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Characterizing Reading Ability in Children with Prenatal Alcohol Exposure

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Characterizing Reading Ability in Children with Prenatal Alcohol Exposure

A dissertation submitted in partial satisfaction
of the requirements for the degree of Doctor of Philosophy

in

Clinical Psychology

by

Leila Glass

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The Dissertation of Leila Glass is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego

San Diego State University

2017

DEDICATION

Throughout my time at the Center for Behavioral Teratology and my involvement in the FASD advocacy network throughout San Diego, I have been constantly amazed by the tireless effort and support present in this community. This study was conceptualized and realized in part due to the sharing and generosity of families affected by fetal alcohol spectrum disorders. I would like to dedicate this work to the continuing effort to improve outcomes for those affected by prenatal alcohol exposure.

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Chapters I, II, III, and IV, in part, are currently being prepared for submission for publication of the material and will be co-authored by Sarah N. Mattson. The dissertation author was the primary investigator and author of this material.

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ABSTRACT OF THE DISSERTATION

Characterizing Reading Ability in Children with Prenatal Alcohol Exposure

by

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Doctor of Philosophy in Clinical Psychology

University of California, San Diego, 2017
San Diego State University, 2017

Professor Sarah N. Mattson, Chair

Despite widespread public health campaigns and increased knowledge of the harmful effects of drinking during pregnancy, greater than 1% of children are estimated to have prenatal alcohol exposure. Reading-related difficulties are of particular concern in the school-age population. The current study aimed to characterize reading performance in children with heavy prenatal alcohol exposure.

Children (6–12y) with histories of heavy prenatal alcohol exposure (n=32) and without (n=40) were administered a two-hour neuropsychological battery, which included multiple measures of reading domains (decoding, fluency, comprehension) and phonological processing (phonological awareness, phonological memory, rapid naming). Caregivers completed assessments of home literacy environment and behavior. Correlation, MANOVA, and regression techniques were conducted to evaluate differences between groups and identify contributing factors for reading performance. Discriminant function and latent class analyses were run to determine whether performance on these measures could aid in differential diagnosis and establish whether distinct subtypes of reading impairment exist.

There were no significant differences on demographic characteristics between groups. Alcohol-exposed children performed significantly worse than their peers on all measures, with the exception of rapid naming. In particular, alcohol-exposed children had relative weaknesses in phonological awareness, decoding, and comprehension. They also had significantly higher rates of reading difficulties in all domains. Aspects of phonological processing accounted for significant variance in reading variables across groups. Exposure history accounted for additional variance in decoding and comprehension. No interaction effects were significant. After other factors were added to the models, vocabulary, behavioral concerns, and attitude towards reading were additional significant contributors. Also, exposure history continued to account for significant variance. Outcome variables distinguished between alcohol-exposed children and controls. Distinct subgroups emerged based on severity of impairment. There were no significant differences between performances on academic domains (reading, spelling, math) for either group.

Alcohol-exposed children had significant difficulties in all aspects of reading, comparable with their performance in math and spelling. They demonstrated specific weaknesses that suggest potential targets for intervention. Cognitive mechanisms that contribute to reading in both typical and neurodevelopmental disorder populations were also found in this population. Therefore, effective interventions in other populations may be utilized to improve outcomes for alcohol-exposed children.

I. Introduction

Despite the known detrimental effects of alcohol on the developing fetus and widespread public health campaigns, 7.6–14.3% of pregnant women in the United States report alcohol consumption, and 1.4% report binge drinking, during pregnancy with no substantial decrease over the past decade (Grant et al., 2004; Thomas, Gonneau, Poole, & Cook, 2014). As approximately 50% of pregnancies are unexpected (Finer & Zolna, 2011), women who drink during childbearing age are at an increased risk of giving birth to a child affected by prenatal exposure (Green, McKnight-Eily, Tan, Mejia, & Denny, 2016). Prenatal alcohol exposure is the leading preventable cause of birth defects, developmental disorders, and intellectual disability (American Academy of Pediatrics, 2000). The continuum of consequences from prenatal alcohol exposure encompasses a heterogeneous group of individuals who vary greatly in terms of cognitive and behavioral functionality.

Prenatal alcohol exposure represents a major public health concern, as the effects are estimated to conservatively affect greater than 1% of school age children (May et al., 2014), with higher prevalence estimates in specific international locations (May et al., 2009; May et al., 2007). The effects of prenatal alcohol exposure lead to a substantial societal and economic burden (Popova, Stade, Bekmuradov, Lange, & Rehm, 2011; Stade et al., 2009). Early identification of affected children and access to effective treatment can improve developmental trajectories; however both have been limited in this population due to the heterogeneity of clinical presentation and under recognition of non-dysmorphic individuals (Chasnoff, Wells, & King, 2015).

The effects of prenatal alcohol exposure may vary based on timing and amount of exposure in addition to other confounding factors such as individual genetic vulnerability (Charness, Riley, & Sowell, 2016). Therefore, the National Institute of Alcohol Abuse and Alcoholism (NIAAA) and the Surgeon General recommend complete abstinence from alcohol during pregnancy (NIAAA, 2013; US Surgeon General, 2005).

Identification

There is relative consensus regarding the medical diagnosis of fetal alcohol syndrome (FAS), which relies on a triad of symptoms: (1) evidence of two or more characteristic facial features, such as short palpebral fissures, smooth philtrum, and a thin vermillion border of upper lip; (2) evidence of prenatal or postnatal growth deficiency with a height or weight of below the 10th percentile at any point of the child's life (corrected for racial norms, if possible); and (3) evidence of deficient brain growth or abnormal morphogenesis (Astley, 2013; Hoyme et al., 2005; Jones et al., 2006). The third criterion can be satisfied by the presence of structural brain abnormalities or microcephaly (head circumference at or below the 10th percentile). Receiving a diagnosis of FAS is often recognized as a qualifying disorder to provide access to referrals and services (Bertrand et al., 2004).

The majority of children affected by prenatal alcohol exposure do not meet all of the physical criteria required for an FAS diagnosis (May et al., 2014). For example, children who present with facial dysmorphology but do not have growth deficiency or structural brain abnormalities may only meet criteria for partial FAS (pFAS). Most importantly, the majority of children affected by prenatal alcohol exposure do not demonstrate clear facial dysmorphology, which can greatly hinder identification of alcohol-affected individuals. Fetal alcohol spectrum disorders (FASD) encompass the continuum of effects that result from prenatal alcohol exposure, including FAS.

A proposed diagnostic system to identify the effects of prenatal alcohol exposure has been incorporated into the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) as a condition requiring further study, referred to as Neurobehavioral Disorder Associated with Prenatal Alcohol Exposure (ND-PAE) (American Psychiatric Association, 2013). A similar term, Neurodevelopmental Disorder Associated with Prenatal Alcohol Exposure, is listed as a prototypical example under Other Specified Neurodevelopmental Disorder. The criteria for ND-PAE require indication that the individual was exposed to alcohol at some point during gestation (including prior to pregnancy recognition) and that the exposure was more than "minimal." The precise dosage is not specific and relies on clinical judgment, although a suggested estimate for minimal exposure is defined as 1–13 drinks per month (and never more than 2 drinks per occasion) prior to pregnancy recognition and/or following pregnancy recognition (American Psychiatric Association, 2013). In addition to exceeding a minimal level of prenatal alcohol exposure, the individual must also have impaired neurocognition, self-regulation, and adaptive functioning. As the location of the disorder in the DSM-5 suggests, there is ongoing research to determine the feasibility, sensitivity, and specificity of the criteria to accurately identify those affected by prenatal alcohol exposure (Kable et al., 2016).

Guidelines for alcohol-related diagnoses along the spectrum are developed to ensure valid and reliable identification (Coles et al., 2016). One significant consequence of the ongoing debate over the diagnostic criteria is the risk that affected children and adults may be under-identified or misdiagnosed and therefore underserved (Chasnoff et al., 2015). The current diagnostic schemas suffer from various shortcomings, including lack of consensus, lack of validation studies, difficulties in balancing sensitivity and specificity given the variation in clinical presentation, and barriers to educating physicians, dissemination, and implementation (Astley, 2014; Larcher & Brierley, 2014; Salmon & Clarren, 2011).

New objective screening tools, including neonatal testing and the development of potential biomarkers, can assist in the identification of alcohol-exposed children at birth (Koren et al., 2014; Zelner et al., 2010; Zelner et al., 2012). However, screening techniques are inherently plagued with various potential ethical and moral issues. These include the risk of disproportionately targeting specific groups, inaccuracy, and the concern of stigma and judgment associated with maternal drinking during pregnancy. The controversy regarding the demarcation of viable life and determination of personhood has also led to issues concerning the criminalization of drinking while pregnant (Drabble, Thomas, O'Connor, & Roberts, 2014; Yan, Bell, & Racine, 2014). A recent review of state responses to alcohol use and pregnancy found that there is great variability in the characteristics of policies, ranging from primarily supportive to primarily punitive (Drabble et al., 2014). Another issue that arises in testing for alcohol exposure at birth is that even if it is possible to accurately determine prenatal alcohol exposure with adequate sensitivity and specificity, it is not certain that an individual will be negatively affected later in life. Both a false positive and a false negative diagnosis may have detrimental effects throughout a child's development.

While it is difficult to accurately assess drinking, retrospective reports identify 10.8 times as many women as risky drinkers when compared to antenatal or prospective reports (Hannigan et al., 2010). While retrospective reports were originally considered to be less accurate, changes in motivation and other factors lead them to be a more effective indicator of prenatal exposure that is validated in the prediction of additional behavioral problems compared to antenatal reports (Hannigan et al., 2010). However, despite the potential validity of retrospective reports, relying on maternal reports alone is not an effective way to identify rates of individuals with prenatal alcohol exposure. A study comparing the prevalence rates of prenatal alcohol exposure based on maternal self-reporting versus objective meconium screening (the earliest stool of the infant) found that the meconium testing yielded over four times as many cases as would have been identified by self-reporting alone (Lange, Shield, Koren, Rehm, & Popova, 2014). Therefore, additional methods of assessing prenatal alcohol exposure may be important to avoid missing affected children.

In an effort to increase the accuracy of identification of children affected by prenatal exposure, researchers have focused on defining the neurobehavioral patterns associated with FASD. A variety of screening checklists have been created to facilitate the differential diagnosis of individuals affected by prenatal alcohol exposure, though only with moderate success (Burd, Klug, Li, Kerbeshian, & Martsolf, 2010;

Fitzpatrick et al., 2013). Parent report measures have also been used to help differentiate alcohol-affected individuals from other clinical groups. For example, the Neurobehavioral Screening Test (NST) consists of ten items from a commonly used behavioral scale (the Child Behavior Checklist) (Nash et al., 2006). The NST was tested in a small group of alcohol-exposed children, children with attention-deficit/hyperactivity disorder (ADHD), and controls, with 86% sensitivity and 82% specificity for detecting alcohol-exposed children. Certain items from the NST were also able to differentiate children with FASD from children with oppositional defiant disorder (ODD) and conduct disorder (CD) (Nash, Koren, & Rovet, 2011).

In order to move beyond subjective checklists and parent reporting measures, researchers have attempted to describe a sensitive and specific neurobehavioral profile of alcohol-exposed children using objective neuropsychological measures (Jacobson, 1998; P. Kodituwakku et al., 2006; Mattson & Riley, 2011; Mattson et al., 2013). While classification accuracies have reached adequate levels when comparing alcohol-exposed children to typically developing controls, the classification rates are lower when comparing exposed children to non-exposed children with other diagnoses, such as ADHD, which is a more important clinical distinction (Mattson et al., 2013). In cases where alcohol exposure is suspected but dysmorphology is not present, the neurobehavioral effects may act as a potential diagnostic phenotype.

Individuals with dysmorphology may be identified regardless of the neurobehavioral profile. Therefore, it is important to create a profile that is able to accurately categorize non-dysmorphic children affected by prenatal alcohol exposure.

A large multi-site study using a standardized neuropsychological battery compared controls, non-exposed children with ADHD, and children who had heavy exposure to alcohol but were not dysmorphic (Mattson et al., 2013). The classification rates were modest when comparing the clinical groups. However, this study had considerable clinical relevance, as the differential diagnosis between non-dysmorphic alcohol-exposed children and other clinical groups is common within clinical settings. A diagnostic tree algorithm including measures of dysmorphology, cognition, psychopathology, and adaptive behavior has reached adequate classification, though feasibility and implementation has yet to be fully evaluated (Goh et al., 2016). The classification rates for the current brief screeners and the neurobehavioral profile indicate that continued efforts are needed for accurate identification (Mattson & Riley, 2011; Koren et al., 2014; LaFrance et al., 2014).

Consequences of Prenatal Alcohol Exposure

Prenatal alcohol exposure negatively impacts fetal development, resulting in a wide range of central nervous system dysfunction that can be apparent in several areas: structurally, neurologically, or functionally (Bertrand et al., 2005). This dysfunction may present as pre- or post-natal growth deficiency, as microcephaly, as facial dysmorphology required for a diagnosis of FAS, as seen through neuroimaging, or as observed in the arenas of neuropsychological and behavioral functioning.

Neuroimaging advances have provided insight into the structural, volumetric, and integrity deficits associated with alcohol exposure. Volumetrically, alcohol-exposed children have reduced overall total brain volume and reduced white, deep, and cortical gray matter (Moore, Migliorini, Infante, & Riley, 2014). These volumetric reductions are seen in the frontal, temporal, and parietal lobe, yet there are mixed findings regarding reduced volume in the occipital lobe (Archibald et al., 2001; Coles et al., 2011; Li et al., 2008; Sowell et al., 2002). There is also strong convergent evidence that volumetric and structural abnormalities exist in the corpus callosum, cerebellum, and basal ganglia (Coles & Li, 2011; Lebel, Roussotte, & Sowell, 2011; Wozniak et al., 2011). In-depth reviews of structural and functional neuroimaging findings in this population are available; see (Moore, Migliorini, Infante, & Riley, 2014; Coles & Li, 2011; Lebel et al., 2011; Norman, Crocker, Mattson, & Riley, 2009). These findings suggest that there are both global structural and functional impairments, with specific areas that are disproportionately affected.

These underlying brain changes relate to the increased risk of neurological symptoms seen in individuals with histories of heavy prenatal alcohol exposure. Alcohol-exposed children have higher rates of seizures, seizure disorders, sleep abnormalities, sensory processing, hearing loss, and impaired motor skills and coordination (Bell et al., 2010; Church & Kaltenbach, 1997; Coffman et al., 2012; Jan et al., 2010; Simmons, Madra, Levy, Riley, & Mattson, 2011; Simmons, Thomas, Levy, & Riley, 2010; Steinhausen & Spohr, 1998; Wengel, Hanlon-Dearman, & Fjeldsted, 2011). This presence of central nervous dysfunction seen in neuroimaging or facial dysmorphology is often reflected and observed in neuropsychological or behavioral performance. Neuropsychological and behavioral research in this population has demonstrated that individuals with a history of heavy prenatal alcohol exposure have a wide range of neurobehavioral deficits, and current ongoing study aims to develop a neurobehavioral profile for fetal alcohol spectrum disorders (Mattson & Riley, 2011).

General Intellectual Function

One of the most robust findings in children with heavy prenatal exposure to alcohol is diminished global cognitive performance (Mattson, Crocker, & Nguyen, 2011; Mattson & Riley, 1998). FASD are a leading identifiable cause of intellectual disability (Pulsifer, 1996), although many children with heavy prenatal alcohol exposure will not meet the DSM-5 criteria. Individuals with alcohol exposure have a continuum of deficits and intelligence scores (IQ) that range from severe intellectual disability to non-impaired (e.g., 40–112) (Mattson et al., 2011). The median IQ of over 400 individuals with FASD (ranging from 6–51 years old) was 86 (Streissguth et al., 2004). This finding has been replicated in 8–16 year olds in a recent multi-site study (Glass, Ware, et al., 2013), suggesting the average individual with heavy prenatal alcohol exposure has an intelligence score approximately 1 standard deviation (SD) lower than the average non-exposed individual. Studies found that 24% of children with FAS and 7–16% of children with fetal alcohol effects[1] met the basic criteria of having an IQ of below 70 (Streissguth, Barr, Kogan, & Bookstein, 1996; Streissguth et al., 2004).

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[1] ‘Fetal alcohol effects’ is an outdated term that refers to individuals with prenatal alcohol exposure who have some, but not sufficient, features to warrant a diagnosis of FAS.

Verbal and nonverbal IQ scores are both affected in this population, and IQ deficits occur in children with and without alcohol-related facial dysmorphia (Mattson, Riley, Gramling, Delis, & Jones, 1998). These IQ deficits in this population are relatively stable and lifelong (Streissguth, 1990) and relate to poor educational, psychiatric, and overall life outcomes (Steinhausen & Spohr, 1998; Streissguth et al., 2004). Even relatively lower maternal alcohol consumption levels are associated with decreased IQ scores after demographic variables are considered; drinking in excess of one ounce of alcohol per day on average shifts the IQ distribution approximately seven points lower, resulting in a nearly 3.5-fold increase in the number of children with subnormal IQ scores (i.e., below 85) (Streissguth, Barr, & Sampson, 1990).

Language

Basic language functioning and the ability to communicate are important in various aspects of life, including verbal expression, literacy, comprehension, and social interactions. Children with FASD have demonstrated deficits in expressive language (the ability to produce verbal or written expression) and receptive language (the ability to comprehend and understand language in addition to delays in language acquisition) (Adnams et al., 2007; Aragón, Coriale, et al., 2008; McGee, Bjorkquist, Riley, & Mattson, 2009; Wyper & Rasmussen, 2011). Expressive and receptive deficits may not deviate from what is expected given general intellectual functioning (McGee, Bjorkquist, Riley, et al., 2009). The underlying cognitive mechanisms of these deficits have yet to be fully elucidated, although they may relate to physical changes associated with neurological changes associated with prenatal alcohol exposure or with impaired auditory and verbal processing. Deficits in the physical aspects of language may contribute to poor expressive language, as alcohol-exposed children demonstrate increased rates of dysarthria and articulation difficulties (Becker, Warr-Leeper, & Leeper, 1990).

An additional underlying component of language that has been evaluated in this population is phonological processing. One prospective longitudinal study of children with lower levels of exposure (averaging 0.34 ounces of absolute alcohol per day) suggested dose-dependent deficits in phonological awareness and processing (Streissguth, Barr, Carmichael Olson, et al., 1994; Streissguth, Sampson, et al., 1994), while a later study comparing children with FAS and average IQ to controls found no group differences (Carmichael Olson, Feldman, Streissguth, Sampson, & Bookstein, 1998). Other studies involving lower levels of exposure found language deficits in basic abilities (Fried & Watkinson, 1988; Gusella & Fried, 1984), while others did not (Fried & Watkinson, 1990; Greene, Ernhart, Martier, Sokol, & Ager, 1990).

It remains difficult to determine the dose response curve between alcohol exposure and academic performance. One study found that one unit of alcohol a day during pregnancy was found not to be associated with lower test scores, though four units or greater on a single occasion throughout pregnancy did lead to adverse effects on childhood academic outcomes (Alati et al., 2013). This was replicated by another study, which found that maternal binge drinking patterns were independently associated with lower academic attainment in a mother's offspring at age 11 (Sayal et al., 2014), though moderate levels of alcohol consumption (one drink per day) were not associated with adverse outcomes. The association with binge drinking was significant even in the absence of daily drinking. Prenatal alcohol exposure on the arithmetic subtests were linear or dose-response, whereas for spelling or reading, a threshold was a better representation of the data (approximately one drink per day in the second trimester) (Goldschmidt, Richardson, Stoffer, Geva, & Day, 1996). This suggests that the neural or teratogenic mechanisms of impairment may be different depending on the area of functioning.

One study found no association between low levels of alcohol and language delay, however children exposed to binge drinking had three-fold increased odds of language delay (O'Leary, Zubrick, Taylor, Dixon, & Bower, 2009). However, these results were not statistically significant, potentially due to limited power from a smaller sample size of binge drinkers (n = 10) who reported binge drinking throughout gestation. It is unclear whether inconsistent results are due to differences in exposure levels, developmental trajectories, within-group variability, or subjectivity of the measures. These basic language difficulties contribute to poor communication abilities in alcohol-exposed children, which may relate to some of the social and behavioral issues (Crocker, Vaurio, Riley, & Mattson, 2009; Ware et al., 2013) as well as contribute to poor academic performance (Church & Kaltenbach, 1997; McGee, Bjorkquist, Riley, et al., 2009).

Learning and Memory

There is robust empirical support for deficits associated with both learning and memory, particularly within the verbal domain (Pei, Rinaldi, Rasmussen, Massey, &

Massey, 2008; Richardson, Ryan, Willford, Day, & Goldschmidt, 2002; Wheeler, Stevens, Sheard, & Rovet, 2012; Willoughby, Sheard, Nash, & Rovet, 2008). The California Verbal Learning Test-Children's Version (CVLT-C) allows for the study of encoding, retrieval, and retention abilities (Delis, Kramer, Kaplan, & Ober, 1994; Goodman, Delis, & Mattson, 1999). Research using this measure found both encoding and retrieval deficits in alcohol-exposed children. However, retention – the amount of material recalled after adjusting for initial learning – appears to be relatively spared (Mattson, Riley, Delis, Stern, & Jones, 1996; Mattson & Roebuck, 2002; Schonfeld, Mattson, Lang, Delis, & Riley, 2001), suggesting that while alcohol-exposed children struggle with the initial learning of verbal information, they are able to retain the information that they do learn. These results have been replicated in different cohorts of heavily exposed children and adults, in children with lower levels of exposure, and using different tasks, providing further evidence for spared retention (Kaemingk, Mulvaney, & Halverson, 2003; Willoughby et al., 2008).

A longitudinal study of low (less than three drinks per week) to moderate (up to one drink per day) prenatal exposure levels did not detect verbal learning and memory deficits at younger ages (at ages five and six years) (Fried & Watkinson, 1990; Fried, O'Connell, & Watkinson, 1992); however, these impairments became apparent later in life (at ages 10 and 14 years) (Richardson et al., 2002; Willford, Richardson, Leech, & Day, 2004). This may indicate that negative effects of prenatal alcohol exposure may become more apparent as cognitive demands increase with age.

Nonverbal memory deficits are less clear in this population, as the existing literature is sparse and sometimes inconsistent (Aragón, Kalberg, et al., 2008; Kaemingk et al., 2003; Mattson & Roebuck, 2002). Inconsistencies may result from discrepancies in sample sizes, tasks, definitions of impairment, and statistical approaches. For example, variables related to the retention of learned information, which are important in verbal memory, are often not included in nonverbal memory studies (e.g., (Uecker & Nadel, 1996, 1998). Discrepant findings may also result from inconsistent attention to lower order cognitive processes. When addressed, lower order processes can help account for higher order deficits. For example, spatial memory impairments in alcohol-exposed children have been explained by deficits in lower order processes, including visual processing (Kaemingk & Halverson, 2000).

Executive Function, Processing Speed and Attention

Parent reports and objective standardized tests of higher order cognition using a wide range of methods provide strong convergent support for executive dysfunction as a hallmark feature of prenatal alcohol exposure (Glass, Graham, et al., 2013; Kodituwakku, Handmaker, Cutler, Weathersby, & Handmaker, 1995; Mattson, Goodman, Caine, Delis, & Riley, 1999; Ware et al., 2012). These deficits occur in alcohol-exposed children with and without an FAS diagnosis and may exist above the influence of IQ (Schonfeld et al., 2001). Deficits exist in multiple executive function domains, including planning, set-shifting, cognitive flexibility, concept formation, working memory, and response inhibition (Connor, Sampson, Bookstein, Barr, & Streissguth, 2000; Kerns, Don, Mateer, & Streissguth, 1997; Kodituwakku et al., 1995; Mattson et al., 1999), and relate to clinically significant impairments in adaptive behavior, social skills, social problem solving, and impulsivity (McGee, Bjorkquist, Price, Mattson, & Riley, 2009; McGee, Schonfeld, Roebuck-Spencer, Riley, & Mattson, 2008; Ware et al., 2012). While alcohol-exposed children with and without ADHD do not differ from children with idiopathic ADHD on neuropsychological measures of executive function (Glass, Ware, et al., 2013), parents report increased executive functioning for those with both ADHD and prenatal alcohol exposure (Nguyen et al., 2014; Ware et al., 2014).

Processing speed impairment is also considered a consistent deficit associated with children with histories of alcohol exposure (Burden, Jacobson, & Jacobson, 2005; Mattson et al., 2011; Willford, Chandler, Goldschmidt, & Day, 2010). Processing deficits appear to be most apparent within the context of higher order complex cognition and are less affected when engaged in automatic processing (Burden et al., 2005).

Alcohol-exposed children also exhibit deficits in vigilance, reaction time, and sustained attention (Burden et al., 2009; Burden et al., 2005; Mattson et al., 2011). Parent and teacher reports corroborate laboratory findings of attention deficits (Glass, Graham, et al., 2013). Attention deficits may be differentially affected by domain, although two studies found greater impairments in sustained visual attention compared to auditory attention (Coles, Platzman, Lynch, & Freides, 2002; Mattson, Calarco, & Lang, 2006), while another study found the opposite pattern (Connor, Streissguth, Sampson, Bookstein, & Barr, 1999).

Disruptive Behaviors

In addition to the wide range of cognitive deficits, behavioral problems are highly prevalent in children with prenatal alcohol exposure and may be more salient to parents and other caregivers. The presence of both behavioral and cognitive deficits may interact and lead to worse academic outcomes, as successful school functioning and performance relies on both abilities in concert. High rates of externalizing problems are consistently reported in alcohol-exposed children (Franklin, Deitz, Jirikowic, & Astley, 2008; Sood et al., 2001). Alcohol-exposed children demonstrate more delinquent behavior (Roebuck, Mattson, & Riley, 1999), exhibit impaired moral decision-making abilities (Schonfeld, Mattson, & Riley, 2005), and are also more likely to lie about their behavior at a young age (Rasmussen, Talwar, Loomes, & Andrew, 2008) compared to nonexposed peers. Delinquent behavior persists into adulthood (Famy, Streissguth, & Unis, 1998; Steinhausen & Spohr, 1998). Elevations of internalizing behaviors, such as anxiety, depression, and being withdrawn, are also reported in this population and exist beyond the presence of facial dysmorphology, intelligence, or demographic factors (Mattson & Riley, 2000; O'Connor & Kasari, 2000; O'Connor & Paley, 2006; Sood et al., 2001).

Both internalizing and externalizing behavioral problems relate to long-term negative life outcomes, including increased legal issues (Fast, Conry, & Loock, 1999; Streissguth et al., 2004), substance abuse issues, (Alati et al., 2008; Baer, Sampson, Barr, Connor, & Streissguth, 2003), and suicidality (Baldwin, 2007; O'Malley & Huggins, 2005; Streissguth et al., 1996). A dose-response effect is apparent between prenatal alcohol exposure and childhood behavioral problems after controlling for education, environment, and psychopathology (Sood et al., 2001).

Psychopathology

In addition to high rates of problem behaviors, prenatal alcohol exposure is associated with increased risk for psychiatric diagnoses, including ADHD, oppositional defiant disorder, depressive disorder, and conduct disorder (Burd, Klug, Martsolf, & Kerbeshian, 2003; Disney, Iacono, McGue, Tully, & Legrand, 2008; Fryer, McGee, Matt, Riley, & Mattson, 2007; Lynch, Coles, Corley, & Falek, 2003; Streissguth et al., 1996). The most common psychiatric diagnosis in individuals with prenatal alcohol exposure is ADHD, with estimates suggesting that that more than 60% of children with FASD receive a diagnosis of ADHD (Burd, Klug, et al., 2003; Fryer et al., 2007; LaDue, Streissguth, & Randels, 1992; O'Connor et al., 2002). Alcohol-exposed children with and without an ADHD diagnosis have been compared to disentangle the behavioral and neuropsychological effects of prenatal alcohol exposure and concomitant ADHD. Behaviorally, the presence of an ADHD diagnosis exacerbates alcohol-related deficits in communication, attention problems, and externalizing behavior (Ware et al., 2014); however, there were no increased cognitive deficits related to having both disorders (Glass, Ware, et al., 2013).

Social Skills and Social Communication

There is strong evidence of impaired interpersonal and social skills in children with prenatal alcohol exposure, such as reduced social competence, clinginess, not getting along with others, being teased or bullied, poor social judgment, and issues responding to social cues (Coggins, Timler, & Olswang, 2007; Kjellmer & Olswang, 2012; Whaley, O'Connor, & Gunderson, 2001), which fail to improve with age (Crocker et al., 2009). Children with prenatal alcohol struggle to balance linguistic and social-cognitive task demands (Coggins, Olswang, Carmichael Olson, & Timler, 2003), often fail to provide sufficient organization and information for communication partners during narratives (Coggins et al., 2007), use ambiguous references and inappropriately distinguish concepts in their stories (Thorne, Coggins, Carmichael Olson, & Astley, 2007), and fail to consider the perspective of the listener during interactions (Timler, Olswang, & Coggins, 2005). These deficits may affect school performance and academic achievement as well as contribute to psychopathology in this population. Fortunately, there is evidence that these deficits can be effectively treated with appropriate intervention (O'Connor et al., 2006).

Academic Achievement in FASD

The cognitive and behavioral impairments associated with the central nervous system dysfunction resulting from prenatal alcohol exposure lead to a very high risk of school failure and poor performance in the academic environment (Burd, Klug, et al., 2003; Church & Kaltenbach, 1997; Streissguth et al., 1990; Streissguth et al., 2004). Poor academic achievement in individuals with prenatal alcohol exposure is associated with increased adverse life outcomes persisting throughout development (Streissguth et al., 1996). As many as 60% of clinically-referred adolescents over the age of 12 were found to have disrupted school experiences (e.g., suspended, expelled, dropping out from school), and 65% received some remedial help with reading and math

(Streissguth et al., 1996). Children and adolescents with histories of heavy prenatal alcohol exposure struggle in all three academic domains – math, reading, and spelling – to varying degrees of severity (Adnams et al., 2007; Carmichael Olson, Sampson, Barr, Streissguth, & Bookstein, 1992; Coles, Kable, & Taddeo, 2009; Glass, Graham, Akshoomoff, & Mattson, 2015; Goldschmidt, Richardson, Cornelius, & Day, 2004; Howell, Lynch, Platzman, Smith, & Coles, 2006). There are increased rates of learning disabilities and disrupted school experiences in children with histories of heavy prenatal alcohol exposure (Chudley et al., 2005; Franklin et al., 2008; Goldschmidt et al., 1996; Rasmussen & Bisanz, 2011; Streissguth et al., 2004).

For children with prenatal exposure to alcohol, deficits in academic achievement exceed what would be expected by intellectual functioning (Kerns et al., 1997). This exacerbation could be due to the combination of behavioral and cognitive impairments. There are complex interactions between cognitive ability, behavioral functioning, socio-emotional functioning, attention deficits, concomitant psychopathology, environmental supports, and access to services, all of which can influence academic outcomes (Kable, Taddeo, Strickland, & Coles, 2015).

The relationship between dose and timing of prenatal alcohol exposure and academic achievement was analyzed in a longitudinal, prospectively identified sample (Goldschmidt et al., 1996). At age six, there was a linear dose-response relationship between prenatal alcohol exposure and performance on standardized arithmetic tasks. Relations between exposure and reading and spelling were better modeled by a threshold model (approximately one drink per day in the second trimester). In terms of neural correlates, volumetric abnormalities in the corpus callosum in particular are associated with verbal learning and memory (O'Hare et al., 2005), and diffusion tensor imaging fractional anisotropy values in cerebellar white matter are associated with math scores (Lebel, Rasmussen, Wyper, Andrew, & Beaulieu, 2010; Santhanam, Li, Hu, Lynch, & Coles, 2009).

Mathematical functioning has been widely researched (Howell et al., 2006; Jacobson, Dodge, Burden, Klorman, & Jacobson, 2011; Streissguth, Barr, Carmichael Olson, et al., 1994; Streissguth, Barr, Sampson, & Bookstein, 1994) and math interventions have been most promising in this population (Kable et al., 2015; Kable, Coles, & Taddeo, 2007). Alcohol-exposed children consistently demonstrate impairments in mathematical functioning, including basic numerical processing and cognitive estimation (Jacobson et al., 2011; Kopera-Frye, Dehaene, & Streissguth, 1996; Meintjes et al., 2010).

Recent investigations have begun to identify the underlying cognitive mechanisms of mathematical functioning and the neural correlates of mathematical deficits. One study found that immediate memory and attention contribute to mathematical functioning (Rasmussen & Bisanz, 2009), while another study found that spatial processing had a significant effect on mathematics achievement (Crocker, Riley, & Mattson, 2015). Weak visual-spatial skills have also been related to poor performance on math tests (Kable et al., 2007). In addition to deficits in underlying cognitive mechanisms, structural and functional abnormalities in the brain have been associated with impaired mathematics achievement in alcohol-exposed children (Lebel et al., 2010; Santhanam et al., 2009).

While math remains the most studied academic domain in children who have histories of prenatal alcohol exposure, these children are also at risk for impairment in other clinically significant academic domains. Despite the clinical relevance and high risk of reading deficits, it has not received the same attention in the FASD literature, nor have evidence-based interventions been implemented, leaving many children potentially struggling and unidentified without effective treatment.

General Reading

The study of reading-related difficulties is a critical, clinically relevant educational domain that has been at the center of education reform at both state and national levels (Committee on the Prevention of Reading Difficulties in Young Children, 1998; National Reading Panel, 2000). Improving reading abilities has been a target due to its inextricable ties to negative outcomes, including grade retention, low vocational success, lack of independence (Dewalt, Berkman, Sheridan, Lohr, & Pignone, 2004), and potential for successful treatment for both typically developing and low IQ populations (Blok, Oostdam, Otter, & Overmaat, 2002; Hall, Hughes, & Filbert, 2000; Lovett, Benson, & Olds, 1990; Torgesen, Wagner, Rashotte, Alexander, & Conway, 1997). Reading achievement, especially for adolescents, is of particular concern, as upwards of 30% of children in middle school are reading two or more grade levels below their grade in the United States (National Assessment of Educational Progress, 2009). In the 2009 International Student Assessment results, the

United States was ranked 14th among all participating nations in reading skills, with limited signs of improvement (Institute of Education Sciences, 2009).

Skilled readers are able to develop and understand meaning from text both accurately and efficiently (Scarborough, 2009). There are many underlying cognitive skills that are interwoven to achieve skilled reading abilities. As language comprehension (comprised of background knowledge, vocabulary, language structure, verbal reasoning, and literacy knowledge skills) becomes increasingly strategic and word recognition (comprised of phonological awareness, decoding, and sight recognition skills) becomes increasingly automatic, these skills combine to execute fluent coordination of word reading and comprehension (Scarborough, 2009). The National Reading Panel concluded, based on a review of over 100,000 published articles, that five skills are necessary for reading, which include both lower order cognitive abilities and higher order reading components (National Reading Panel, 2000). This conclusion was based on converging evidence and factor analysis of underlying mechanisms important for reading achievement in typically developing children (Fletcher, 2009; Vellutino, Fletcher, Snowling, & Scanlon, 2004).

Identification of Reading Disorders

The two most commonly diagnosed disabilities in school-age children are specific learning disorders and ADHD. The prevalence of learning disorders, depending on the definition used, varies from 5% to 17.5% (American Psychiatric Association, 2013),(American Psychiatric Association, 2013; Interagency Coordinating Committee on Fetal Alcohol Syndrome, 2007; Vellutino et al., 2004), with almost 80% of children diagnosed with a learning disorder having a reading disability (Aaron, Joshi, Gooden, & Bentum, 2008). In the past, learning disorders were diagnosed using a discrepancy model (a significant difference between global intellectual ability and achievement) (American Psychiatric Association, 2000); however, recent findings demonstrate that this model is neither reliable nor relevant for efficacious educational interventions (Aaron et al., 2008; Fletcher et al., 2002). Furthermore, the discrepancy model under-identifies learning disorders, missing difficulties faced by those with low IQ scores, including children with heavy prenatal alcohol exposure (Conners & Olson, 1990; Vellutino, Scanlon, & Lyon, 2000).

Within the alcohol-exposed population, as children generally have decrements in general intellectual functioning (LaDue et al., 1992; Streissguth et al., 1996), a significant discrepancy between reading and IQ scores may be difficult to demonstrate, reducing the ability of children with FASD to access appropriate services. Other models have been proposed within the last few decades to capture reading disorders that are more accepted and evidence-based, including the low achievement definition, the simple reading component model, the response to intervention model, and using cut-off scores; however, each has its own costs and benefits, as is true with any model attempting to balance specificity and sensitivity (Aaron et al., 2008; Fletcher et al., 1989).

Theoretical Models of Reading Deficits

There are many different theories proposed to model the development of reading skills (Scarborough, 2009; Snowling, 2000; Vellutino et al., 2004), and this study is conducted under the well accepted and evidence-based shared elements in the theoretical models proposed in the behavioral literature. Most commonly, reading development models include the conceptualization that there are many different underlying interacting processes (including the most researched: phonological awareness, rapid naming, and basic language abilities) that lead to the development of skilled reading (Committee on the Prevention of Reading Difficulties in Young Children, 1998; National Reading Panel, 2000).

Children are generally thought to experience two different forms of reading problems: decoding difficulties (primarily related to phonological processing and the basis of dyslexia) and reading comprehension difficulties (Snowling & Hulme, 2011). Decoding difficulties are often thought to have an etiological basis from the phonological pathway (the ability to match phonemes and morphemes as shown on the right phonological process below), whereas comprehension deficits are caused by higher-level language difficulties, including semantics, grammar (the ability to conduct word reading by recognizing the word in a semantic or orthographic lexicon, on the left of the figure), and other cognitive processes (Castles & Coltheart, 1993, 2004; Scarborough, 2009).

As decoding develops, according to this view, reading comprehension becomes more aligned with listening comprehension, which leads to successful reading. Deficits in any of these components can interfere and constrain the development of reading comprehension. While reading models may differ in mediation, moderation, and deficit approaches, they primarily share the same underlying mechanisms of learning to be a skilled reader, echoed by the exhaustive research of the National Reading Panel (National Reading Panel, 2000). Deficits in any sub-skills important to reading may result in reading impairment. Most of the research focused on predicting reading achievement from an early intervention standpoint assesses pre-reading variables and later reading achievement scores to determine the relationship between components and reading success. Both longitudinal and cross-sectional studies have provided considerable evidence for these foundations of early reading development. Although many of the underlying cognitive abilities have been found to relate to each other, they are also found to contribute independently to reading skills (Barker, Sevcik, Morris, & Romski, 2013; Frijters et al., 2011; Kudo, Lussier, & Swanson, 2015; Morris et al., 2012; Wise et al., 2010).

Phonological processing has been considered a ‘core’ deficit in dyslexia (Snowling, 2000; Vellutino et al., 2004). Research has consistently supported that aspects of phonological processing are the most salient predictors for reading achievement including basic reading/decoding, fluency, and comprehension (Cirino et al., 2002; Lovett et al., 1994; Scarborough, 1998; Torgesen, Rose, Lindamood, Conway, & Garvan, 1999; Vellutino et al., 2004; Wagner et al., 1997; Wagner & Torgesen, 1987). Other predictors that are also found to contribute significantly to performance include vocabulary, basic language skills, and grammatical skills (Bell, McCallum, & Cox, 2003; Fletcher, 2009; Muter, Hulme, Snowling, & Stevenson, 2004; National Reading Panel, 2000; Vellutino et al., 2004; Willcutt et al., 2001).

Phonological awareness is one's ability to process and manipulate phonemes, while rapid naming includes the ability to automatically retrieve phonemes from long-term memory. Rapid automatized naming and phonological awareness are shown to relate highly, yet also independently underlie the successful development of reading skill (Capellini & Lanza, 2010; Catts, Gillispie, Leonard, Kail, & Miller, 2002; Furnes & Samuelsson, 2011; Schatschneider, Carlson, Francis, Foorman, & Fletcher, 2002). Both phonological awareness and rapid automatized naming also independently predict reading ability and difficulties from the start of kindergarten (Bishop, 2006). Phonological memory generally refers to short-term memory for phonetically coded material, which is separate from working memory or attention utilized in understanding written material or processing/manipulating information. Working memory contributes significantly to comprehension, regardless of how it is measured (in the visual or verbal domain) (Kudo et al., 2015). Working memory has also been shown to independently predict reading success in both comprehension and fluency (Swanson & Jerman, 2007) better than the contribution of IQ (Alloway & Alloway, 2010; Gathercole, Alloway, Willis, & Adams, 2006).

As the components of phonological processing are separate skills, they are generally thought to differentially predict reading ability (Berninger, Cartwright, Yates, Swanson, & Abbott, 1994; Kudo et al., 2015). Phonological awareness is thought to have a stronger association with basic decoding, whereas fluency may relate stronger with rapid naming (Committee on the Prevention of Reading Difficulties in Young Children, 1998; National Reading Panel, 2000). Underlying cognitive abilities and reading achievement may also correlate differently for those with intact and impaired reading abilities, respectively, or vary based on age or grade (Kibby, Lee, & Dyer, 2014; Wagner et al., 1997). A recent study investigated how measures of decoding, fluency, and comprehension overlap and found differing patterns for typical readers versus those with impairment (Cirino et al., 2013).

There may be distinct developmental trajectories for reading skills, as phonological awareness may influence more early decoding-dependent tasks while rapid automatized naming may influence later word identification and fluency tasks (Snowling, Gallagher, & Frith, 2003). These two skills have demonstrated the strongest effect sizes in predicting reading ability compared to behavior, orthography, memory, and IQ (Al Otaiba & Fuchs, 2006; Olitsky & Nelson, 2003; Vaessen & Blomert, 2010).

There are also individual differences in the precursors of reading skills that can interact either as protective effects or as additional risk factors (Snowling et al., 2003). For example, it has been proposed that the ability to complete explicit phonological awareness tasks may depend on metacognitive ability in addition to phonological processing (Finestack, 2013), suggesting that higher general cognitive ability may be able to compensate if there are any delays. This is supported by studies that found performance IQ moderates the risk of reading impairment in children who have a history of speech/language deficits (Snowling, Bishop, & Stothard, 2000). IQ does not appear to affect response to intervention in general; rather, there has been a general uncoupling of reading and IQ (Ferrer, Shaywitz, Holahan, Marchione, & Shaywitz, 2010). Further, the underlying cognitive abilities proposed by the National Reading Panel are more predictive of reading skills than IQ (Gresham & Vellutino, 2010). Gresham and Vellutino argue that “we have better and more direct measures of reading achievement and individual differences in the ability to learn to read that are more closely related to the key phonological core constructs, which have been shown to underlie reading ability. Such measures are more time efficient than most measures of intelligence and they are more highly predictive of response to reading interventions than are measures of intelligence.” p.16, (Gresham & Vellutino, 2010).

Neuroanatomical Correlates of Reading

Reading is a learned skill influenced by both developmental maturation and experience. Structural and functional brain imaging have various identified brain regions that are related to reading (Schlaggar & McCandliss, 2007). Most commonly reported is the relation between developmental dyslexia and cerebellar structure and function (Eckert et al., 2003; Fulbright et al., 1999; Vlachos, Papathanasiou, & Andreou, 2007). However, this is not universally reported, as a recent fMRI study found that cerebellar functioning was not related to academic reading performance or response to intervention (Barth et al., 2010). There may be specific areas of the cerebellum that are most important, as children with decoding impairments demonstrated no difference in overall grey or white matter volumes, though reduced volume in the anterior lobe of the cerebellum was noted compared to typically developing controls (Fernandez, Stuebing, Juranek, & Fletcher, 2013).

More recent white matter studies found greater fractional anisotropy (FA) for poor readers in tracts connecting with the temporoparietal and inferior frontal readers relative to typical readers. However, for the occipitotemporal region, FA was greater for older poor readers, but smaller for younger ones, suggesting that projections from the anterior cerebellum have a regulatory effect on cortical pathways important for reading (Fernandez et al., 2015). This provides information regarding the cerebellar theory of dyslexia where abnormalities reduce automaticity of decoding skills.

Better baseline word reading, fluency, and rapid naming are associated with decreased volume in the left inferior parietal cortex (Houston et al., 2014). Additionally, intervention has been found to change functional connectivity. A meta-analysis indicated changes in functional activation following reading intervention in the left thalamus, right insula/inferior frontal, left inferior frontal, right posterior cingulate, and left middle occipital gyri (Barquero, Davis, & Cutting, 2014). As there is significant overlap between brain regions affected by prenatal alcohol and brain regions associated with reading achievement, this alcohol-exposed population may be at higher risk for difficulties in this domain.

Reading in Children with Heavy Prenatal Alcohol Exposure

The risk of poor reading performance in children with heavy prenatal alcohol exposure is elevated due to lower general cognitive functioning and impaired verbal abilities. Alcohol-exposed children have additional increased risk of reading impairment due to the common co-occurrence of an ADHD diagnosis (Fryer et al., 2007) and frequent presence of cerebellar abnormalities (Jones & Smith, 1973; O'Hare et al., 2005; Sowell et al., 1996), which are both associated with higher rates of reading deficits (Barth et al., 2010; Dykman & Ackerman, 1991; Eckert et al., 2003; Shaywitz et al., 1995; Willcutt et al., 2001). Despite the lack of general research attention, there have been consistent reports of children with prenatal alcohol exposure demonstrating deficits in reading and spelling in the context of larger studies (Adnams et al., 2007; Kodituwakku, 2007; Streissguth, Barr, Carmichael Olson, et al., 1994).

School-age children with FASD score approximately 1.0–1.5 SD below the mean of typically developing children on basic reading and spelling, with children with FAS scoring slightly worse than non-dysmorphic alcohol-exposed children (Howell et al., 2006). Academic impairments may be compounded by the high co-occurrence of various behavioral issues, which are also associated with a higher rate of academic difficulties (Mautone et al., 2009; Semrud-Clikeman et al., 1992). Currently, the full effects of academic deficits in adults are unknown, although one study found that reading abilities were, on average, at a fourth-to-fifth grade level and spelling was at a third grade level (Streissguth et al., 1991).

While the nature of reading performance has not been comprehensively examined in the alcohol-exposed population, studies have demonstrated overall weakness in verbal abilities, including semantic abilities (Adnams et al., 2001; Becker et al., 1990), word naming (Mattson & Riley, 1998), expressive and receptive language (McGee, Bjorkquist, Riley, et al., 2009), comprehension (Conry, 1990), fluency (P. W. Kodituwakku et al., 2006), verbal learning (Mattson et al., 1996), and delays in language acquisition (Church & Kaltenbach, 1997). Alcohol-exposed children also demonstrate impairments in the underlying components of literacy skills, including phonological processing and rapid automatized naming (Adnams et al., 2007; Glass et al., 2015; Streissguth, Barr, Carmichael Olson, et al., 1994). A recent study found that in addition to the expected contributions of phonological processing for spelling, working memory may also be an important consideration in developing interventions (Glass et al., 2015).

Reading Intervention

Experts in the field of reading intervention argue for a “virtuous circle” whereby theory informs practice and evaluation of effective interventions informs theories to develop the most refined understanding of the nature and causes of children’s reading difficulties, ultimately leading to the best interventions (Bowyer-Crane et al., 2008; Snowling & Hulme, 2011).

While reading interventions are sometimes only moderately effective, as 65–75% of children designated as reading disabled early on continue to read poorly throughout school, early intervention has been touted as a method of reducing reading disorders in children at risk (Scarborough, 1998). Effective intervention for reading is particularly important, as early success in acquiring pre-literacy skills leads to later reading achievement. Failing to learn to read by third or fourth grade may be indicative of lifelong problems in learning new skills, as there is an increasing gap if no intervention is implemented. This increasing gap is sometimes referred to as the ‘Matthew Effect,’ an effect whereby those who are behind in reading become further and further behind without treatment (Bast & Reitsma, 1998; Stanovich, 1988). The age at the onset of intervention, the etiology of dysfunction, and the amount of time spent in reading treatment also affect response to intervention (Vaughn et al., 2008; Wanzek & Vaughn, 2008). Effective intervention at any point can be beneficial, as children identified as having poor reading comprehension at eight years show a similar profile throughout development, indicating no spontaneous recovery and suggesting that earlier initiation of services is often more effective (Nation, Cocksey, Taylor, & Bishop, 2010).

The most successful reading interventions target the specific deficits present in a given population using evidence-based approaches (Fletcher et al., 2002; Lovett et al., 1990; Lyon & Moats, 1997; Stage, Abbott, Jenkins, & Berninger, 2003; Vellutino et al., 1996). Targeted intervention programs have been effective in many populations (Fien et al., 2014), and the intensity, type, and duration of instruction differs according to the severity of deficits in either single- or multiple-component reading processes. Therefore, training in any one specific component may not be sufficient to produce improvement in other reading skills depending on the original profile of functioning (Lyon & Moats, 1997; Snowling & Hulme, 2012). The importance of a multi-component intervention has been echoed in various reading intervention protocols, as students often demonstrate problems in word level reading, fluency, and comprehension, supporting the need to integrate instruction across reading components and differentiate according to individual student needs (Cirino et al., 2013; Vellutino et al., 2000; Vellutino et al., 1996; Wolff, 2011).

Most of the current interventions for children with reading impairment are often only moderately effective, potentially because they do not target the specific areas of deficits or lack a theoretical basis (Galuschka, Ise, Krick, & Schulte-Korne, 2014; Pennington et al., 2009). Targeting phonemic awareness, and phonological processing in general, is currently the most supported area of reading intervention across the population of typically developing children with reading deficits (Cologon, Cupples, & Wyver, 2011; Fletcher et al., 2002; Galuschka et al., 2014; Lovett et al., 1994; Palmer et al., 2013; Vellutino et al., 2004).

There is evidence supporting phonologically-based interventions in ameliorating decoding difficulties, and a smaller, but increasingly robust, evidence base showing that interventions to improve oral language and vocabulary can improve reading comprehension (Snowling & Hulme, 2012). Lovett and colleagues provides further support for targeted interventions, demonstrating that a phonics treatment program implemented for three groups of children with phonological deficits, visual-naming speed deficits, or both had the greatest gains in the phonological deficit group and showing that deficit-targeted interventions were most effective (Lovett, Steinbach, & Frijters, 2000). In a comparison of three unique interventions targeted at different pre-reading processes in young children with weak phonological skills, a phonemically-explicit condition was most effective, producing the greatest growth in reading skills (Torgesen et al., 1999).

While underlying cognitive variables may predict reading abilities, they may not necessarily predict response to intervention. Responders and non-responders to intervention have been found to not differ on a variety of variables related to reading (Fletcher et al., 2011), and a recent evaluation of current research demonstrates a continued need to understand which individual characteristics lead to the most effective response to intervention and ultimately improved reading outcomes (Denton, 2012). Other studies have found that phonological processing, rapid naming ability, and verbal ability differentiated students with adequate and inadequate response to intervention (Vaughn et al., 2010; Vaughn et al., 2008; Wanzek & Vaughn, 2008). Across multiple meta-analyses, phonological awareness and rapid naming were also consistently associated with the degree of intervention response (Al Otaiba & Fuchs, 2006; Nelson, 2003; Olitsky & Nelson, 2003). Specific groups may have differential responses to reading intervention, with specific cognitive variables predicting the degree of reading outcomes even after controlling for type of intervention, phonological awareness, and rapid naming (Frijters et al., 2011).

Theoretically driven interventions are particularly important, as reading interventions have demonstrated differential success depending on the precise targets of intervention and specific impairments present in a given population (Blok et al., 2002; Burgoyne et al., 2012; Hall et al., 2000; Lovett et al., 1990; Torgesen et al., 1997; Torgesen et al., 1999). The effects of comorbid psychopathology, low general intelligence, or the presence of behavioral problems may interact with reading-related abilities and affect the efficacy of treatment (Morgan, Farkas, Tufis, & Sperling, 2008). For example, reading deficits may be caused by a pure dyslexia syndrome or may be partially caused by inattentive ADHD behavior that exacerbates the risk factor of a smaller phonological processing deficit. While both lead to the same result of poor reading performance, the treatment and intervention approach required may differ (Aaron, Joshi, Palmer, Smith, & Kirby, 2002). Further home literacy environment and attitude towards reading also may contribute to poor performance (McKenna & Kear, 1990; Rashid, Morris, & Sevcik, 2005).

Even with the current advances in understanding the underlying mechanisms of reading impairment for children with average or high average intellectual abilities, fairly little is known about the relationship between phonological processing, other cognitive abilities, and reading ability in children with intellectual disability, and therefore many interventions have little to no empirical support. Children with intellectual disability have been found to underperform compared to mental age-matched peers in reading, which may be partially due to other deficits in the underlying cognitive mechanisms, including low working memory and processing speed associated with low general intelligence (Bonifacci & Snowling, 2008).

There are distinct patterns of strengths and weaknesses in specific reading components of children with intellectual disability, which vary depending on etiology (Channell, Loveall, & Conners, 2013). On the whole, children with intellectual disability generally score lower than typically developing children on word recognition and phonological decoding but score similarly to typically developing children on orthographic processing and rapid automatized naming, suggesting specific areas of deficits that may mediate reading success that can be further investigated by population (Channell et al., 2013).

Specific Considerations for Reading Interventions in FASD

The development of evidence-based interventions for FASD is a critical research need that has been repeatedly documented (Kalberg & Buckley, 2006, 2007; Premji, Benzies, Serrett, & Hayden, 2007). Preliminary studies have demonstrated that children with FASD can make significant gains with effective instruction (Kable et al., 2015; Kerns, Macoun, MacSween, Pei, & Hutchison, 2016). For example, children with FASD learned a verbal rehearsal strategy that improved their digit span performance (Loomes, Rasmussen, Pei, Manji, & Andrew, 2008). Further, recent studies have found self-regulation and executive function trainings result in improved parent reports and inhibitory control and storytelling improvements (Nash et al., 2015; Wells, Chasnoff, Schmidt, Telford, & Schwartz, 2012). Computerized and attention focused interventions have also been moderately efficacious (Kerns, MacSween, Vander Wekken, & Gruppuso, 2010; Pei, Flannigan, Walls, & Rasmussen, 2016). Math studies focused on self-regulation and monitoring have been effective in pilot studies and community-based intervention (Kable et al., 2015; Kable et al., 2007).

Currently, only one literacy-focused intervention has been implemented for children with FASD (Adnams et al., 2007). It was conducted in South Africa and was determined to be “possibly efficacious” based on the Chambless criteria used to define empirically supported therapies (Kodituwakku & Kodituwakku, 2011). Children with FASD were randomly assigned to either a treatment group or no treatment group and compared to an untreated non-exposed control group. The treatment intervention consisted of 38 hours of therapy (19 hours of phonological awareness and literacy training and 19 hours of language therapy). Post intervention, performance of both FASD groups remained worse than the controls. However, the treatment condition did result in significant gains in syllable manipulation, written letters, and non-word spelling. Although these results suggest modest efficacy of targeted cognitive interventions in children with FASD, the authors note that these findings are limited, as cognitive mechanisms contributing to spelling were not assessed nor were variables that may mediate literacy.

Clinicians and researchers have advocated for the importance of specific modifications for teaching strategies and classroom environments to aid children with histories of prenatal alcohol exposure (Green, 2007; Kalberg & Buckley, 2006; Kodituwakku & Kodituwakku, 2011; Premji et al., 2007). Despite the advances in understanding the precise neuropsychological deficits associated with FASD, few empirically supported interventions have been implemented (Burd, Klug, et al., 2003; Kodituwakku & Kodituwakku, 2011). However, targeted interventions (Adnams et al., 2007; Kable et al., 2015; Kable et al., 2007; Peadon, Rhys-Jones, Bower, & Elliott, 2009) and patient advocacy (Boys et al., 2016; Duquette, Stodel, Fullarton, & Hagglund, 2006) can facilitate outcomes.

Early identification and effective treatments for alcohol-exposed children could result in better outcomes; however, both are currently limited in terms of both access to services and the generation of effective interventions (Bertrand et al., 2005; Kodituwakku & Kodituwakku, 2011; Premji et al., 2007). In the federal Individuals with Disabilities Education Act (IDEA) of 2007, FAS is listed as a presumptive eligibility diagnosis allowing individuals to obtain services. Unfortunately, the children who are affected by prenatal alcohol exposure but do not meet the criteria for FAS or an intellectual disability (or other eligible diagnosis) may not qualify for these services. Children with the prototypical example of Other Specified Neurodevelopmental Disorder or the proposed ND-PAE diagnosis may not meet the strict eligibility criteria even though they have similar neurobehavioral impairments as children with FAS (Mattson et al., 1998).

Currently, the most common and feasible method of receiving services for an alcohol-related neurodevelopmental disorder is to qualify for services under a different diagnosis, such as intellectual disability or ADHD, or to qualify under a specific catch-all category based on functioning and symptomology, such as the Other Health Impairment (OHI) category of IDEA. Legal precedents providing services for individuals with intellectual disability, or those requiring similar services, have facilitated access to services. Section 504 plans can help with classroom accommodations, yet fall short of creating an individualized plan (Senturias, 2014).

Individuals with FASD may require the services of numerous providers, including primary care, specialist centers, occupational therapy, physical therapy, psychosocial skills training, and educational specialists (Rogers-Adkinson & Stuart, 2007). There are several FASD service centers (McFarlane & Rajani, 2007) that provide models for the continued development of resources. However, there is no easy or practical way to standardize the service needs for children, as each child will have unique patterns of deficits and may require a more individualized approach. Semistructured interviews revealed that there were no standardized special education classes that were appropriate for all alcohol-affected children, as each child required individual supports based on their own pattern of functioning (Autti-Ramo, 2000).

Reading Summary

Poor performance in reading and literacy is a national priority due to its high prevalence, moderate success of intervention efforts, and association with long-term negative outcomes, including decreased vocational success (Dewalt et al., 2004). There is converging evidence regarding the precise underlying mechanisms contributing to reading ability in typically developing children (Lyon et al., 2001; Vellutino et al., 2004). This knowledge has led to the creation of new interventions for children with reading disorders supported on both empirical and theoretical bases. However, interventions have been differentially successful for specific populations or types of impairments. Children with histories of heavy prenatal alcohol exposure are at high risk of reading difficulties due to well-documented cognitive deficits, known neurological abnormalities, and common co-occurrence of psychopathology.

As of now, the underlying mechanisms of reading-related impairment in children affected by heavy prenatal alcohol exposure have not been comprehensively examined, and this lack of knowledge hinders the potential for effective intervention. This current study aims to characterize reading and reading-related deficits in children with heavy prenatal alcohol exposure.

Specific Aims and Hypotheses

The primary aim was to characterize reading ability in children with prenatal alcohol exposure to inform the development of evidence-based recommendations.

Aim 1. ***Evaluate and characterize performance on reading and related cognitive processes in children with heavy prenatal alcohol exposure and controls***. Underlying cognitive abilities (phonological awareness, memory, and rapid automatized naming) and different components of reading (decoding, fluency, and comprehension) will be assessed in children with heavy prenatal alcohol exposure and controls.

Hypothesis 1a: Children with prenatal alcohol exposure will perform worse than controls on all measures of reading and related cognitive abilities.

Hypothesis 1b: There will be higher rates of reading difficulty in children with prenatal alcohol exposure compared to controls.

Hypothesis 1c: There will be a pattern of relative strengths and weaknesses in the underlying cognitive abilities and reading composites for alcohol-exposed children, rather than a general dampening effect.

Aim 2. ***Assess the relations between underlying cognitive mechanisms and reading ability for children with heavy prenatal alcohol exposure, and determine if they differ from typically developing controls.*** Using correlation and multiple regression techniques, the contribution of underlying cognitive abilities on different aspects of reading ability will be assessed in children with heavy prenatal alcohol exposure and controls.

Hypothesis 2a: Performance on all underlying cognitive tasks will be positively associated with reading abilities. It is expected that the cognitive mechanisms will differentially contribute to the individual reading components and that these patterns differ by group, indicated by a significant interaction.

Hypothesis 2b: The cognitive contributions and effects of alcohol exposure will contribute significant variance above and beyond the effects of demographic variables and theoretically related constructs.

Aim 3. ***Determine if there are unique patterns of deficits that can accurately classify alcohol-exposed children and controls or if specific subtypes of reading deficits exist.*** Investigate whether performance on reading and underlying cognitive is able to differentiate groups and determine if subtypes of reading difficulties exist within the alcohol-exposed group.

Hypothesis 3a: Using discriminant function analysis, groups will be differentiated based on the specific patterns of deficits in reading variables.

Hypothesis 3b: Latent class analysis will indicate that there are specific reading subtypes (i.e., comprehension vs. decoding) for the alcohol-exposed group.

Chapters I, II, III, and IV, in part, are currently being prepared for submission for publication of the material and will be co-authored by Sarah N. Mattson. The dissertation author was the primary investigator and author of this material.

II. Methods

General Method

Children and their primary caregivers were recruited for participation in an ongoing research protocol, which included behavioral measures and a brief neuropsychological assessment conducted by a trained examiner (LG). Recruitment was conducted via clinical referral, community outreach programs, and word of mouth. Informed consent and assent was obtained from each caregiver and subject, respectively, in accordance with the Institutional Review Board at San Diego State University. All participants were given a financial incentive for participation and received a written summary of their individual research results.

Subjects

School-age children (1^{st}–7^{th} grade) with histories of heavy prenatal alcohol exposure (AE, n = 32) and with no or minimal alcohol exposure (CON, n = 40) were recruited and assessed. Children of all races, ethnicities, and sexes between 6:0–12:11 years of age were actively recruited to participate.

AE group. Children were included in the AE group if they had a confirmed history of heavy prenatal alcohol exposure, defined as a pattern of maternal consumption of more than four alcoholic drinks per occasion or at least 14 drinks per week throughout pregnancy. Prenatal alcohol exposure was confirmed retrospectively using medical history, birth records, social services records, or maternal report. In many cases, precise measures of alcohol consumption were unavailable. In these cases, mothers reported to be "alcoholic" or alcohol abusing or dependent during pregnancy sufficiently met criteria.

CON group. Children included in the CON group were recruited from the community to create a representative comparison group for alcohol-exposed children. Children were excluded from the control group if they had parent-reported histories of greater than minimal prenatal alcohol exposure or if prenatal alcohol exposure was suspected or unknown. Minimal exposure was defined as no more than one drink per week on average and never more than two drinks on any occasion during pregnancy. This information was obtained through maternal report and parental disclosure.

All children received a dysmorphology exam as part of ongoing projects (Mattson et al., 2010) by an expert dysmorphologist (Dr. Kenneth Lyons Jones) to determine alcohol-related diagnoses using standard criteria. Nine children in the alcohol-exposed group met criteria for fetal alcohol syndrome (FAS), defined as the presence of two of three markers of facial dysmorphology (short palpebral fissures, smooth philtrum, and thin vermillion) and the presence of either microcephaly and growth deficiency (Jones et al., 2006).

Exclusion Criteria: Children were excluded from the study based on the following criteria: (1) Significant physical (e.g., uncorrected vision impairment, hemiparesis) or psychiatric (e.g., active psychosis) disability that would preclude participation, (2) other *known* causes of mental deficiency (e.g., chromosomal abnormalities, congenital hyperthyroidism, prenatal/postnatal ischemic attack), (3) significant head injury with loss of consciousness greater than 30 minutes, or (4) failing a hearing test (audiometry), described below. Children were not excluded from either group for behavioral concerns or other psychopathology to maintain generalizability and representativeness and to further enhance clinical utility.

All children were screened for the presence of psychopathology using a brief, standardized clinical interview with the caregiver, the C-DISC-4.0 (Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). Rates of psychopathology (ADHD, depression, anxiety) in the control group map onto nationally reported rates (Merikangas, Nakamura, & Kessler, 2009), see Table 1. As expected, the rate of diagnoses was higher in the AE group compared to the control group. Per caregiver report, 11 alcohol-exposed children were taking medication at the time of testing.

Table 1: Psychopathology for children with histories of prenatal alcohol exposure (AE) and controls (CON) based on the C-DISC-4.0, a structured parent interview

Met positive C-DISC-4.0 diagnostic criteria within the past year	AE *n* = 31	CON *n* = 39
ADHD - Combined	9	1
ADHD - Inattentive	6	1
ADHD - Hyperactive	1	0
Oppositional Defiant Disorder	10	1
Specific Phobia	7	2
Separation Anxiety	4	0
Generalized Anxiety Disorder	3	2
Nocturnal Enuresis	2	4
Suicidal Ideation	2	1
Social Phobia	2	0
Trichotillomania	1	0
Obsessive Compulsive Disorder	1	0
Conduct Disorder	1	0
Depressive Episode	1	0
Manic Episode	1	0
Panic Disorder /Agoraphobia / Selective Mutism	0	0
Posttraumatic Stress Disorder	0	0
Tourette Syndrome / Tic Disorder	0	0
Substance Abuse	0	0

Procedure

Children participated in a single two-hour neuropsychological assessment session comprised of standardized assessments and questionnaires described in detail below. Caregivers of children also completed assessments that measure demographic and pregnancy variables, family history, behavioral functioning, and environment. All testing was conducted in a quiet room with a noise-cancelling machine to minimize any outside sound.

Children were administered a binary audiometry hearing screening (pass/fail at 20 dB). For school-age children, hearing impairment is defined as unilateral or bilateral sensorineural and/or conductive hearing loss greater than 20 dB in the frequency region most important for speech recognition (approximately 500–4000 Hz) per the American Speech-Language Hearing Association (American Academy of Audiology Task Force, 2011). One child was excluded from the study after failing the audiometry screening and was referred to a pediatric audiologist for a complete audiological evaluation. All sessions were video-recorded, and error control methods were utilized to ensure accurate and valid data collection. Breaks were used to minimize testing fatigue and motivate participation.

Measures

The reading battery included select subtests from psychometrically sound and well-validated measures of reading and related cognitive abilities, see Table 2.

Table 2: Measures utilized in the reading battery

		Measure	Subtest		Description
Reading Achievement	Fluency	WJ	*Reading Fluency*		Assesses reading speed and semantic processing speed and involves reading printed statements rapidly and responding by circling yes or no
Reading Achievement	Fluency	WIAT	*Oral Reading Fluency*		Assesses speed, accuracy, and fluency of contextualized oral reading. Student reads passages aloud. Fluency is the average number of words read correctly per minute.
Reading Achievement	Decoding	WJ	*Basic Reading*	*Letter Word Identification*	Assesses the ability to read real words
Reading Achievement	Decoding	WJ	*Basic Reading*	*Word Attack*	Assesses the ability to read phonetically correct nonwords
Reading Achievement	Decoding	WIAT	*Basic Reading*	*Word Reading*	Assesses the ability to read real words
Reading Achievement	Decoding	WIAT	*Basic Reading*	*Pseudoword Decoding*	Assesses the ability to read phonetically correct nonwords
Reading Achievement	Comprehension	WJ	*Passage Comprehension*		Assesses comprehension using a cloze procedure to assess sentence-level comprehension by requiring the student to read a sentence or short passage and fill in missing words
Reading Achievement	Comprehension	WIAT	*Reading Comprehension*		Assesses reading comprehension through silent and out-loud reading and answering questions based on grade-equivalent passages
Phonological Processing	Phonological Awareness	CTOPP	*Elision*		Assesses the extent to which an individual can say a word and they say what is left after dropping out designated sounds
Phonological Processing	Phonological Awareness	CTOPP	*Blending Words*		Assesses the ability to combine sounds to form words
Phonological Processing	Phonological Awareness	CTOPP	*Phoneme Isolation*		Assesses the ability to identify target sounds
Phonological Processing	Working Memory	CTOPP	*Memory for Digits*		Assesses the ability to repeat digits forward
Phonological Processing	Working Memory	CTOPP	*Nonword Repetition*		Assesses the ability to repeat nonwords that range in length from 3 to 15 sounds
Phonological Processing	Rapid Naming	CTOPP	*Rapid Digit Naming*		Assesses the speed to name numbers
Phonological Processing	Rapid Naming	CTOPP	*Rapid Letter Naming*		Assesses the speed to name letters

The variables were chosen based on shared elements from widely accepted reading theories that provide support for the components that contribute most to gaining reading skills and have been used widely in learning disorder research centers supported by the NIH. Multiple measures were utilized to provide a reliable estimate for each cognitive construct and to reduce measurement error (Scarborough, 2009). The use of multiple indicators for a single construct has been well established as best practice within the NIH sponsored learning disorder research centers (LDRC); Dr. Jack Fletcher states, "approaches to the assessment of reading comprehension need to incorporate multiple indicators to enhance the precision in which the underlying latent variables are measured" (Fletcher, 2006).

Woodcock Johnson – Third Edition, Tests of Achievement, WJ-III TA (Woodcock, McGrew, & Mather, 2001). The WJ-III TA was chosen due to its use in the field of learning disorders and its strong psychometric properties, including a large, geographically diverse normative sample. The subtests WJ-III TA, listed below, are considered the best process-approach predictors of reading achievement (Bell et al., 2003; Fletcher et al., 2002; Fletcher et al., 1994). In addition, the WJ-III has excellent reliability ($r = 0.918$) (Woodcock et al., 2001).

Wechsler Individual Achievement Test – Third Edition, WIAT -III (Wechsler, 2009). The WIAT-III was chosen due to its high psychometric properties, use in school settings, and its domain-specific coverage in academic areas specified by federal law for identifying a learning disability (Burns, 2010). It has been previously used in children with heavy prenatal alcohol exposure and other populations with developmental disorders (Brown, Giandenoto, & Bolen, 2000; Howell et al., 2006).

Comprehensive Test of Phonological Processing – Second Edition, CTOPP-2 (Wagner, Torgesen, Rashotte, & Pearson, 2013). The CTOPP-2 is grounded in the theoretical foundation of the three constructs that comprise phonological abilities: phonological awareness, phonological memory, and rapid naming, which have been confirmed via factor analysis. The CTOPP is commonly used to identify the strengths and weaknesses in specific components of phonological processing, is widely used in research and in school settings, and has adequate internal consistency (<.8).

General Cognitive Abilities – Estimate of IQ. An estimate of general cognitive function was assessed as part of a larger ongoing study. All children had an estimate of IQ within one year of completing the reading battery. Children received either the Wechsler Intelligence Scale for Children – Fourth Edition, WISC-4 (Wechsler, 2004) or the Differential Abilities Scale – Second Edition, DAS-II (DAS-II; (Elliott, 2007). The scores on these measures were highly correlated and capture general cognitive abilities, and therefore were taken as an estimate of overall IQ.

Peabody Picture Vocabulary Test – Fourth Edition (PPVT-IV) (Dunn & Dunn, 2007) The PPVT-IV was given to assess receptive vocabulary for Standard American English. It is a well-validated and reliable measure of vocabulary that removes the added cognitive skill of retrieving and expressing the word vocally.

Elementary Reading Attitude Survey (ERAS) (Henk & Melnick, 1995; McKenna & Kear, 1990; Melnick, Henk, & Marinak, 2009). The ERAS scale includes 20 questions with a four-item Likert scale presented as Garfield pictures. Questions include how a child feels about reading out loud in class, taking a reading test, reading books at home, answering questions about reading, starting a new book, and reading for fun. When a child was unable to read and answer the questions, the items were read out loud. The ERAS has internal consistency across sex, ethnicity, and grade level, with all internal consistency coefficients exceeding .75.

Home Literacy Environment Questionnaire (HLE). (Debaryshe & Binder, 1994; Farver, Xu, Lonigan, & Eppe, 2013; Lonigan, Burgess, & Anthony, 2000). The HLE Questionnaire is well validated in pediatric populations and has been shown to relate to reading constructs in typical and delayed reading populations (Lonigan et al., 2000; Rashid et al., 2005; Senechal & Lefevre, 2014; van der Schuit, Peeters, Segers, van Balkom, & Verhoeven, 2009).

In addition to the individual subtests described in the tables above, other relevant subtests were administered to gain a full understanding of functioning, including WIAT-III Numerical Operations and WIAT-III Spelling. Further, caregivers completed a variety of questionnaires to assess psychopathology, including the Child Behavior Checklist, CBCL (Achenbach & Rescorla, 2001), and a brief clinical interview, C-DISC-4.0 (Shaffer et al., 2000).

Statistical Analyses

Statistical analyses were conducted using SPSS v.22 (SPSS, 2010) and Mplus 7 (Muthén & Muthén, 2015). To mitigate potential floor or ceiling effects, children with an IQ estimate of exceeding 3SD below the mean (FSIQ/GCA = 55) or above the mean (FSIQ/GCA = 145) were excluded from both groups. One child, a control subject, was excluded from further analysis due to an IQ of over 145. Data for all subtests of interest were assessed for outliers using boxplot analysis (1.5xIQR) to identify outliers by group. Across the nine dependent variables, there were four outliers for specific variables (two from the AE group, two from the CON group). When possible, outliers were removed from analyses only for the measure for which it was an outlier; however, this was not possible for the repeated measure analysis (a subject score that was an outlier on any one of the four domains included was removed entirely). Statistical significance was determined under an alpha level of $p < .05$, with type 1 error protection for follow up tests (Bonferroni correction).

Demographic Information

Demographic information was analyzed using chi-square statistics for categorical variables (race, ethnicity, sex, handedness) and analysis of variance (ANOVA) statistics for continuous variables (age, socioeconomic status [SES] as measured by Hollingshead (Hollingshead, 1975), IQ estimate [from WISC-IV FSIQ or DAS GCA within a year], Home Literacy Environment, Elementary Attitudes Towards Reading, and CBCL total behavioral problems). Demographic variables were considered as covariates and included if they were significantly correlated with the dependent variables and did not interact with group membership.

Prior to all analyses, the differences in performance between subjects with FAS and subjects with heavy prenatal alcohol exposure without FAS were examined. If the groups were not significantly different, they were combined. There were 31 children with histories of heavy prenatal alcohol exposure. Of those, 9 had a diagnosis of FAS, as described above. Demographically, there were no differences between the children with heavy prenatal alcohol exposure with or without FAS on sex, race, ethnicity, age, SES, or handedness (*p*s > .063). There were also no differences on Home Literacy Environment, Elementary Attitude Toward Reading, IQ estimate, or vocabulary (PPVT) (*p*s > .099) between these subgroups. As there were no significant differences, the AE group comprised children with and without an FAS diagnosis.

Statistical Analyses

Aim 1. *Evaluate and characterize performance on reading and related cognitive processes in children with heavy prenatal alcohol exposure and controls*.

For multi-method assessment and error reduction purposes, each reading component (fluency, decoding, comprehension) and cognitive mechanism (phonological memory, phonological awareness, rapid naming) comprised two or more subtests. The CTOPP creates the three cognitive mechanism composites based on factor analytic strategies using the normative sample. For the reading subtests, correlations were conducted to ensure appropriate composites were created. For further data reduction, the relations between the individual reading components were examined and, as correlations exceeded .8, composites were created. The composites themselves were highly correlated (> .8), therefore a ‘Reading Achievement’ composite was created.

For hypothesis 1a, two multivariate analyses of variance (MANOVA) were conducted; one for lower order cognitive mechanisms and one for reading composites.

Each MANOVA had Group (AE, CON) as the between-subjects factor and cognitive mechanism (phonological memory, phonological awareness, rapid naming) or reading composite (fluency, decoding, comprehension) as the within-subject factor, respectively. Significant group differences on domains were followed up to determine precise deficits on individual subtests. Demographic variables were included as covariates as appropriate. A significant main effect of group, with alcohol-exposed children performing worse than their peers on all measures, was expected.

For hypothesis 1b, z-tests were used to compare the prevalence of reading impairment across group. This was conducted for all reading composites. Reading impairment was defined as performance of 1 SD below the mean (SS=85 or z-score = -1). To increase ecological validity, an 'at risk' cut-off of 25% was also utilized. It was expected that there would be a significantly greater number of individuals in the AE group who meet the criteria compared to their peers.

For hypothesis 1c, an assessment of relative strengths and weaknesses was evaluated by using repeated-measures MANOVA to examine individual differences by group if there was a significant interaction between group and the within-subjects variable. It was expected that there would be unique areas of concern for alcohol-exposed children, rather than a dampening effect. No pattern was expected in controls.

Aim 2. *Assess the relationship between underlying cognitive mechanisms and reading for children with prenatal alcohol exposure, and determine if they differ from controls.*

For hypothesis 2a, multiple regression analyses were conducted to evaluate the contribution of underlying cognitive processes (phonological awareness, phonological memory, and rapid naming) to each reading composite and overall reading achievement. Group (exposure history) was added in step 2 to determine if it accounted for additional variance, and the group x cognitive variable interactions were added in step 3 to see if contributions differed by group. It was expected that there would be significant interactions and a distinct pattern of positive relations between underlying cognitive mechanisms and reading skill by group and reading composite.

For hypothesis 2b, the same regression analyses conducted above included appropriate covariates, including home literacy environment, attitude towards reading, vocabulary, and demographic variables. It was expected that the cognitive abilities and group would account for a significant amount of variance above and beyond the additional factors. It was expected that there would continue to be significant interactions, suggesting distinct contributors for reading composite by group.

Aim 3. *Determine if there are unique patterns of deficits that can accurately classify alcohol-exposed children and controls or if specific subtypes of reading abilities exist.*

For hypothesis 3a, a discriminant function analysis was run with three different sets of variables (all six reading variables, the three CTOPP variables, and the IQ estimate). Discriminant function coefficients (DFC) expressing practical significance (greater than or equal to .30) for individual subtests were compared. It was expected that these measures would reveal modest classification accuracy (~75%).

For hypothesis 3b, a latent class analysis (LCA) was run within the AE group to determine if there were specific clusters of reading impairment (i.e., decoding deficits versus comprehension deficits), similar to the distinct subtypes of reading impairment in ADHD (Bonafina, Newcorn, McKay, Koda, & Halperin, 2000). It was expected that a 2 or 3 class solution would be the best-fitting model, and that the classes would reveal distinct types of reading impairment in the alcohol-exposed group (i.e., those with impaired passage comprehension versus those with impaired phonological decoding). The analyses were run using the WIAT variables and validated using the WJ variables.

Chapters I, II, III, and IV, in part, are currently being prepared for submission for publication of the material and will be co-authored by Sarah N. Mattson. The dissertation author was the primary investigator and author of this material.

III. Results

Demographic Information

There were no significant group differences on age [$F(1, 69) = < .000$, $p = .990$], SES [$F(1, 66) = .118$, $p = .733$], home literacy environment [$F(1, 63) = .593$, $p = .444$], and attitudes towards reading (ERAS) [$F(1, 66) = .412$, p = .523]. There were also no significant differences between groups on handedness [χ^2 ($df = 2$) = 2.097, $p = .351$], ethnicity [χ^2 ($df = 2$) = .864, $p = .353$], sex [χ^2 ($df = 1$) = .319, $p = .572$], reading grade [χ^2 ($df = 7$) = 5.198, $p = .636$] or race [χ^2 ($df = 4$) = 9.329, $p = .053$]. For grade,

Table 3: Demographic information for children with histories of prenatal alcohol exposure (AE) and controls (CON)

Variable	**AE (*n* = 31)**	**CON (*n* = 39)**
Sex [*n* (% Female)]	17 (54.8)	24 (61.5)
Handedness [*n* (% Right)]	25 (80.6)	36 (92.3)
Race [*n* (% White)]	24 (77.4)	30 (76.9)
Ethnicity [*n* (% Hispanic)]	11 (35.5)	11 (28.2)
Age [*M* (SD)]	9.1 (1.98)	9.1 (1.87)
SES [*M* (SD)]	46.3 (14.56)	47.5 (13.58)
Home Literacy Environment [M (SD)]	4.2 (0.71)	4.4 (0.87)
Elementary Reading Attitude Scale [M (SD)]	52.0 (14.94)	54.1 (11.52)
PPVT-IV, Vocabulary [*M* (SD)]*	95.6 (12.20)	112.7 (10.75)
IQ estimate [*M* (SD)]*	83.0 (10.91)	107.2 (11.18)
CBCL Total Behavioral Problems [*M* (SD)]*	66.0 (8.20)	47.0 (8.86)
FAS Diagnosis [*n* (% FAS)]	9 (29.0)	0.0 (0.0)

*significant at p <.05 (AE < CON)

four children in the AE group reportedly waited an extra year before beginning kindergarten and one child was repeating 6th grade. As age and grade were highly correlated, only one would be included in the model if appropriate due to issues of multicollinearity. Consistent with previous studies, the AE group had significantly lower IQ estimates than the CON group, as measured by the DAS-II and WISC-IV [$F(1, 68) = 80.547$, $p < .001$], and lower vocabulary, PPVT-IV [$F(1, 67) = 37.53$, $p < .001$], though AE was still in the average range. The AE group did have significantly higher parent-reported behavioral concerns, per the CBCL [$F(1, 64) = 78.02$, $p < .001$], see Table 3.

Creation of Composite Variables

For the reading subtests, correlations were conducted to ensure appropriate composites were created, see Table 4. Across groups, the correlations for comprehension (WJ Passage Comprehension, WIAT Reading Comprehension, $r^2 = .8$), fluency (WJ Reading Fluency, WIAT Oral Reading Fluency, $r^2 = .8$), and decoding (WJ Basic Reading, WAIT III Basic Reading, $r^2 = .9$) all met the proposed criteria to create composite variables. Composite variables were made by standardizing the standard scores (creating z-scores) and averaging across WIAT and WJ for each variable. As the three reading composites were also correlated >.8, an overall reading achievement composite was created by taking the average of the three individual composites.

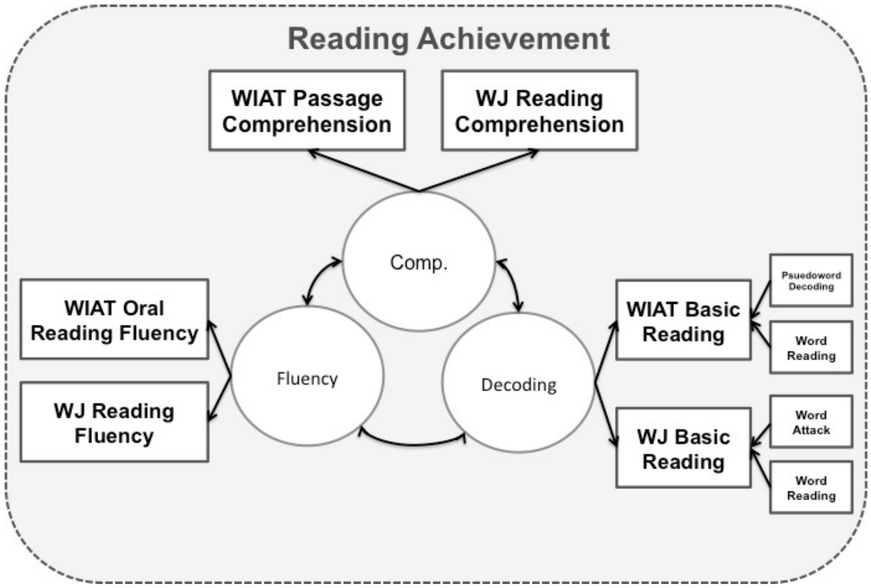


Figure 1: Creation of composite variables for reading achievement from the Woodcock Johnson (WJ) and Wechsler Individual Achievement Test (WIAT)

Assessment of Demographic Variables and Covariates

The relations between demographic variables, theoretically implicated constructs, and outcome measures were examined to determine the appropriate inclusion of factors within the regression model. Appropriateness of a covariate was determined by testing that the covariate was (1) significantly correlated with the dependent variable and (2) did not interact with the independent variable (i.e., group). Across groups, no demographic variables (sex, age, SES, grade, handedness, ethnicity) were significantly correlated with any of the reading composites (*p*s > .05). There were significant correlations between HLE and Fluency, and between ERAS and Fluency, Comprehension, and Reading Achievement. Further, there were significant correlations between CBCL Total Problems and all reading composites as well as PPVT-IV and all reading composites, see Table 4.

Table 4: Correlations between demographic variables and reading variables for children with histories of prenatal alcohol exposure (AE) and controls (CON)

	Group	**Grade**	**Hand**	**HLE**	**ERAS**	**SES**	**Sex**	**Race**	**Ethnicity**
Age	Total	**.956****	-.070	-.168	-.040	.027	-.145	-.012	.028
	AE	**.951****	-.210	**-.552***	.145	.224	-.077	-.171	.041
	CON	**.962****	.101	.035	-.254	-.134	-.204	.113	.017
Grade	Total		-.068	-.174	-.062	-.036	-.167	.036	.073
	AE		-.226	**-.512***	.077	.109	-.166	-.071	.174
	CON		.143	-.004	-.231	-.159	-.173	.120	-.025
Hand	Total			-.003	-.005	-.197	-.002	.031	-.179
	AE			.138	-.076	-.137	-.044	.209	-.219
	CON			-.086	.138	-.267	.075	-.148	-.170
HLE	Total				.032	-.046	-.039	-.061	.107
	AE				.014	.058	-.061	.176	-.268
	CON				.036	-.119	-.030	-.193	**.349***
ERAS	Total					-.169	-.217	**.267***	.053
	AE					-.093	**.361***	-.318	-.010
	CON					-.259	.052	-.249	.139
SES	Total						.166	-.041	-.149
	AE						.124	-.233	-.088
	CON						.195	.101	-.205
Sex	Total							-.126	-.055
	AE							.116	-.120
	CON							**-.318***	.027
Race	Total								-.204
	AE								-.035
	CON								**-.343***

Note: *significant at $p < .05$, ** $p < .01$, *** $p < .001$. HLE = Home literacy environment, ERAS = Elementary reading attitude scale, SES = Socioeconomic status. Bold indicates a significant correlation.

Table 4, continued: Correlations between demographic variables and reading variables for children with histories of prenatal alcohol exposure (AE) and controls (CON)

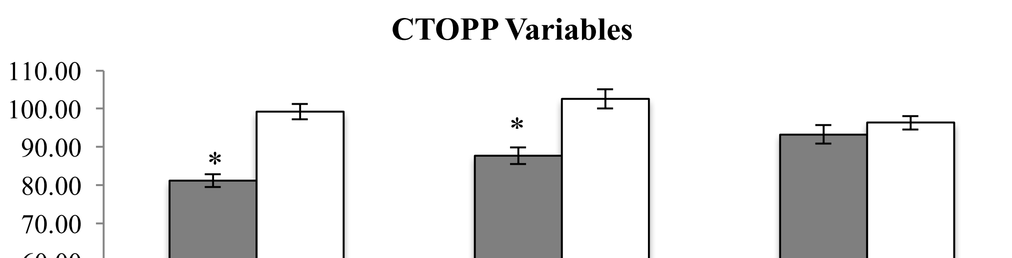
	Group	Decoding	Fluency	Comprehension	Reading Achievement
Age	Total	-.038	-.125	-.106	-.013
	AE	.232	**.416***	.085	.313
	CON	-.272	-.173	**-.346***	-.282
Grade	Total	.071	.217	-.022	.083
	AE	**.391***	**.486****	.144	**.382***
	CON	-.203	-.105	-.224	-.186
Hand	Total	-.072	-.113	.010	.008
	AE	-.252	-.283	-.041	-.153
	CON	**.339***	.304	**.327***	**.391***
HLE	Total	**-.255***	**-.292***	-.131	-.223
	AE	-.256	**-.460***	-.052	-.283
	CON	**-.434****	-.330	**-.378***	**-.420***
ERAS	Total	.205	**.307***	**.253***	**.376****
	AE	.106	.194	.268	.355
	CON	.290	**.448****	.213	**.403***
SES	Total	.088	-.040	.102	.070
	AE	-.103	-.065	.150	.123
	CON	.211	.004	.024	.065
Sex	Total	.084	.155	.224	.174
	AE	.117	.260	.352	.370
	CON	.009	.075	.137	.059
Race	Total	.055	.070	.056	.082
	AE	.128	.155	.174	.159
	CON	-.030	-.084	-.067	-.052
Ethnicity	Total	-.001	.146	-.156	.000
	AE	**.583****	**.421***	.095	**.395***
	CON	**-.348***	-.075	-.257	-.236

Note: *significant at $p < .05$, ** $p < .01$, *** $p < .001$. HLE = Home literacy environment, ERAS = Elementary reading attitude scale, SES = Socioeconomic status. Bold indicates a significant correlation. Red shading indicates relations with reading composites across groups.

Aim 1. *Evaluate and characterize performance on reading and related cognitive processes in children with heavy prenatal alcohol exposure and controls*.

Phonological Processing

The alcohol-exposed group performed significantly worse than the control group on phonological awareness and phonological memory, with no group differences seen on rapid naming. Using an alpha level of .001 to evaluate homogeneity assumptions, Box's M test of homogeneity of covariance (p = .079) and Levene's homogeneity test (ps > .049) were not statistically significant. Using Wilk's criterion as the omnibus test statistic, the combined dependent variables resulted in a significant main effect for group [$F(3, 66) = 15.991$, $p < .001$, $p\eta^2 = .421$]. To probe the significant omnibus effect, ANOVAs were conducted on each dependent variable. There was a significant effect of group (alcohol exposure) on phonological awareness [$F(1, 68) = 43.781$, $p < .001$, $p\eta^2 = .392$] and phonological memory [$F(1, 68) = 18.633$, $p < .001$, $p\eta^2 = .215$], with AE < CON for each composite. There was not a significant effect of group on rapid naming [$F(1, 68) = .1.082$ $p = .302$, $p\eta^2 = .016$].



	Phonological Awareness	Phonological Memory	Rapid Naming
ALC	81.19	87.65	93.26
CON	99.26	102.54	96.33

Figure 2: Comprehensive Test of Phonological Processing (CTOPP) variables for children with histories of prenatal alcohol exposure (AE) and controls (CON)

Reading Composites

The alcohol-exposed group performed significantly worse than the control group on all three reading composites (decoding, fluency, and comprehension) and overall reading achievement, see Figure 3. Using an alpha level of .001 to evaluate homogeneity assumptions, Box's M test of homogeneity of covariance (p = .151) and Levene's homogeneity test (ps > .197) were not statistically significant. Using Wilk's criterion as the omnibus test statistic, the combined dependent variables resulted in a significant main effect for group [$F(3, 60) = 18.285$, $p < .001$, $p\eta^2 = .478$]. To probe the significant omnibus effect, ANOVAs were conducted on each dependent variable. There was a significant effect of group (alcohol exposure) on decoding [$F(1, 62) = 31.968$, $p < .001$, $p\eta^2 = .340$], fluency [$F(1, 62) = 6.740$, $p = .001$, $p\eta^2 = .156$], and comprehension [$F(1, 62) = 43.885$, $p < .001$, $p\eta^2 = .414$], with AE < CON.

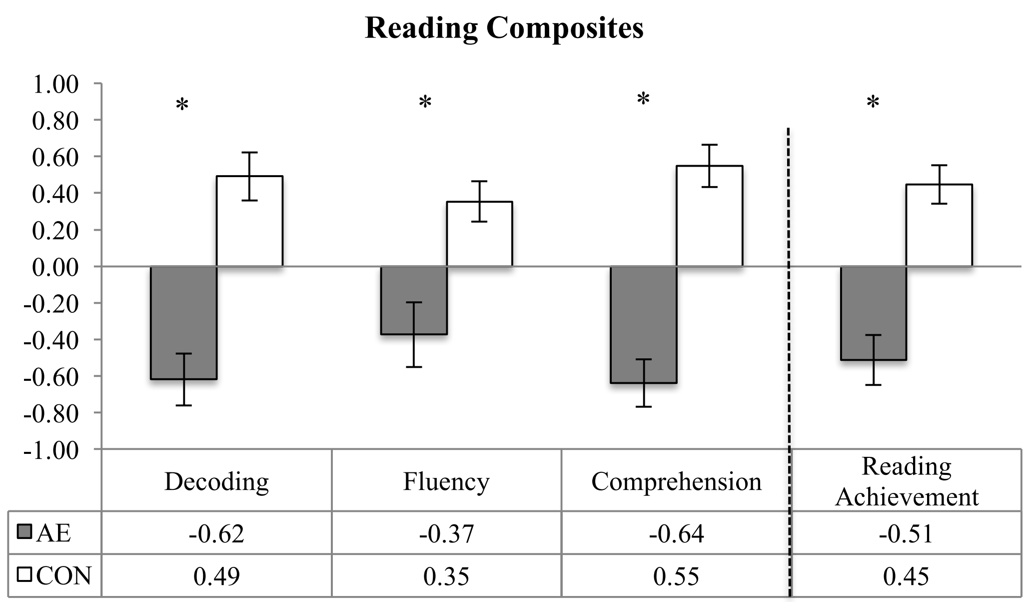


Figure 3: Reading composites for children with histories of prenatal alcohol exposure (AE) and controls (CON)

Follow-up Reading Components (All Variables)

A follow-up analysis was conducted on each individual subtest of each reading composite, as there were significant group differences on all reading composites. As children in school are often only assessed on either the WIAT or the WJ, a MANOVA was run using all six reading variables to evaluate whether group differences remained on each subtest for each measure. The alcohol-exposed group performed significantly worse than the control group on all individual variables for both the WIAT and the WJ, see Table 5. Using an alpha level of .001 to evaluate homogeneity assumptions, Box's M test of homogeneity of covariance (p = .144) and Levene's homogeneity test (ps > .137) were not statistically significant. Using Wilk's criterion as the omnibus test statistic, the combined dependent variables resulted in a significant main effect for group [$F(6, 61) = 8.844$, $p < .001$, $p\eta^2 = .465$]. To probe the significant omnibus effect, ANOVAs were conducted on each of the six dependent variables.

Table 5: Means and comparisons of individual reading subtests for children with histories of prenatal alcohol exposure (AE) and controls (CON)

	Variable/Composite	**AE M (SD)**	**CON M (SD)**	**F**	**Sig (*p*)**	**$p\eta^2$**
Comprehension	WJ Passage Comprehension	87.68 (12.00)	101.87 (10.45)	31.009	<.001	.320
	WIAT Reading Comprehension	87.48 (12.76)	106.77 (12.23)	38.261	<.001	.367
Fluency	WJ Reading Fluency[a]	96.03 (15.99)	109.03 (16.17)	10.884	.002	.142
	WIAT Oral Reading Fluency	85.48 (23.94)	103.05 (16.78)	9.738	.003	.129
Decoding	WJ Basic Reading	94.94 (10.44)	109.36 (9.80)	34.800	<.001	.345
	WIAT Basic Reading	88.96 (13.30)	106.92 (15.75)	25.411	<.001	.278

Note: For variable descriptions, see Table 2. [a]Two children had scores for which no norms were available.

Prevalence

There was a significantly higher rate of reading difficulty in the AE group relative to the control group across all composites and all measures, see Tables 6a, 6b. For hypothesis 1b, z-tests were used to compare the proportions of reading difficulties across group. Two sample chi-square statistics are equivalent to z-statistics, as chi-square is the square of the z-score. Reading difficulty was defined as performance of 1 SD below the mean for the z-score (< 1.0) and 1SD below the mean for the normative standard score (SS < 85) (Fletcher et al., 2002; Francis et al., 2005). An 'at risk' cut-off of below the 25th percentile of the normative sample (SS=90), was also utilized (Cutting & Levine, 2010).

Table 6a: Number of individuals with reading difficulties based on three criteria for children with histories of prenatal alcohol exposure (AE) and controls (CON)

Criteria	Group	Decoding [*n*/N (%)]		Fluency [*n*/N (%)]		Comprehension [*n*/N (%)]	
z-score < 1.0	AE	10/31 (32.3)*		7/29 (24.1)*		9/30 (30.0)*	
	CON	2/39 (5.1)		1/36 (2.8)		0/38 (0.0)	
< 1SD (SS < 85)		**WJ**	**WIAT**	**WJ[a]**	**WIAT**	**WJ**	**WIAT**
	AE	5/31 (16.1)*	12/31 (38.7)*	7/29 (24.1)*	11/31 (35.5)*	12/31 (38.7)*	10/31 (32.3)*
	CON	0/39 (0.0)	3/39 (7.7)	1/39 (2.6)	3/39 (7.7)	3/39 (7.7)	1/39 (2.6)
< 25th percentile (SS < 90)		**WJ**	**WIAT**	**WJ[a]**	**WIAT**	**WJ**	**WIAT**
	AE	10/31 (32.3)*	15/31 (48.4)*	12/29 (42.6)	15/31 (48.4)*	17/31 (54.8)*	17/31 (54.8)*
	CON	1/39 (2.6)	4/39 (10.3)	5/39 (12.8)	5/39 (12.8)	6/39 (15.4)	3/39 (7.7)

Note: * indicates significant difference, $p < .05$, AE > CON. The three criteria are z-score < 1.0, 1SD below the mean of the normative sample (SS < 85), and below the 25th percentile of the normative sample (SS < 90). [a]Two children had scores for which no norms were available.

Table 6b: Statistical results to support table 6a

Criteria	Decoding		Fluency		Comprehension	
z-score < 1.0	$\chi^2 = 8.950, p = .003$		$\chi^2 = 6.790, p = .009$		$\chi^2 = 13.139, p < .001$	
< 1SD (SS < 85)	**WJ**	**WIAT**	**WJ**[a]	**WIAT**	**WJ**	**WIAT**
	$\chi^2 = 6.774, p = .009$	$\chi^2 = 9.869, p = .002$	$\chi^2 = 7.457, p = .006$	$\chi^2 = 8.337, p = .004$	$\chi^2 = 9.869, p = .002$	$\chi^2 = 11.498, p = .001$
< 25th percentile (SS < 90)	**WJ**	**WIAT**	**WJ**[a]	**WIAT**	**WJ**	**WIAT**
	$\chi^2 = 11.498, p = .001$	$\chi^2 = 12.698, p < .001$	$\chi^2 = 7.235, p = .007$	$\chi^2 = 10.706, p = .001$	$\chi^2 = 12.187, p < .001$	$\chi^2 = 18.811, p < .001$

Note: * indicates significant difference, $p < .05$, AE > CON. The three criteria are z-score < 1.0, 1SD below the mean of the normative sample (SS < 85), and below the 25th percentile of the normative sample (SS < 90). [a]Two children had scores for which no norms were available.

Strengths and Weaknesses

The pattern of performance for phonological processing and reading composites were examined to evaluate the presence of relative strengths and weaknesses.

CTOPP

A 2 x 3 repeated measures MANOVA, with group (AE, CON) as the between-subjects factor and CTOPP variable (PA, PM, RN) as the within-subjects factor, was conducted. Mauchly's test of spherecity indicated that the assumption of spherecity had not been violated ($p = .111$). Using an alpha level of .001 to evaluate homogeneity assumptions, Box's M test of homogeneity of covariance ($p = .079$) and Levene's homogeneity test (ps > .049) were not statistically significant. In relation to controls, the AE group was impaired on the CTOPP, although patterns of relative strengths and weaknesses differed by group. This was supported by a significant group x CTOPP interaction [$F(2, 136) = 12.046$, $p < .001$, $p\eta^2 = .150$]. The main effects of group

[F(1,68) = 24.395, $p < .001$, pη^2 = .264] and CTOPP variables [F(2,136) = 5.749, p = .004, pη^2 = .078] were also significant. As the interaction was significant, the performance patterns were examined separately by group using pairwise comparisons with Bonferroni correction. For AE, phonological awareness scores were significantly lower than phonological memory (p = .033) and rapid naming ($p < .001$) scores, with no significant difference between phonological memory and rapid naming (p = .088). For CON, rapid naming scores were significantly lower than phonological memory scores (p = .016), with no other significant differences [phonological awareness versus phonological memory (p = .269), phonological awareness versus rapid naming (p = .305)], for scores see Figure 2.

Reading Composites

A 2 x 3 repeated measures MANOVA, with group (AE, CON) as the between-subjects factor and reading composite variable (decoding, fluency, comprehension) as the within-subjects factor, was conducted. Mauchly's test of spherecity indicated that the assumption of spherecity had not been violated (p = .984). Using an alpha level of .001 to evaluate homogeneity assumptions, Box's M test of homogeneity of covariance (p = .151) and Levene's homogeneity test (ps > .197) were not statistically significant. The AE group had difficulty on measures of reading, although the pattern of performance differed by group. This was supported by a significant group x reading composite interaction [F(2, 124) = 8.773, $p < .001$, pη^2 = .124]. There was not a significant effect of reading composite (p = .223), though there was a significant effect of group [F(1,62) = 31.740, $p < .001$, pη^2 = .339]. Therefore, patterns were examined by group. For AE, fluency was significantly higher than decoding (p = .012) and comprehension (p = .006), while decoding and comprehension did not differ from each other (p = 1.00). Therefore, there was a relative strength in fluency and a relative weakness in comprehension and decoding for alcohol-exposed children. There were no significant differences in the CON group for any pairwise comparisons [decoding versus fluency (p = .468), decoding versus comprehension (p = 1.00), fluency versus comprehension (p = .204)], for composite scores see Figure 3.

Aim 2. *Assess the relationship between underlying cognitive mechanisms and reading ability for children with and without heavy prenatal alcohol exposure, and determine if they differ from typically developing controls.*

For hypothesis 2a, cognitive mechanisms contributed significantly to reading performance, and the relations did not differ by group. Correlation analyses between the underlying cognitive mechanisms and reading components were conducted, see Table 7. Hierarchical multiple regression analyses were conducted to evaluate the contribution of underlying cognitive processes to all reading composites. Cognitive variables were added in model one, group was added in model two, and the interaction terms were added in model three, see Table 8 for results. In model one, the cognitive variables accounted for significant variance in all reading composites. For decoding, comprehension, and reading achievement, model fit improved significantly with the addition of group. The addition of group did not improve model fit significantly for fluency. The introduction of the interaction terms in model three did not account for a significant increase in variance accounted for in any of the reading composites.

Table 7: Correlations between phonological processing variables from the CTOPP and reading composites for children with histories of prenatal alcohol exposure (AE) and controls (CON)

	Group	PA	PM	RN
Phonological Awareness (PA)	Total		**.671****	**.416****
	AE		.282	.266
	CON		**.678****	**.583****
Phonological Memory (PM)	Total			**.389****
	AE			.133
	CON			**.573****
Rapid Naming (RN)	Total			
	AE			
	CON			

	Group	Decoding	Fluency	Comprehension	Reading Achievement
Phonological Awareness (PA)	Total	**.778****	**.636****	**.758****	**.759****
	AE	**.675****	**.658****	**.558***	**.633****
	CON	**.679****	**.469****	**.630****	**.647****
Phonological Memory (PM)	Total	**.578****	**.514****	**.628****	**.621****
	AE	.312	.300	**.370***	.311
	CON	**.504****	**.524***	**.578****	**.633****
Rapid Naming (RN)	Total	**.629****	**.567****	**.393***	**.520****
	AE	**.659****	**.586****	.254	**.505****
	CON	**.716****	**.575****	**.602****	**.684****
Decoding	Total		**.825****	**.851****	**.946****
	AE		**.885****	**.702****	**.928****
	CON		**.696****	**.809****	**.914****
Fluency	Total			**.792****	**.920****
	AE			**.772****	**.955****
	CON			**.766****	**.893****
Comprehension	Total				**.941****
	AE				**.892****
	CON				**.929****

Note: *significant at $p < .05$, ** $p < .01$, *** $p < .001$. Red shading indicates relations with reading composites across groups. Bold indicates a significant correlation

.

Table 8: Summary of results of the hierarchical linear regression analyses evaluating relations between phonological processing variables and reading composites

		Decoding			Fluency			Comprehension		
Model 1		Total Adj. R^2 = .696, $F(3,64)$=48.207, $\boldsymbol{p}$ **< .001**			Total Adj. R^2 = .480, $F(3,64)$=20.092, $\boldsymbol{p}$ **< .001**			Total Adj. R^2 = .577, $F(3,64)$=29.182, $\boldsymbol{p}$ **< .001**		
		B	**ß**	***p***	**B**	**ß**	***p***	**B**	**ß**	***p***
	PA	.560	.603	**<.001**	.316	.376	**.004**	.480	.527	**<.001**
	PM	.050	.056	.563	.074	.093	.466	.221	.253	**.030**
	RN	.327	.342	**<.001**	.346	.400	**<.001**	.098	.105	.257
Model 2		Total Adj. R^2 = .746 ΔR^2 = .052, $\boldsymbol{p}$ **= .001**			Total Adj. R^2 = .501 ΔR^2 = .028, p = .069			Total Adj. R^2 = .668 ΔR^2 = .092, $\boldsymbol{p}$ **< .001**		
		B	**ß**	***p***	**B**	**ß**	***p***	**B**	**ß**	***p***
	PA	.355	.383	**.001**	.180	.215	.163	.212	.233	.065
	PM	.023	.026	.773	.056	.070	.574	.186	.213	**.040**
	RN	.412	.432	**<.001**	.402	.465	<.001	.210	.223	**.012**
	Group	-.583	-.317	**.001**	-.386	-.232	.069	-.762	-.422	**<.001**
Model 3		Total Adj. R^2 = .736 ΔR^2 = .004, p = .827			Total Adj. R^2 = .519 ΔR^2 = .041, p = .168			Total Adj. R^2 = .652 ΔR^2 = .002, p = .944		
		B	**ß**	***p***	**B**	**ß**	***p***	**B**	**ß**	***p***
	PA	.344	.131	.011	.071	.085	.658	.213	.234	.156
	PM	-.013	-.014	.916	.144	.180	.326	.197	.225	.150
	RN	.429	.449	<.001	.284	.139	.047	.163	.173	.212
	Group	-.492	-.268	.015	-.148	-.089	.542	-.725	-.402	.002
	PA x Group	.114	.063	.623	.435	.267	.128	.030	.017	.907
	PM x Group	.100	.063	.554	-.034	-.024	.868	.012	.008	.951
	RN x Group	-.034	-.025	.824	.157	.128	.397	.077	.058	.653

Note: PA: Phonological Awareness, PM: Phonological Memory, RN: Rapid Naming, Group: presence, absence of heavy prenatal alcohol exposure history (AE, CON). Gray font indicates additions to model did not result in a significant increase in model fit, therefore the previous model should be interpreted. Bold indicates significant *p*-values. For reference, an initial model with group included as the sole predictor of reading variables had total adjusted R^2 values of .340 for decoding, .162 for fluency, .452 for comprehension, and .356 for reading achievement.

Table 8, continued: Summary of results of the hierarchical linear regression analyses evaluating relations between phonological processing variables and reading composites

		Reading Achievement		
Model 1		Total Adj. $R^2 = .651$, $F(3,64)=39.539$, $\boldsymbol{p < .001}$		
		B	**ß**	***p***
	PA	.452	.540	**<.001**
	PM	.115	.144	.170
	RN	.257	.298	**.001**
Model 2		Total Adj. $R^2 = .712$ $\Delta R^2 = .062$, $\boldsymbol{p = .001}$		
		B	**ß**	***p***
	PA	.249	.298	**.013**
	PM	.088	.110	.247
	RN	.341	.396	**<.001**
	Group	-.577	-.348	**.001**
Model 3		Total Adj. $R^2 = .707$ $\Delta R^2 = .010$, $p = .571$		
		B	**ß**	***p***
	PA	.210	.250	.099
	PM	.109	.137	.338
	RN	.292	.338	.009
	Group	-.455	-.275	.018
	PA x Group	.193	.119	.382
	PM x Group	.026	.018	.872
	RN x Group	.067	.055	.643

Note: PA: Phonological Awareness, PM: Phonological Memory, RN: Rapid Naming, Group: presence, absence of heavy prenatal alcohol exposure history (AE, CON). Gray font indicates additions to model did not result in a significant increase in model fit, therefore the previous model should be interpreted. Bold indicates significant *p*-values. For reference, an initial model with group included as the sole predictor of reading variables had total adjusted R^2 values of .340 for decoding, .162 for fluency, .452 for comprehension, and .356 for reading achievement.

Table 9: Correlations between other factors (vocabulary, IQ estimate, behavioral concerns) and reading composites for children with histories of prenatal alcohol exposure (AE) and controls (CON)

	Group	IQ Estimate	Behavioral concerns	Decoding	Fluency	Compre -hension	Reading Achievement
Vocab	Total	.700**	**-.549****	**.540****	**.519****	**.638****	**.613****
	AE	.488**	-.067	.352	.324	**.503****	**.428***
	CON	.484**	-.319	.289	**.482****	**.363***	**.428****
IQ Estimate	Total		**-.634****	**.716****	**.659****	**.794****	**.786****
	AE		-.105	**.506****	**.626****	**.620****	**.612****
	CON		-.267	**.541****	**.542****	**.617****	**.689****
Behavior	Total			**-.419****	**-.327***	**-.475****	**-.430****
	AE			.095	.082	-.109	.086
	CON			.003	-.053	.094	-.033

Note: *significant at $p < .05$, ** $p < .01$, *** $p < .001$. Vocabulary measured by standard score, Peabody Picture Vocabulary Test – 4th edition (PPVT-IV), IQ estimate as assessed by either the WISC-IV or DAS-II within one year of assessment. Behavior assessed by parent reported Child Behavior Checklist (CBCL) T-score. Red shading indicates relations with reading composites across groups. Bold indicates a significant correlation.

Covariates for Regression

For hypothesis 2b, the model was tested with additional factors that are theoretically related to reading variables. Attitudes towards reading, vocabulary, behavioral concerns, and home literacy environment were added to the model. These factors and the cognitive variables contributed to reading performance, with no differences across group. Alcohol exposure significantly contributed to reading performance after controlling for these additional factors and cognitive variables. The relations between demographic and other factors (age, race, ethnicity, sex, SES, home literacy environment, elementary reading attitude scale, vocabulary, behavioral problems) were examined using correlations, see Tables 3 and 9. The correlations indicated that the measure of vocabulary (PPVT), parent-reported behavioral concerns

(CBCL), and home literacy environment (HLE) were significantly associated with decoding. These variables and the attitudes towards reading scale (ERAS) were significantly associated with fluency. For comprehension and overall reading achievement, PPVT, CBCL, and ERAS were appropriate covariates to include in the model and were added in model one along with the CTOPP variables. Group was again added for model two, and the interactions were added for model three. See Table 10 for full results. With the additional factors included, the fit of model one (additional factors and cognitive variables) was significant. Model fit improved significantly for all reading composites (decoding, fluency, comprehension, and reading achievement) with the addition of group; however, the interaction terms included in model three did not account for a significant increase in explained variance.

Table 10: Summary of results of the hierarchical linear regression analyses evaluating relations between phonological processing variables and reading composites with additional factors contributing to performance

	Decoding			**Fluency**			**Comprehension**		
Model 1	Total Adj. R^2 = .713, $F(6,51)$=24.576, p **< .001**			Total Adj. R^2 = .600, $F(7,43)$=11.728, p **< .001**			Total Adj. R^2 = .613, $F(6,50)$=15.772, p **< .001**		
	B	**ß**	***p***	**B**	**ß**	***p***	**B**	**ß**	***p***
PPVT	.015	.211	**.046**	.027	.446	**.002**	.020	.296	**.015**
CBCL	.000	.001	.995	.003	.044	.721	-.001	-.010	.926
HLE	-.076	-.063	.443	-.146	-.137	.187	-	-	-
ERAS	-	-	-	.014	.193	**.047**	.008	.098	.281
PA	.502	.522	**<.001**	.186	.220	.177	.383	.416	**.005**
PM	-.091	-.094	.359	-.079	-.093	.483	.082	.088	.455
RN	.375	.367	**<.001**	.299	.334	**.004**	.137	.140	.175
Model 2	Total Adj. R^2 = .742 ΔR^2 = .031, p **= .012**			Total Adj. R^2 = .652 ΔR^2 = .052, p **= .009**			Total Adj. R^2 = .694 ΔR^2 = .078, p **< .001**		
	B	**ß**	***p***	**B**	**ß**	***p***	**B**	**ß**	***p***
PPVT	.011	.162	.111	.023	.388	**.003**	.016	.234	**.031**
CBCL	.011	.141	.192	.015	.330	.103	.017	.238	**.048**
HLE	-.098	-.083	.296	-.174	-.162	.096	-	-	-
ERAS	-	-	-	.013	.186	**.041**	.006	.083	.308
PA	.502	.506	**.006**	.023	.028	.867	.199	.215	.124
PM	-.015	-.017	.565	-.037	-.043	.730	.128	.138	.194
RN	.466	.399	**<.001**	.341	.381	**.001**	.187	.192	**.041**
Group	-.396	-.204	**.012**	-.729	-.401	**.009**	-.947	-.493	**<.001**
Model 3	Total Adj. R^2 = .732 ΔR^2 = .005, p = .774			Total Adj. R^2 = .686 ΔR^2 = .047, p = .075			Total Adj. R^2 = .684 ΔR^2 = .008, p = .702		
	B	**ß**	***p***	**B**	**ß**	***p***	**B**	**ß**	***p***
PPVT	.011	.162	.131	.017	.283	.030	.013	.201	.088
CBCL	.011	.142	.207	.014	.209	.120	.019	.009	.044
HLE	-.101	-.084	.299	-.174	-.163	.085	-	-	-
ERAS	-	-	-	.019	.272	.005	.013	.166	.072
PA	.327	.340	.041	.005	.005	.979	.286	.317	.087
PM	-.103	-.107	.417	.035	.042	.800	.089	.101	.534
RN	.485	.475	<.001	.159	.178	.261	.094	.098	.517
Group	-.546	-.267	.067	-.411	-.226	.185	-1.057	-.564	.001
PA x Group	.148	.082	.593	.373	.240	.201	-.264	-.148	.365
PM x Group	.109	.058	.582	.055	.034	.794	.160	.097	.433
RN x Group	-.132	-.084	.453	.282	.211	.143	.128	.091	.499

Note: PA: Phonological Awareness, PM: Phonological Memory, RN: Rapid Naming, Group: presence, absence of heavy prenatal alcohol exposure history (AE, CON). Gray font indicates additions to model did not result in a significant increase in model fit, therefore the previous model should be interpreted. Bold indicates significant p-values. For reference, an initial model with group included as the sole predictor of reading variables had total adjusted R^2 values of .340 for decoding, .162 for fluency, .452 for comprehension, and .356 for reading achievement.

Table 10, continued: Summary of results of the hierarchical linear regression analyses evaluating relations between phonological processing variables and reading composites with additional factors contributing to performance

		Reading Achievement		
Model 1		Total Adj. $R^2 = .717$, $F(6,47)=23.349$, $\boldsymbol{p} < \mathbf{.001}$		
		B	**ß**	***p***
	PPVT	.018	.313	**.004**
	CBCL	.003	.045	.645
	HLE	-	-	-
	ERAS	.013	.188	**.021**
	PA	.369	.454	**.001**
	PM	<.001	<.001	.997
	RN	.224	.260	**.005**
Model 2		Total Adj. $R^2 = .784$ $\Delta R^2 = .063$, $\boldsymbol{p} < \mathbf{.001}$		
		B	**ß**	***p***
	PPVT	.015	.251	**.009**
	CBCL	.017	.265	**.012**
	HLE	-	-	-
	ERAS	.013	.184	**.010**
	PA	.232	.286	**.018**
	PM	.031	.039	.674
	RN	.267	.310	**<.001**
	Group	-.739	-.438	**<.001**
Model 3		Total Adj. $R^2 = .782$ $\Delta R^2 = .011$, $p = .465$		
		B	**ß**	***p***
	PPVT	.013	.224	.024
	CBCL	.018	.282	.011
	HLE	-	-	-
	ERAS	.016	.224	.004
	PA	.308	.379	.015
	PM	-.020	-.025	.852
	RN	.192	.223	.080
	Group	-.724	-.429	.002
	PA x Group	-.073	-.046	.735
	PM x Group	.159	.107	.300
	RN x Group	.136	.107	.338

Note: PA: Phonological Awareness, PM: Phonological Memory, RN: Rapid Naming, Group: presence, absence of heavy prenatal alcohol exposure history (AE, CON). Gray font indicates additions to model did not result in a significant increase in model fit, therefore the previous model should be interpreted. Bold indicates significant *p*-values. For reference, an initial model with group included as the sole predictor of reading variables had total adjusted R^2 values of .340 for decoding, .162 for fluency, .452 for comprehension, and .356 for reading achievement.

Aim 3. *Determine if there are unique patterns of deficits that can accurately classify alcohol-exposed children and controls or if specific subtypes of reading deficits exist.*

For hypothesis 3a, results indicated that reading and related variables were successful in accurately classifying alcohol-exposed children and controls. Discriminant function coefficients (DFC) expressing practical significance (greater than or equal to .30) for individual variables were compared to determine the most efficient battery of cognitive ability assessments that distinguish the groups. A discriminant function analysis was performed using six variables as predictors of membership in a diagnostic group. Predictors were standardized (z-scores) for phonological memory, phonological awareness, rapid naming, and the composites of fluency, comprehension, and decoding. The diagnostic groups were individuals with and without alcohol exposure. Using an alpha level of .001 to evaluate the homogeneity of covariance matrices assumption, Box's M test was not statistically significant (p = .340).

Only one discriminant function was significant [X^2 (6) = 56.358, p < .001] and was considered noteworthy based on statistical and practical significance. This discriminant function maximally separated individuals in the AE group (M = -1.456) from the CON group (M = 1.092). The standardized discriminant function coefficients for the discriminant function were as follows: comprehension (=.740), decoding (=.523), fluency (-.335), phonological awareness (=.495), rapid naming (=-.759), and phonological memory (=-.053). These weights and loadings suggest that the best predictors of distinguishing between individuals with and without heavy prenatal alcohol exposure are comprehension, decoding, fluency, phonological awareness, and rapid naming. Specifically, alcohol-exposed individuals scored lower on all variables with values greater than |.03|. Overall, 90.5% of the sample was correctly classified into their diagnosis group, exceeding the value for classification based on chance (50.0%). At the group level, 92.6% of the individuals with alcohol exposure were correctly classified and 88.9% of the control group was classified correctly. Follow-up analyses indicated that the three reading composites alone (decoding, fluency, comprehension) classified 82.8% of the sample (AE: 85.7%, CON: 80.6%) and CTOPP variables (30-minute battery) classified 87.0% of the sample (AE: 96.7%, CON: 79.5%). For comparison, the IQ estimate (1–2-hour battery) correctly classified 87.0% of the sample (AE: 90.0%, CON: 84.6%).

For hypothesis 3b, three classes emerged in the alcohol-exposed group based on severity of reading difficulties (poor readers, below-average readers, and average readers). A latent class analysis (LCA) was conducted on the WIAT subtests and on the WJ subtests to determine whether there were specific subtypes of reading difficulties present in the alcohol-exposed group. While it was expected that subtypes of reading difficulties would emerge, consistent with subtypes found in learning disorder or ADHD populations (e.g., decoding versus comprehension) (Bonafina et al., 2000), the results from this study found that there were three classes based on severity instead. This was true for both the WIAT and the WJ reading subtests.

For the WIAT, LCA testing 1-, 2- and 3-class solutions were fit to the three subtests. The model fit indices for each LCA are available in Table 11. AIC and sBIC fit indices suggest that the 3-class solution is marginally better than the 2-class solution. The inferential LMRT test indicates that the 2-class solution fits better than the 3-class solution. On the other hand, the entropy values suggest that there is marginally greater confidence in the percentage of individuals who are correctly classified with the 3-class solution as opposed to the 2-class solution. Based on substantive interpretation, neither the 2-class nor 3-class solutions have conditional response probabilities (CRPs) that easily discriminate the classes. Considering both fit indices (AIC, sBIC, LMRT) and substantive interpretation (CRPs and entropy), the 3-class solution appears to be a superior fit.

Latent class probabilities for each class in the 3-class solution were 16.1% (*n* = 5) in class 1, 51.6% (*n* = 16) in class 2, and 32.3% (*n* = 10) in class 3. Considering the conditional response probabilities in the WIAT, class 1 is defined as poor readers, class 2 is defined below-average readers, and class 3 is defined as average readers.

Table 11: Overall model fit and conditional response probabilities for WIAT variables in children with histories of prenatal alcohol exposure (AE)

	AIC	**sBIC**	**LMRT (*p*-value)**	**Entropy**
Class 1	788.061	777.972		
Class 2	755.652	738.837	.0457	.954
Class 3	740.672	717.130	.3654	.964

Conditional Response Probabilities for 2-Class Solution

Item	**Class 1**	**Class 2**
WIAT Decoding	75.54	93.71
WIAT Fluency	51.06	97.64
WIAT Comprehension	74.03	92.23

Conditional Response Probabilities for 3-Class Solution

Item	**Class 1**	**Class 2**	**Class 3**
WIAT Decoding	77.40	80.13	97.72
WIAT Fluency	40.00	79.07	103.17
WIAT Comprehension	70.20	84.15	94.74

For the WJ, The LCA testing 1-, 2- and 3-class solutions were fit to the three subtests. The model fit indices for each LCA are available in Table 12. AIC and sBIC fit indices suggest that the 3-class solution is marginally better than the 2-class solution. The inferential LMRT test also indicates that the 3-class solution is better than the 2-class solution, which is consistent with the entropy values. Considering both fit indices (AIC, sBIC, LMRT) and substantive interpretation (CRPs and entropy), the 3-class solution appears to be a superior fit.

Latent class probabilities for each class in the 3-class solution were 12.90% (*n* = 4) in class 1, 48.4% (*n* = 15) in class 2, and 38.7% (*n* = 12) in class 3. While classes with fewer than 5 individuals are suspect due to the small sample size, this is considered appropriate to interpret with caution. Considering the conditional response probabilities in the WJ, class 1 is defined as poor readers, class 2 is defined below-average readers, and class 3 is defined as average readers.

Table 12: Overall model fit and conditional response probabilities for WJ variables in children with histories of prenatal alcohol exposure

	AIC	sBIC	LMRT (*p*-value)	Entropy
Class 1	727.478	717.389		
Class 2	703.800	686.984	.3761	0.783
Class 3	692.167	668.625	.0412	0.906
Conditional Response Probabilities for 2-Class Solution				
Item		**Class 1**		**Class 2**
WJ Decoding		86.332		100.608
WJ Fluency		82.289		106.119
WJ Comprehension		77.506		94.384
Conditional Response Probabilities for 3-Class Solution				
Item		**Class 1**	**Class 2**	**Class 3**
WJ Decoding		76.745	92.259	104.669
WJ Fluency		73.854	91.210	110.800
WJ Comprehension		68.086	86.307	96.255

Post-Hoc Analyses

Additional analyses were conducted to further understand the composition of reading difficulties by group. The relation of reading to performance on other academic domains was also examined.

Descriptive analyses of composition of reading difficulties by group

Exploratory descriptive analyses examined the composition of reading difficulties within each group based on the reading composites (fluency, decoding, and comprehension), see Table 13. There was no indication of a specific area of reading difficultly. Approximately half of the alcohol-exposed group had at least one area of reading difficulty (defined as a z-score < 1.0 on a given reading composite), whereas the rate was less than 10% in the control group. In the alcohol-exposed group, seven children had one area of difficultly, two children had two areas of difficulty, and six children had three areas of difficulty. When examining the distribution of instances of reading difficulty for a given reading composite (z-score < 1.0, 29 instances overall), frequencies were consistent for fluency, decoding, and comprehension across groups.

Table 13: Composition of reading difficulty for children with histories of prenatal alcohol exposure (AE) and controls (CON)

	AE $n = 31$	**CON** $n = 39$
At least 1 area of difficulty [*n* (%)]	15 (48.4%)	3 (7.7%)
1 area/2 areas/3 areas of difficulty (*n*/*n*/*n*)	7 / 2 / 6	2 / 0 / 1
Distribution of Reading Difficulties by Area		
Fluency [*n* (%)]	9 (29.0%)	2 (5.1%)
Decoding [*n* (%)]	10 (31.0%)	2 (5.1%)
Comprehension [*n* (%)]	10 (31.0%)	1 (2.6%)

Note: Reading difficulty defined as a z-score < 1.0 on a given reading composite.

Comparison of reading to other academic domains

Reading abilities are also associated with other academic abilities, such as math and spelling (Willcutt et al., 2013). Therefore, correlations between reading, math, and spelling were conducted to examine these relations, see Table 14. As expected, overall, and for each group individually, there were significant correlations between reading (decoding, fluency, comprehension, and overall achievement) and spelling and math, respectively.

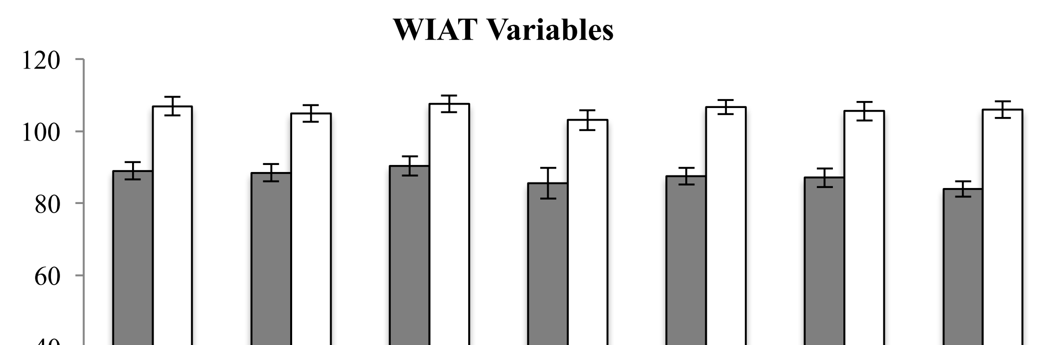
Table 14: Correlations between spelling and numerical operations and reading composites for children with histories of prenatal alcohol exposure (AE) and controls (CON)

	Group	Numerical Processing	Decoding	Fluency	Compre-hension	Reading Achievement
WIAT Spelling	Total	**.724****	**.857****	**.712****	**.746****	**.809****
	AE	**.598****	**.794****	**.724****	**.607****	**.751****
	CON	**.599****	**.804****	**.572****	**.678****	**.731****
WIAT Numerical Operations	Total		**.676****	**.581****	**.765****	**.706****
	AE		**.481****	**.570****	**.593****	**.570****
	CON		**.501****	**.361***	**.605****	**.508****

Note: *significant at $p < .05$, ** $p < .01$, *** $p < .001$. Red shading indicates relations with reading composites across groups. Bold indicates a significant correlation.

To evaluate potential differences in performance across academic domains (reading, math, and spelling) and determine whether there were relative strengths and weaknesses by group, a 2 x 6 repeated measures MANOVA was conducted, with group (AE, CON) as the between-subjects factor and WIAT variables (Word Reading, Pseudoword Decoding, Oral Reading Fluency, Reading Comprehension, Spelling, Numerical Operations) as the within-subjects factor. Results indicated that alcohol-exposed children performed worse than controls on all WIAT subtests. There were no relative strengths or weaknesses across academic domains noted for either group.

Mauchly's test of spherecity indicated that the assumption of spherecity had been violated ($p < .001$), and therefore Greenhouse-Geisser correction was utilized. Using an alpha level of .001 to evaluate homogeneity assumptions, Box's M test of homogeneity of covariance ($p = .591$) and Levene's homogeneity test (ps > .026) were not statistically significant. Using Greenhouse-Geisser correction, there was not significant group x WIAT Interaction [$F(1.3.042, 206.883) = .748$, $p = .526$] or a significant main effect of WIAT [$F(1.3.042, 206.883) = 2.091$, $p = .102$]. There was a significant effect of group [$F(1,68) = 38.154$, $p < .001$, $p\eta^2 = .359$]. Therefore, within-subjects analyses were repeated by group to ensure there were no differences between individual subtests on the WIAT, with pairwise comparisons corrected using Bonferroni. By group, there were no significant main effects of WIAT subtest. When examining relations within group, there were no significant pairwise comparisons, indicating no significant difference on performance across WIAT subtests.



	Basic Reading	Pseudoword Decoding	Word Reading	Oral Reading Fluency	Reading Comp.	Spelling	Numerical Operations
■AE	88.97	88.45	90.42	85.48	87.48	87.07	84.00
□CON	106.92	104.90	107.56	103.05	106.77	105.54	106.00

Figure 4: Performance on WIAT subtests for children with histories of prenatal alcohol exposure (AE) and controls (CON)

Chapters I, II, III, and IV, in part, are currently being prepared for submission for publication of the material and will be co-authored by Sarah N. Mattson. The dissertation author was the primary investigator and author of this material.

IV. Discussion

The current study aimed to characterize and evaluate reading ability in children with heavy prenatal alcohol exposure. Overall, children with histories of heavy prenatal alcohol exposure performed significantly worse than their peers on measures of phonological processing and reading. In examining phonological processing, alcohol-exposed children demonstrated a relative weakness in phonological awareness compared to rapid naming or phonological memory. Further, children with alcohol exposure demonstrated a relative strength in fluency compared to lower performance on measures of reading comprehension and decoding.

This study suggests that there are similar underlying cognitive mechanisms that contribute to reading achievement regardless of exposure history. However, the presence of prenatal alcohol exposure contributes significantly to reading performance after accounting for phonological processing development, vocabulary, behavioral concerns, attitudes towards reading, and home literacy environment. This suggests that there are significant effects of phonological processing contributing to reading performance that can serve as effective targets for intervention, but they are not a sufficient explanatory mechanism. Therefore, interventions that are effective in other populations may also be successful in alcohol-exposed children by targeting the same underlying mechanisms. However, it is important to also consider other factors related to alcohol exposure that may also have a significant effect. Characterizing the underlying mechanisms of poor reading is important, as alcohol-exposed children had significantly higher rates of reading difficulty across all modalities, fluency, decoding, and comprehension.

Reading variables were able to classify alcohol-exposed children to the same extent as previous studies (~90%). While it is unlikely that these variables will be used to identify prenatal alcohol exposure, it does offer evidence that their poor performance in this domain is a distinguishing feature of this population. There did not appear to be specific subtypes of reading difficulty (such as comprehension issues versus decoding issues), but rather groups emerged based on degrees of severity of reading difficulties. Therefore, reading difficulties would be not characterized as dyslexia or a specific reading disorder, but rather as multifactorial deficits in the underlying mechanisms that contribute to higher order reading measures.

Reading performance and related cognitive abilities

Alcohol-exposed children are impaired when compared to non-exposed controls on various aspects of verbal academic functioning (Adnams et al., 2007; Glass et al., 2015; Goldschmidt et al., 2004; O'Leary, Taylor, Zubrick, Kurinczuk, & Bower, 2013; Rose-Jacobs et al., 2012). However, most studies have used fairly simple tasks, primarily relying on single oral word reading. The few studies that have investigated reading and spelling consistently report that children with prenatal alcohol exposure demonstrate deficits in these areas (Adnams et al., 2007; Glass et al., 2015; Howell et al., 2006; Kodituwakku, 2007; O'Leary et al., 2013; Streissguth, Barr, Carmichael Olson, et al., 1994). Generally, school-age children with FASD perform approximately 1.0–1.5 SD below the mean of typically developing children on reading and spelling tasks, whereas individuals with facial dysmorphology consistent with an FAS diagnosis have been shown to score 2–3 SD below the mean (Howell et al., 2006). These levels of difficulty in reading are consistent with performance on reading measures in the current study.

While reading achievement was at the level expected given general cognitive performance in this population, it is an important area to target for intervention, as reading is critical for development and has been shown to improve substantially, even in populations with lower IQ scores. Further, poor reading can have significant negative effects both in the educational realm and in daily life. A study found that heavy prenatal alcohol exposure during the first trimester increases the likelihood of not reaching the reading benchmark by more than twofold, and this may be due to a dose-dependent relation between prenatal alcohol exposure and the underlying development of phonological processing (Streissguth, Barr, Carmichael Olson, et al., 1994). This is consistent with Goldschmidt's prospective studies (1996, 2004), though there are differences between sensitive period (first versus second trimester). The idea of a diathesis-stress model, with poor phonological processing and heavy exposure leading to worse outcomes, suggests a potential group of alcohol-exposed individuals who have a higher risk of reading difficulties. Unfortunately, precise information regarding the dosage and timing of alcohol exposure in utero was not available for the current study. However, it is important to note that even the effects of low-to-moderate prenatal alcohol exposure on academic achievement may be difficult to measure due to a variety of confounding factors and should not be underestimated (Jacobson & Jacobson, 2014).

In this study, children were administered measures assessing the three main aspects of phonological processing (rapid naming, phonological awareness, and phonological memory) that are the most supported predictors for reading achievement (Cologon et al., 2011; Fletcher et al., 2002; Galuschka et al., 2014; Lovett et al., 1994; Palmer et al., 2013; Vellutino et al., 2004). Alcohol-exposed children performed significantly worse than their peers on phonological awareness and phonological memory, extending previous studies (Adnams et al., 2007; Glass et al., 2015; Streissguth, Barr, Carmichael Olson, et al., 1994). There was no significant difference on rapid naming between children with and without alcohol exposure. This is consistent with studies supporting intact functioning on basic speeded naming tasks and deficits when tasks become more complicated (Burden et al., 2005), although is contrary to a previous study of impaired speeded naming (Rasmussen et al., 2013). Note, however, there was no control group in this study, which limits interpretation.

Within the alcohol-exposed group, there was a relative weakness in phonological awareness compared to the other aspects of phonological processing. While the three components of phonological processing highly relate, they have been found to independently contribute and differentially predict types of reading ability. Further research should attempt to comprehensively assess rapid naming across modalities (visual, verbal) to better understand performance in this population.

In terms of higher order reading variables, alcohol-exposed children performed significantly worse on measures of decoding and comprehension compared to fluency, which was a relative strength. This confirms previous literature (Mattson et al., 2011) where verbal fluency was generally less impaired than other areas. Comprehension and decoding could be considered more cognitively demanding compared to fluency, which is consistent with previous research showing that the adverse effects associated with alcohol exposure are seen more prominently on tasks of greater complexity (Kodituwakku, Kalberg, & May, 2001). Further, when examining the strengths and weaknesses in phonological processing and reading variables, the results of this study suggest that a weakness in phonological awareness may underlie the difficulties in decoding and comprehension, whereas intact rapid naming may support the relative strength of reading fluency in alcohol-exposed children. Relative contributions are discussed below.

While memory is generally considered a core deficit within alcohol-exposed children (and is significantly worse than controls), alcohol-exposed children in the current study may have performed better on the phonological memory task of the CTOPP given that it was a forward digit span test requiring little to no strategy in terms of manipulating information or remembering semantically clustered words. In other words, the phonological memory task of the CTOPP could potentially be seen as an attention task rather than a memory task (though the child was cued frequently to stay on task by the standardized audio recording). Therefore, additional evaluation of the relation between reading and working memory is a worthwhile endeavor, as understanding the profile of functioning may indicate where resources should be allocated.

Within the control group there was no difference between reading components, as expected. Rapid naming was significantly lower than phonological memory (though within the average range) and could be considered an artifact of above average performance on rapid naming compared to average performance on other skills within the control group.

Contributing factors to reading performance

Cognitive predictors significantly contributed to all components of reading, including decoding, fluency, and comprehension, as well as overall reading achievement in differential patterns. These predictors (phonological awareness, phonological memory, rapid naming) are well supported in the literature for both typically developing readers and those with difficulties (Vellutino, Tunmer, Jaccard, & Chen, 2007). A recent meta-analysis assessed 48 studies looking at specific cognitive and intelligence measures in children with and without reading disabilities (1SD below the mean) at the age of 10 (Kudo et al., 2015) and substantiated the findings of the National Reading Panel supporting relations between phonological processing and reading (National Reading Panel, 2000; Vellutino et al., 2004). In a study quantifying how the cognitive predictors relate to later reading, it was found that phonological processing, rapid naming, language comprehension, and nonverbal reasoning explained 50.3% of the variance, demonstrating that cognitive abilities may assist in classifying, identifying, and instructing students with reading difficulties (Fuchs et al., 2012). These results are also in line with Pennington's multiple deficits view of dyslexia and indicate that poor reading outcomes are likely due to multiple interacting variables (Carroll, Solity, & Shapiro, 2015). Using only phonologically processing variables, that 47–72% of the variance was accounted for in reading measures, which increased to 60–72% with the inclusion of other factors including vocabulary, behavioral concerns, home literacy environment, and attitudes towards reading.

Contrary to the hypothesis that there would be different predictors based on history of alcohol exposure, there were no interactions with subject group. This remained true after accounting for other factors that are theoretically related. While the cognitive mechanisms contributed to the individual reading components to various degrees, evidenced by distinct patterns of significant predictors for each reading component, these relations did not differ by group, as evidenced by no interaction with group. This suggests that the same underlying mechanisms should be targeted for intervention regardless of history of prenatal alcohol exposure, similar to the evidence from a variety of other populations of children with reading difficulties. Importantly, while there were no significant interactions with group, prenatal alcohol exposure remained a significant predictor when added to the model for all four reading composites, indicating that a history of prenatal alcohol exposure is associated with worse reading performance even after accounting for other variables.

In addition to the significant effect of group, phonological awareness and rapid naming were significant predictors of decoding performance. Of these significant predictors, phonological awareness had the greatest impact on decoding performance (with a 1SD increase resulting in 0.5SD increase in decoding performance), followed by rapid naming and exposure history. Vocabulary and rapid naming were significant predictors for fluency and comprehension along with the effect of group, while attitude towards reading was an additional predictor for fluency and behavioral concerns was an additional predictor for comprehension. Of the significant predictors for fluency, history of prenatal alcohol exposure, vocabulary, and rapid naming had the greatest impact, followed by attitude towards reading. Of the significant predictors for comprehension, group had the greatest effect (with alcohol exposure associated with an approximately -0.5 SD decrease in comprehension), followed by behavioral concerns, vocabulary, and rapid naming. Lastly, for overall reading achievement, vocabulary, behavioral concerns, attitude towards reading, phonological awareness, and rapid naming were significant predictors, in addition to a history of alcohol exposure. Of these significant predictors for overall reading achievement, alcohol exposure again had the greatest effect, followed by rapid naming, phonological awareness, behavioral concerns, vocabulary, and attitude towards reading.

These findings are consistent with research in other developmental disorders, indicating that there is a strong relationship between phonological processing skills and reading ability regardless of the etiology of potential deficits (Cologon et al., 2011; Fletcher et al., 2002; Frijters et al., 2011; Lovett et al., 1994; Snowling & Hulme, 2012; Vellutino et al., 2004). However, as alcohol exposure contributed significant variance to reading performance as well, exposure history should also be considered within a holistic conceptualization. This is especially pertinent in the context of all other variables, where a history of alcohol exposure did not attenuate the contribution of other factors that predict reading, and, vice versa, these other factors did not attenuate the significant effect of alcohol exposure.

Understanding the underlying factors that contribute to reading performance in this population (and others) can lead to the creation, implementation, evaluation, and dissemination of effective interventions. However, it is important to consider other factors that may relate to response efficacy (Barth et al., 2010; Denton, 2012; Fletcher et al., 2011; Vaughn et al., 2010). Effective interventions have been conducted for alcohol-exposed individuals for mathematics (Kable et al., 2015), indicating improvement is possible. Further, reading interventions have been effective in other populations, including ones with similar decrements in IQ and behavioral concerns, suggesting that targeted interventions that focus on the core underlying mechanisms of reading functionality, while considering the other contributing factors, could be successful for alcohol-exposed children. Considerations for intervention for alcohol-exposed children are discussed in more detail below.

Prevalence

Determining the best methodology for identifying children at risk of academic failure or the rate of academic performance deficits is a convoluted question with various stakeholders. There are costs and benefits associated with over identifying children versus under identifying children. In this population, there is added concern regarding stigma. Having a diagnosis of a learning disorder is one method of accessing services in school. Learning disorders are the most prevalent diagnosis in childhood, with prevalence rates estimated between 5–15% (American Psychiatric Association, 2013). While learning disorders were previously operationalized using a discrepancy model, requiring a significant difference between global intellectual ability and achievement (American Psychiatric Association, 2000; Moll, Kunze, Neuhoff, Bruder, & Schulte-Korne, 2014), this model has not been empirically supported (Fletcher et al., 2002; Vellutino et al., 2000). Further, it was particularly detrimental for children who have lower general intelligence, such as alcohol-affected individuals, as it limited the potential for a significant discrepancy.

Currently, the criteria to identify learning disabilities as codified in the DSM-5 specify a definition using a low achievement cut-off (approximately 1 to 2.5SD) based on age or grade appropriate standards (American Psychiatric Association, 2013). Very few studies have examined the prevalence rates of learning disorders in children with histories of alcohol exposure; however, studies report estimates from 17% to 35% in this population, second only to the rate of ADHD (Bhatara, Loudenberg, & Ellis, 2006; Burd, Cotsonas-Hassler, Martsolf, & Kerbeshian, 2003). A recent study found that alcohol-exposed individuals were more likely to meet criteria for other health disability, developmental delay, or emotional/behavioral disorders rather than a specific learning disability (Boys et al., 2016). One potential explanation for the lower rate of learning disorders is that most children with prenatal alcohol exposure do not have a specific learning disability, but rather are at risk for poor performance or failure across several academic domains.

The current study focused on identifying children at risk of reading difficulty or demonstrating difficulty on reading measures, rather than a diagnosis of a specific learning disorder. Consistent with the hypotheses, there were increased rates of reading difficulties across reading components in children with prenatal alcohol exposure compared to controls. Using a cut-off score of 1 SD (to balance specificity and sensitivity) and a previously accepted cut-off of 25th percentile for 'at risk' (Cutting & Levine, 2010), alcohol-exposed children had significantly higher rates of reading difficulty compared to their peers. Approximately 25% to 50% of children with prenatal alcohol exposure meet these cut-offs on one or more domains. However, it is important to note that cut-off scores are not without limitations (Fletcher et al., 2002; Francis et al., 2005). These results indicate that there are significantly higher rates of difficulties in reading in alcohol-exposed populations that deserve greater attention (Glass et al., 2016).

Classification

Performance on reading and underlying cognitive was able to successfully differentiate children with alcohol exposure from non-exposed individuals at a classification accuracy rate of over 80%. These rates are consistent with classification accuracies seen elsewhere for longer batteries (Goh et al., 2016; Mattson et al., 2013). There are many reasons why individuals may have low reading abilities. Therefore, caution should be used in interpreting the clinical utility of these classification accuracies for alcohol-exposure status. Rather, these results provide support for the conclusion that reading performance separates alcohol-exposed children from their peers and that it should be routinely evaluated.

While it was hypothesized that there would be unique subgroups of reading difficulties (such as comprehension versus decoding), indicating a ‘classic’ reading disability, the results indicated that children who had one area of difficulty likely had other areas of difficulty as well. Further, within the alcohol-exposed group, the profiles or classes that emerged from the analyses were based on severity of impairment deficits, with distinct groups emerging that were 2 SD below the mean, 1 SD below the mean, and of average performance. This adds to previous literature substantiating the heterogeneity of performance in the alcohol-exposed population, though refutes the presence of specific reading disabilities.

These results are consistent with patterns seen in other developmental disorders. A recent study comparing individuals with neurofibromatosis-1 (NF-1) to children with reading disabilities found a similar pattern of deficits (Cutting & Levine, 2010). Many NF-1 children, similar to children with FASD, are not typically classified as specifically having an LD due to other diagnoses or lower IQ. Therefore, recommendations from this population may be beneficial for alcohol-exposed individuals, whereas a diagnosis of a learning disorder may not be appropriate.

Comparison with math

Mathematics is considered to be particularly vulnerable to the teratogenic effects of alcohol exposure and has been the most extensively studied academic area within the realm of prenatal alcohol exposure (Goldschmidt et al., 1996; Howell et al., 2006; Jacobson et al., 2011; Streissguth, Barr, Carmichael Olson, et al., 1994). This emphasis on mathematics has resulted in one of the few effective evidence-based interventions for this population (Kable et al., 2015; Kable et al., 2007). Consistent with the extant literature, the current study also found that alcohol-exposed children were significantly worse than peers on math performance. However, contrary to expectation math performance was not significantly lower than all reading variables. It is possible that the sample size led the analysis to be underpowered to detect the effect of mathematical functioning as worse than reading. However, even if this was the case, there was still an effect of alcohol exposure for all measures of decoding, fluency, and comprehension, indicating continued areas of concern. As reading is incredibly important for daily functioning, even a lesser detrimental effect may still result in greater functional deficits. Further, there is considerable comorbidity between difficulties in math and reading (Willcutt et al., 2013), and both should be monitored and evaluated for potential intervention.

In examining the literature, the mean performance across subtests is generally consistent with other studies administering the WIAT to children with prenatal alcohol exposure (Howell et al., 2006; Nash et al., 2013). In Howell et al., (2006), the group with facial dysmorphology consistent with FAS had reading and spelling scores of approximately 78 and math scores of 75 for math reasoning and 73 for numerical operations, indicating slightly worse, but not drastically different performance. For the non-dysmorphic alcohol-exposed group, all scores (reading, spelling, numerical operations, and math reasoning were between 83 and 79 with SD of 13–16, indicating no differences between subtypes, similar to the current findings. Therefore, these results indicate that all aspects of academic functioning should be screened for in children with alcohol exposure, as they may have difficulties across domains.

Other factors to consider

I found that cognitive mechanisms (phonological processing variables), vocabulary, attitude towards reading, and behavioral concerns were all significant predictors of reading performance. Therefore, in addition to the recommendations above discussing targeting specific cognitive variables, it is also important to support reading in the home environment (which also impacts vocabulary), reinforce a positive attitude towards reading, and continue behavioral management (Senechal & Lefevre, 2014). Alcohol-exposed children may not be able to access the material as effectively if there are ongoing behavioral concerns, which are highly prevalent in this population. Further increasing the home literacy environment by partaking in shared book reading and encouraging continued reading can also assist in better vocabulary and reading performance (Rashid et al., 2005; Senechal & Lefevre, 2014), even for individuals with intellectual disability (van der Schuit et al., 2009). Additionally, attitude towards reading was a significant predictor for reading. Interestingly, elementary school children, even if poor readers, often have a somewhat favorable outlook on reading in first grade (Lazarus & Callahan, 2000). However, over time positive attitudes tend to decrease, leading to decreased time spent reading and an overall higher likelihood for worse reading performance.

Prenatal alcohol-exposure accounted for significant variance above and beyond the variance accounted for by the underlying cognitive mechanisms, vocabulary, attitude, home literacy environment, and behavioral concerns. While reading performance was based on a multifactorial model, it is important to consider the holistic environment and potential other risk factors that were not specified in the model. It is possible that these factors may be important though other mechanisms (e.g., children with behavioral issues not encoding the reading material taught in class) (Dilnot, Hamilton, Maughan, & Snowling, 2016).

Thus, even though variables included in the models in this study account for a significant portion of the variance in reading performance, there are still other factors, both independent and related to alcohol exposure, that are not fully elucidated that may also influence performance. Many children who have alcohol exposure are often exposed to other substances in utero, including most commonly nicotine. A longitudinal sample of 5,119 school age children divided into three groups of nicotine exposure (high, >17mg/day ~1pack, low ≤17 mg/day, and no exposure) found a relation between high exposure and reading performance (Cho, Frijters, Zhang, Miller, & Gruen, 2013). This corroborates other findings that demonstrate that prenatal nicotine exposure was associated with an increased risk of decreased reading skills after adjusting for confounders/mediators (Anthopolos, Edwards, & Miranda, 2013). Poor decoding of single words and phonological deficits were most apparent, whereas other areas, such as reading speed, were less affected, similar to the results in the current study. The effect of poor performance on decoding measures was most pronounced in children with high levels of nicotine in conjunction with a phonological deficit, suggesting another potential diathesis-stress model in addition to the one seen with heavy prenatal alcohol exposure.

Another variable that was not modeled and is known to be important for reading is genetic predisposition and family risk status of dyslexia (Christopher et al., 2015; Christopher et al., 2016). Unfortunately, it was difficult to assess parental psychopathology or presence of a genetic basis for reading disorders in this study. However, parent reports at the time of testing indicated the rate of learning disorders present in the family was minimal for both groups. Further, studies have found that while family history is important, cognitive predictors such as phonological awareness, rapid automatized naming, and executive skills continue to account for significant variance (Thompson et al., 2015). As a specific learning disorder profile did not emerge in this study, family history of learning disorders may be less relevant in this population.

In the consideration of other cognitive factors, the importance of executive function has also been predictive of academic functioning and reading (Berninger, Abbott, Cook, & Nagy, 2016; Cirino et al., 2016). Results from a recent study found that processing speed contributed to the overlap between reading and attention (as well as math and attention), whereas verbal comprehension contributed to the overlap between reading and math. Specific executive functions were related to specific outcomes (working memory to math, inhibition to attention). However, a study of 229 children with dyslexia found that progress in reading was not affected by executive function and that there was only a small relation between executive function and reading (Walda, van Weerdenburg, Wijnants, & Bosman, 2014). Further studies should assess these relations in alcohol-exposed children, as executive dysfunction is considered a core deficit in this population and may contribute significantly to reading performance as well as performance in other academic domains.

Reading interventions and considerations for FASD

Even in populations with lower IQ, phonological awareness mediates the relation between group membership (typically developing versus intellectual disability) and reading ability, suggesting a similar target for intervention for all individuals struggling with reading (Barker et al., 2013). The importance of phonological awareness has been confirmed in recent studies of children with mild intellectual disability, which found that, similar to typically developing children, phonological processing strongly predicts reading skills (Barker et al., 2013; Channell et al., 2013; Conners, 1992). The underlying cognitive skills (word decoding, vocabulary, language comprehension) and nonverbal reasoning predicted both lower level and higher level reading comprehension in children with intellectual disability and a matched control group (van Wingerden, Segers, van Balkom, & Verhoeven, 2014).

Further, studies in children with fragile X syndrome have also found that phonological awareness was associated with reading outcomes similar to the patterns seen in typical development (Adlof, Klusek, Shinkareva, Robinson, & Roberts, 2015; Klusek et al., 2015). Children with Williams's syndrome often have impaired passage comprehension resulting from underlying deficits in the cognitive abilities of phonological awareness and non-word reading accuracy (Menghini, Verucci, & Vicari, 2004). In spina bifida myelomeningocele, a neurodevelopmental disorder associated with particular problems in math and generally less affected word reading deficits, rapid naming ability mediates the relationship between group and later academic outcomes, suggesting another target for intervention, or at the very least, an understanding of the underlying cognitive mechanisms for reading (Barnes et al., 2014). In children with Down Syndrome, word reading, phonological awareness, and listening comprehension were all significant predictors of reading comprehension both cross-sectionally and over a period of almost two years (Laws, Brown, & Main, 2016). Interestingly, the authors found children with Down syndrome understood fewer written sentences than the typical group, and contrary to prediction, received no advantage from printed sentences than spoken sentences, despite the lower memory load. Children with Down syndrome, similar to children with prenatal alcohol exposure, demonstrate a wide range of performance across cognitive and behavioral domains (Naess, Melby-Lervag, Hulme, & Lyster, 2012). Given that the predictors of reading performance for alcohol-exposed individuals are similar to those for other neurodevelopmental disorders (with similar heterogeneous cognitive and behavioral profiles), interventions targeting these predictors may have success across populations (Allor, Mathes, Roberts, Cheatham, & Champlin, 2010; Hill & Lemons, 2015).

Children with intellectual disability may also require additional time and training with greater scaffolding (Loveall & Conners, 2013), though targeting phonological processing has been shown to improve reading. This may be true as well for children with prenatal alcohol exposure. It is possible that due to the neurocognitive and behavioral effects of prenatal alcohol exposure, the type of instruction and amount of time spent learning the core underlying components of reading, such as phonological awareness, are not enough to solidify the foundational skills to build upon for adequate reading performance. Therefore, alcohol-exposed children may also require additional support in these areas to effectively reach the same reading achievement. Specific phonological training has been found to result in improved decoding ability in children with Down syndrome (Burgoyne et al., 2012; Kennedy & Flynn, 2003); however, not all studies found long-term maintenance of the gains, nor did improvements in decoding necessarily generalize to reading (Burgoyne et al., 2012). When children with Down syndrome were compared to children with other intellectual disability, an additional deficit of impaired verbal short term memory was noted, indicating another target for intervention that was potentially not utilized (Ratz, 2013). Therefore, for children with FASD, it may be important to consider additional cognitive and behavioral concerns related to prenatal alcohol exposure, such as executive function deficits, despite the same underlying mechanisms of reading.

There have been several reviews of interventions for children and adolescents with fetal alcohol spectrum disorders within the past decade (Burd, 2006; Kodituwakku, 2010; Paley & O'Connor, 2011; Peadon et al., 2009). Interventions must consider the cognitive and behavioral impairments that may affect a child’s academic achievement, as both may contribute to deficits in overall functioning

(Jirikowic, Gelo, & Astley, 2010). For example, the selective vulnerability of mathematical functioning to prenatal alcohol exposure has led to the development of promising math interventions. A 15-week, randomized clinical trial found that those in the program demonstrated significant gains in math that persisted over six months and has been successfully disseminated into the community (Kable et al., 2015; Kable et al., 2007). While interventions have continued in other areas of impairment for children with FASD, such as math and social skills, targeted treatments for reading have not yet had widespread dissemination (Kable et al., 2007; Peadon et al., 2009). Despite the general lack of evidence-based interventions for alcohol-exposed children, there have been specific education recommendations that may generally improve academic functioning, which include using a structured environment, providing additional concrete examples, and using repetition (Kodituwakku & Kodituwakku, 2011; Peadon et al., 2009).

Further, there are moderately successful reading interventions that have been implemented in similar populations, as discussed above, in children with mild intellectual disability and in children with ADHD (Forness, Cantwell, Swanson, & Hanna, 1991; Forness, Swanson, Cantwell, & Youpa, 1992; Toplak, Connors, Shuster, Knezevic, & Parks, 2008). Unfortunately, few are based on evidence of precise deficits present in the population, and it is unclear whether they can be effectively applied to children with prenatal alcohol exposure (Rucklidge & Tannock, 2002; Willcutt et al., 2001).

The previous successful efforts in creating evidence-based interventions in other areas for children with FASD by modifying existing programs, such as social skills (O'Connor et al., 2006) and math (Kable et al., 2015; Kable et al., 2007), supports the feasibility of adapting reading interventions to suit the specific needs of affected children.

To date, one literacy intervention program has been conducted in children with FASD. It was conducted in South Africa and produced significant improvement in certain pre-literacy and literacy variables (Adnams et al., 2007). Despite these gains, alcohol-exposed children were still significantly different from controls, demonstrating improvement, but not mastery of the skills. For the underlying cognitive mechanisms related to language and literacy, rehearsal training and neurocognitive habilitation training demonstrated improvement, specifically in working memory span and executive functioning (Loomes et al., 2008).

A recent pilot study (Kerns et al., 2016) advocated for process specific training that leads to meaningful functional improvements. Out of an FASD group of *n*=10, five individuals were receiving academic/behavior support with three having additional speech-language therapy. Further, the range of IQ was from 65–122, emphasizing the heterogeneity of the population. They found significant benefit with a computerized attention task to improve oral word fluency. However, the extent to which these findings are replicated is important, as others have found that targeting only attention or working memory on the computer does not necessarily generalize to school settings (Melby-Lervag & Hulme, 2013). Alternatively, focusing on phonological awareness and processing has been shown to generalize and lead to persistent gains (Alexander, Andersen, Heilman, Voeller, & Torgesen, 1991; Vaughn & Wanzek, 2014).

In other populations, as discussed above, the most effective reading interventions are based on targeting specific deficits in the underlying mechanisms of reading achievement for a population (Ardila, Ostrosky-Solis, & Mendoza, 2000; Fletcher et al., 1996; Fletcher et al., 2002; Foorman & Al Otaiba, 2009; Share & Stanovich, 1995). Even though reading may not be impaired beyond expectations for IQ (Carmichael Olson et al., 1998; Streissguth et al., 2004), there is still potential for effective intervention; children with intellectual disability have achieved successful improvement with targeted interventions (Conners, 1992; Vellutino et al., 2000; Vellutino et al., 1996). Further, IQ scores do not differentiate between poor readers who responded well to intervention and those who did not, are not related to reading outcomes, and are no longer supported in the diagnosis of reading disorders (Ferrer et al., 2010; Fletcher et al., 2011; Vellutino et al., 2004). Phonological processing and rapid naming are more often significantly associated with intervention response (Al Otaiba et al., 2011; Lovett et al., 2000; Vaughn & Fletcher, 2012).

The results in this study indicate that children with prenatal alcohol exposure have the same underlying cognitive mechanisms as other populations. There appears to be converging empirical evidence that phonologically-based approaches can be beneficial in children and adolescents with other developmental disabilities, including Down syndrome, intellectual disability, and autism spectrum disorder (Randel, Adlof, Klusek, & Roberts, 2015). Further, improving reading skills is possible for children with intellectual disability. A longitudinal study found significant gains in reading progress for students with IQ scores between 40–69 with a comprehensive daily reading intervention (Allor et al., 2010), highlighting both the need for comprehensive training and demonstrating the opportunity for reading improvement in children with lower IQ scores. Students with mild to moderate intellectual disability learned basic reading skills when exposed to consistent, explicit, and comprehensive reading instruction (Allor et al., 2010).

A recent paper comparing single case studies of alternate treatments for reading comprehension for students with autism spectrum disorders found that incorporating applied behavior analysis into the typical reading intervention approach was more effective in improving reading comprehension and on task behavior (El Zein, Solis, Vaughn, & McCulley, 2014). Further, a review of 20 studies relating to Down syndrome found that children with Down syndrome rely on phonological awareness skills in learning how to read, which suggests that targeted phonics reading intervention may be beneficial in at least some of these children (Lemons & Fuchs, 2010). In fact, curriculum-based measurement for 38 individuals showed reading growth in some students with intellectual disability when teachers differentiate instruction based on the student's reading ability (Hill & Lemons, 2015). As the IQ profile of FASD is generally equivalent or higher than Down syndrome, this type of targeted interventions may work in the FASD population as well.

The results of this study indicate that the cognitive predictors and effects associated with prenatal alcohol exposure were above and beyond the effects of demographic variables such as attitudes towards reading and home literacy environment. Interventions need to balance the use of environmental modifications and the many additional factors at play with alcohol-affected children (Green, 2007). The heterogeneity of academic, behavioral, and cognitive function in children with FASD makes it extremely difficult to create a one size fits all academic curriculum. For instance, the range of intellectual function in these children is quite broad, and therefore effective interventions must cater to a wide range of abilities. In addition, programs must understand and address the interplay between cognitive, academic, social, emotional, and behavioral challenges. For example, poor performance may be due to behavioral impulsivity or executive dysfunction, both of which are common deficits in FASD. There are other predictors that are correlated with inattentive/overactive behaviors in internationally adopted children (which are overrepresented in the sample used in this study) that indicate that older age at adoption, longer time in the adoptive home, and smaller family size were associated with greater parent-rated difficulties (Helder, Brooker, Kapitula, Goalen, & Gunnoe, 2016). Further, these difficulties were associated with poorer reading performance, expressive language, and adoptive family functioning.

Assessment of school-based services for children with FASD is a burgeoning area of research. In the classroom, a combination of evidence-based interventions may be the most efficacious, as they can target various areas simultaneously. Since 60–

95% of alcohol-exposed children are diagnosed with ADHD (Fryer et al., 2007; Mattson et al., 2011), it may be worthwhile to investigate the feasibility of repurposing existing, empirically supported ADHD interventions or interventions for other populations for use in children with FASD. Unfortunately, the availability of interventions has fallen far below the needs of alcohol-exposed children, and many of these programs are still being studied to assess generalizability, feasibility, and efficacy.

Limitations

While clinically relevant, these results must be considered within the context of several limitations. Data were collected in a cross-sectional manner, limiting the ability to comment on the trajectory of academic functioning or expected outcomes. Further, there were many factors that may influence academic achievement that were not explicitly addressed, including family history of a learning disability. This was collected on parent questionnaires, and only 3 of 31 alcohol-exposed children had a reported first degree relative with a learning disability. However, many responses were unknown or reported for an adoptive parent. This study was able to capture a wide range of contributing factors on both the child level (intelligence, attitudes toward reading, demographic variables, behavioral concerns) and the home level (home literacy environment, SES). However, given the high rate of adoptive and foster care in the alcohol-exposed group and the lack of knowledge regarding psychopathology in the biological parents, there was limited access to genetic or hereditary information.

Further, some of the children in the study have participated in intervention or augmentative classrooms for reading or other academic areas, which may have changed their current level of functioning. In reviewing parent questionnaires, 15 of 31 alcohol-exposed students and 2 of 39 control students were noted as having accessed services such as an independent study, IEP, 504 plan, additional resource time, pull-out, personal aid, or extra help outside of school. While I did not systematically assess the services or quality of the instruction, these are additional factors to consider. However, even with the provision of additional services, alcohol-exposed children continued to perform worse than controls. Further, it is worth noting that only half of the children within the AE group were receiving any additional support at school.

While several studies have found changes in the contribution of specific cognitive mechanisms to reading across development, it was not be possible to break individual groups into different age groups due to sample size limitations. The contribution of age was evaluated by assessing age as a covariate and evaluating correlations; however, this is considered an exploratory study that will need replication in various age groups and using longitudinal data to answer additional questions regarding changes that occur throughout the developmental trajectory. Nonetheless, all scores are age-normed to facilitate interpretation.

As diminished intellectual ability is repeatedly reported in FASD populations, there is a potential for floor effects. Outliers were removed from both groups if they had IQ scores greater than three standard deviations from the mean (SS=100) to protect against ceiling or floor effects. It is not appropriate to covary for IQ for a variety of statistical and methodological reasons, including reduced generalizability, non-representativeness, and overcorrected results (Dennis et al., 2009). Importantly, IQ does not appear to affect response to intervention in general; rather, there has been a general uncoupling of reading and IQ (Ferrer et al., 2010). Research has supported this separation (Fletcher et al., 2011; Gresham & Vellutino, 2010). However, there was significant relation between IQ and reading ability, as expected. Further, while a potential speech or language delay was not accounted for explicitly, expressive vocabulary (PPVT) was included in the models and contributed significantly (and group remained significant).

Only children with histories of heavy prenatal alcohol exposure were assessed. Some studies have found that low to moderate alcohol exposure during pregnancy was not associated with poorer language development, therefore additional research is needed to full understand the dose-response relationship between exposure and performance. Currently, the national and international consensus is that there is currently no safe level of alcohol exposure for development, and the general convention is to advise abstinence from alcohol during pregnancy.

Implications and future directions

These data suggest that children with histories of heavy prenatal alcohol exposure perform significantly worse than their peers on reading and related measures. The underlying cognitive mechanisms of reading abilities are the same in other typically developing children and other children with developmental disabilities.

Therefore, there is reason to believe that evidence-based interventions targeting the specific underlying mechanisms may be effective for children with prenatal alcohol exposure. However, is also important to consider the full neurobehavioral profile in advocating for, evaluating, creating, and implementing interventions.

Children with heavy prenatal alcohol exposure are likely to have an especially complex set of factors contributing to educational attainment from higher likelihoods of history of abuse, foster care or adoptive care, and a distinct, yet heterogeneous neurobehavioral profile. As the majority of children with FASD are enrolled in general education classrooms (Boys et al., 2016; Howell et al., 2006), it is recommended that these children receive a thorough, comprehensive evaluation to uncover potentially 'invisible' special needs that may be missed or misinterpreted that can be incorporated into an effective educational plan. In a recent study, it was found that approximately 50% of alcohol-exposed children had difficulty in academics (Boys et al., 2016), demonstrating minimal improvement in over 25 years from previous studies (Streissguth et al., 1991; Streissguth, Barr, Carmichael Olson, et al., 1994; Streissguth, Barr, Kogan, & Bookstein, 1997).

A recent interagency collaboration suggested several areas for improving educational outcomes, including: FASD awareness and education in schools; understanding FASD as a comorbid disorder ideally in the context of a medical diagnosis similar to acquired brain injury; FASD specific interventions including collaboration between clinicians and school psychologists; advocacy for children with

FASD; conducting a full neuropsychological assessment; and continuing interagency collaboration (Boys et al., 2016).

Further, just as it may be helpful to utilize knowledge of reading intervention from other developmental disabilities, it is also worthwhile to utilize the knowledge gained from the development of other interventions for children with prenatal exposure (Kable et al., 2015; Kable et al., 2007). This study was the first to simultaneously evaluate various theoretically supported predictors of decoding, fluency, and comprehension in alcohol-exposed individuals. However, replication is required in larger samples, which would also allow for the assessment of potentially differential contributing factors for adequate readers versus struggling readers.

Conclusion

Children with prenatal alcohol exposure perform worse on reading and related cognitive measures relative to their peers, with a distinct profile of strengths and weaknesses. Further, a history of prenatal alcohol exposure was significantly associated with reading above and beyond the performance on the core cognitive predictors of reading, vocabulary, attitude towards reading, and behavioral concerns. The factors that contribute to reading performance in alcohol-exposed children are similar to the factors important for reading in both typically developing children and children with other neurodevelopmental disorders. As reading interventions targeting these underlying mechanisms of reading performance have been effective in other populations, there is hope that they can be adopted to improve outcomes for alcohol-exposed children.

Chapters I, II, III, and IV, in part, are currently being prepared for submission for publication of the material and will be co-authored by Sarah N. Mattson. The dissertation author was the primary investigator and author of this material.

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