# Evidence-Based Assessment and Intervention for Dyscalculia and Maths Disabilities in School Psychology

Robert A. Reeve and Carolyn Waldecker

## Evidence-Based Assessment and Intervention for Maths Disabilities

In today's world, children are required to keep track of an unprecedented amount of numerical information (computers, smartphones, etc.). Despite maths education, many children remain innumerate, and some suffer from a severe form of maths processing difficulty, known as dyscalculia (Butterworth, 2005). The negative consequences of dyscalculia are well known: adult dyscalculics are more likely than their numerate peers to be unemployed, experience mental illness, and be imprisoned (Parsons & Bynner, 2005). Children with dyscalculia often experience rejection by peers, self-concept difficulties, and school phobia (Butterworth & Yeo, 2004). Despite the importance of numeracy in the modern environment, dyscalculia has attracted little interest until recently, relative to other developmental learning disorders (e.g. dyslexia) (Bishop, 2010; Chinn, 2015). As Bishop notes, it was not until recently that funding agencies in the USA and UK began to support studies into the nature of developmental dyscalculia: between 2000 and 2010 NIH spent $107.2 million funding dyslexia research and $2.3 million funding dyscalculia research. Moreover, the socio-economic benefit of understanding the nature of dyscalculia cannot be overstated: improvements in a nation's maths ability are linked directly to increases in GNP (Butterworth, Varma, & Laurillard, 2011; OECD, 2010).

In this chapter we describe the current status of knowledge about developmental dyscalculia (DD),[1] as well as suggest assessment and intervention practices. There is little doubt that the ways in which DD is conceptualized have changed radically over the last 20 years—changes which have implications for assessment as well as intervention practices. Most likely, these changes will continue to occur, and one of our goals is to highlight challenges facing researchers and practitioners alike. The possibility that a single assessment method is suitable for all aged children is becoming more remote. Indeed, one of the themes of the chapter is to highlight challenges associated with

R.A. Reeve
Melbourne School of Psychological Sciences, The Redmond Barry Building, The University of Melbourne, Melbourne, VIC 3010, Australia
e-mail: r.reeve@unimelb.edu.au

C. Waldecker, Psy.D. (✉)
The Hagedorn Little Village School and Neurodevelopmental Diagnostic Center, Jack Joel Center for Special Children,
750 Hicksville Road, Seaford, NY 11783, USA
e-mail: Carolyn.Waldecker@littlevillage.org; cwaldecker@gmail.com

---

[1] We distinguish between developmental dyscalculia and acquired acalculia (see Reeve & Humberstone, 2012). The latter is often associated with acquired brain insult (e.g. stroke), while DD is evident early in life and likely reflects brain dysfunction (see Nieder & Dehaene, 2009).

© Springer International Publishing Switzerland 2017
M. Thielking, M.D. Terjesen (eds.), *Handbook of Australian School Psychology*,
DOI 10.1007/978-3-319-45166-4_10

the diagnosis of dyscalculia in young children; that is, before computation difficulties become evident in school settings.

## Maths Disability (Developmental Dyscalculia): Definitions and Symptoms

While it is now widely accepted that DD is a unique and specific learning difficulty associated with "maths" learning, this was not always the case. Many educators, psychologists, and school counsellors considered maths difficulties a form of dyslexia (see Miles & Miles, 1992). However, a distinction between arithmetic and reading disabilities has been recognized for at least 100 years. Temple (1997, p. 257) cites the work of Hinshelwood (1917):

> *We also see the converse condition, boys who excel in their studies in other departments, but are the greatest duffers in arithmetic…Stephenson once saw a boy, 10 years of age, who experienced extraordinary difficulty reading numbers, without any corresponding difficulty as to letters and words.*

Over the last 20 years, however, many studies have investigated the origins and developmental sequelae of so-called "number sense" difficulties (Butterworth, 1999; Dehaene, 1997), and phrases such as "number blindness" are now part of the learning difficulties lexicon (Butterworth et al., 2011). Nevertheless, while there are likely pure forms of DD, unrelated to other learning difficulties (Henik, Rubinsten, & Ashkenazi, 2011), DD is occasionally co-morbid with other learning difficulties. In approximately 25 % of cases, for example, DD overlaps with dyslexia (see Butterworth, 2005). Some studies find that children with DD have working memory and/or general intelligence deficits, relative to their peers; however, other studies find no relationship between general cognitive deficits and DD (Gray & Reeve, 2014; Landerl, Bevan, & Butterworth, 2004; Reeve, Reynolds, Humberstone, & Butterworth, 2012).

Before defining DD more formally, it is important to note there are many reasons for being bad at maths (inappropriate teaching, missing class, behavioural problems, anxiety, etc.). And it is equally important to recognize that maths depends on a range of sub-skills that are integrated in the service of maths problem-solving development. In the young these include (but are not limited to) counting, estimating, number fact knowledge, etc., and the skill range grows with age.

## Defining Developmental Dyscalculia

According to the Diagnostic and Statistical Manual of Mental Disorders, Version 5 (DSM 5), Developmental Dyscalculia (DD) is defined as a specific learning deficit associated with difficulties processing numerical information, learning arithmetic facts, and performing calculations (American Psychiatric Association, 2013, see p. 67). The DSM 5 suggests prevalence rates of 2 %; however, international prevalence rates suggest a figure between 6 and 8 % for DD (Hamak, Astilla, & Preclaro, 2015; Reeve et al., 2012; Reigosa-Crespo & Castro, 2015; Zhou & Cheng, 2015). The American Psychiatric Association (2013) offers a very general behavioural definition of DD, defining it as a specific learning disorder characterized by impairments in learning basic arithmetic facts, processing numerical magnitude, and performing accurate and fluent calculation. Children with DD experience difficulty acquiring number concepts, exhibit confusion over maths symbols, and experience problems learning and remembering number facts (Bugden & Ansari, 2015).

The DSM 5 (APA, 2013) definition does not consider the origins of DD, nor how it should be treated. On the basis of evidence, DD is best considered a neurological and/or genetic coherent syndrome that reflects a specific core deficit (Butterworth et al., 2011) (discussed later). In other words, DD is a maths domain specific phenomenon, comprising unique maths processing deficits that likely have an organic origin (Reeve & Gray, 2015). This characterization has assessment and intervention implications (discussed later).

Nevertheless, with some exceptions, a diagnosis of DD, and *ipso facto* its definition, depends on computation performance, which means a formal diagnosis cannot be made until after the beginning of formal education. Moreover, a diagnosis of DD is often based on an arbitrary cut-point on standardized test performance (e.g. below the tenth percentile on computation), which in the absence of other information is difficult to interpret. As noted above, there could be different reasons for being bad at maths.

**Common symptoms**. Because there is relatively little work describing DD, there is no definitive list of symptoms. We list here some common symptoms (see the following websites for additional information on DD[2]). Not all children may show all symptoms, and because of an absence of research we do not know whether the symptoms identified in childhood remain in adulthood (apart from computation difficulties).

**Older descriptions of developmental dyscalculia-like behaviours**. The claim that number processing deficits have an organic basis was first made in the 1920s by Gerstmann, when he observed finger agnosia (an inability to distinguish among fingers) and left-to-right orientation difficulties, which are often associated with acalculia (a problem with counting and other maths functions that can occur later in life, see Miller & Hynd, 2004; Reeve & Humberstone, 2011). These deficits are associated with neighbouring neuroanatomical regions of the intraparietal cortex (Butterworth, 2005; Dehaene, Piazza, Pinel, & Cohen, 2003). The intraparietal sulcus (IPS) and left angular gyrus are implicated in number representation (Nieder & Dehaene, 2009).

The claim that maths difficulties have a non-verbal, neurological origin was made by Rourke (1995) who argued for a specific non-verbal disability associated with poor maths ability (Rourke, 1995; Rourke & Strang, 1978). They examined the relationships between motor, psychomotor and perceptuo-tactile competencies, reading, writing, as well as arithmetic abilities. They found children with normal reading and writing, but marked arithmetic deficits significantly correlated with psychomotor (a timed maze test, the Grooved Pegboard Test, and the Tactual Performance Test) and perceptuo-tactile (Tactile Perception, Finger Agnosia, Finger Tip Number-Writing Perception, Coin Recognition) test performance. This pattern of deficits is roughly analogous to those found by Gerstmann in the 1920s. Nevertheless, it is evident that so-called NVL abilities per se are more evident in older than younger children (i.e. 9- to 14-year-olds, compared to 7- to 8-year olds—see Rourke, 1995).

The term developmental dyscalculia (DD) was first used by Kosc (1974) to characterize a range of arithmetic difficulties. Kosc described six types of DD: (1) verbal dyscalculia is difficulty understanding maths terms; (2) practognostic dyscalculia is difficulty representing objects mathematically; (3) lexical dyscalculia is difficulty reading maths symbols; (4) graphic dyscalculia is difficulty writing maths symbols, (5) ideaognostic dyscalculia is difficulty understanding maths ideas; and (6) operational dyscalculia is difficulty with mental calculation procedures.

Three points should be made about Kosc's DD descriptions. First, they reflect commonly observed maths difficulties, many of which are co-morbid with other deficits (e.g. with dyslexia). Second, it is possible a common difficulty may underlie Kosc's categories. Thirdly, Kosc does not suggest causes that might underlie these different types of DD. Nevertheless, one or more of these DD difficulties will likely be encountered by teachers and/or clinicians. Three questions require answers: (1) are each of these categories separate types of dyscalculia; (2) what intervention process is appropriate for these DD difficulties; and (3) what is the impact of invention on maths abilities more generally. Moreover, these descriptions of DD do not consider its origins.

## Developmental Dyscalculia: Contemporary Neuropsychological Research Evidence

Current neurological and/or genetic research evidence suggests DD is a core number deficit (Reeve & Gray, 2015). Twin studies show that

---

[2] Brian Butterworth: www.mathematicalbrain.com; Roi Cohen Kadosh: https://cohenkadosh.psy.ox.ac.uk; Anna Wilson: Dyscalculia—www.aboutdyscalculia.org.

DD may be heritable (Butterworth & Kovas, 2013): genetic analysis suggests number ability is heritable (accounting for 32 % of shared variance—see Tosto et al., 2014). Analyses of atypical genetic family groups suggest a possible locus on the X chromosome, though this does not mean that all cases of dyscalculia are necessarily inherited or associated with the X chromosome (Rodic et al., 2015). Functional neuroimaging confirms specific brain areas are activated by numerical processing (Butterworth, 2010) and are neuroanatomically distinct from regions serving general executive functions (Nieder & Dehaene, 2009).

Since DD is thought to have a genetic/neurological component, a research goal has been to identify procedures that identify core number deficits as early in life as possible. Research has identified at least two core number abilities, namely, the abilities to rapidly and precisely enumerate small sets of objects (e.g. dots) and rapidly comparing the magnitude of quantities (e.g. identifying which of two sets of dots contains more dots) support maths development (Reeve et al., 2012).

Number/quantity comparison tasks assess the speed and accuracy with which the relative magnitude of two numerical values is identified (e.g. “which quantity/number is larger”) (Locuniak & Jordan, 2008 Reeve et al., 2012). DD children experience difficulties making number/quantity comparisons (Price, Holloway, Räsänen, Vesterinen, & Ansari, 2007; Reeve et al., 2012). Price et al. (2007), for example, showed that compared to non-DD children, DD children were less accurate, and were much slower in making comparison judgments. They also found non-symbolic magnitude comparison abilities (e.g. comparing the numerosity of dots in two arrays) predicted arithmetic abilities.

The failure to quickly name small sets of objects (e.g. dots) without counting (known as subitizing) is also implicated in DD (Landerl et al., 2004; Reeve et al., 2012). Children who are unable to subitize are unable to specify the numerosity of small numbers of dots without counting, and are also very poor at arithmetic (Arp, Taranne, & Fagard, 2006; Landerl et al., 2004; Reeve et al., 2012). Subitizing deficits are associated with right parietal disruptions, particularly the intraparietal sulcus and evident in several disorders, including Turner’s syndrome (TS) (Bruandet, Molko, Cohen, & Dehaene, 2004), cerebral palsy (CP) (Arp et al., 2006), Velocardiofacial syndrome (VCFS—also known as Chromosome 22q11.2 Deletion syndrome, or DS22q11.2) (Simon, Bearden, Mc-Ginn, & Zackai, 2005), Fragile X syndrome (FXS), and Williams (WS) syndrome (Paterson, Girelli, Butterworth, & Karmiloff-Smith, 2006). From a diagnostic perspective, the failure to subitize is associated with difficulty linking number words and sets, the acquisition of cardinal meaning of number words, part-whole number relations, and transformations of set numerosity (i.e. arithmetic) (Reeve & Gray, 2015).

Evidence for the existence of the two core number systems in infancy is well documented. Infants’ ability to discriminate difference between two non-symbolic quantities (i.e. sets of objects) has been found in several paradigms: habituation (Xu & Spelke, 2000), cross-modal discrimination (Izard, Sann, Spelke, & Streri, 2009), and numerical change detection (Starr, Libertus, & Brannon, 2013). Izard and colleagues showed that newborns (49-h-old neonates) could discriminate between two numerosities presented in different modalities (i.e. visual and auditory), which suggests infants possess something akin to an abstract representation of quantity. Infants are also able to represent small numbers of objects precisely. For instance, findings from manual search and ordinal choice paradigms suggest infants can precisely represent and keep track of sets of 1, 2, and 3 objects, but not 4 objects or more (Feigenson & Carey, 2005; Feigenson, Carey, & Hauser, 2002).

We suggest that both precise number enumeration and number comparison abilities should be used as DD markers in young and older children—we return to this point in the next section.

## Developmental Dyscalculia: Assessment and Interventions

Most educators and school psychologists are aware that significantly more is known about reading instruction, assessment, and intervention than about mathematics (Maricle, Psimas-Frazer, Muenke, & Miller, 2010). There is not currently one assessment battery that is used to diagnose a mathematics learning disability. Most practitioners utilize a combination of standardized assessments of cognitive ability and academic achievement to detect patterns that may explain a student's deficient mathematical performance. Given the number of cognitive abilities that are utilized within the academic area of mathematics, a comprehensive assessment is needed to fully evaluate the possible factors that may impact acquisition and utilization of maths skills. An accurate assessment is not only extremely important to fully understand the area of deficit, but is also crucial for the development and implementation of an appropriate intervention.

## Cognitive Assessments

An assessment to determine the presence of a learning disability in the area of mathematics should fully assess the cognitive processes that have been found to be associated with maths performance. According to Carroll-Horn-Cattell (CHC) theory of cognitive abilities, quantitative knowledge and reasoning (Gq), Comprehension Knowledge (Gc), Fluid Reasoning (Gf), Short-Term Memory–Working Memory (Gsm/Gsm-Wm), Processing Speed (Gs), Visual-Spatial Thinking (Gv) and at a young age, Auditory Processing (Ga) have been found to have an impact on mathematical knowledge and performance (Floyd, Evans, & McGrew, 2003; Mather, Wendling, & Woodcock, 2001). With regard to Gq, measures of calculation, maths fluency, quantitative concepts, and applied problems are logically associated with academic achievement in the area of mathematics. Research has indicated that Gc, which is often defined as the breadth and depth of an individual's store of accumulated knowledge of a culture and the effective use of that knowledge (McGrew & Flanagan, 1998), is associated with mathematical ability in that maths skills are associated with comprehension knowledge of mathematics (Maricle et al., 2010). Fluid reasoning (Gf) is defined as the ability to form and recognize logical relationships among patterns and made deductive and inductive inferences (McGrew, 2005). Gf was found to have a moderate correlation with mathematical calculations and moderate to strong correlation to maths reasoning skills (Floyd et al., 2003). Short-term memory, specifically working memory, has also been found to play an important role in mathematical achievement, as all mathematical tasks require the ability to hold numerical quantities within short-term, working, or long-term memory (Maricle et al., 2010). Processing Speed (Gs), or the ability to perform simple cognitive tasks quickly and efficiently, is related to the automaticity of retrieval of simple maths facts, often measured in tasks of mathematical fluency. Students with deficits in Gs would likely perform poorly on mathematical tasks that are measured under time constraints (Maricle et al., 2010). The relationship between visual-spatial thinking (Gv) and mathematics achievement has revealed mixed findings, with some studies indicating that Gv plays a negligible role in calculation and higher-level maths skills, while other researchers suggest that visual-spatial abilities are associated with the development of mathematical skills (Floyd et al., 2003). While this area should certainly be assessed as part of a comprehensive assessment battery, it need not be the focus of an evaluation of a child experiencing difficulties in the area of mathematics. Lastly, Auditory Processing (Ga), or the ability to perceive, attend to, and analyse patterns of sound and speech, has been found to be associated with the early stages of development of mathematical calculation skills (Floyd et al., 2003).

There are a variety of standardized assessments which allow for the evaluation of these cognitive processes, including the Wechsler scales, the Woodcock Johnson assessment batteries, the Kaufman assessment batteries, and the KeyMath diagnostic assessment (see Table 1).

The Woodcock Johnson III: Tests of Cognitive Abilities (WJIII-COG, Woodcock, McGrew, & Mather, 2001a) is based on CHC theory and therefore assesses all of the areas described above. The WJIII-COG allows for the assessment of Gc, Gf, Gsm-Wm, Gv, and Ga. The Woodcock Johnson IV: Tests of Cognitive Abilities (WJ IV

**Table 1** Battery of tests useful in assessment of mathematical abilities

| Assessment instrument | Associated areas measured |
|---|---|
| Wechsler (WAIS-IV[a]; WISC-IV[a] or WISC-V; WPPSI-IV[a]) | Verbal comprehension, working memory, perceptual reasoning, and processing speed |
| Woodcock-Johnson (WJ III COG[a]; WJ-IV COG) | Crystallized intelligence, fluid reasoning, short-term memory/working memory, visual-spatial processing, auditory processing |
| Wechsler Individual Achievement Test (WIAT-II[a], WIAT-III) | Academic achievement, specifically mathematical calculation, applied problem-solving, and maths fluency |
| Woodcock-Johnson (WJ III ACH[a]; WJ IV ACH; WJ IV ECAD) | Academic achievement, specifically Quantitative Reasoning (Gq), with tasks assessing calculation, maths fluency, quantitative concepts, and applied problems. WJ IV ECAD includes specific subtest on number sense (magnitude and quantity estimations) |
| Kaufman Assessment Battery for Children (K-ABC-II) | Assesses short-term memory, visual-spatial thinking, long-term retrieval, fluid reasoning, and comprehension knowledge |
| Kaufman Test of Educational Achievement (KTEA-III) | Academic achievement measuring mathematical concepts and application, maths computation, and maths fluency |
| KeyMath 3 Diagnostic Assessment[a] | Basic mathematical concepts, computational skills, and problem-solving |
| Dyscalculia Screener | Computerized measure assessing dot enumeration, number comparison, single digit arithmetic, and reaction time |

[a] Indicates Australian versions/norms or Australian and New Zealand language adapted editions are available

COG, Schrank, McGrew, & Mather 2014a) was recently published, though Australian norms have not yet been created for this measure. The Kaufman Assessment Battery for Children—Second Edition (KABC-II, Kaufman & Kaufman, 2004) also assesses various CHC factors including Gc, Gf, Gsm, and Glr (long-term retrieval). The Wechsler Intelligence Scale for Children—Fourth Edition (WISC-IV, Wechsler, 2003) is also widely used standardized assessments for evaluating learning difficulties in the area of mathematics. The Wechsler Intelligence Scale for Children—Fifth Edition was recently published (WISC-V; Wechsler, 2014), though Australian norms are not yet available. Both the WISC-IV and WISC-V assess verbal comprehension, working memory, perceptual reasoning, and processing speed.

## Assessments of Academic Achievement

In addition to assessing specific cognitive areas associated with the acquisition and development of mathematics skills, a specific assessment of mathematical achievement should be conducted in order to determine where, in fact, the breakdown in skills occurs. This can be difficult using current standardized assessment measures of academic achievement, as it was been noted that these are often too general and include too many different types of items in order to truly lead the examiner to the specific cause of a student's difficulty in mathematics.

The Woodcock Johnson III: Tests of Achievement (WJIII-ACH) (Woodcock et al., 2001a, 2001b) has subtests assessing Quantitative Reasoning (Gq), with tasks specifically assessing calculation, maths fluency, quantitative concepts, and applied problems. Updated Woodcock Johnson batteries including the Woodcock Johnson IV Tests of Academic Achievement (WJ IV ACH) (Schrank, McGrew, & Mather, 2014b) and the Woodcock Johnson IV Early Cognitive and Academic Development (WJ IV ECAD) (Schrank, McGrew, & Mather, 2015) have been recently published. Though Australian norms have not yet been developed for these measures, they include subtests specifically assessing quantitative reasoning. The WJ IV ECAD, which can be used with children between the ages of 3 and 7 years or those up to 9 years old with a documented cognitive delay, includes a subtest entitled Number Sense, which assesses number recognition, counting, and sequencing as well as magnitude and quantity estimation (Schrank et al., 2015), allowing for early detection of some of the core deficits involved in developmental dyscalculia. The Wechsler Individual Achievement Test—Third Edition

(WIAT-III) (Wechsler, 2009) The WIAT-III assesses mathematical calculation, applied problem-solving, and maths fluency. These assessment measures also both contain subtests assessing reading skills, which may be important to examine if it is found that a student's deficits in mathematics may be associated with difficulties in reading and comprehending instructions or the content word problems.

The Kaufman Test of Educational Achievement—Third Edition (KTEA-III, Kaufman & Kaufman, 2014) is also an individually administered standardized assessment battery that allows for the examination of mathematical skills including arithmetic concepts, application of mathematical principles and reasoning, number concepts, operations, time and money, concepts of measurement, geometry, and higher-level mathematical concepts. Items are presented in an auditory format but include a visual stimulus. This assessment measure also includes a paper-and-pencil computation task that requires the examinee to solve written mathematical problems including addition, subtraction, multiplication, division, fractions, decimals, square roots, exponents, and algebra (Lichtenburger & Smith, 2005).

In addition to the above-mentioned general assessments of academic achievement, assessment measures specifically examining mathematics are also available. KeyMath 3 Diagnostic Assessment (Connolly, 2008) is a standardized assessment measure for individuals between the ages of 4½ and 21 years that evaluates three general content areas: basic mathematical concepts, computational skills, and problem-solving.

It is evident that a number of standardized psychometric tests can be used to diagnose children's arithmetic difficulties. The question of whether these tests are able to diagnose DD specifically remains. We suggest that one way to address this issue would be to use a two-phase test approach to the assessment of DD. Standard psychometric tests would comprise the first phase, and a neurological core number test could comprise the second more definitive phase. Butterworth's (2003) Dyscalculia Screener test (available in Australia) could serve the latter purpose (as could specifically designed number comparison and precise number, dot enumeration tests—described in the previous section). The Dyscalculia Screener is a computerized test in which the examinee uses the keyboard to respond. This assesses both symbolic and non-symbolic mathematical skills such as dot enumeration, number comparison, and single digit arithmetic. This screener also records reaction time, thus assessing both accuracy and speed.

We see several advantages for a two-phase test approach. As noted earlier, there are many reasons for being poor at maths and psychometric tests will not differentiate among these reasons and DD. On the basis of extensive core number research (described above) however, we know that number comparison and precise number test do differentiate between DD and other reasons for being poor at maths. Moreover, the two core number tests can be used with very young and older children, as well as adults, to identify dyscalculia.

## Patterns in Deficits Associated with Developmental Dyscalculia

When examining the patterns of deficits or weaknesses found in the results of cognitive and academic testing, it is helpful to keep in mind the suggested subtypes of this disorder that were previously described within this chapter. Hale et al. (2008) suggest that the Numeric-Quantitative Knowledge subtype of developmental dyscalculia is most commonly associated with below average performance on tasks of numerical operations and slightly below average scores in the area of maths reasoning. In addition, these individuals commonly present with low average skills on tasks of working memory and processing speed (particularly on the WISC-IV). These deficits are all associated with the horizontal intraparietal sulcus, which is located within the parietal cortex.

In contrast, the Dyscalculia-Gerstmann Syndrome is associated with a different pattern of deficits. Wilson and Dehaene (2007) describe individuals with this subtype of dyscalculia to have severe deficits on tasks of numerical operations as well as maths reasoning tasks, in addition to low average verbal comprehension abilities.

In examining cognitive profiles, students with this pattern of deficits demonstrate their poorest performance on the following WISC-IV subtests: Information, Arithmetic, Block Design, and Picture Completion. Deficits are also found within the area of processing speed (Hale et al., 2008). This subtype of dyscalculia is associated with impairments in the left parietal lobe, specifically the angular gyrus, left inferior frontal and/or temporal language areas, or the left basal ganglia (Wilson & Dehaene, 2007).

The Mild Executive/Working Memory subtype of developmental dyscalculia (Hale et al., 2008) is, as its name suggests, mild with regard to deficits found on mathematics subtests. This subtype reflects those with average performance in the areas of numerical operations and maths reasoning, and the majority of cognitive skills intact. Individuals with this subtype may have difficulty on tasks such as Information, Digit Span Backward, Arithmetic, and Matrix Reasoning. This is related to frontal-striatal dysfunction.

The Fluid/Quantitative Reasoning subtype is associated with average numerical calculations, low average maths reasoning, and difficulties on tasks of fluid reasoning such as Matrix Reasoning and Picture Concepts. Difficulties on the Arithmetic subtest of the WISC-IV were also found to be associated with this subtype (Hale et al., 2008).

School psychologists are typically familiar with many of the assessment tools described above, which makes the role of school psychologists extremely important in the identification of developmental dyscalculia in youth. Careful analysis of the pattern of deficits within these evaluations allows for accurate diagnoses to be made, as well as identification of the appropriate interventions to target areas of deficiency.

## Additional Considerations in Assessing Difficulties in Mathematics

The presence of anxiety as it relates to performance in mathematics should be considered, and screened for when deemed appropriate. Mathematics anxiety has been associated with poor mathematical performance (REF). The Revised Mathematics Anxiety Rating Scale (RMARS; Alexander & Martray, 1989) is a 25-item checklist to assess for the presence of anxiety related to mathematical tasks and performance. The addition of such a measure into a larger assessment of mathematical ability could assist in identifying anxiety, which may be contributing to or exacerbating difficulties in the area of mathematics, as intervention may also be appropriate within the emotional as well as academic realm. In addition, it is important to rule out other aspects, which may have an impact on academic achievement such as a lack of behavioural engagement (i.e. conduct problems, poor school attendance). These may have a detrimental impact on academic achievement without the presence of a true learning disability (Wang & Eccles, 2011).

## Obstacles to Identifying Appropriate Interventions

Several key factors make it difficult when attempting to determine which intervention(s) may be appropriate in remediating mathematics deficits in a particular student. First, the academic area of mathematics is vast, involving a wide variety of knowledge, skills, and procedures. These range from basic concepts such as number identification and counting to more abstract concepts such as time, speed, and direction. Depending on the grade of the student, he/she may be required to recall specific computational facts and procedures, estimate magnitudes, and solve complex word problems requiring the student to independently determine the necessary mathematical operation. While all of the above-mentioned tasks are related to mathematics, they involve a variety of cognitive processes, which leads us to the second factor complicating the determination of an appropriate intervention: the current lack of a comprehensive theory of the cognitive processes related to mathematical learning disabilities. This lack of consensus has resulted in a large number of specific cognitive abilities that may be impacting the development and/or utilization of mathematical skills and knowledge. Cognitive processes including working memory (Mabbott & Bisanz, 2008; Meyer, Salimpoor, Wu, Geary, & Menon, 2010; Zheng, Swanson, & Marcoulides, 2011), executive functions (Mazzocco & Kover, 2007) including set shifting (Clark, Pritchard, & Woodward, 2010), inhibition (Andersson, 2008), planning, self-regulation (Montague, 2007), and metacognition (Rosenzweig, Krawec, & Montague, 2011) all appear to play a role in the application of mathematical skills.

One final challenge in determining an effective intervention for deficits in mathematics is the high rate of co-morbidity that dyscalculia has with other disorders. Dyslexia and dyscalculia co-occur frequently, with an estimated combined prevalence of 10 % and a co-morbidity rate of approximately 40 % (Wilson et al., 2015). This is particularly problematic when a student presents with difficulties with word problems or story problems, which require a student to identify what information is relevant, what information is missing, and what calculation must be performed (Fuchs et al., 2008). Another developmental disorder that often co-occurs with developmental dyscalculia is Attention Deficit/Hyperactivity Disorder (ADHD), with estimated co-morbidity rates ranging from 5 to 30 % (Capano, Minden, Chen, Schachar, & Ickowicz, 2008; Langberg, Vaughn, Brinkman, Froehlich, & Epstein, 2010; Mayes & Calhoun, 2007; Miranda, Soriano, Fernández, & Meliá, 2008). The lack of attention to detail and self-monitoring while engaging in mathematical calculations clearly has the potential to negatively impact accuracy.

The multiple demands, cognitive processes, and possible co-morbidities associated with deficits in mathematics point to the need for a comprehensive assessment in order to provide information regarding the potential impact of all of these factors in order to determine which areas may be contributing to the deficit in this academic area. Given the number of factors that may be involved in mathematical deficits, many interventions involve multiple components and dimensions. There is not one instructional method or intervention that will work for all students (Fuchs et al., 2008), and it is important to utilize a student's baseline level of functioning and mathematical knowledge when choosing an intervention.

## General Components of Effective Interventions

School psychologists are essential in determining the appropriate interventions, which should not only be based in empirically based techniques, but should also directly target the skills that were found to be area of deficit in the formal assessment conducted. Fuchs et al. (2008) suggested seven guiding principles for effective interventions for students with mathematical disabilities. The first principle suggested is instructional explicitness, which involves didactic instruction which directly addresses the information that the child needs to learn. Building upon this, the second principle focuses on the instructional design to minimize the learning challenge of the student. This involves clear and precise explanations of logically sequenced instruction in order to assist the student in closing the achievement gap. Methods should utilize and focus on the strengths of a student in order to maximize the chance for success. The third guiding principle for effective interventions is to utilize a strong conceptual basis for any procedures that are taught. If a student has a true conceptual understanding of what he/she is learning, it will help prevent learning gaps, failure to maintain skills, and difficulty with integration of skills. Only after a student has a firm conceptual understanding of the processes being taught, these skills should be drilled and practised. The fifth principle involved a cumulative review in order to incorporate not only the skill that has just been taught, but those on which it was based or is related. Another important principle that is often overlooked is the use of motivators to help students regulate their attention and behaviour. When a student realizes that a particular subject area, skill, or activity is difficult for him/her or when he/she has experienced repeated failure, this may result in avoidance or emotional stress. In order to address this, the use of motivators or reinforcers is important. These can either be tangible in nature or may be more intrinsic ("beat your score"). Regardless, those working with students must keep in mind the need to address their level of motivation, attention, and self-regulation (see www.interventioncentral.org/behavioral-intervention-modification for examples). Lastly, ongoing progress monitoring must occur in order to determine if the intervention being utilized is effective for the student. Despite the use of an empirically based intervention, progress monitoring must occur in order to determine if the intervention being utilized is effective for a particular student. Curriculum-based measurement (CBM) is often utilized in order to determine the effectiveness of an intervention for a given student (Hosp, Hosp, & Howell, 2007). This classroom-based assessment is short in duration, typically lasting only a few minutes. The teacher utilizes the mathematics curriculum and administers a test assessing specific concepts/applications or calculations, and counts the number of correct and incorrect responses made in the time allotted to find the child's score. Scores can be graphed weekly in order to determine if progress is being made. (Curriculum-based measurement resources can be found at http://www.interventioncentral.org/teaching-resources/downloads)

## Early Numeracy Interventions

Early numeracy skills such as counting, number knowledge, and number operations have been found to be highly predictive of mathematical computation and problem-solving skills through the third grade, even when variables such as reading ability, age, and general cognitive factors were controlled for (Jordan, Glutting, & Ramineni, 2009; Jordan, Glutting, Ramineni, & Watkins, 2010; Jordan, Kaplan, Ramineni, & Locuniak, 2009; Locuniak & Jordan, 2008). In addition, knowledge in these areas forms the foundation for higher-level mathematics skills. As such, interventions within this area are important for early learners who are struggling in the area of mathematics. Several interventions have been developed that target early numeracy skills, including the *Number Sense Interventions* (Jordan & Dyson, 2014). This programme was developed by researchers in the field of number sense and early numeracy, and provides evidence-based interventions for the development of key maths skills such as oral counting, number recognition, and numeral writing. It includes 24 scripted lessons of approximately 30 min each. Specific skills addressed involve recognizing quantities and numerals, making associations between numerals and quantities, writing numerals, solving story problems, and solving written equations.

## Mathematics Fluency Interventions

Maths fluency is the ease and accuracy of carrying out a basic calculation, and is an important tool for solving most basic maths problems. Developing automaticity with basic maths facts may improve a students' ability to learn, develop, and apply more advanced mathematical skills and concepts (Shapiro, 2004). A simplistic intervention that has been utilized in order to assist students in increasing fluency and accuracy in basic mathematical skills is the Cover-Copy-Compare (CCC) method (Hansen, 1978; McGuigan, 1975). This method was initially utilized to assist students in improving their spelling, but has since been extended to mathematics facts (Skinner, Turco, Beatty, & Rasavage, 1989). Students are taught to view multiplication problems and their associated answers on the left side of a sheet of paper, cover up the problem and answer, write the problem and answer on the right side of the page, and uncover to check their response. Students proceeded to the next problem if a correct response was made or rewrite the response if it was incorrect. The Cover-Copy-Compare method and variations of this basic procedure incorporate several components of effective instruction such as modelling, opportunities to practise, and corrective feedback. Though this method is simplistic, a meta-analytic study looking at the effects of the CCC method and variations of this procedure found that such interventions are effective in assisting students in acquiring knowledge of mathematical facts and increasing mathematics fluency. The strongest effects were found when this method was utilized in conjunction with other evidence-based interventions (Joseph et al., 2012).

## Metacognitive Interventions

Metacognition refers to higher-order thinking strategies that assist in controlling cognitive processes in order to execute a task. In solving mathematics problems, several metacognitive processes may be utilized: visualization, estimation, self-instruction, and self-questioning (Rosenzweig et al., 2011). The use of metacognitive skills is often assessed using "think-aloud protocols" in which individuals actively verbalize their thoughts and cognitive activities while engaging in an activity (Ostad & Sorenson, 2007). Such "think-aloud" methods may be useful in determining specific areas of weakness in a student's skills, specific error patterns, or the use of inappropriate strategies during problem-solving activities. Specific interventions have been developed that focus on strengthening metacognitive skills in order to improve mathematical problem-solving. *Solve It*! is a scripted curriculum designed to teach mathematical problem-solving by engaging students in a series of steps that allow them to actively participate in metacognitive processing and demonstrate higher-order problem-solving skills (Montague, 2003). *Solve It*! can be utilized to teach mathematical problem-solving skills by explicating teaching students how to understand a task, analyse and solve a problem, and evaluate their answer. This intervention includes aspects which address metacognitive skills such as self-instruction, self-questioning, and self-monitoring through use of a SAY, ASK, CHECK procedure (Rosenzweig et al., 2011). Research has demonstrated that middle school students who received *Solve It*! instruction reported using significantly more strategies than students who did not receive this intervention, and appears to improve students problem-solving accuracy by providing them with an increased number of effective strategies to successfully solve problems (Krawec, Huang, Montague, Kressler, & de Alba, 2013).

## Quantitative Reasoning/Problem-Solving Interventions

Many students possess the ability to correctly solve basic mathematical calculations, but experience difficulty when required to engage in higher-level problem-solving. *FAST DRAW* is an evidence-based intervention that utilizes an eight-step strategy to assist students in systematically solving mathematical word problems. FAST DRAW is a mnemonic for the steps to remind the students what information must be gathered and the sequence in which they should gather that information. First the student must **F**ind the question within the problem, then **A**sk themselves to identify the parts of the problem. Once this is complete, the student can **S**et up the numbers in a vertical format and **T**ie down the sign or numerical operation that should be utilized. The student **D**iscovers the sign that must be utilized to perform the operation, **R**eads the problem, thinks of the **A**nswer or draws lines to figure out the answer, then **W**rites the answer down (Harris, Miller, & Mercer, 1995).

School psychologists should play several roles in intervening with students with developmental dyscalculia. Not only should school psychologists consult with teachers in determining the most appropriate intervention given the specific areas of deficit, but they should also be actively involved in assisting teachers in ensuring that the interventions are being implemented appropriately. Lastly, progress monitoring and analysis of this data is essential in order to determine the effectiveness of the intervention. School psychologists must be continually checking in to ensure that the intervention being utilized is resulting in improvement in skills. Unfortunately, however, many schools in Australia are not resourced appropriately to have a school psychologist on staff to spend the time needed to diagnose DD, capacity build teachers to provide the most appropriate individualized intervention for DD, ensure fidelity to a treatment approach, and evaluate outcomes. What a difference it would make to many students struggling with DD (and other learning disabilities) if they had access to school psychologists who could provide this level of support.

## Developmental Dyscalculia: Summary

The purpose of this chapter has been to review the status of DD knowledge and especially the implications for assessment and intervention practices. We began the chapter by emphasizing the value of numeracy for survival in today's world; and in our view, this value will increase further rather than diminish. Despite a relatively lack of investment in DD from national funding agencies, we now understand a great deal about the neuropsychological bases of DD, and in particular the significance or core number deficits. The diagnostic importance of the two core number deficits (i.e. precise number and approximate number abilities) cannot be understated. We know that these two abilities can be assessed from infancy upwards, and that performance differences in them are associated with maths performance throughout the childhood years. We suggested that data from core number assessment (e.g. Butterworth's, 2003, Dyscalculia Screener) could be used to supplement data from traditional psychometric assessments of maths difficulties. As noted earlier, there are many reasons for being bad at maths, differences among which will not be identified by psychometric tests. We advocate a two-phase test procedure for identifying DD: in the first phase, a psychometric test is used to identify maths difficulties; in the second, a core number test is used to identify DD. Given that we are able to identify DD with more precision, it remains to be seen what kind of intervention processes will best work with children with DD. The variability in areas of deficit in children with DD makes it difficult to make general statements about specific interventions, several empirically based interventions exist that have been found to be effective in the development of mathematical understanding, skills, and abilities in a variety of areas (i.e. early numeracy, fluency, quantitative reasoning).

## Case Study

Student: John Smith
Age: 7 years, 8 months
Year: 1
School: ABC Primary School

## Reason for Referral

John was referred to the school psychologist by his teacher due to difficulties with basic mathematical principles such as addition and subtraction.

## Background Information

John was born following an uncomplicated pregnancy, and no concerns arose during or after delivery. He achieved all developmental milestones within normal limits. There are no concerns regarding John's hearing or vision. John began attending school at the age of 5. His family moved after his first year of schooling, and John adjusted to his new school and home without difficulty. It was reported that John has experienced difficulties in the area of mathematics since beginning school. His parents report it took John longer than expected to learn to count with one-to-one correspondence, and as such he had difficulty identifying quantities accurately. John's current teacher reported that John's accuracy in counting has improved significantly, but he often provides incorrect answers on basic addition and subtraction problems. He does not appear to automatically recognize the answer to basic maths problems without having to actively carry out the calculation. No concerns regarding John's behaviour, attention span, or other academic areas were reported.

## Classroom Observations

John was observed in his classroom in order to gain additional information regarding his reported difficulties, and a mathematics work sample was reviewed. When the teacher instructed the class to take out their maths books, a sudden change in John's affect was observed. While he was smiling and appeared quite content during the previous lesson, John was noted to lower and shake his head before retrieving his book. John was able to follow all teacher directives during a lesson, but appeared to have difficulty completing independent work. He was noted to look around at his peers while they worked. John's teacher noticed this and came to his desk in order to review the lesson in relation to his independent work. An analysis of John's work sample revealed frequent errors on rather simplistic addition and subtraction problems. His answer was frequently off by one or two, and on multiple occasions John carried out the incorrect mathematical operation (e.g. added instead of subtracted).

## Tests Administered

Wechsler Intelligence Scale for Children, fourth Edition (WISC-IV)
Wechsler Individual Achievement Test, second Edition (WIAT-II)
Dyscalculia Screener

## Summary of Test Results

Results indicated John's verbal comprehension and perceptual reasoning abilities fell within the average range compared to his same-aged peers, while his working memory fell within the low average range and his processing speed fell below average. Assessment of John's ability in the area of numerical operations fell significantly below average, as he was unable to correctly calculate single digit addition or subtraction problems. John's mathematical reasoning ability was found to be within the lower limits of the average range, indicating stronger abilities when working with applied problems as opposed to straightforward calculations. In contrast, John's abilities in the areas of reading, writing, and oral language all fell within the average range for his current grade level.

The results of the Dyscalculia Screener revealed John does not possess automaticity with regard to basic mathematical concepts such as number comparison. His reaction time when asked to determine which number was quantitatively larger was significantly longer than would be expected given his age, and his overall accuracy was far below the expected level. These results confirm that John does not possess some of the foundational knowledge upon which mathematical operations such as addition and subtraction are built.

Overall, the findings from the psychoeducational assessment combined with John's educational history were consistent with the diagnostic criteria for a specific learning disorder with impairment in mathematics, otherwise known as dyscalculia.

## Educational Recommendations

| Remediation | Accommodations |
|---|---|
| • Utilize an intervention that focuses on early number sense, and skills such as counting, number knowledge, and basic calculations (e.g. Number Sense Interventions) | • Allow John extra time to complete calculations, as his ability to solve problems is not yet automatic |
| • Help John develop the idea of number sequence by utilizing a number line to answer basic questions such as: "What number comes just before…?" "What number comes just after…?" Work with segments of numbers and fade use of the number line as each segment is mastered | • Emphasize quality over quantity or speed. Focus on accuracy, understanding, and persistence when working on maths problems rather than speed or rapid recall of facts |
| • Utilize multisensory teaching/learning practices as often as possible. Manipulatives such as blocks can be utilized to make calculations more concrete in nature | |

## Test Yourself Quiz

1. What is "number sense" and "numeracy" and how do these concepts relate to difficulties in mathematics?

2. What are some of the cognitive abilities associated with mathematics achievement? How does the wide range of cognitive skills involved impact the assessment process?
3. What guiding principles do Fuchs et al. (2008) suggest in identifying an appropriate and effective interventions for deficits in mathematics?

## References

Alexander, L., & Martray, C. (1989). The development of an abbreviated version of the Mathematics Anxiety Rating Scale. *Measurement and Evaluation in Counseling and Development, 22*, 143–150.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders, (DSM-5®)*. Arlington, VA: American Psychiatric Publishing.

Andersson, U. (2008). Mathematical competencies in children with different types of learning difficulties. *Journal of Educational Psychology, 100*(1), 48–66. doi:10.1037/0022-0663/100.1.48.

Arp, S., Taranne, P., & Fagard, J. (2006). Global perception of small numerosities (subitizing) in cerebral-palsied children. *Journal of Clinical and Experimental Neuropsychology, 28*(3), 405–419. doi:10.1080/13803390590935426.

Bishop, D. V. (2010). Which neurodevelopmental disorders get researched and why? *PLoS ONE, 5*(11), e15112. doi:10.1371/journal.pone.0015112.

Bruandet, M., Molko, N., Cohen, L., & Dehaene, S. (2004). A cognitive characterization of dyscalculia in Turner syndrome. *Neuropsychologia, 42*(3), 288–298. doi:10.1016/j.neuropsychologia.2003.08.007.

Bugden, S., & Ansari, D. (2015). How can developmental neuroscience constrain our understanding of developmental dyscalculia? In S. Chinn (Ed.), *The Routledge international handbook of dyscalculia and mathematical learning difficulties* (pp. 18–43). New York: Routledge.

Butterworth, B. (1999). *The mathematical brain*. London: Macmillan.

Butterworth, B. (2003). *Dyscalculia screener*. London: NferNelson.

Butterworth, B. (2005). Developmental dyscalculia. In J. I. D. Campbell (Ed.), *Handbook of mathematical cognition* (pp. 455–468). New York: Psychology Press.

Butterworth, B. (2010). Foundational numerical capacities and the origins of dyscalculia. *Trends in Cognitive Sciences, 14*(12), 534–541. doi:10.1016/j.tics.2010.09.007.

Butterworth, B., & Kovas, Y. (2013). Understanding neurocognitive developmental disorders can improve education for all. *Science, 340*(6130), 300–305. doi:10.1126/science.1231022.

Butterworth, B., Varma, S., & Laurillard, D. (2011). Dyscalculia: From brain to education. *Science, 332*(6033), 1049–1053. doi:10.1126/science.1201536.

Butterworth, B., & Yeo, D. (2004). *Dyscalculia guidance: Helping pupils with specific learning difficulties in maths*. London: NferNelson.

Capano, L., Minden, D., Chen, S. Z., Schachar, R. J., & Ickowicz, A. (2008). Mathematical learning disorder in school-age children with attention-deficit hyperactivity disorder. *Canadian Journal of Psychiatry, 53*, 392–399.

Chinn, S. (2015). The Routledge international handbook of dyscalculia and mathematical learning difficulties: An overview. In S. Chinn (Ed.), *The Routledge international handbook of dyscalculia and mathematical learning difficulties* (pp. 1–17). New York: Routledge.

Clark, C. A., Pritchard, V. E., & Woodward, L. J. (2010). Preschool executive functioning abilities predict early mathematics achievement. *Developmental Psychology, 46*(5), 1176–1191. doi:10.1037/a0019672.

Connolly, A. J. (2008). *KeyMath 3 diagnostic assessment*. Bloomington, MN: Pearson.

Dehaene, S. (1997). *The number sense: How the mind creates mathematics*. Oxford: Oxford University Press.

Dehaene, S., Piazza, M., Pinel, P., & Cohen, L. (2003). Three parietal circuits for number processing. *Cognitive Neuropsychology, 20*(3–6), 487–506. doi:10.1080/02643290244000239.

Feigenson, L., & Carey, S. (2005). On the limits of infants' quantification of small object arrays. *Cognition, 97*(3), 295–313. doi:10.1016/j.cognition.2004.09.010.

Feigenson, L., Carey, S., & Hauser, M. (2002). The representations underlying infants' choice of more: Object files versus analog magnitudes. *Psychological Science, 13*(2), 150–156. doi:10.1111/1467-9280.00427.

Floyd, R. G., Evans, J. J., & McGrew, K. (2003). Relations between measures of Cattell-Horn-Carroll (CGC) cognitive abilities and mathematics achievement across the school-age years. *Psychology in the Schools, 40*, 155–171. doi:10.2002/pits.10083.

Fuchs, L. S., Fuchs, D., Powell, S. R., Seethaler, P. M., Cirino, P. T., & Fletcher, J. M. (2008). Intensive intervention for students with mathematics disabilities: Seven principles of effective practice. *Learning Disability Quarterly, 31*(2), 79–92. doi:10.2307/20528819.

Gray, S. A., & Reeve, R. A. (2014). Preschoolers' dot enumeration abilities are markers of their arithmetic competence. *PLoS ONE, 9*(4), e94428. doi:10.1371/journal.pone.0094428.

Hale, J. B., Fiorello, C. A., Miller, J. A., Wenrich, K., Teodori, A., & Hemzel, J. N. (2008). WISC-IV interpretation for specific learning disabilities identification and intervention: A cognitive hypothesis testing approach. In A. Prifitera, D. H. Saklofske, & L. Weiss (Eds.), *WISC-IV clinical assessment and intervention* (2nd ed., pp. 109–171). New York: Elsevier.

Hamak, S., Astilla, J., & Preclaro, H. R. (2015). The acquisition of mathematical skills of Filipino children with learning difficulties: Issues and challenges. In S. Chinn (Ed.), *The Routledge international handbook of dyscalculia and mathematical learning difficulties* (pp. 203–216). New York: Routledge.

Hansen, C. L. (1978). Writing skills. In N. G. Haring, T. C. Lovitt, M. D. Eaton, & C. L. Hansen (Eds.), *The fourth R: Research in the classroom* (pp. 93–126). Columbus, OH: Merrill.

Harris, C. A., Miller, S. P., & Mercer, C. D. (1995). Teaching initial multiplication skills to students with disabilities in general education classrooms. *Learning Disabilities Research & Practice, 10*(3), 180–195.

Henik, A., Rubinsten, O., & Ashkenazi, S. (2011). The "where" and "what" in developmental dyscalculia. *The Clinical Neuropsychologist, 25*(6), 989–1008. doi:10.1080/13854046.2011.599820.

Hinshelwood, J. (1917). Congenital word-blindness. London: H. K. Lewis.

Hosp, M. K., Hosp, J. L., & Howell, K. W. (2007). *The ABCs of CBM: A practical guide to curriculum-based measurement*. New York: Guilford Press.

Izard, V., Sann, C., Spelke, E. S., & Streri, A. (2009). Newborn infants perceive abstract numbers. *Proceedings of the National Academy of Sciences, 106*(25), 10382–10385. doi:10.1073/pnas.0812142106.

Jordan, N. C., & Dyson, N. (2014). *Number sense interventions*. Baltimore, MD: Paul H. Brookes.

Jordan, N. C., Glutting, J., & Ramineni, C. (2009). The importance of number sense to mathematics achievement in first and third grades. *Learning and Individual Differences, 20*(2), 82–88. doi:10.1016/j.lindif.2009.07.004.

Jordan, N. C., Glutting, J., Ramineni, C., & Watkins, M. W. (2010). Validating a number sense screening tool for use in kindergarten and first grade: Prediction of mathematics proficiency in third grade. *School Psychology Review*, *39*(2), 181–185. Accession Number: 52223870.

Jordan, N. C., Kaplan, D., Ramineni, C., & Locuniak, M. N. (2009). Early maths matters: Kindergarten number competence and later mathematics outcomes. *Developmental Psychology, 45*(3), 850–867. doi:10.1037/a0014939.

Joseph, L. M., Konrad, M., Cates, G., Vajcner, T., Eveleigh, E., & Fishley, K. M. (2012). A meta-analytic review of the cover-copy-compare and variations of this self-management procedure. *Psychology in the Schools, 49*(2), 122–136. doi:10.1002/pits.20622.

Kaufman, A. S., & Kaufman, N. (2004). *Kaufman assessment battery for children* (2nd ed.). Circle Pines, MN: American Guidance Service.

Kaufman, A. S., & Kaufman, N. (2014). *Kaufman test of educational achievement* (3rd ed.). Bloomington, MN: NCS Pearson.

Kosc, L. (1974). Developmental dyscalculia. *Journal of Learning Disabilities, 7*(3), 164–177. doi:10.1177/002221947400700309.

Krawec, J., Huang, J., Montague, M., Kressler, B., & de Alba, A. M. (2013). The effects of cognitive strategy instruction on knowledge of maths problem-solving processes of middle school students with learning disabilities. *Learning Disability Quarterly, 36*(2), 80–92. doi:10.1177/0731948712463368.

Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8–9-year-old students. *Cognition, 93*(2), 99–125. doi:10.1016/j.cognition.2003.11.004.

Langberg, J. M., Vaughn, A. J., Brinkman, W. B., Froehlich, T., & Epstein, J. N. (2010). Clinical utility of the Vanderbilt ADHD Rating Scale for ruling out comorbid learning disorders. *Pediatrics, 126*(5), e1033–e1038. doi:10.1542/peds.2010-1267.

Lichtenburger, E. O., & Smith, D. R. (2005). *Essentials of WIAT II and KTEA II assessment*. New York: Wiley.

Locuniak, M. N., & Jordan, N. C. (2008). Using kindergarten number sense to predict calculation fluency in second grade. *Journal of Learning Disabilities, 41*(5), 451–459. doi:10.1177/0022219408321126.

Mabbott, D. J., & Bisanz, J. (2008). Computational skills, working memory, and conceptual knowledge in older children with mathematics learning disabilities. *Journal of Learning Disabilities, 41*(1), 15–28. doi:10.1177/0022219407311003.

Maricle, D. E., Psimas-Frazer, L., Muenke, R. C., & Miller, D. C. (2010). Assessing and intervening with children with maths disorders. In D. C. Miller (Ed.), *Best practices in school neuropsychology: Guidelines for effective practice, assessment, and evidenced-based intervention* (pp. 521–549). Hoboken, NJ: Wiley.

Mather, N., Wendling, B. J., & Woodcock, R. W. (2001). *Essentials of WJ III tests of achievement assessment*. New York: Wiley.

Mayes, S. D., & Calhoun, S. L. (2007). Wechsler Intelligence Scale for Children—third and fourth edition predictors of academic achievement in children with attention-deficit/hyperactivity disorder. *School Psychology Quarterly, 22*(2), 234–249. doi:10.1037/1045-3830.22.2.234.

Mazzocco, M. M., & Kover, S. T. (2007). A longitudinal assessment of executive function skills and their association with maths performance. *Child Neuropsychology: A Journal on Normal and Abnormal Development in Childhood and Adolescence, 13*(1), 18–45. doi:10.1080/09297040600611346.

McGrew, K. S. (2005). The Cattell–Horn–Carroll theory of cognitive abilities: Past, present, and future. In D. P. Flanagan & P. L. Harrison (Eds.), *Contemporary intellectual assessment: Theories, tests, and issues* (2nd ed., pp. 136–181). New York: Guilford Press.

McGrew, K., & Flanagan, D. (1998). *The intelligence test desk reference (ITDR): Gf-Gc cross-battery assessment*. Boston: Allyn & Bacon.

McGuigan, C. A. (1975). *The add-a-word spelling program* (Working Paper No. 53). Seattle: University of Washington, Experimental Education Unit.

Meyer, M. L., Salimpoor, V. N., Wu, S. S., Geary, D. C., & Menon, V. (2010). Differential contribution of specific working memory components to mathematics achievement in 2nd and 3rd graders. *Learning and Individual Differences, 20*(2), 101–109. doi:10.1016/j.lindif.2009.08.004Miles.

Miles, T. R., & Miles, E. (1992). *Dyslexia and mathematics*. New York: Routledge.

Miller, C. J., & Hynd, G. W. (2004). What ever happened to developmental Gerstmann's syndrome? Links to other pediatric, genetic, and neurodevelopmental syndromes. *Journal of Child Neurology, 19*(4), 282–289. doi:10.1177/088307380401900408.

Miranda, A., Soriano, M., Fernández, I., & Meliá, A. (2008). Emotional and behavioral problems in children with attention deficit-hyperactivity disorder: Impact of age and learning disabilities. *Learning Disability Quarterly, 31*(4), 171–185. doi:10.2307/25474650.

Montague, M. (2003). *Solve it! A practical approach to teaching mathematical problem solving skills*. Reston, VA: Exceptional Innovations.

Montague, M. (2007). Self-regulation and mathematics instruction. *Learning Disabilities Research & Practice, 22*(1), 75–83. doi:10.1111/j.1540-5826.2007.00232.x.

Nieder, A., & Dehaene, S. (2009). Representation of number in the brain. *Annual Review of Neuroscience, 32*, 185–208. doi:10.1146/annurev.neuro.051508.135550.

OECD. (2010). *Factbook 2010: Economic, environmental and social statistics*. Paris: Organization for Economic Cooperation and Development.

Ostad, A., & Sorenson, P. M. (2007). Private speech and strategy-use patterns: Bidirectional comparisons of students with and without mathematical disabilities in a developmental perspective. *Journal of Learning Disabilities, 40*(1), 2–14. doi:10.1177/00222194070400010101.

Parsons, S., & Bynner, J. (2005). *Does numeracy matter more?* London: National Research and Development Centre for Adult Literacy and Numeracy. ISBN 1 90 5188 09 9.

Paterson, S. J., Girelli, L., Butterworth, B., & Karmiloff-Smith, A. (2006). Are numerical impairments syndrome specific? Evidence from Williams syndrome and Down's syndrome. *Journal of Child Psychology and Psychiatry, 47*(2), 190–204. doi:10.1111/j.1469-7610.2005.01460.x.

Price, G. R., Holloway, I., Räsänen, P., Vesterinen, M., & Ansari, D. (2007). Impaired parietal magnitude processing in developmental dyscalculia. *Current Biology, 17*(24), R1042–R1043. doi:10.1016/j.cub.2007.10.013.

Reeve, R., & Gray, S. (2015). Number difficulties in young children: Deficits in core number? In S. Chinn (Ed.), *The Routledge international handbook of dyscalculia and mathematical learning difficulties* (pp. 44–59). New York: Routledge.

Reeve, R., & Humberstone, J. (2011). Five-to 7-year-olds' finger gnosia and calculation abilities. *Frontiers in Psychology, 2*, 359. doi:10.3389/fpsyg.2011.00359.

Reeve, R. A., & Humberstone, J. (2012). Dyscalculia in Young Children: Cognitive and Neurological Bases. In N. M. Seel (Ed). Encyclopaedia of the Sciences of Learning (pp. 1062-1065). New York: Springer. Doi: 10. 1007/978-1-4419-428-6_725.

Reeve, R., Reynolds, F., Humberstone, J., & Butterworth, B. (2012). Stability and change in markers of core numerical competencies. *Journal of Experimental Psychology: General, 141*(4), 649–666. doi:10.1037/a0027520.

Reigosa-Crespo, V., & Castro, D. (2015). Dots and digits: How do children process the numerical magnitude? Evidence from brain and behaviour. In S. Chinn (Ed.), *The Routledge international handbook of dyscalculia and mathematical learning difficulties* (pp. 115–124). New York: Routledge.

Rodic, M., Zhou, Z., Tikhomirova, T., Wei, W., Malykh, S., Ismatulina, V., Sabirova, E., Davidova, Y., Tosto M. G., Lemelin, J-P, & Kovas, Y. (2015). Cross-cultural investigation into cognitive underpinnings of individual differences in early arithmetic. Developmental Science, 18, 165–174. DOI: 10.1111/desc.12204

Rosenzweig, C., Krawec, J., & Montague, M. (2011). Metacognitive strategy use of eighth grade students with and without learning disabilities during mathematical problem solving: A think aloud analysis. *Journal of Learning Disabilities, 44*(6), 508–520. doi:10.1177/0022219410378445.

Rourke, B. P. (1995). *Syndrome of nonverbal learning disabilities: Neurodevelopmental manifestations*. New York: Guilford Press.

Rourke, B. P., & Strang, J. D. (1978). Neuropsychological significance of variations in patterns of academic performance: Motor, psychomotor, and tactile-perceptual abilities. *Journal of Pediatric Psychology, 3*(2), 62–66. doi:10.1093/jpepsy/3.2.62.

Schrank, F. A., McGrew, K. S., & Mather, N. (2014a). *Woodcock Johnson IV tests of cognitive abilities*. Rolling Meadows, IL: Riverside Publishing.

Schrank, F. A., McGrew, K. S., & Mather, N. (2014b). *Woodcock Johnson IV tests of achievement*. Rolling Meadows, IL: Riverside Publishing.

Schrank, F. A., McGrew, K. S., & Mather, N. (2015). *Woodcock Johnson IV early cognitive and academic development*. Rolling Meadows, IL: Riverside.

Shapiro, E. S. (2004). *Academic skills problems: Direct assessment and intervention* (3rd ed.). New York: Guilford Press.

Simon, T. J., Bearden, C. E., Mc-Ginn, D. M., & Zackai, E. (2005). Visuospatial and numerical cognitive deficits in children with chromosome 22q11.2 deletion syndrome. *Cortex, 41*(2), 145–155. doi:10.1016/S0010-9452(08)70889-X.

Skinner, C. H., Turco, T. L., Beatty, K. L., & Rasavage, C. (1989). Cover, copy, and compare: A method for increasing multiplication performance. *School Psychology Review, 18*, 412–420.

Starr, A., Libertus, M. E., & Brannon, E. M. (2013). Infants show ratio-dependent number discrimination regardless of set size. *Infancy, 18*(6), 927–941. doi:10.1111/infa.12008.

Temple, C. (1997). *Developmental cognitive neuropsychology*. Hove, Sussex: Psychology Press.

Tosto, M. G., Hanscombe, K. B., Haworth, C. M. A., Davis, O. S. P., Petrill, S. A., Dale, P. S., Malykh, S., Plomin, R., & Kovas. (2014). Why do spatial abilities predict mathematical performance? Developmental Science, 17, 462–470. DOI: 10.1111/desc.12138.

Wang, M., & Eccles, J. S. (2011). Adolescent behavioral, emotional, and cognitive engagement trajectories in school and their differential relations to educational success. *Journal of Research on Adolescence, 22*(1), 31–39. doi:10.1111/j.1532-7795.2011.00753.x.

Wechsler, D. (2003). *Wechsler intelligence scale for children* (4th ed.). San Antonio, TX: Harcourt Assessment.

Wechsler, D. (2009). *Wechsler individual achievement test* (3rd ed.). San Antonio, TX: Harcourt Assessment.

Wechsler, D. (2012). *Wechsler preschool and primary scale of intelligence* (4th ed.). San Antonio, TX: NCS Pearson.

Wechsler, D. (2014). *Wechsler intelligence scale for children* (5th ed.). San Antonio, TX: NCS Pearson.

Wilson, A. J., Andrewes, S. G., Struthers, H., Rowe, V. M., Bogdanovic, R., & Waldie, K. E. (2015). Dyscalculia and dyslexia in adults: Cognitive bases of comorbidity. *Learning and Individual Differences, 32,* 118–132. doi: 10.1016/j.lindif.2014.11.017.

Wilson, A. J., & Dehaene, S. (2007). Number sense and developmental dyscalculia. In D. Coch, G. Dawson, & K. Fischer (Eds.), *Human behavior, learning, and the developing brain: Atypical development* (pp. 212–238). New York: Guilford.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001a). *Woodcock-Johnson III tests of cognitive abilities*. Itasca, IL: Riverside Publishing.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001b). *Woodcock-Johnson III tests of achievement*. Itasca, IL: Riverside Publishing.

Xu, F., & Spelke, E. S. (2000). Large number discrimination in 6-month-old infants. *Cognition, 74*(1), B1–B11. doi:10.1111/infa.12008.

Zheng, X., Swanson, H. L., & Marcoulides, G. A. (2011). Working memory components as predictors of children's mathematical word problem solving. *Journal of Experimental Child Psychology, 110,* 481–498. doi: 10.1016/j.jeco.2011.06/001.

Zhou, X., & Cheng, D. (2015). When and why numerosity processing is associated with developmental dyscalculia. In S. Chinn (Ed.), *The Routledge International Handbook of dyscalculia and mathematical learning difficulties* (pp. 115–124). New York: Routledge.