scholars Award, total value $18,000
2018 - 2019	Ontario Graduate Scholarship, University of Western Ontario, total value $15,000
2018 – 2019	C. Kingsley Allison Research Grant Winner, Developmental Disabilities Program, University of Western Ontario, total value $8,500
2016 – 2017	Gordon Winocur Research Excellence Prize, Developmental Psychology Recognition Winner – Trent University, total value $325
2015 – 2016	In-Course Scholarship – Trent University, total value $1,000
2015 - 2016	Dean's List Honour Roll Recipient, Trent University

Community Engagement

2021 - 2023	Western Undergraduate Psychology Journal Editor, University of Western Ontario.
2017 - 2020	Western Women in Neuroscience Diversity in STEM Conference Chair, University of Western Ontario.
2019 – 2020	Graduate Student Representative for Space Planning Committee, University of Western Ontario.
2019 - 2020	Elementary Psychology Mentorship Program, University of Western Ontario.
2018 - 2019	Canadian National Brain Bee Competition, University of Western Ontario.

AD HOC Referee

Journal of Autism and Developmental Disorders
Western Undergraduate Psychology Journal

Certificates

Oct 2018	Autism Diagnostic Observation Schedule (ADOS-2) Advanced Research and Clinical Training. University of Michigan. Department of Psychiatry.
Feb 2018	Heart saver CPR AED (C) Adult, Child, Infant, Exam. Heart and Stroke Foundation of Canada.
Jan 2017	Applied Suicide Intervention Skills Training (ASIST). Trent University.