

Dyscalculia Across Disciplines: An Overview of the Literature

Lisa L. Morin, Ph.D.,
Old Dominion University

Jugnu Agrawal, Ph.D.
George Mason University

Abstract

This article provides an overview of the term *dyscalculia* across three different databases. The definitions, measures and variables used in research, and the general outcomes related to dyscalculia across disciplines are highlighted. The results of the overview emphasize that identification of dyscalculia is still in its infancy. The majority of the participants in the identified studies were from grades K-4. Studies were limited to concepts of number sense and mathematical calculations. Implications for practitioners are also discussed.

Keywords: dyscalculia, mathematics, learning disability, mathematics learning disability

Introduction

In 2015, the Assistant Secretary of the United States Department of Education's Office of Special Education and Rehabilitative Services issued a policy guidance letter clarifying the appropriateness of using terms such as *dyslexia*, *dyscalculia*, and *dysgraphia* when the use of these terms will contribute to "ensuring a high-quality education for children with specific learning disabilities" (Yudin, 2015, October 23). The most recent edition of the *Diagnostic and Statistical Manual of Mental Disorders* (DSM-V; American Psychiatric Association, 2013) also uses the term *dyscalculia*, defining it as "a pattern of difficulties characterized by problems processing numerical information, learning arithmetic facts, and performing accurate or fluent calculations" (p. 67).

In a seminal article published in 1974, Kosc defined *dyscalculia* as a term used to refer to a learning disability in arithmetic computation. Since that time, researchers in the fields of psychology, cognitive neuroscience, and education have made advancements in understanding dyscalculia and determining evidence-based practices for students with dyscalculia. Researchers currently use the terms *dyscalculia* and *developmental dyscalculia*, along with *mathematics learning disability*, across disciplines. However, researchers tend to work within, rather than across, their respective fields. This lends itself to an investigation of information across the fields of psychology, cognitive neuroscience, and education.

Research conducted on the topic of dyscalculia across different disciplines fails to account for the multiple perspectives that can aid with the understanding of the term *dyscalculia*. An overview of the term *dyscalculia* and its constructs across disciplines can assist educators in providing more comprehensive services to students diagnosed with this disability. The research questions guiding this overview were: How is dyscalculia defined across disciplines? What are the similarities and the differences? Specifically, (a) what measures were used in the research across the different fields to determine the presence or severity of dyscalculia, (b) what are the variables related to dyscalculia across disciplines, (c) what are the general outcomes from the

research across disciplines, (d) are there themes and patterns regarding the conclusions across disciplines, and (e) how do the conclusions drawn relate to best practices in teaching?

Methods

A literature search was conducted across databases representing three different fields, specifically PsychInfo (psychology), Medline (cognitive neuroscience), and ERIC (education), terms *dyscalculia* AND *learning disab** (in truncated form). This search yielded 61 articles in the PsychInfo database, 54 articles in the Medline database, and 21 articles in the ERIC database. Some duplicates were removed. Exclusionary criteria included informational articles, literature reviews (i.e., articles that did not include original research), articles that dealt with adults, case studies or articles based on questionnaires, and articles that highlighted a disability in which dyscalculia was considered only one characteristic of that disability. Once exclusionary criteria were applied and overlapping articles across databases were accounted for, 39 articles were included in the review (see Figure 1). Thirty percent of the articles were checked by both authors to ensure consistency of the application of inclusionary and exclusionary criteria. The search and review of articles across three databases is a replication of research conducted by Basho (2015) on characteristics of executive functioning skills across databases.

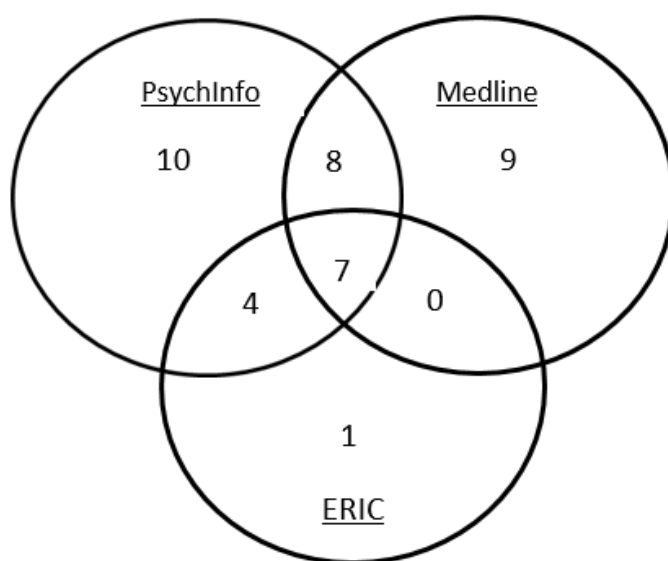


Figure 1. Articles meeting criteria across databases included in this review.

Since this was an exploratory overview, articles were included irrespective of the date of publication. The two earliest articles identified in the search were published in 1993 and were located in the Medline database. In 1995, two more articles were identified which appeared in the PsychInfo database. It was not until 1997 that an article meeting our search criteria on the topic of and using the term *dyscalculia* appeared in the ERIC database. Since 2010, use of the term *dyscalculia* and research involving dyscalculia has increased across databases. In 2014 eight articles were identified in this search across all databases (see Figure 2).

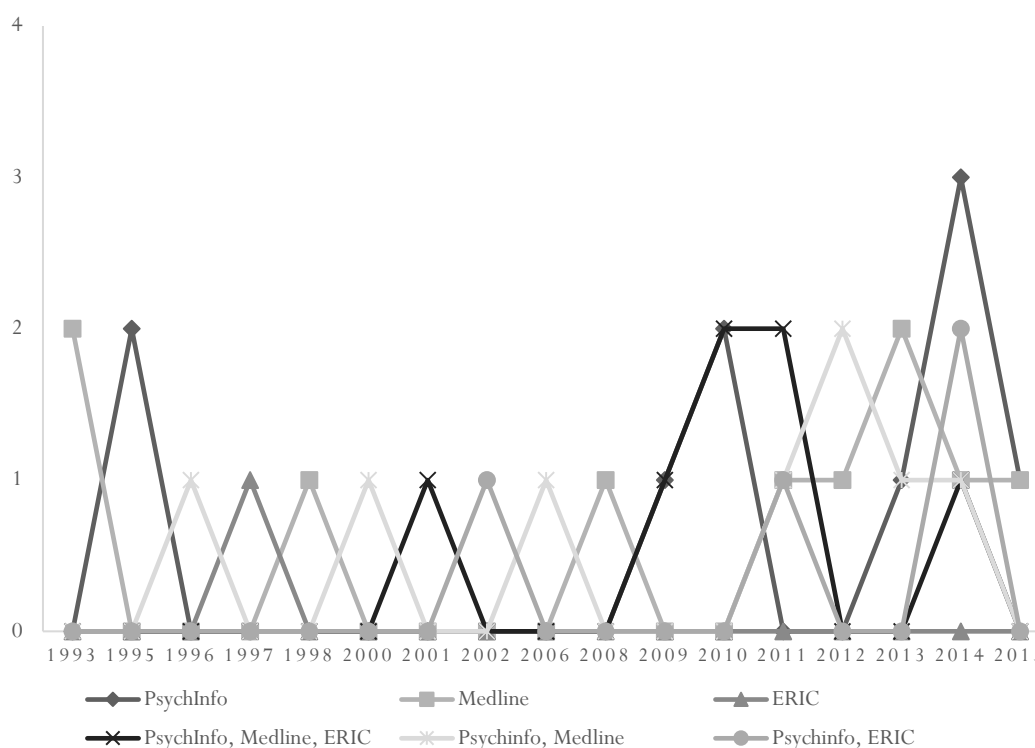


Figure 2. Numbers of articles included in this review by year published.

Across the three databases, researchers from 15 countries published research investigating dyscalculia included in this review. The country from which researchers published the most articles, seven, on the topic of dyscalculia was Israel; many of the authors overlapped across the articles (e.g., Gross-Tsur, Manor, & Shalev, 1996; Shalev, 1997; Shalev, Auerbach, Manor, & Gross-Tsur, 2000; Shalev & Gross-Tsur, 1993; Shalev, Manor, Amir, & Gross-Tsur, 1993; Shalev, Manor, Auerbach, & Gross-Tsur, 1998; Shalev, Manor, Kerem, Ayali, Badichi, Friedlander, & Gross-Tsur, 2001). Researchers from Switzerland wrote five articles on the topic of dyscalculia that were considered in this review; many of the authors of these articles also overlapped (e.g., Kucian et al., 2011; Kucian, Loenneker, Dietrich, Dosch, Martin, & Von Aster, 2006; Rotzer, Kucian, Martin, Von Aster, Klaver, & Loenneker, 2008; Rotzer, Loenneker, Kucian, Martin, Klaver, & Von Aster, 2009). Only three articles included in this review were contributed by researchers in the United States. Two of these articles included overlapping authors (Mazzocco, Feigenson, & Halberda, 2011; Mazzocco, Murphy, Brown, Rinne, & Herold, 2012).

Findings

Definitions

The majority of articles considered included a definition of the term *dyscalculia*. Many definitions simply defined *dyscalculia* in generic terms, such as a mathematics learning disorder (Behzadi, Rahimi, & Mohamadi, 2014), mathematical learning disability (Wilson et al., 2006) or as “poor mathematical skills” (Boets, De Smedt, & Ghesquiere, 2011, p. 1075). Some definitions

highlighted the discrepancy between achievement and intellectual ability (Ashkenazi, Rosenberg-Lee, Tenison, & Menon, 2012; Mussolin et al., 2010). One definition highlighted difficulty with math calculations (Mogasale, Patil, Patil, & Mogasale, 2012), while one listed four subskills affected by dyscalculia: number sense, math fact memorization, calculation, and math reasoning (Schulte-Körne, 2014). None of the definitions mentioned difficulties with math problem solving, while many touched on students' difficulties with number sense or computation. Hence, the definitions seemed to pinpoint difficulties that are more procedural rather than conceptual.

Some definitions, however, more specifically defined *dyscalculia* in terms of neuroscience, as involving “difficulties representing and manipulating numerical information nonverbally and visuo-spatially, in learning and remembering arithmetic facts and in executing arithmetic procedures” (Rotzer et al., 2009, p. 2859), or “presumed to be due to impairments in brain function” (Kucian et al., 2011, p. 782). Interestingly, these articles highlighting dyscalculia in terms of neuroscience spanned disciplines.

Concept Areas

Across all three databases and 39 articles, researchers focused on different skills and concept areas on which their results were based. Although a few articles did not expound on the targeted skills, the vast majority of researchers focused on tasks involving basic number sense and computation, specifically addition, subtraction, multiplication, estimation and memorization of math facts. This finding is consistent with the definitions used by researchers: Skill areas focused on procedural, rather than conceptual knowledge. One article found in the PsychInfo database focused on number line acuity (Friso-van den Bos et al., 2015) and another article found in the Medline database focused on the Approximate Number System (Noël & Rousselle, 2011). Few articles focused on higher order math skills, such as spatial number representation and math reasoning (Kucian et al., 2011) and math tasks involving working memory (Maehler & Schuchardt, 2011; Rotzer et al., 2009). Only one article focused on the skill of word problems (Gonzalez & Espinel, 2002). None of the articles investigated math skills involving division or algebra.

Participants

Across all three databases and 39 articles, there were a total of 6,026 participants, although three articles (Noël & Rousselle, 2011; Schulte-Körne, 2014; Tünde, 2009) did not specify the number of participants. The grade levels for participants mainly ranged from K through 4 with only 406 participants in grades 5 through 9 (Mazzocco, Feigenson, & Halberda, 2011; Shalev, Manor, Auerbach, & Gross-Tsur, 1993; Tünde, 2009). Nineteen studies did not specify the grade levels for the participants. The majority of the articles did not provide details of the demographic and socioeconomic status of the participants.

Assessments

A multitude of assessments were used to diagnose dyscalculia across the three databases and the 39 articles. Assessments were used to measure IQ (González & Espinel, 2002; Maehler & Schuchardt, 2011, Shalev, Manor, Auerbach, & Gross-Tsur, 1998) arithmetic skills (De Visscher & Noël, 2014; Shalev et al., 2001), numeracy skills (Julio-Costa et al., 2015; Shalev, 1997; Shalev, Manor, Amir, & Gross-Tsur, 1993;), and poor school performance screenings (Cowan & Powell, 2014; Mazzocco, Feigenson, & Halberda, 2011; Mogasale, Patil,

Patil, & Mogasale, 2012). Additional assessments were utilized to assess reading (Shalev, 1997; Shalev & Gross-Tsur, 1993; Shalev, Manor, Amir, & Gross-Tsur, 1993), spelling (Shalev, 1997), writing (Mogasale, Patil, Patil, & Mogasale, 2012; Shalev & Gross-Tsur, 1993; Shalev, Manor, Amir, & Gross-Tsur, 1993), and working memory skills (Archibald, Cardy, Joanisse, & Ansari, 2013; Cowan & Powell, 2014). Some studies relied on medical assessments and fMRIs (Boets, De Smedt, & Ghesquière, 2011; Rotzer et al., 2009). Word problems were assessed in only one study (González & Espinel, 2002). Most of the studies relied on more than one measure to diagnose dyscalculia. Out of a total of 39 articles, four did not list the specific assessments used (Gitanjali, 1995; Karande, Doshi, Thadani, & Sholapurwala, 2013; Niklas & Schneider, 2014; Noël & Rousselle, 2011).

Purpose

Four common themes that emerged from the purposes of the articles on dyscalculia were 1) factors that cause/predispose students to dyscalculia, 2) measures/tools used to identify dyscalculia, 3) subskills that characterized dyscalculia, and 4) interventions for supporting students with dyscalculia.

1) Factors that cause/predispose students to dyscalculia:

- Familial disposition of dyscalculia (Shalev et al., 2001)
- Comorbidity of dyscalculia with LD and ADHD (Mammarella et al., 2013; Shalev, 1997)

2) Valid measures/tools that were used across articles to diagnose dyscalculia:

- IQ-performance discrepancy (Maehler & Schuchardt, 2011)
- Approximate Number System (Weber fraction measure) (De Visscher & Noël, 2014; Mazzocco, Feigenson, & Halberda, 2011; Piazza et al., 2010)
- Cognitive model (Shalev, Manor, Anir, & Gross-Tsur, 1993)
- Brain differences (Ashkenzai, Rosenberg-Lee, Tension, & Menon, 2012; Kucian et al., 2006; Mussolin et al., 2010; Noël & Rousselle, 2011; Rotzer et al., 2009)

3) Subskills that characterize dyscalculia:

- Domain general factors associated with dyscalculia/Cluster analysis (Archibald, Cardy, Joanisse, & Ansari, 2013; Cowan & Powell, 2014)
- Arithmetic skills deficits (Ashkenzai, Rosenberg-Lee, Tenison, & Menon, 2012; Friso-van den Bos et al., 2015; Mogasale, Patil, Patil, & Mogasale, 2012)
- Working memory deficits (De Visscher & Noël, 2014; Kajbaf, Lahijanian, & Abedi, 2010; Rotzer et al., 2009)

4) Interventions that have been successful in supporting the learning of students with dyscalculia (Behzadi, Rahimi, & Mohamadi, 2014; Beygi, Padakannaya, & Gowramma, 2010; Gitanjali, 1995; Wilson et al., 2006)

Intervention

Only 4 out of 39 studies included classroom-based interventions for dyscalculia to support participants' mastery of mathematical skills. Researchers used the Concrete-Representational-Abstract (CRA) sequence to teach computation (Beygi, Padakannaya, & Gowramma, 2010). Others used computer-assisted learning targeting spatial number representation, number sense tasks, mathematical reasoning, and mathematics fact fluency skills (Käser et al., 2013; Kucian et al., 2011; Wilson et al., 2006), which were identified as

effective interventions. One study also explored the user engagement models for intervention software (Käser et al., 2013). More details about these interventions can be found in the implications for practitioners section.

Discussion

There are critical implications for researchers and practitioners associated with this search and review of articles on the topic of dyscalculia. First, dyscalculia has been studied by a limited number of researchers across different countries. For example, of the three articles included in this review that were contributed by researchers in the United States, two articles included overlapping authors (Mazzocco, Feigenson, & Halberda, 2011; Mazzocco, Murphy, Brown, Rinne, & Herold, 2012). Israel and Switzerland, the countries contributing most of the articles considered, had many overlapping authors across articles. Standards established for identification of evidence-based practices suggest that experimental effects must be replicated across different researchers (Horner et al., 2005); specifically, Kratochwill et al. (2013) recommended “at least three research teams with no overlapping authorship” (p. 33). This standard indicates the need for further research to establish the knowledge base of dyscalculia worldwide.

Additionally, there is very little consistency of definitions of dyscalculia within each discipline, not to mention across disciplines (i.e., educational, medical, and psychological). Furthermore, the majority of the studies focused on elementary school students (K-5) and basic, procedural math skills. Math skills involving division or algebra were not investigated in any of the articles. Higher order math skills, math tasks involving working memory, and word problems were targeted in only a few studies. Although it must be acknowledged that there is intervention research involving students with math disabilities, interventions targeting dyscalculia were almost nonexistent (less than $\frac{1}{8}$ of all articles considered).

Based on the results of this analysis, researchers across disciplines need consensus on a working definition of dyscalculia. Research needs to be broadened to include all students affected across K-12 settings and across all math concepts and strands. Since NCTM incorporates both process and concept standards, the correlation between dyscalculia and these standards needs to be investigated (NCTM, 2000). In addition, as states and school districts implement Multi-Tiered Systems of Supports (MTSS), an integral part of the Every Student Succeeds Act (ESSA), described as “a layered continuum of evidence-based practices and systems” (Colorado Department of Education, 2015, p. 1) more intervention-driven research is necessary to help teachers determine appropriate supports for students with dyscalculia at every tier of instruction.

Implications for Practitioners

The CRA sequence and computer-assisted learning emerged as the two, main evidence-based math interventions for students with dyscalculia. CRA has been widely researched for teaching place value (Bryant, Bryant, Gersten, Scammacca, & Chavez, 2008), addition and subtraction (Flores, 2010; Flores, Hinton, & Strozier, 2014; Sealander, Johnson, Lockwood, & Medina, 2012), multiplication (Flores, Hinton, & Schweck, 2014; Flores, Hinton, Strozier, 2014; Mancl, Miller, & Kennedy, 2012), fractions (Butler, Miller, Chrehn, Babbitt & Pierce, 2003; Misquitta, 2011) and algebra (Maccini & Hughes, 2000; Witzel, 2005; Witzel, Mercer, & Miller, 2003) to students with dyscalculia. The CRA sequence is embedded in the explicit instruction framework. The explicit instruction framework involves the use of

demonstration, modeling, and guided practice followed by independent practice and immediate feedback (Witzel, 2005). For CRA sequence, the teacher guides the student through a mathematical concept and its corresponding computational process through the use of manipulatives and visual representations that illustrate the concept along with numbers. Abstract representations or numbers are presented simultaneously with the concrete and representational phases. Concrete and representational phases serve as prompts until the student develops the ability to comprehend and compute at the abstract level (Agrawal & Morin, 2016).

Computer-assisted learning that provides targeted practice is a powerful support for students struggling with spatial number representation, number sense tasks, mathematical reasoning, and mathematics fact fluency skills. Game-based approaches are one effective way to actively engage and motivate students, while also providing immediate feedback (Ahmed & Mutalib, 2015). Virtual manipulatives can also be used to actively engage students in learning (Shin et al., 2017). Instructional applications that can be accessed on smartphones or tablets can also be helpful for some students with LD (Bryant et. al., 2015). In choosing software, there are certain things a teacher must keep in mind: the program should 1) be theory based (e.g., taking into account the natural progression and development of math abilities and conceptual understanding); 2) provide motivation and reinforcement for students; and 3) adapt and adjust according to student performance, which can vary widely across students with LD, in order to meet the specific needs of students (Käser et al., 2013). When choosing software, it is critical that teachers screen any form of computer-assisted learning to ensure that it meets these criteria.

Limitations

This search was conducted as an overview rather than an exhaustive review of the literature. Along with the limitations implicit to the research on dyscalculia and discussed in the previous section, seven articles were not available because they were published in another language, and only the abstract was provided in English (Behzadi, Rahimi, & Mohamadi, 2014; Bolla, 2014; Kajbaf, Lahijanian, & Abedi, 2010; Niklas & Schneider, 2014; Rappo, Alesi, & Pepi, 2014; Shalev, Manor, Amir, & Gross-Tsur, 1993; Tunde, 2009). Although there is a research base for mathematical intervention for students with mathematical difficulties, these studies do not specifically use the term *dyscalculia* and were not included in this analysis.

Conclusion

Although dyscalculia was initially defined 40 years ago, defining dyscalculia is still ongoing and identification of dyscalculia is still in its infancy. There is a lack of consistency and gaps across and within fields related to concept areas, participants, assessments, and purposes and interventions in dyscalculia research. More research is needed related to these topics, specifically research that includes students from a broader age and grade level, and concept areas as well as practitioner research and a need for sharing of effective intervention strategies for students with dyscalculia.

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