**University of Alberta**

*Mathematics and Working Memory Development in Children with*

*Fetal Alcohol Spectrum Disorder*

by

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requirements for the degree of *Doctor of Philosophy*

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Dedication

I would like to dedicate this project to all the families and children with Fetal Alcohol Spectrum Disorder (FASD) who participated in this project, to the many children with FASD with whom I have worked over the years, and to all other children who, each day, courageously tackle the lifelong challenges of this preventable disability.

Abstract

Children with FASD often have significant deficits in mathematics and working memory. Understanding these deficits is important for enhancing our knowledge of how children with FASD develop and might improve their functioning. The goal of this study was to examine mathematics and working memory in younger (4 to 6 years of age) and older (7 to 9 years) children with FASD. Children completed standardized tests of mathematics and working memory as well as simple arithmetic problems presented verbally and nonverbally. It was expected that children with FASD would have deficits in mathematics and working memory, but I also examined whether distinct pattern of strengths and weakness emerged and whether performance differed with age. Because children with FASD have deficits in working memory and because in other children working memory has been implicated in math performance, it was expected that the math difficulties common in FASD may be related to underlying deficits with working memory. Finally, I wanted to determine what types of representation children with FASD appear to be using to solve arithmetic problems. Children with FASD displayed deficits on many components of mathematics. Quantitative concepts appear to be a significant area of difficulty for older children with FASD, and older children performed worse, relative to the norm, than younger children on the quantitative concepts subtest. The children also showed difficulties on many aspects of working memory, and a distinctive working memory profile emerged, with performance being lowest on the central executive components of working memory but quite high on recall of words and nonwords. Nonword recall may be specific area of relative strength for young children with FASD. Working memory measures were highly correlated with many of the math

subtests, indicating that working memory deficits may be an underlying factor in the math deficits common in FASD. The results of this study have implications for assessment, instruction, and intervention with children with FASD. Identifying areas of specific difficulty as well as factors related to the mathematics deficits is the first step toward enhancing the academic, and specifically mathematics, development of children with FASD.

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# CHAPTER I

# INTRODUCTION

Children with Fetal Alcohol Spectrum Disorder (FASD) face many challenges, including deficits in cognitive, physical, behavioral, emotional, and/or social functioning. The cognitive deficits of FASD are not fully understood, and exploring these deficits is invaluable for enhancing our knowledge of the neuropsychological sequelae of these individuals and, ultimately, for improving diagnosis and treatment. Mathematics has been identified as a particular area of weakness for children with FASD. However, little is known about *why* children with FASD have such difficulty with mathematics. In the present research I sought to determine whether there are certain components of mathematics that are particularly difficult for children with FASD and whether these math difficulties may be related to underlying deficits with working memory. Further, I examined how children with FASD solve mathematics problems and specifically what types of models of representation they appear to use to solve arithmetic problems. The findings of this study are essential for determining why children with FASD are having such difficulty with mathematics and thus have implications for how these mathematics difficulties might be ameliorated with instruction.

## *History and Incidence of FASD*

Fetal Alcohol Syndrome (FAS) was first identified in 1973 by Jones and Smith. Recognition was based on case studies (Jones, Smith, Ulleland, & Streissguth, 1973) in which researchers noted a similar pattern of malformations among infants born to alcoholic mothers. In France, Lemoine and colleagues (1968) noticed similar damage to offspring of alcoholic parents, although concerns about maternal alcohol consumption date as far back as 1899 by Dr. Sullivan, who noted that maternal intoxication among mothers in prison resulted in damage to fetuses and stillbirths (cited in Streissguth, 1997). Published research on FASD began in the late 1970s and 1980s and is proliferating today. However, FASD, as compared to many other developmental disorders (e.g., autism, Down syndrome), is still a relatively "new" disorder and there are still many questions that are yet to be answered.

The worldwide incidence of FAS in the general population has been estimated at .97/1000 births (Abel, 1995) although estimates may be highly variable across different countries. In a population-based Seattle study, Sampson et al. (1997) estimated the incidence of FAS to be 3/1000 births, with the combined occurrence of FAS and Alcohol Related Neurodevelopmental Disorder (ARND) to be 1/100 births. Although there are no official statistics on the prevalence of FASD in Canada, Health Canada has estimated the rate to be 9/1000 births (AADAC, 2004). FAS is the most common known cause of mental retardation and occurs more often than the two most common birth defects (Down syndrome and spina bifida) combined (National Institute of Alcohol Abuse and Alcoholism, 1990). Yet, FAS is one of the only causes of mental retardation that is clearly preventable. FASD puts an enormous cost on society, with a devastating economic impact (Abel & Sokol, 1991).

*Diagnosis and Classification*

Prenatal alcohol exposure can lead to a range of outcomes including FAS, partial FAS, and ARND. These diagnostic outcomes fall under the umbrella term Fetal Alcohol Spectrum Disorder (FASD). The term FASD is not intended for use as a clinical diagnosis, but it is an umbrella term used to describe the full range of outcomes observed among individuals with prenatal alcohol exposure. Three criteria have been identified to diagnose FAS: (1) growth deficiency in weight and/or height; (2) facial features that may include short palprebal fissures, smooth philtrum, thin upper lip, flat midface, and short nose; and (3) damage to the central nervous system (CNS) (Clarren & Smith, 1978; Sokol & Clarren, 1989). CNS dysfunction may include microcephaly, cognitive deficits, learning problems, attentional difficulties, hyperactivity, and motor problems (Streissguth, 1997). A history of prenatal alcohol exposure is also required.

The term Fetal Alcohol Effect (FAE) has been used to describe children who do not have all the characteristics of FAS (namely absence of some or all facial features and/or lack of growth deficiency) but still have prenatal alcohol exposure and some CNS dysfunction. (Clarren & Smith, 1978). In 1996, the Institute of Medicine (IOM) (Stratton et al.) differentiated between five different types of prenatal alcohol effects: FAS with and without confirmed alcohol exposure, as well as partial FAS, ARND, and Alcohol Related Birth Defect (ARBD). Partial FAS includes those with confirmed maternal alcohol exposure, evidence of some facial characteristics, and either growth, CNS deficits, or a complex pattern of behavioral or cognitive abnormalities. ARBD refers to individuals with some congenital physical abnormalities and a history of maternal alcohol exposure. Lastly, ARND includes those with CNS deficits or a complex pattern of behavioral or cognitive abnormalities, as well as a history of maternal alcohol exposure.

Shortly after the IOM report the Fetal Alcohol Syndrome Diagnostic and Prevention Network (FAS DPN) 4-digit coding system was developed at the University of Washington (Astley & Clarren, 1999). This system ranks diagnostic information in the areas of growth deficiency, facial phenotype, brain dysfunction, and alcohol use. The magnitude of expression of each diagnostic feature is ranked independently on a 4-point scale, with 1 reflecting complete absence of the FAS feature and 4 reflecting a strong "classic" presence of the FAS feature. More recently, in Canada Chudley et al. (2005) are now recommending a multidisciplinary approach to diagnosis harmonizing the IOM classifications and the 4-Digit Diagnostic Code approaches.

Few children prenatally exposed to alcohol actually show all the facial features and growth deficiency required to diagnose FAS. This finding can result in many false negatives, in that affected individuals with prenatal alcohol exposure but who do not have the facial characteristics may not be identified (Sampson, Streissguth, Bookstein, & Barr, 2000). Further, Streissguth and O'Malley (2000) noted that face-based diagnoses may be problematic because it is not the face that needs services. In fact, the FAS face is the result of alcohol exposure during a very short period of vulnerability during pregnancy. In mice, there is a highly specific window in gestation (day 7) during which alcohol exposure must occur in order to produce facial features of FAS, a period that corresponds roughly to early during the first trimester in humans (Sulik, Johnston, & Webb, 1981). Streissguth and O'Malley (2000) suggested that the FAS face is not a good marker for children exposed outside this period in gestation, nor is it a good marker for adolescents or adults becuase these facial characteristics may diminish with age. Further, they note that and unlike the face, the brain may be vulnerable to the effects of alcohol throughout the entire pregnancy. Ultimately, Chudley et al. (2005) suggested that "in the wide array of FASDs, facial dysmorphology is often absent and, in the final analysis, has little importance compared with the impact of prenatal alcohol exposure on brain function" (p. 56).

Mattson et al. (1998) compared children with FAS to those prenatally exposed to alcohol without full FAS and found similar neuropsychological deficits among both groups, regardless of whether the children had the physical features of FAS. Individuals with FAS and FAE also do not show meaningful differences on tests of cognitive abilities, secondary disabilities, and behavioral problems (Sampson et al., 2000). In fact, Conner and Streissguth (1996) suggested that CNS deficits in FAE may be as severe as, or even worse, than in individuals with FAS. Thus, diagnosis should focus on CNS deficits, a direction that has strong implications for future research because there is an increased need to identify the unique neuropsychological profile of these individuals or among subsets of individuals to determine precise diagnostic criteria.

Children with FASD also may exhibit structural and functional brain damage (see Streissguth, 1997 for a review) and many primary neuropsychological deficits as well as secondary disabilities. Secondary disabilities include mental health problems, trouble with law, confinement, alcohol and drug abuse, and dropping out of school (Streissguth, 1997). Neuropsychological impairments in individuals with FASD include deficits in executive functioning (Rasmussen, Witol, & Horne, 2005; Rasmussen & Bisanz, 2005a; Rasmussen, 2005), memory, attention, visual-spatial abilities, declarative learning, planning, cognitive flexibility, and processing speed (Carmichael Olson et al., 1998). Relative to other individuals, children with FASD also tend to have a lower IQ, achievement deficits, and learning problems (Streissguth et al., 1994a), as well as language and motor delays (for a review see Mattson & Riley, 1998).

*Mathematics in Individuals with FASD*

Mathematics has been identified as a specific area of difficulty for individuals with FASD. Streissguth and colleagues (1994a) published a longitudinal, prospective, population-based study on over 500 offspring selected from 1529 pregnant women. Approximately 250 of the mothers were classified as heavier drinkers and about 250 as infrequent drinkers or as abstaining from alcohol, based on maternal report of alcohol use during mid-pregnancy. Children were tested during and at 4, 7, 11, and 14 years of age with papers being published at all ages. Children were assessed on a number of outcome variables including IQ, academic achievement, neurobehavioral ratings, cognitive and memory measures, and teacher ratings, among other measures. Not all measures were administered at all ages. The effects of prenatal alcohol exposure on the various outcome variables were analyzed while controlling for many confounding variables such as maternal drug use (including nicotine), maternal nutrition, socio-demographic and familial education, and other life stresses.

At age 4 years, Streissguth, Barr, Sampson, Darby, and Martin (1989) found that the arithmetic subtest of the Wechsler Preschool and Primary Scales of Intelligence (WWPSI) was most highly correlated with prenatal alcohol exposure of all the verbal subtests. Similarly, at 7 years, arithmetic was the subtest most related to prenatal alcohol exposure on the Wide Range Achievement Test (WRAT) and was one of two subtests (the other being digit span) most affected on the WISC-R (Streissguth, Barr, & Sampson, 1990). Carmichael Olson, Sampson, Barr, Streissguth, and Bookstein (1992) looked at the relation between prenatal alcohol exposure and academic functioning at age 11 and found that of all the national achievement tests scores (arithmetic, reading, language, spelling), arithmetic was most related to alcohol exposure. Finally, at age 14 the arithmetic subtest of the WISC-R was again most salient for prenatal alcohol exposure (Streissguth et al. 1994b). Furthermore, 91% of the children with heavy prenatal alcohol exposure who performed poorly on arithmetic at age 7 were still low at age 14, highlighting the stability and robustness of this finding. In their final paper Streissguth et al. (1994a) highlighted the recurrent finding that arithmetic is especially difficult for individuals with FASD. It is important to note that in these studies potential confounding variables were controlled, effects were generally dose dependent, and for older children maternal binge drinking appeared to be most related to lower arithmetic performance.

In a related view, Goldschmidt, Richardson, Stoffer, Geva, and Day (1996) examined the relation between prenatal alcohol exposure among mothers who reported drinking heavily while pregnant and academic achievement of offspring at 6 years of age using the WRAT-R. The authors found that drinking during the second trimester predicted difficulties in reading, spelling, and arithmetic accounting for 18%, 20%, and 26% of the variances, respectively. These effects were significant even after controlling for covariates including other prenatal and postnatal drug use, maternal psychosocial characteristics, maternal sociodemographic characteristics (i.e., education, income), family arrangement, and other child characteristics. Furthermore, after controlling for IQ, prenatal alcohol exposure was still significantly related to arithmetic but only marginally related to reading and spelling. Lastly, it was found that alcohol exposure had a threshold relation with reading and spelling (approximately 1 drink/day) but a linear dose-dependent relation with arithmetic. Similarly, Jacobson et al. (1998) found specific arithmetic deficits in children moderately exposed to alcohol, despite having an average IQ.

Coles et al. (1997) compared 7-year-old children with FASD, Attention-Deficit Hyperactivity Disorder (ADHD), and control children on various cognitive and achievement measures. The authors found that arithmetic was one of the measures that differentiated children with FASD from those with ADHD, in that children with FASD showed deficits in arithmetic relative to controls and children with ADHD did not. In another study, Coles et al. (1991) examined the cognitive and academic abilities of children aged 5 to 9 years from three groups: a control group not exposed to alcohol; a group whose mothers stopped drinking during the second trimester; and group whose mothers drank throughout the pregnancy. Of the achievement subtests (faces/places, math, riddles, reading/decoding) from the Kaufman Assessment Battery for Children (K-ABC), math was the lowest score among both the alcohol exposed groups, but not the control group. In addition, the control group performed significantly better than both the alcohol exposed groups on math but only scored higher than the group prenatally exposed throughout the entire pregnancy on the reading subtest. Hence, children with FASD display deficits in math relative to other achievement measures, and math is the only achievement measure affected in individuals exposed to lower doses of alcohol.

Arithmetic deficits have also been documented in adults with FASD. Streissguth et al. (1991) found that adolescents and adults with FAS performed the poorest on the arithmetic subtest of the WRAT-R, with participants on average scoring at the second grade level for arithmetic, third grade for spelling, and fourth grade for reading. Furthermore, adults with FAS both with average and below average IQ have been found to score lowest on the arithmetic subtest of the WRAT-R, and only arithmetic scores were lower than predicted based on IQ (Kerns et al., 1997).

Kopera-Frye, Dehaene, and Streissguth (1996) specifically examined number processing in adults (aged 12 to 44) with FASD and control participants matched on age, gender, and education level. Participants were tested on number reading, writing, and number comparison tests where participants were to circle the larger of two numbers. They also completed exact and approximate calculation of addition, subtraction, and multiplication. On the proximity judgment test the participants circled one of two given numbers that was about the same quantity as the target number (e.g., 15: 17 or 27). Lastly, the participants completed a cognitive estimation test in which they were presented with questions for which they had to provide a reasonable estimate, such as "what is the length of a dollar bill?" or "how heavy is the heaviest dog on earth?" Before testing judges determined what would be the acceptable range for guesses.

The group with FASD made significantly more errors than the controls on cognitive estimation, proximity judgement, exact calculation of addition, subtraction and multiplication, and approximate subtraction. Furthermore, the highest number of participants was impaired on cognitive estimation, followed by approximate subtraction. Although the FASD group tended to answer with the correct units of measurement (feet, pounds) on the cognitive estimation test, their range of answers was far broader than those of the controls. For example, one participant answered 5 feet for the length of a dollar bill. Hence, despite having intact number reading, writing, and comparison skills, the participants displayed deficits in many other areas of number processing, particularly calculation and cognitive estimation. The authors cited research indicating that the frontal lobe is involved in cognitive estimation. Kopera-Frye et al. (1996) suggested that perhaps impairments in exact calculation may be related to left frontal lesions and impairments in cognitive estimation to right frontal lesions. Using a similar math battery with 13-year-olds, Jacobson et al. (2003) found prenatal alcohol exposure to be related to exact addition, subtraction, and multiplication, approximate subtraction and addition, and proximity judgment and number comparison. Two main factors emerged: calculation (exact and approximate) and magnitude representation (number comparison and proximity judgment). Thus it appears that the math deficits evident in FASD may be in two different areas, one relating more to calculating and the other involved in estimation and magnitude representation.

Similar to other areas of research in FASD, little research has been conducted on math abilities in preschool children prenatally exposed to alcohol. In another study, however, Kable and Coles (2003, April) looked at the relation between prenatal alcohol exposure and math and reading outcome measures in 4-year-old children. Over 500 children were assessed, including a high-risk (high alcohol exposure) and low-risk (low alcohol exposure) groups based on maternal report of prenatal alcohol exposure. The authors found that after controlling for birth weight and gestational age, income and maternal resources, child's school involvement, academic stimulation in home, child's IQ, maternal pathology, and smoking, the high-risk group performed significantly lower than the low risk-group on math but not reading.

Innovative research by Riikonen, Partanen, Salonen, and Verho (1999) has examined specific brain areas involved in mathematics in children with FAS. The authors used MRI and SPECT to locate areas of brain abnormality in 11 children (ages 3 to 7 years) with FAS. All but one of the participants showed deficits in arithmetic performance. The authors found hypoperfusion (decreased blood supply) to the left parietoccipital area. More generally the left parietal region has been implicated in mathematical thinking and calculation (Whalen, McCloskey, Lesser, & Gordon, 2002). Riikonen et al. concluded that abnormalities in this area of the brain might lead to the mathematical deficits common in FAS, although further research would be needed to substantiate this claim.

Thus there is ample evidence indicating that individuals with FASD have specific deficits in math and particularly arithmetic. These findings have been consistent across a multitude of both longitudinal-prospective studies and group comparison studies, even after controlling for many confounding variables and IQ. However, in much of this research arithmetic was not the focus of the research and conclusions were usually based on the arithmetic subtest of the WISC-R and WRAT-R. Because on these standardized tests only accuracy is typically examined, we do not know much about how the children are solving the problems and, particularly, what aspects of the problems are difficult for individuals with FASD. The arithmetic deficits are well documented and the next step is to ascertain why math is such a salient area of weakness in FASD. One way to answer the question of why children with FASD do so poorly in mathematics is to examine the profile of strengths and weakness they show in mathematics. Identifying particular types of math problems or even general areas of math (e.g., calculation, pattern recognition, problems solving, using formula etc.) that are difficult for children with FASD is the first step toward modifying instruction to improve performance in these areas. Few, if any, researchers have examined such profiles in math among young children with FASD.

Furthermore, identifying these profiles is important for understanding the underlying psychology that generates the unique patterns. Understanding how children with FASD think, learn, represent, and process mathematical information will enhance our understanding of the cognitive elements of this disorder and will also enhance our teaching techniques. We also do not know how math abilities develop in children with FASD. Identifying the development of their math skills is essential for understanding what math skill sets they start out with and whether these skills appear to develop with age as in non-FASD children, or whether children with FASD develop slower thus falling further behind their peers with increasing age.

*Working Memory, Executive Functioning, and Mathematics*

Baddeley and colleagues have defined working memory as a three-component system used for short-term storage and manipulation of information required for diverse cognitive tasks (Baddeley, 1992; Baddeley & Hitch, 1974). The *visuospatial sketchpad* is for holding and manipulating visual-spatial information, and the *phonological loop* is for maintaining and rehearsing verbal information (Baddeley, 1992). The *central executive*, an attentional controlling system, is involved in planning, selective attention, set shifting, and inhibition (Baddeley, 1996). Baddeley's three-component model of working memory has been supported in many studies with adults and more recently in a large-scale study in children aged 6-15 years (Gathercole, Pickering, Ambridge, & Wearing, 2004).

Executive functioning has been defined as higher-order cognitive processes involved in goal-oriented behaviour including planning, organized search, inhibition, working memory, set shifting, flexible thinking, strategy employment, and fluency (Welsh & Pennington, 1988; Welsh, Pennington, & Grossier, 1991). Some researchers define working memory as a component of EF, whereas others define the central executive component of working memory as involving EF processes. In this paper, I will refer to the central executive component of working memory as involving some EF process, but it certainly does not involve all the EF processes. There is evidence indicating that children and adults with FASD have deficits in EF (Mattson, Goodman, Caine, Delis, & Riley, 1999; Rasmussen 2005; Schonfeld, Mattson, Lang, Delis, & Riley, 2001) and working memory (Carmichael Olson et al., 1998; Kodituwakku, Handmaker, Cutler, Weathersby, & Handmaker, 1995; Streissguth et al. 1990). In fact, Burden, Jacobson, Sokol, and Jacobson (2005) found that working memory was the aspect of attention that was most negatively affected by maternal alcohol consumption. Kable and Coles (2003, April) suggested that EF and working memory deficits may account mathematical difficulties in children prenatally exposed to alcohol. Similarly, Kopera-Frye et al. (1996) suggested that mathematics performance in FASD may be related to frontal lobe (EF) functioning and specifically that the left frontal lobe may be implicated in exact calculation and the right frontal lobe may be implicated in cognitive estimation.

Linking working memory and EF to math performance is common in the literature on children's math development. There is ample evidence implicating all three components of working memory to mathematics performance in both children and adults (Adams & Hitch, 1997; Furst & Hitch, 2000; Logie, Gilhooly, & Wynn, 1994; Swanson, 1994). In children, math disabilities are linked to deficits on measures of the visual-spatial working memory and the central executive (Gathercole & Pickering, 2000a; Geary, Hoard, & Hamson, 1999; McLean & Hitch, 1999; Siegal & Ryan, 1989). Children who are poor at mathematics problem solving are also impaired on the three components of working memory (Passolunghi & Siegel, 2001; Swanson & Sachse-Lee, 2001). Gathercole and Pickering (2001) found that students with special educational needs (learning difficulties) were impaired on many working memory measures (particularly the central executive) and they concluded that poor working memory abilities may be an important factor resulting in academic delays. EF also predicts performance in mathematics. Bull and Scerif (2001) found that among 7-year-olds mathematics performance was related to EF performance on the WCST, Stroop task, and the counting span (a measure of the central executive component of working memory). The authors concluded that children of low mathematical skill have significant difficulty inhibiting information and learned strategies, and maintaining information in working memory.

Despite the documented EF, working memory, and math deficits in FASD and a multitude of research implicating EF and working memory in mathematics, *no researchers have examined the relations among EF, working memory, and math in FASD*. In light of evidence that math difficulties in typically developing children may arise from working memory and EF deficits, I propose that EF and particularly working memory deficits may be related to mathematical deficits common in FASD. Thus, in this study I examined mathematics and working memory development in preschool and early elementary children with FASD. Research in this area is imperative for gaining insights into the nature of math difficulties in FASD as well as for understanding individual differences in math. It is proposed that working memory and executive processes are important for mathematics as the child must remember and manipulate numbers, solve problems, and retrieve answers, which would place special demand on working memory.

Perhaps some areas of math involving concepts, pattern recognition, problem solving, and reasoning would demand the executive components of working memory than simply calculation, which would presumably involve more rote memory and retrieval. Research with preschool children is particularly important because very little is known about mathematics development in preschoolers with FASD. Such knowledge may provide important insights into the origins of math deficits.

*Mental Model of Arithmetic*

Identifying factors like working memory that may be related to math deficits in children with FASD is one important way to advance our understanding of why children with FASD have such difficulty in math. Another method is to examine how the children are representing arithmetic information. One model of arithmetic representation that has been proposed among preschool children is a mental model of arithmetic. Preschool children perform much better when arithmetic problems are presented nonverbally than verbally, but this difference is negligible for school age children (Jordan, Huttenlocher, & Levine, 1992; Levine, Jordan, & Huttenlocher, 1992; Rasmussen & Bisanz, 2005). One explanation for this consistent pattern of results is that preschool children solve nonverbal problems using a mental model (Huttenlocher, Jordan, & Levine, 1994). When using a mental model, a child forms a visual representation of the problem in which internal tokens are mapped onto external objects. Children then imagine tokens being added to or subtracted from this internal representation. Nonverbal problems are much easier to encode and solve using a mental model than verbal problems because they involve external objects that can easily be visualized. The representations and processes involved in a mental model may be readily available to preschool children, whereas verbal problems require conventional arithmetic skills and symbols that are not so readily available. Rasmussen and Bisanz (2005) also found that preschoolers performed much better on nonverbal than verbal arithmetic problems and that performance on nonverbal problems was best predicted by measures of visual-spatial working memory, indicating the use of a mental model of arithmetic. Thus, the use of mental models in preschool children appears to depend on visual spatial working memory. In contrast, school age children performed equally well on nonverbal and verbal problems, and performance on the verbal problems was best predicted by phonological working memory. In both groups, problems with added irrelevant information were the most difficult and in some cases were predicted by the central executive component of working memory.

*Issues to Be Explored*

In the present study younger (aged 4-6 years) and older children (aged 7-8) children with FASD were assessed on tasks measuring the three components of working memory, tests of mathematics calculation and reasoning, and verbal and nonverbal arithmetic problems both with and without added irrelevant information as used in Rasmussen and Bisanz (2005). Three main issues are addressed. The first is whether children with FASD show mathematics and working memory deficits that distinguish them from the non-FASD population in terms of average performance, profiles of relative strengths and weaknesses, and age-related differences. I assessed how children with FASD compare to population norms on standardised tests of mathematics and working memory. This comparison is important for determining whether our sample does indeed show working memory and mathematics deficits as evident in other research. I also wanted to determine whether these deficits were specific to mathematics and not to other cognitive areas (e.g., picture vocabulary). Next I examined profiles of strengths and weaknesses in WM and math in young children with FASD, which is important for identifying particular areas of weakness that may be refined with instruction. Examining profiles is also important to demonstrate the cognitive underpinnings of such patterns, thus enhancing our understanding of the how children with FASD learn but also for how to better teach them. Further, I made age-related comparisons to determine whether there were age differences (relative to the norm) in mathematics and working memory skills. This comparison is important for determining the developmental trajectory of these deficits, as some skills may improve with age, or some skills may even worsen with age.

The second issue is whether working memory is related to mathematics performance in children with FASD. This issue was addressed by examining correlations between the working memory and mathematics batteries. Identifying whether working memory is related to math deficits and whether it is an underlying factor in math development provides insights into *why* children with FASD have difficulties in math and also what types of mathematics problems are most difficult. If working memory is found to be a factor in math development in children with FASD, this finding could provide insights about the psychological processes that are evoked when children with FASD do mathematics. Further, this finding could have important implications for how to best teach mathematics to children with FASD. Perhaps some working memory abilities can be strengthened by teaching children strategies for rehearsing and retaining information. Also decreasing the working memory demand of arithmetic problems may be beneficial for children with poor working memory abilities.

The third issue is how children with FASD represent information in arithmetic problems at different ages. Specifically, I examined whether different components of working memory are differentially related to performance on various arithmetic problems (nonverbal/verbal and standard/irrelevant) and whether there are age-related differences in these relations as found in Rasmussen and Bisanz (2005). This comparison is important for determining whether preschool children with FASD show evidence of using a mental model and whether children in early elementary school appear to use a more verbal or phonological approach as found in Rasmussen and Bisanz (2005). Examining model use in children with FASD is particularly important for determining whether preschool children with FASD begin learning mathematics with the same mental model as in typically developing children, a model that may provide the bases for development of arithmetic skills. Moreover, by also studying children in preschool and Grades 1 and 2 we can learn a great deal about the development of arithmetic from preschool to early elementary school when children begin to use symbols, as it may be the symbolic nature of mathematics that is particularly difficult in FASD.

No control group was used in this study. There are many reasons for this choice. First, there is a significant amount of research clearly indicating that children with FASD display deficits in mathematics relative to control groups and norm samples, but we wanted to study the *nature* of these deficits and learn about is how mathematics develops in children with FASD. The questions about age-related differences in the relations among working memory and arithmetic and about different models of representation in mathematics can all be answered without a control group. Because standardised tests of working memory and mathematics were used, we also can examine how the children compare to the norm on a variety of working memory and arithmetic measures, which will provide valuable contextual information on their functioning relative to other children and on their profile of skills and weaknesses. Further, comparisons can be made to the results of Rasmussen and Bisanz (2005) in terms of comparing general performance level and patterns of correlations. Second, it is very difficult to find an appropriate control group for children with FASD. Children with FASD typically have many other negative life factors (living in foster homes, lower SES, lower IQ, minority group status, etc.) that are very difficult to match. Even if we were to match on some of these factors, matching on some variables may result in unmatching on other variables (Stigler & Miller, 1993). For instance, if we matched both groups on IQ there may be other factors among the control group that may have resulted in a low IQ and we may not be matching on these other potentially meaningful variables. Hence, the control group itself may not be representative of the general population, because of their low IQ, making it difficult to make meaningful generalizations. Also, it is difficult to make causal interpretations in matching studies (Stigler & Miller, 1993).

# CHAPTER II

# METHOD

Children were tested on the WJ-III arithmetic and picture vocabulary subtests, WMTB-C, as well as verbal and nonverbal arithmetic tasks. All tests were conducted in one session lasting about two hours. Children were given breaks whenever needed. Some children were unable or unwilling to complete some of the measures. During testing the parent/guardian completed the BRIEF. Data were also obtained when possible from the child's medical files, including their IQ score, FASD diagnostic results, and demographic information.

*Participants*

We tested 32 children (14 males and 18 females) all with of FASD. All participating children had received a medical diagnosis of an alcohol-related disorder falling under the umbrella term FASD (ARND, FAS, Neurobehavioral Disorder: Alcohol Exposed, Static Encephalopathy: Alcohol Exposed). Of these children, 22 were in the younger (preschool) age group with a mean age (in years;months) of 5;6 (range 4;6 to 6;10) and 10 were in the older (Grades 1 and 2) group with a mean age of 7;10 (range 7;0 to 9;2). IQ scores obtained from the medical files were available for 21 of the children. The average IQ was 82.0 (with a standard deviation of14.8), as measured with the Wechsler Intelligence Scales for Children-Third Edition, Wechsler Preschool and Primary Scale of Intelligence-Revised, McCarthy Scales of Children's Abilities, or Bayley Scales of Infant Development.

The children were recruited though the Glenrose Rehabilitation Hospital FASD clinic, other medical FASD diagnostic clinics, First Nations communities, and various

FASD community agencies. Twenty-five of the children were reported (by guardian or parent) to be Aboriginal (referring to Canadian First Nations, Inuit, or Metis), 2 Caucasian, and 5 of other ethnicities. At the time of the study 5 children lived with their biological mother, 2 with their biological father, 3 with a grandparent, 16 with a foster parent, and 6 with an adoptive parent.

*Materials and Procedures*

*Working Memory Test Battery for Children (WMTB-C).* The WMTB-C (Gathercole & Pickering, 2001) includes four measures of the phonological loop (digit recall, word list matching, word list recall, and nonword list recall), two measures of visual-spatial working memory (block recall and mazes memory), and three measures of the central executive (listening recall, counting recall, and backward digit recall). Some subtests do not have norms for children under age 6, so these subtests were not administered to the children in the younger group. Thus children in this group were tested on the digit recall, word list matching, word list recall, nonword list recall, block recall, and backward digit recall. Those same subtests, as well as the mazes memory and counting recall, were administered to the older group. None of the children were administered the listening recall test due to time constraints and demands on the children. Each subtest yields a standard score with a mean of 100 and standard deviation of 15.

The WMTB-C has been validated against existing well-established tests of achievement (Gathercole & Pickering, 2001). In children, all the measures of phonological working memory correlate strongly with and load on the same factor (Gathercole & Pickering, 2000b). The digit recall has a test-retest reliability of .81 (Gathercole et al., 2004) and .68 with 4- to 5-year-olds (Gathercole, 1995). The test-retest reliabilities are .55 for nonword list recall and .72 for word list recall (Gathercole et al., 2004). For the measures of visual spatial working memory the block recall and mazes memory tests have test-retest reliabilities of .53 and .62, respectively (Gathercole et al., 2004). In 6- and 7-year-old children, all of the central executive measures correlate strongly with and load on the same factor (Gathercole & Pickering, 2000b). Listening recall has a test-retest reliability of .62, and backward digit span has been reported to have a high split-half reliability (Gathercole & Pickering, 2000b) and a test-test reliability of .62 (Gathercole, et al., 2004). Counting recall has a test-retest reliability of .62.

*Woodcock-Johnson-III (WJ-III) Test of Achievement Mathematics Test.* The mathematics test four subtests: (1) calculation, which consists of math calculation and math fact problems that the child solves on a worksheet; (2) math fluency, in which children must answer basic addition and subtraction problems on a worksheet as fast as they can; (3) applied problems, which measures the ability to analyze and solve math problems; and (4) quantitative concepts, which involves identifying math terms, formulas, sequences, and number patterns. Each test yields a separate standard score with a mean of 100 and standard deviation of 15. There are no norms on the calculation and math fluency subtest for under the age of 6 so these two subtests were not administered to most members of the younger group.

*Woodcock-Johnson-III (WJ-III) Test of Achievement Picture Vocabulary.* On this task children are asked to name pictured objects ranging from common to less common. Performance is converted into a standard score with a mean of 100 and standard deviation of 15.

*Arithmetic problems.* Children completed arithmetic problems, presented in two different conditions: nonverbal problems presented visually with blocks, and verbal problems presented aloud by the experimenter. For each condition there were two different problem types: standard two-term addition problems and two-term addition problems with extra, irrelevant information. For each age group the same set of six problems was to be solved in each condition and problem type, for a total of 24 problems completed.

For children in the younger group, operands ranged from 1 to 5 and answers ranged from 3 to 8. For the older children, operands ranged from 2 to 7 and answers ranged from 6 to 12. During the first session, children completed a simple practice example for each condition and problem type. Feedback was given on practice problems. For test problems, the experimenter recorded the child's answer and any audible or visible behavior that demonstrated use of solution procedures (e.g., counting on fingers, reciting the question components, spontaneous self-reports). No feedback was provided to the children.

Standard verbal problems were presented with reference to common objects, for example, "If you had 5 apples and I gave you 3 more apples, how many apples would you have all together?" An example of a verbal irrelevant information problem was "I want to know how many apples you have. If I you had 5 apples and I gave you 2 oranges and 3 more apples, how many apples would you have all together?"

Nonverbal problems were presented with poker chips, modeled after the procedure used by Jordan et al. (1992). The child and experimenter each had a bin with equal numbers of chips. For standard problems, the experimenter placed chips on the table in full view of the child and said, "I am going to place some chips on the table. See?" The experimenter then, for example, placed five white chips on table. "Now I am going to cover it up, ready?" The experimenter covered the chips with a box that had a hole in one end. "Watch! I am going to add this many chips in the box." The experimenter then added, for example, three white chips through the hole in the side of the box, all in view of child. "Can you show me how many chips are under the box now, using your own chips?" The child was to place the appropriate number of chips on the table using his or her chips. These problems were always presented using white chips.

For the irrelevant-information problems the experimenter said, for example, "I want you to show me how many red chips I have under my box. I am going to place some chips on the table. See?" The experimenter then placed five red chips on table. "Now I am going to cover it up, ready? Watch! I am going to add this many chips in the box." The experimenter added two white chips (irrelevant information), then three red chips in view of child. Can you show me how many red chips are under the box now, using your own chips?" The child had to place the appropriate number and color of chips on the table, ignoring the irrelevant chips. The color of the chips being added and the irrelevant color changed for each problem.

# CHAPTER III

# RESULTS AND DISCUSSION

Data from the WJ-III and the WMTB-C were analysed to determine whether children showed deficits on the math and working memory subtests and also to determine whether a distinct profile of performance emerged. Next I examined whether age was related to performance on the subtests. Correlations between the working memory and math measures were also calculated for both age groups. Lastly, I examined performance on the verbal and nonverbal arithmetic problems as well as relations with working memory.

*WJ-III*

Children in the older group completed all four math subtests, but the majority of the children in the younger group only completed the applied problems and quantitative concepts subtests because norms for children under age 5 years 6 months are not available for the other two subtests (calculation and math fluency). However, a few children ($n$=3) in the younger group were old and capable enough to complete the calculation and math fluency tests, and so these tests were also administered to these children. For intercorrelations among the mathematics subtests of the WJ-III for children with FASD and the norm sample, see Appendix A. Mean standardized scores for all children who took each subtest are illustrated in Figure 1. In general, performance was slightly above average on the picture vocabulary test but well below average on all mathematics subtests.

Analyses were conducted separately for each age group. Means are presented in Table 1. Among the younger children, performance differed considerably across the

*Figure 1.* Performance of children with FASD (aged 4 to 9 years) on the mathematics and picture vocabulary subtests of the WJ-III. Sample sizes are 13 for calculation and math fluency, 32 for applied problems, 29 for quantitative concepts, and 30 for picture vocabulary.

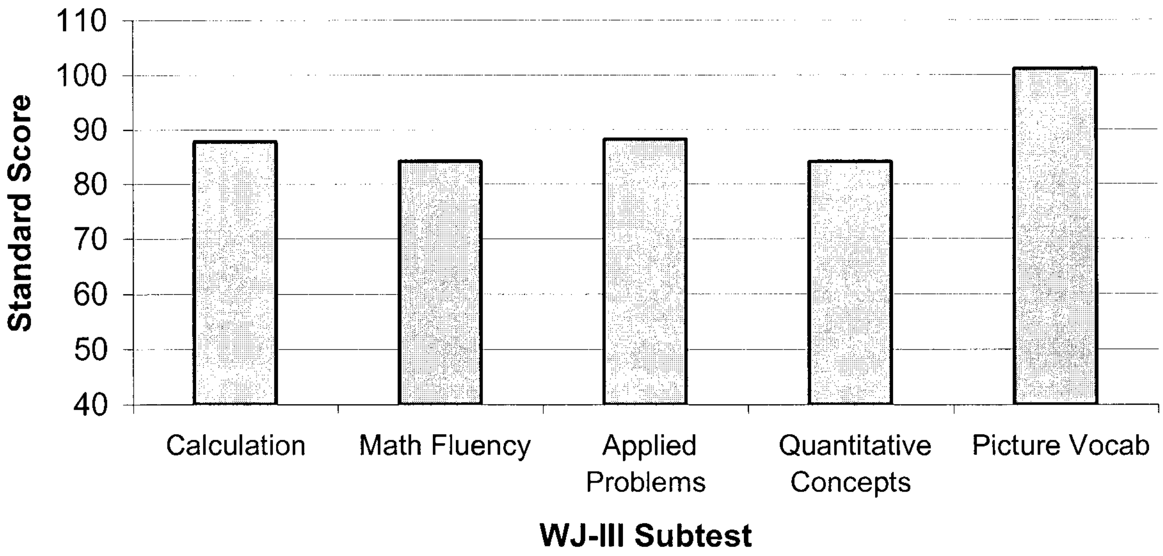


Table 1

*Mean Standard Scores (SD) of Children with FASD aged 4 to 6 years and 7 to 9 years on Subtests of the WJ-III*

| WJ-III Subtest | 4-6 years | 7-9 years |
|---|---|---|
| Calculation | n/a | 84.2 (11.0) |
| Math Fluency | n/a | 81.8 (11.0) |
| Applied Problems | 90.0 (13.7) | 84.2 (10.1) |
| Quantitative Concepts | 87.35 (15.17) | 76.9 (11.4) |
| Picture Vocabulary | 105.5 (12.8) | 92.3 (9.9) |

three subtests of the WJ-III, $F(2, 36) = 28.80$, $p < .001$. Analyses of contrasts revealed that performance on picture vocabulary test was significantly higher than on applied problems and quantitative concepts, $F(1\ 36) = 58.33$, $p < .001$, but the two math subtests did not differ from each other, $F(1, 36) = 1.22$, $p > .05$. Both math subtests, but not the picture vocabulary subtest, were significantly lower than the mean of 100 using a 99% confidence interval. Thus these younger children with FASD show deficits in mathematics but not in picture vocabulary.

For the older children, performance differed across the five subtests of the WJ-III, $F(4, 32) = 5.45$, $p < .01$. Analyses of the contrasts revealed that performance on the picture vocabulary test was significantly higher than on the four math subtests combined, $F(1, 32) = 17.04$, $p < .001$, and also higher than each individual math subtest (*ps* < .05). Furthermore, among the math subtests, performance on the quantitative concepts subtest was lower than the other three subtests, $F(1, 32) = 3.96$, $p < .05$. Thus, older children appear to have special difficulty with the material included in the subtest on quantitative concepts. For the older children, all math subtests, but not the picture vocabulary subtest, were significantly lower than the mean of 100 using a 99% confidence interval.

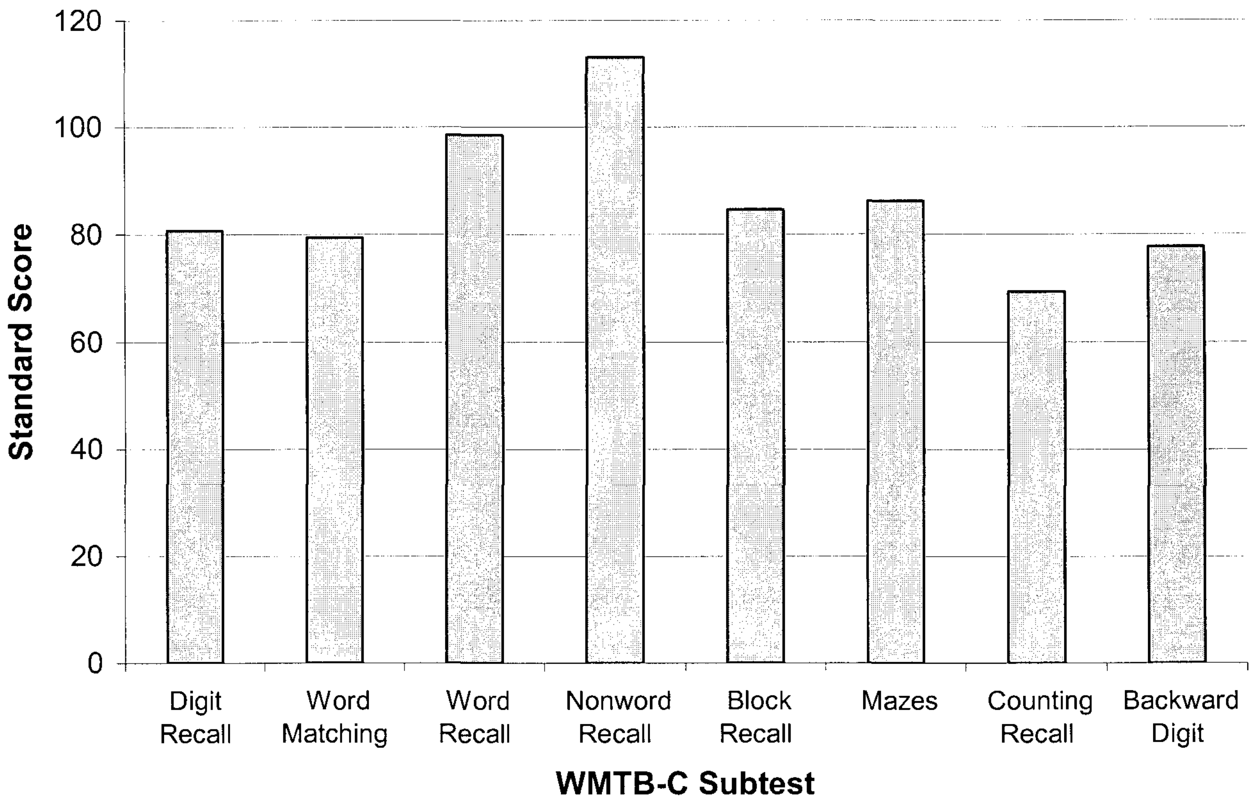
Correlations between WJ-III subtest scores and age were calculated to determine whether there were age effects. Correlations with age (in months) were used instead of an ANOVA with age as a factor because of the small sample size in the older group and also because correlations take into account the age differences across the entire sample and within each age group. However, due to the small sample size and the limited age range on some tests, some correlations may have limited sensitivity. Age correlated negatively with performance on most subtests, but only significantly with quantitative concepts, $r(28) = -.41, p < .05$, and picture vocabulary, $r(28) = -.61, p < .01$.

Analyses of standardized scores from the WJ-III thus yield three notable findings. First, children with FASD in both age groups showed deficits on all the age-appropriate mathematics subtests of the WJ-III. These deficits appear to be specific to mathematics as the children scored below the norm only on the math subtest but not on the non-math picture vocabulary test. These findings support previous research indicating that children with FASD display difficulties in math, but this study further demonstrates that these deficits occur across many domains of math (from fluency and calculation to math reasoning and number patterns) and occur despite average vocabulary skills. Second, quantitative concepts are especially difficult for the older children. Third, children with FASD appear to perform worse with increasing age, relative to the norm, on tests of quantitative concepts and picture vocabulary.

*WMTB-C*

Children in the older group were administered all subtests of the WMTB-C, and children in the younger group were administered all subtests except the mazes and counting recall subtests, which are not designed to be administered to children under the age of 5 years 7 months. However, a few children ($n$=3) in the younger group were old and capable enough to compete these subtests. Mean standardized scores for all children who took each subtest are illustrated in Figure 2. Mean performance on most working memory tasks was more than one standard deviation below the mean, indicating difficulty with working memory. However, there were some exceptions. Performance was in the average range on word list recall and performance was above average on

*Figure 2.* Performance of children with FASD (aged 4 to 9 years) on the WMTB-C. Sample sizes are digit recall (*n*=31), word matching (*n*= 28), word list recall (*n*=31), nonword list recall (*n*=31), block recall (*n*=31), mazes (*n*=10), counting recall (*n*=12), backward digit recall (*n*=29).



nonword list recall. Performance was more than two standard deviations below the mean on counting recall. Thus, overall, word list recall and nonword list recall appear to areas of strength in working memory, whereas counting recall is an clearly area of weakness.

Analyses were conducted separately for each age group. Means are presented in Table 2. A very similar pattern of performance is noted across the two age groups. Performance varied across subtests for the younger children, $F(5, 80) = 25.6, p < .01$. Nonword recall and word list recall were higher than all other subtests, and they also differed from each other, *p*s < .05, using Tukey's Honestly Significant Difference (HSD) test. For the younger children performance on all subtests of the WMTB-C were significantly lower than the mean of 100 (using 99% confidence interval), with two exceptions: word list recall did not differ from the mean; and nonword list recall was higher than the mean. Performance also differed across subtests for the older children, $F(7, 41) = 5.9, p < .01$, where performance on the nonword recall was higher than all other subtests, and word recall was higher than counting recall ( $p < .05$, Tukey HSD).[1] For the older children performance on all subtests of the WMTB-C were significantly lower than the normative mean of 100 (using 99% confidence interval), with three exceptions: word list recall and word list matching did not differ from the mean; and nonword list recall was higher than the mean. Age did not correlate with performance for any of the subtests. Performance was lowest on measures of the central executive and backward digit recall for both groups and especially counting recall for older children. Thus tests of the central executive are particularly difficult for children with FASD, perhaps because these tasks involve some executive functioning

[1] For both age groups the means used in the ANOVA may differ slightly from those presented in Table 2 because of missing data on some subtests, resulting in smaller sample sizes for some ANOVAs.

Table 2

*Mean Standard Scores (SD) of Children with FASD aged 4 to 6 years and 7 to 9 years on Subtests of the WMTB-C*

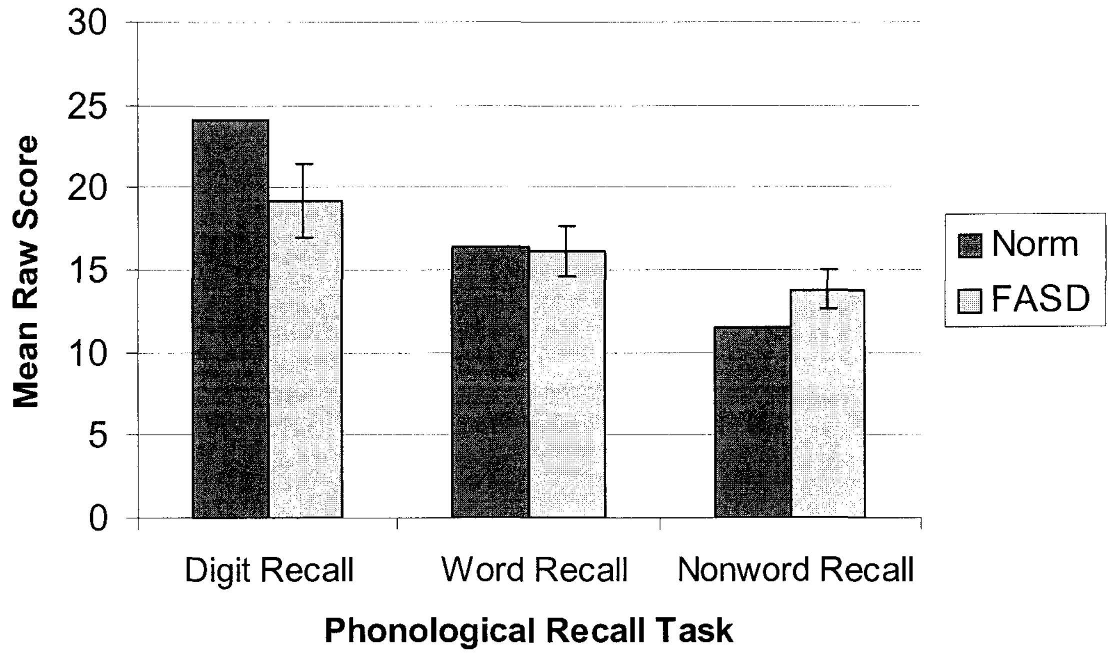
| WMTB-C Subtest | 4-6 years | 7-9 years |
|---|---|---|
| Digit Recall | 79.7 (15.7) | 82.9 (17.2) |
| Word List Matching | 77.6 (13.8) | 82.7 (26.6) |
| Word List Recall | 100.1 (16.2) | 95.20 (13.2) |
| Nonword List Recall | 113.9 (16.6) | 111.5 (13.5) |
| Block Recall | 84.0 (14.7) | 85.7 (19.7) |
| Backward Digit Recall | 76.4 (17.1) | 80.67 (18.7) |
| Mazes | n/a | 86.7 (9.2) |
| Counting Recall | n/a | 69.9 (11.6) |

processes and individuals with FASD display significant deficits on executive functioning (see Rasmussen, 2005).

The high performance in both age groups on word list and nonword list recall contrasts markedly with performance on other measures. I next examined whether there was a difference in the raw scores on the three recall measures of the phonological loop (digit recall, word list recall, and nonword list recall). Raw scores (reflecting the total number correct across all trials) were used instead of standard scores because standard scores are relative to age and do not reflect directly the amount of information an individual recalls. Thus standardized scores may mask any potential effects related to memory span or capacity. We did not include the word list matching subtest in this analysis because it is not a recall test and thus the raw scores do not correspond in a meaningful way to those of the other recall tests. Analysis of variance revealed an effect of recall task, $F(2, 58) = 55.37$, $p < .001$, in that children recalled the most items on the digit recall ($M = 19.19$, $SD = 4.85$), followed by word list recall ($M = 16.07$, $SD = 3.35$), and then nonword list recall ($M = 13.84$, $SD = 2.50$). Figure 3 displays the mean raw scores on the phonological recall tasks across age in our sample and that of the norm (the mean raw score required to obtain a standard score of 100 across the ages used in this study). It is evident that, relative to the norm, the children with FASD recall less information on digit recall, about the same on word list recall, and more information on nonword list recall.

In summary, performance on the WMTB-C yielded some important findings. First, children showed difficulty on many measures of working memory. Second, however, the children performed in the average range and above average on word recall

*Figure 3.* Mean raw score performance of children with FASD (aged 4 to 9 years) compared to the norm sample from the WMTB-C on measures of phonological working memory. For the norm sample the mean raw score was obtained by calculating the mean raw score required to obtain a standard score of 100 at each age level and then weighting these scores according to the number of children in our sample in each age group. Data for the norm sample are taken from the WMTB-C manual (Pickering & Gathercole, 2001). The bars represent the 99% confidence intervals.



and nonword list recall, indicating that these may be areas of strength in memory for children with FASD. Third, performance was poorest on measures of the central executive, indicating that the executive functioning demands of these tasks may pose significant difficulty for children with FASD.

*Relations Between Working Memory and Math*

Correlations between the WJ-III and WMTB-C are presented in Table 3. Math performance (calculation, applied problems, and quantitative concepts) was highly correlated with measures of phonological working memory and to a lesser extent with the backward digit span measure of the central executive. Thus, among children with FASD phonological working memory appears to be related to mathematical performance.

Because the relation between working memory and math may differ depending on age, we calculated the correlations between the WJ-III and WMTB-C for 4- to 6-year-olds (Table 4) and for 7- to 9-year-olds (Table 5). Due to small sample sizes, particularly in the older group, some of the significance tests lack power and results must be regarded as suggestive. For the young children some measures of phonological working memory were strongly correlated with both measures of mathematics, and the backward digit span also correlated with applied problems. Thus for young children with FASD, phonological working memory appears to be strongly related to math performance. Among the older children phonological working memory was highly correlated with applied problems, quantitative concepts, and to a lesser extent with calculation. A measure of visual-spatial working memory (block recall) and the central executive (backward digit recall) were also related to performance on applied problems and quantitative concepts. Thus, similar to the younger children, for the 7- to 8-year-olds measures of phonological working

Table 3

*Correlations between Standard Scores on the WJ-III and WMTB-C Among All Children*

| | Digit Recall | Word Matching | Word Recall | Nonword Recall | Block Recall | Mazes | Counting Recall | Backward Digit |
|---|---|---|---|---|---|---|---|---|
| Calculation | .56* | .67* | .51 | -.02 | .11 | .37 | .26 | .51 |
| Math Fluency | .46 | .32 | .35 | -.20 | .08 | .49 | -.16 | .23 |
| Applied Problems | .58** | .33 | .57** | .50** | .22 | .04 | .11 | .51** |
| Quantitative Concepts | .54* | .36 | .54** | .52** | .25 | .04 | .13 | .32 |

*Note.* On the WJ-III, the sample size was 13 for calculation and math fluency, 31 for applied problems, and 29 for quantitative concepts. On the WMTB-S, the sample size was 10 for mazes, 12 for counting recall, and 28 to 31 on all other subtests.

*$p$ < .05, **$p$ < .01

Table 4

*Correlations between Performance on the WJ-III and WMTB-C among Young Children aged 4 to 6 years with FASD*

| | Digit Recall | Word Matching | Word Recall | Nonword Recall | Block Recall | Backward Digit |
|---|---|---|---|---|---|---|
| Applied Problems | .53* | .25 | .53* | .58** | .05 | .50* |
| Quantitative Concepts | .53* | .20 | .51* | .62** | .16 | .36 |

*Note.* The sample size was 22 applied problems, 20 for quantitative concepts, and 18 to 21 on the subtest of the WMTB-C. *$p < .05$, **$p < .01$

Table 5

*Correlations between Performance on the WJ-III and WMTB-C among Children aged 7 to 9 years with FASD*

| | Digit Recall | Word Matching | Word Recall | Nonword Recall | Block Recall | Mazes | Counting Recall | Backward Digit |
|---|---|---|---|---|---|---|---|---|
| Calculation | .50 | .74* | .23 | -.16 | .25 | .33 | .16 | .25 |
| Math Fluency | .50 | .39 | .16 | -.24 | .28 | .49 | -.37 | .18 |
| Applied Problems | .90** | .62 | .64* | .21 | .68* | -.11 | -.30 | .75* |
| Quantitative Concepts | .93** | .79* | .64 | .24 | .68* | .13 | -.38 | .56 |

*Note.* On the WJ-III, the sample size was 10 on calculation, math fluency, and applied problems, and 9 on quantitative concepts. On the WMTB-C the sample size was 7 on mazes, 8 on counting span, 9 on backward digit recall and 10 on all other subtests. *$p < .05$, **$p < .01$

memory appear to be important for mathematics. However, unlike the younger children, among the older children visual-spatial working memory was also strongly related to mathematics performance. Furthermore, among the older children, the math fluency tests did not correlate with any working memory measures. Perhaps this result occurred because the math fluency test is timed and the children have to answer simple addition and subtraction problems as fast as they can. Thus the children likely used retrieval, which would not require much in terms of working memory, instead of counting-based procedures.

*Arithmetic Problems*

The children in the two age groups completed different arithmetic problems so that ceiling or floor effects could be avoided. For each age group data were analyzed with a 2(Condition: nonverbal, verbal) x 2(Problem Type: standard, irrelevant) repeated measures analysis of variance. For the younger children, there was no difference in accuracy between nonverbal problems ($M = 1.95$, $SD = 1.48$) and verbal problems ($M = 1.68$, $SD = 1.50$), $F(1, 19) = < 1$, but accuracy on irrelevant problems ($M = 1.20$, $SD = 1.34$) was much lower than on standard problems ($M = 2.40$, $SD = 1.59$), $F(1, 19) = 14.71$, $p < .001$. Condition and problem type interacted, $F(1, 19) = 6.44$, $p < .05$. The source of this interaction was that performance was higher on nonverbal than verbal standard problems, $F(1, 20) = 8.18$, $p < .01$, but this difference was negligible for irrelevant-information problems, $F(1, 19) < 1$. The finding that accuracy on standard nonverbal problems exceeded that on standard verbal problems is consistent with previous findings with non-FASD children (Jordan et al., 1992; Levine et al., 1992; Rasmussen & Bisanz, 2005). Also consistent with previous research (Rasmussen &

Bisanz, 2005), problems with added irrelevant information were much more difficult than standard problems for younger children.

For the older children there was no effect of condition. Thus, similar to previous research with non-FASD children (Jordan et al., 1992; Levine et al., 1992; Rasmussen & Bisanz, 2005), older school-aged children with FASD perform equally well on verbal and nonverbal problems. Unlike the findings of Rasmussen and Bisanz, there was no effect of problem type among the older children with FASD. However, the trend was in the predicted direction (with performance lower on irrelevant problems than standard problems). Because of the small sample size in this group, the statistical test may have lacked sufficient power.

The performance of the 4- to 6-year-olds, as compared to Rasmussen and Bisanz (2005), is presented in Figure 4 and the 7- to 9-year-olds in Figure 5. The children with FASD in this study performed much lower than the non-FASD children in Rasmussen and Bisanz in all conditions, despite the fact that the children with FASD were older. For the younger children differences between the FASD and non-FASD children were most notable when irrelevant information was present, indicating these problems were particularly difficult for children with FASD. However, for the older children differences were most notable in the nonverbal standard condition. One reason for such a discrepancy on this condition may be that in the study by Rasmussen and Bisanz (2005) many of the children developed a strategy to solve these nonverbal problems efficiency. Specifically, they used their fingers to represent the chips, thus limiting demands on working memory. Children with FASD rarely showed use of this strategy.

*Figure 4.* Arithmetic performance of younger children with FASD (mean age 5yrs, 6mos) compared to non-FASD children (5yrs, 3mos) in Rasmussen and Bisanz (2005) on nonverbal standard (NS), nonverbal irrelevant (NI), verbal standard (VS), and verbal irrelevant (VI) arithmetic problems.

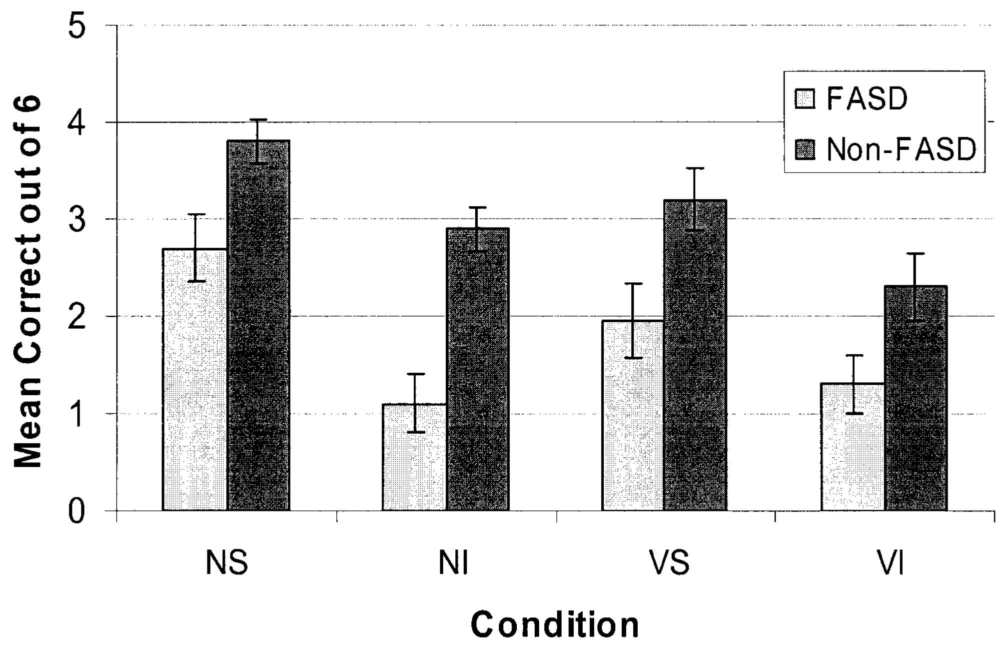
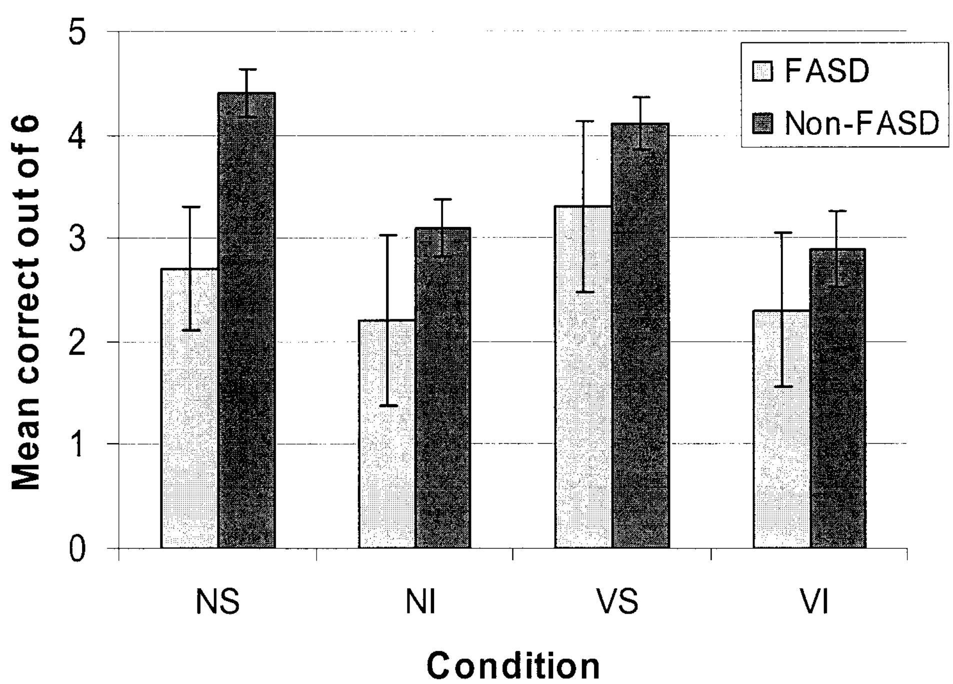


*Figure 5.* Arithmetic performance of older children with FASD (mean age 7yrs, 10mos) compared to non-FASD children (6yrs, 11mos) in Rasmussen and Bisanz (2005) on nonverbal standard (NS), nonverbal irrelevant (NI), verbal standard (VS), and verbal irrelevant (VI) arithmetic problems.



Next I examined whether working memory was related to arithmetic performance, and whether this relation varied depending on problem type and the age of the sample. These analyses were conducted to determine which types of models of representation the children with FASD appeared to use. To determine the relation between working memory and the arithmetic problems performance on the arithmetic problems was correlated with the raw scores on the WMTB-C. Raw scores were used because estimates of memory capacity, not how well the children do compared to the norm, is presumed to be critical for performance on the arithmetic tasks. Correlations between working memory measures and performance on the arithmetic problems are presented in Table 6 for the 4- to 6-year-olds and Table 7 for 7- to 9-year-olds.

For the younger children performance on the verbal standard problems correlated with some measures of phonological working memory and backward digit recall (central executive), and performance on the nonverbal standard problems correlated with backward digit recall. Thus, measures of phonological working memory and the central executive again appear to be highly predictive of arithmetic performance in young children. A measure of the central executive predicted performance on the nonverbal problems, perhaps because the children attempted to code these nonverbal problems verbally and such re-coding would demand the central executive. The nonverbal-irrelevant and verbal-irrelevant problems did not correlate with any of the working memory measures, perhaps because on these problems was very low for these children, and thus a possible floor effect and limited variability in scores could mask any relations with working memory that may exist. For the older children, performance on all arithmetic problems was highly related to measures of phonological, visual-spatial, and

Table 6

*Correlations between Performance on the Arithmetic Problems and WMTB-C among Children aged 4 to 6 years with FASD*

| | Digit Recall | Word Matching | Word Recall | Nonword Recall | Block Recall | Backward Digit |
|---|---|---|---|---|---|---|
| Nonverbal Stand | .30 | .19 | .27 | .25 | .07 | .61** |
| Nonverbal Irrel | .37 | .02 | .43 | .11 | .02 | .42 |
| Verbal Stand | .47* | .40 | .46* | .31 | .23 | .47* |
| Verbal Irrel | .19 | .20 | .20 | -.02 | .00 | .33 |
| Mean (SD) | 17.6 (4.2) | 6.4 (6.2) | 15.4 (3.2) | 13.4 (2.5) | 16.2 (3.5) | 3.9 (4.0) |

*Note.* $N = 18$ to 22, $^{*}p < .05$, $^{**}p < .01$

Table 7

*Correlations between Performance on the Arithmetic Problems and WMTB-C among Children aged 7 to 9 years with FASD*

| | Digit Recall | Word Matching | Word Recall | Nonword Recall | Block Recall | Mazes | Counting Recall | Backward Digit |
|---|---|---|---|---|---|---|---|---|
| Nonverbal Stand | .78* | .64 | .93** | .70* | .76* | .06 | .35 | .73* |
| Nonverbal Irrel | .81** | .50 | .62 | .34 | .77* | .59 | .17 | .64 |
| Verbal Stand | .75* | .61 | .80** | .60 | .89** | .18 | .24 | .76* |
| Verbal Irrel | .85** | .50 | .84** | .58 | .77* | .42 | .12 | .71* |
| Mean (SD) | 22.5 (4.7) | 14.4 (10.7) | 17.4 (3.4) | 14.7 (2.4) | 20.7 (5.9) | 10.7 (4.2) | 11.3 (2.3) | 8.3 (4.6) |

*Note.* $N = 9$, except on mazes ($n$=7) and counting recall ($n$=8), *$p < .05$, **$p < .01$

central executive (backward digit recall) components of working memory. Thus similar to the WJ-III for older children, measures of phonological working memory and visual-spatial working memory were strongly related to performance on all problem types. We also analyzed the data using a multiple regression to determine the unique contribution of each working memory task (as used in Rasmussen & Bisanz, 2005); however this analysis yielded results very similar to the correlations.

If the younger children are predominantly using a mental model approach, then we would expect measures of visual-spatial working memory to predict performance best on arithmetic problems, particularly on nonverbal problems. Likewise, if older children are using a predominantly phonological or verbal approach, then we would expect measures of phonological working memory to predict performance best, particularly on verbal problems as in Rasmussen and Bisanz (2005) with non-FASD children. However, this is not what we found with children with FASD. For the younger children, measures of phonological working memory and the backward digit span correlated with arithmetic performance, and there were no strong relations with visual-spatial working memory, indicating that young children with FASD do not appear to predominantly use a mental model approach. For the older children measures of phonological, visual-spatial, and the central executive components of working memory correlated with arithmetic performance, and the children did not appear to primarily use a verbal or phonological approach.

# CHAPTER IV

# GENERAL DISCUSSION

The goal of this project was to examine mathematics and working memory in young children (aged 4 to 9 years of age) with FASD. Standardized tests of mathematics (WJ-III mathematics battery) and working memory (WMTB-C) were administered to determine whether children with FASD showed deficits in mathematics and working memory, whether a distinct pattern of strengths and weakness emerged, and also whether performance differed with age. Next, I examined whether these math difficulties may be related to underlying deficits with working memory. Children were also tested on simple arithmetic problems presented verbally and nonverbally to examine how they solve such problems and specifically the types of representation they appear to use.

## *Mathematics and Working Memory*

Children with FASD displayed difficulties on all math tests of calculation, fluency, applied problems, and quantitative concepts, despite showing adequate picture vocabulary skills. These tests measure fundamental math skills including calculation, number facility, automaticity, math facts, problem solving, reasoning, number patterns, and knowledge of math terms and formulas. The quantitative concepts subtest, which measures knowledge of math terms and formulas as well as the ability to identify number sequences and patterns, was particularly difficult for the older children. Furthermore, older children performed worse, relative to the norm, than younger children on the quantitative concepts subtest. To our knowledge, this study is the first to document age-related differences in math skills (relative to norms) in children with FASD.

Overall, the children with FASD showed deficits on many tests of working memory and scored more than one standard deviation below the normative mean on most measures. Some interesting patterns emerged. In contrast to the low performance on most measures, performance was in the average range on the word list recall test and above average on the nonword recall test, despite being well below average on digit recall. When examining the raw performance on the three phonological recall tasks, the children remembered slightly more digits than words, followed by nonwords, even with the large difference in standard scores. In comparison to the norm, children with FASD recalled fewer digits, about the same number of words, and slightly more nonwords. The test of nonword recall is typically much harder than digit and word recall for non-FASD children, and although nonword recall still was more difficult for the children with FASD (as evident in the raw scores) it was not as difficult as would be expected based on the standardized scores.

This finding of superior standardized performance on memory for nonwords over words and digits was surprising. Cowan (1997) suggested that changes in knowledge may be related to developmental increases in memory span. In particular, knowledge aids performance on working memory tasks because it allows one to link information into meaningful patterns and also to use strategies such as chunking (see Simon, 1974). Children have lexical knowledge for memory of words but less so for nonwords (Cowan, 1997). Thus, for normal children nonwords may be more difficult to remember than words and digits because they lack meaning and thus are more difficult to tie to pre-existing knowledge in memory. Further, strategies, such as chunking, that could be used effectively for digit and word recall may not work well on memory for nonwords. Thus, one reason children with FASD may do better than the norm on nonwords, but far below the norm on digits is that they may not make use of the potentially meaningful information in the material they are trying to remember. Furthermore, they may lack knowledge of strategies, such as chunking, that would assist their performance on digit and word recall. Both of these explanations would result in lower standardized scores on digit and word recall as compared to nonword recall.

The profile of memory performance was similar across the two age groups, with children showing deficits on most measures of working memory. For both age groups performance was lowest on the central executive measures of working memory. Perhaps these central executive processes are more difficult because they not only involve immediate memory of information (as in other memory tasks) but they also involve executive functions such as manipulation of information in memory, selective attention, and even inhibition. Thus, these tasks would place extra demand on EF, which is often cited as a deficiency in children with FASD (Rasmussen, 2005).

*The Relation Between Working Memory and Math*

Working memory was highly correlated with math performance on the WJ-III. For the younger children measures of phonological working memory and backward digit span were related to math performance (applied problems and quantitative concepts). Similarly, among the older children phonological working memory was strongly related to mathematics (applied problems, quantitative concepts, and calculation) and the backward digit span was related to a lesser extent to mathematics. However, visual-spatial working memory was also highly related to performance among the older children.

*Arithmetic Problems*

Consistent with previous research (Jordan et al., 1992; Levine et al., 1992; Rasmussen & Bisanz, 2005) with non-FASD children, for the younger children with FASD nonverbal standard arithmetic problems were much easier than verbal standard problems and problems with added irrelevant information were also more difficult than standard problems. For the older children there was no difference in performance between nonverbal and verbal problems, which again is consistent with previous findings.

Next we examined whether working memory was related to performance on the arithmetic problems, and whether these relations differed depending on the age group of the sample. For the younger children only measures of phonological working memory and the backward digit span were related to arithmetic performance. Thus, similar to the results found with the WJ-III, phonological working memory and the central executive appear to be highly predictive of arithmetic performance in young children. This result is in contrast to the findings of Rasmussen and Bisanz (2005) with non-FASD children, who found for nonverbal problems visual-spatial working memory was the best predictor, supporting the idea that they were using a mental model. These results do not lend further support to the use mental models for young children with FASD. Perhaps children with FASD do not rely on visual-spatial working memory as non-FASD children do (Hitch, Halliday, Schaafstal, & Schraagen, 1988) or they do not recognize the effectiveness of such visualization techniques. Or perhaps young children with FASD use a variety of procedures (some effective and some not), which may mask possible mental model use if it is only used among a subset of the children. The backward digit span predicted performance on the nonverbal problems, perhaps because the children attempted to code these nonverbal problems verbally and such re-coding would demand the central executive. Even though these children did not appear to use a mental model (as there were no relations with visual-spatial working memory), performance on nonverbal problems was still higher than verbal problems. One explanation for this finding is that even if they are not using a mental model, perhaps these nonverbal problems are still easier than verbal problems because the verbal problems consist of all verbally presented numbers and words that may confuse the children. Perhaps these young children are more familiar in dealing with numerical quantities represented with objects rather than with numeric symbols, and thus it is easier for them to code a set of objects into an internal psychological code than going from an auditory code to an internal code. The notion that these children have difficulty with verbally presented numbers is consistent with their very poor performance on the digit span and backward digit span.

For the older children, measures of phonological, visual-spatial, and the central executive working memory were highly related to arithmetic performance, again similar to the results found with the WJ-III. However, other researchers have found older school age children without FASD to rely more on phonological working memory over visual-spatial working memory (Hitch et al., 1988; Rasmussen & Bisanz, 2005). Thus again the children with FASD do not appear to perform like non-FASD children. Visual-spatial working memory also appears to be important for these older children with FASD, and perhaps this outcome reflects a delayed development in children with FASD, as they are relying on visual-spatial working memory and not yet relying most on phonological working memory as in non-FASD children.

*Implications*

There is a disturbingly small amount of intervention research in FASD (Premji, 2004) and most interventions use generic methods and strategies that are not specifically geared towards the special cognitive characteristics of children with FASD. If we better understand the cognitive characteristics of a particular special population (e.g., FASD), then we can begin to understand development and improve functioning by tailoring instruction and intervention to unique needs. Clearly instruction geared toward improving mathematics performance would be important for children with FASD, but what is needed is instruction that is based on a cognitive analysis of the target population. Although there is no specific research in this area with children with FASD, there have been successful mathematics instructional studies that are based on cognitive analysis with students with learning disabilities. For instance, in a number of experiments Naglieri and colleagues taught students with learning disabilities cognitive strategies for improving their planning processes (via self reflection and verbalization of strategies) when doing arithmetic. This approach resulted in an increase in their arithmetic performance, particularly for those who were poor in planning initially (Naglieri & Johnson, 2000, Naglieri & Gottling, 1995; Naglieri & Gottling, 1997). This method may be particularly useful for children with FASD, who also have been found to perform poor on tests of planning (see Rasmussen, 2005, for a review).

The finding of age-related differences (relative to the norm) on quantitative concepts has significant implications for instruction and intervention with children with FASD and highlights the importance or early detection of problematic areas in FASD. By identifying specific areas of difficulty and skills that may decrease with age (quantitative concepts), we can begin intervention and modify instruction to improve these skills early on so perhaps there is not such a decrement with age.

The unique memory profile that emerged is also of importance. Memory for words and nonwords appear to be areas of strength for children with FASD. Perhaps these strengths can be built upon to help children with FASD remember things in the classroom and home environment. The children with FASD showed deficits on other components of memory (visual-spatial, central executive) and it appears that there may be something unique about memory for numbers that makes the digit span particularly difficult among the phonological recall tasks for children with FASD. This finding may be due to lack of sufficient knowledge and strategies that may aid memory for numbers. If children with FASD are found to lack sufficient knowledge and use of memory strategies, then perhaps instruction and intervention can be modified to teach children with FASD metacognitive strategies that will assist their performance on many tasks. Teaching memory strategies such as rehearsal techniques has led to increases in memory span (Turley-Ames, 2003), even among individuals with Down Syndrome (Comblain, 1997). However, less is known about whether these increases in memory span result in meaningful increases in domains that may require working memory, such as math.

The strong links between working memory abilities and mathematics has significant implications for instruction and intervention with children with FASD. Working memory may be an underlying deficit resulting in poor mathematics among children with FASD. Perhaps teaching children strategies for remembering information can strengthen working memory abilities, which may make doing mathematics easier for them. Also, decreasing the working memory demands of some math problems by using visual aides or breaking problems into simple steps may enhance mathematics performance among children with FASD. Gathercole and Pickering (2001) suggest that working memory assessments may be useful in identifying children that are at risk for poor academic achievement, and such early indicators of difficulty could be applied to children with FASD.

*Qualifications*

Despite the notable findings of this study, there are some qualifications that need to be addressed. The sample size in this study was small, especially in the older group, which decreases the power. Thus some statistical tests, particularly in the older group, may have been significant if we had a larger sample size and more power. However, small sample size is a common issue in research on FASD, and particularly with children with FASD (see Rasmussen, 2005, for a review), because of the limitations in obtaining an appropriate sample. Even though our sample size was moderate at 32, it is still adequate when compared to the literature. There are a relatively few number of children with a confirmed medical diagnosis of FASD, and recruiting participants can be difficult because many of them are on foster care or live in remote areas.

It must be acknowledged that comparing the performance of children with FASD to normative samples does not account for differences between the two groups related to factors such as socio-economic status, environmental factors, living arrangements, and parental status. Another point worth making is that the majority of our sample (78%) was Aboriginal. Thus, it is unclear whether our results apply to all children with FASD, or if they mainly reflect the patterns of Aboriginal children with FASD. In some respect, the high number of Aboriginal participants may decrease the generalizability of our findings.

Nevertheless, this pattern is not in contrast to the demographics of children diagnosed through the Glenrose Rehabilitation Hospital FASD clinic, where the majority of the children diagnosed there are reported to be Aboriginal. This pattern may reflect a higher prevalence of FASD in Aboriginal children or a referral bias among Aboriginal children, and further research is needed to determine the source of this pattern. Because of the high number of Aboriginal children diagnosed at the Glenrose Hospital (one the few diagnostics clinics in Alberta), a higher number of Aboriginal children in this study was almost inevitable. Thus, I feel that these results are generalizable to the diagnosed FASD population in Alberta. Even if there are some limitations in generalizing to the broader FASD population, this is really the first research to specifically examine mathematics and working memory in young children with FASD and thus provides a starting point and basis for further research with other demographic groups. Furthermore, in many published studies on FASD it is common to have an overrepresentation of minority groups. The majority of our sample were also not residing with their biological parents and were in foster care of adopted. However, this pattern is typical of that seen in the Alberta FASD populations.

*Future Directions*

In reviewing research on math disabilities (MD), Gersten, Jordan, and Flojo (2005) noted that many children with MD have significant difficulty with calculation fluency, arithmetic combinations, and in developing efficient counting strategies, and that reading difficulties are linked to math difficulties. We have demonstrated that children with FASD display difficulties with calculation and fluency, but less is known about strategy use and links with reading among children with FASD. Research in these areas is imperative for enhancing our knowledge of the math deficits in FASD and for determining whether children with FASD display math profiles similar to children with MD. Further, Gersten et al. (2005) identified early indicators of MD in young children, which included difficulties with magnitude comparison (number sense), counting strategies, fluency in number identification, and working memory (particularly the backward digit span). Such early indicators of potential MD may be particularly useful for early identification of math deficits in young children with FASD, which may lead to improvements in instruction and even diagnostic practices. The authors go on to describe research on intervention for children with MD. In particular they describe research by Hasselbring et al. (1998) about a computer program that has helped children with MD use more efficient retrieval strategies rather than relying on counting on their fingers. Other interventions included teaching children math strategies and enhancing number sense. Using intervention techniques that have proved to be effective for children with difficulties in math, coupled with instruction and intervention that is based on research focused on understanding the unique mathematical deficits and cognitive characteristics of children with FASD, is likely be the best approach for developing effective intervention programs for children with FASD. Research on various intervention techniques for children with FASD is imperative.

The unique memory profile of children with FASD calls for further research in this area to determine what types of memory strategies, if any, children with FASD use when recalling numbers and words. Also, research on whether teaching children with FASD strategies for remembering information results in an improvement in working memory abilities or even math performance would be useful. Examining whether decreasing the working memory demand of mathematics problems (e.g., with visual cues or by breaking problems into distinct steps) is also important for learning about the relation between working memory and mathematics among children with FASD.

Longitudinal research on the development of working memory and mathematics abilities among children with FASD is essential. This research would be important for determining the developmental trajectory of math deficits in children with FASD and for clarifying connections with math abilities and age-related changes. Further, longitudinal research would be important to determine whether early working memory deficits predict later math performance, as suggested by Gathercole and Pickering (2001).

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# APPENDIX

Table A1

*Correlations among the Mathematics Subtests of the WJ-III for Children with FASD (Above the Diagonal) and for the Norm Sample (Below the Diagonal)*

| WJ-III Math Subtests | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1. Calculation | -- | .72 | .66 | 72 |
| 2. Math Fluency | .65 | -- | .68 | .72 |
| 3. Applied Problems | .68 | .57 | -- | .85 |
| 4. Quantitative | .55 | .54 | .64 | -- |

*Note*. Correlations for the norm sample were taken from the WJ-III Technical Manual (McGew & Woodcock, 2001). All correlations are significant, $\alpha = .05$.