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Diagnosis of Dyscalculia: A Comprehensive Overview

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ABSTRACT

The aim of this article is to provide an overview of symptoms, causes and diagnosis of Dyscalculia based on current research findings.This paper reviews selected literature spanning from 2001 to date from PubMed, PsycINFO, Springer, ERIC databases using the keywords: dyscalculia, mathematical disability and math disorder and selectively reviewed articles for the diagnostic of Dyscalculia in general.

The acquisition of mathematical skills is a development process that begins well before school starts. As a result, the children already start with different mathematical prior knowledge in the initial class. In order to be able to identify children at risk for a weakness in arithmetic (technical term: dyscalculia) at an early stage and to adequately support their needs, it is essential to set up a well-functioning diagnosis. According to the International Classification of Diseases (ICD-10), Dyscalculia belongs to the specific developmental disorders and is characterized by impairment in speech, motor activity and visual-spatial perception. The discrepancy between intelligence and expected arithmetic abilities is the essential criterion for the diagnosis of Dyscalculia. A comprehensive examination, also suitable for therapeutic intervention preparation, should take etiological conception of Dyscalculia into account as well as impairments in visual information processing. This should be reflected in the deliberate selection of appropriate test procedures. Recent diagnosis of Dyscalculia does not only account the classroom-based math performance and IQ into account, but also impaired basic skills associated with Dyscalculia into account while IQ discrepancy and appropriate IQ test for Dyscalculia remain a controversial topic.

An innovative aspect of this work is synthesizing comprehensive view of Dyscalculia and its diagnosis using multidisciplinary approach which could be helpful for researchers across disciplines.

KEYWORDS

Dyscalculia, Comprehensive Overview, Well-functioning Diagnosis

INTRODUCTION

People with Dyscalculia have problem in understanding numbers and quantities. These lead to difficulties in estimating quantities, counts and simple computational tasks. This leads to poor performance in mathematics and other subjects (e.g. physics, chemistry) as well as difficulties in various everyday situations, starting with reading the clock (Burny et al., 2012) for dealing with personal financial matters (Patton, Cronin, Basset & Koppel, 1997). According to the international diagnostic Manual of the WHO (ICD-10, Dilling, Mombour & Schmidt, 2011), a person is considered Dyscalculic (F81.2) when the computational power of a child is significantly below the level that can be expected based on their age, General Intelligence and schooling. Current surveys show that about 3-7% of all children and young people are Dyscalculic (Shalev et.al. 2000). Very often, Dyscalculia occurs in combination with Dyslexia or ADHD on (Gross-Tsur, Manor & Shalev, 1996; by Aster et al., 2007). This article summarizes the research findings of Dyscalculia Diagnosis based on current research findings.

SYMPTOMS

In children with Dyscalculia, the development of so-called basic mathematical skills is impaired. They have difficulty comparing sets (more / less) and numbers (larger/smaller), naming and writing numbers, and often show large gaps in counting skills. Gaupp, Zoelch & Schumann-Hengsteler, 2004; Landerl, Bevan & Butterworth, 2004). According to some researchers, they can only count if the objects were in a specific order and cannot count backward or in steps larger than one (Gaupp et al., 2004; Moser Opitz, 2005).

Another Symptom of Dyscalculia is difficulties in understanding the decimal system (Landerl & Kaufmann, 2008; Moser Opitz, 2005). These are shown in so-called number Turners ("twenty-three" is written as 32), in position errors ("one hundred eight" is written as 1008) and in errors in tasks to the bundling principle ("how many bundles of ten can be made with 78 tiles?). Although eight to nine-year-old children with dyscalculia make these errors somewhat less frequently, they show increased response times when reading and require more time when writing Arabic numbers (Landerl et al., 2004), i.e., difficulty in quickly assigning numbers to number words and vice versa.

Children with Dyscalculia also show a massive impairment in learning and retrieving arithmetic facts (e.g. "3 + 4 = 7") (Gaupp et al., 2004; Geary & Hoard, 2001; Geary, Hoard & Bailey, 2012;

Gersten, Jordan & Flojo, 2005). They do not succeed in storing the results of simple computational tasks and later retrieve them directly from memory. This leads to children using counting strategies for a very long time, even with simple arithmetic tasks, often with the help of their fingers (Jimenez Gonzales & Garcia Espinel, 2002; Moser Opitz, 2005; Pixner & Kaufmann, 2008; Patwary, et al. 2019). This procedure is not only error-prone, but also takes a lot of time.

The symptoms of Dyscalculia also include missing or incorrect ideas about the computational steps that must be performed for certain tasks ("mathematical procedure") (Geary & Hoard, 2001). The children learn mathematical procedures (e.g. the procedure for multi-digit subtraction tasks) by heart, but do not understand them due to their deficits in the understanding of quantities and numbers (including the decimal system). For a new task, perform the same computational steps in the same order, even if the new task requires a modified procedure (see Moser Opitz, 2005).

Children with dyscalculia are more likely to show psychological Abnormalities comparing to non-affected children (Auerbach, Gross-Tsur, Manor & Shalev, 2008; Prior, Smart, Sanson & Oberlaid, 1999; von Aster, 1996). Some abnormalities (e.g. attention deficits) can occur independently of the computational disorder. Depressive symptoms, aggressive behavior and anxiety may be a reaction to school problems and failure experiences (Auerbach et al., 2008; Huntington & Bender, 1993). Many children with a computational disorder develop math and exam fears, which manifest themselves over years and lead to a general refusal behavior, whereby the achievements also fall off in other subjects (Krinzinger & Kaufmann, 2002; Rubinsten & Tannock, 2010).

The stability of Dyscalculia symptoms is comparatively low in the first two school years. About one third of the children who show weak computing performance in the first grade already achieve average performance one year later (Geary et al., 2000). However, stability increases towards the end of Primary School. An Israeli longitudinal study (Shalev, Manor & Gross - Tsur, 2005) examined the computational power of children who were diagnosed with a computational disorder in 5th grade. Also, six years later (in the 11. Most children in this group experienced difficulties in numeracy: 95% were among the weakest quarter of their age group. However, only 40% still met the diagnostic criteria for a computational disorder. A particularly stable Symptom of the computational disorder are deficits in arithmetic fact knowledge (Gaupp et al., 2004; Geary et al., 2012). An American study (Jordan, Hanich & Kaplan, 2003) examined primary school children over a period of one and a half years (middle of 2nd grade to end of 3rd grade). It was found that children with low numeracy showed little improvement in the retrieval of arithmetic facts, while the knowledge of arithmetic facts increased significantly in the other children.

CAUSES

Computation is very complex and demands the interaction of numerous brain functions. Children Dyscalculia show significantly reduced activity in the brain regions that belong to the neural network of quantity and number processing during the processing of simple computational tasks (Ashkenazi, Rosenberg-Lee, Tenison & Menon, 2012; Kucian et al., 2006). This is probably the result of a genetic deficiency of congenital core competencies, which leads to certain cognitive functions not developing according to developmental tasks (Butterworth, 2005; von Aster et al., 2007). For example, the connection between an Arabic numeral ("8") and the corresponding set is usually activated automatically. Experimental studies have shown that this is not the case in people with Dyscalculia (Rubinsten & Henik, 2006). Numbers are to you like words without meaning.

Other basic mathematical skills are also impaired in the case of computational error (Gaupp et al., 2004; Landerl et al., 2004; von Aster et al., 2005). These include fast (on one glance) estimating of small quantities, comparing quantities (more / less) and numbers (larger / smaller), naming and writing down numbers, as well as the development of a mental number line. Deficits in general cognitive functions, such as memory, processing speed and visual-spatial functions, were also reported (overview in Landerl & Kaufmann, 2008).

Family and twin studies indicate a genetic component of Dyscalculia (Alarcon, DeFries, Gillis Light & Pennington, 1997; Docherty et al., 2010; Petrill et al., 2012; Alom, Patwary, & Khan, 2019; Shalev et al., 2001). Studies on neurophysiological correlates using MRI, fMRI and ERPs were able to identify brain regions that correlate with different computational processes (overview in Vogel & Ansari, 2012). The activation of the intraparietal Sulcus (IPS) of both hemispheres was found, for example, depending on the ability to detect numerical distances between numbers. The linguistic processing of numbers in computational operations, on the other hand, is associated with activation in the left angular gyrus.

Studies with children with dyscalculia confirmed the importance of IPS for estimating and comparing amounts. Kucian et al. (2006) found less activation in children with dyscalculia in a numerical estimation task (e.g., 4 + 3 = 9 or 6). Further studies confirm the connection between lower IPS activation and basic numerical abilities (Kaufmann, Vogel et al., 2009; Price, Holloway, Räsänen, Vesterinen & Ansari, 2007).

COMORBIDITY OF DYSCALCULIA

Common comorbid disorders include Attention Deficit / Hyperactivity Disorder (ADHD, up to 40%) and Dyslexia. The comorbidity of Dyscalculia with Dyslexia varies between 25 and 40 %, depending on the examination methods, the samples examined and the classification (Landerl & Moll, 2010).

PRECURSOR SKILLS AND EARLY INTERVENTION

In order for children to learn the basic arithmetic methods, they must master the so-called basic mathematical skills (Krajewski, 2008). In addition to the above-mentioned skills, this also includes the ability to count correctly, i.e. to know the numbers, to assign exactly one number to each object and to understand that the last number mentioned reflects the counted quantity. Longitudinal studies confirm that pre-school skills such as counting and number knowledge (e.g. " which number is greater? 5 or 4?") can predict the later computational power (Aunola, Leskinen, Lerkkanen & Nurmi, 2004; Locuniak&Jordan, 2008) and that children with a computational disorder often have weaker mathematical basic skills already in kindergarten (Gersten et al., 2005; Krajewski & Schneider, 2009; Patwary, Omar, & Tahir, 2020; Stock, Desoete & Roeyer, 2010; Weißhaupt, Peucker & Wirtz, 2006).

Various test methods can be used to identify so-called risk children of preschool age (e.g. ZAREKI-K, von Aster, Bzufka, Horn, Weinhold Zulauf & Schweiter, 2009, or TEDI-MATH, Kaufmann, Nuerk et al., 2009). Early support is of particular importance for these at-risk children. The aim of early intervention should be to improve numerical knowledge and develop efficient counting strategies. This can be achieved through playful Exercises (e.g., dice or Board games) (Griffin & Case, 1997; Siegler & Ramani, 2008; Wilson, Dehaene, Dubois & Fayol, 2009). For the German-speaking area, there is also the early funding programme "Mengen, zählen, Zahlen" (Krajewski, Nieding & Schneider, 2007), which demonstrably improves basic mathematical skills (Krajewski, Renner, Nieding & Schneider, 2008; Patwary, 2017).

DIAGNOSTICS

Neuropsychological diagnostics according to ICD-10

The core of the diagnostics is the implementation of a standardized computing test. According to the recommendations of ICD-10 (Dilling et al., 2011), a discrepancy of the computing power to the age standard is necessary for the diagnosis of a computational disorder (age discrepancy). To determine the IQ discrepancy recommended by ICD-10, an intelligence test is performed.

There are various standardized test methods with which the computing power can be examined. These differ, among other things, in terms of test content, execution (individual vs. Group test, duration of execution) and the quality of standardization. Some test procedures are primarily based on the mathematics curricula (e.g. the Tests of the DEMAT series), while other procedures check in particular the competences that are known to be impaired in the computational disorder (criterion-oriented test procedures, e.g. ZAREKI-R, by Aster et al., 2006). Moser, Opitz and Ramseier (2012) recommend choosing a test method that covers both areas, i.e. not only interrogates the teaching material, but also collects the core symptoms of the computational disorder. The Heidelberg Computer Test (HRT 1-4, Haffner, Baro, Parzer & Resch, 2005) in primary schools and the BASISMATH 4-8 (Moser Opitz et al., 2010) for older students. Another key example of such a screener is one developed by Butterworth (2003). This is the most common commercial screener used across UK and is Also known as the Dyscalculia screener.

Children whose difficulties in arithmetic are due to environmental factors (inadequate instruction, lack of support or too little practice) do not meet the criteria for a computational disorder. The diagnosis of computational disorder must also not be made if deficits in seeing or hearing are the cause of the difficulties in computing. The same applies to neurological disorders, as well as mental or psychiatric disorders.

The basic criterion for diagnosing of Dyscalculia according to ICD-10 is a performance of the affected child that differs from the general intelligence, age and grade level attended. According to the diagnostic guidelines (MAS), the school assessment of performance should be well below the expected performance of all corresponding school children (<3%). As a diagnostic criterion for the diagnosis of a computational disorder, the discrepancy between intelligence and computing power - measured with standardized test methods – should amount to at least 2 standard deviations.

The most common exclusion criterion in a non-verbal IQ below 70. In such a case, low intelligence (F7) must be diagnosed.

Suitable methods are test batteries such as the WISC-IV (Petermann et. al. 2012), with which the performance can be differentiated based on a profile based on different types of tasks. In Tab. 1 shows the different diagnostic criteria in a concise form.

Table 1 *Review of essential skill areas in dyscalculia diagnosis. (Hrsg, 2007)*

Skill	**Task**
Ability to count	Counting forwards and backwards as well as counting forwards and backwards with finger
Transcoding performance	Converting Arabic numerals to numerals and vice versa
Number-Quantity Assignment	Allocate numerals and Arabic numerals using objects (concrete), illustrations (pictorial) and symbols (e.g. tally list; abstract)
Number awareness	Determine numerical words and objects correlation based on estimation
Analog representation on the number line	Small: left, large: right
Mental arithmetic	Addition, subtraction, multiplication, division in number ranges according to class level
Written arithmetic	Addition, subtraction, multiplication, division in number ranges according to class level
Number word recognition	Auditory and visual presentation
Understanding math rules	Understanding of Transfer and analogy; commutative, associative and distributive law
Memory	Working Memory, Long-Term Memory (Multiplication Tables)

Word problems	Reading skills, understanding tasks, transcoding performance

The IQ-discrepancy criterion

The criteria of ICD-10 (Dilling et al., 2011) require that there is a clear difference between IQ and computing power is present. The IQ discrepancy should be at least 2 standard deviations (ICD-10 research criteria). Jacobs and Petermann (2005) recommend a "softer" criterion of 1.5 standard deviations for clinical practice.

In the scientific literature, the IQ-discrepancy criterion is considered to be quite critical, and several authors do not recommend the IQ discrepancy criterion (see Ehlert, Schroeders & Fritz Stratmann, 2012; Moser Opitz, & Ramseier, 2012; von Aster et al., 2007). There are several reasons for this. On the one hand, there are methodological problems, because many intelligence tests contain subtests that record the computational power, so that children with low computational power are at a disadvantage. In addition, the common computational tests differ in terms of their content, i.e. they partly collect different mathematical competences. As a result, different computational tests can lead to different results in the same child (Ehlert et al., 2012; Huber, Moeller & Nuerk, 2012). The discrepancy between IQ and computing power thus also depends on the computing test used. An American longitudinal study also shows that the diagnosis of Dyscalculia is more stable over time if it is based on the age discrepancy criterion and not on the IQ discrepancy criterion (Mazzocco & Myers, 2003). Another Argument against the IQ discrepancy criterion is that numerically weak children who meet the IQ discrepancy Criterion have the same difficulties in arithmetic as numerically weak children who do not meet this criterion. The two groups apply similar solution strategies when solving computational problems and provide comparable services (Ehlert et al., 2012; Jimenez Gonzales & Garcia Espinel, 1999, 2002; Moser Opitz, 2005; Patwary & Omar, 2016; Akter, Sadekin, & Patwary 2020).

Diagnostic process

According to AWMF ("Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e.V." or Association of the Scientific Medical Societies in Germany), The diagnosis of suspected arithmetic disorder can be displayed in a dynamic process over 4 levels (. Tab. 2).

Table 2 *Levels of Diagnosis process for Dyscalculia*

Level 1	**Level 2**	**Level 3**	**Level 4**
Medical history and exploration	**Basic Diagnostics**	**Differential and in-depth diagnostics**	**Findings**
Current problems	Intelligence test	Attention	Test interpretation and discussion of findings
Course of development	Computing test	Ability to learn and remember	Fault-specific advice
Socioemotional Status (resources and deficits)	Standardized questionnaires	Visual information processing	Compensation for disadvantages
	Reading-spelling-weakness diagnosis	Language and motor skills	Therapy planning
		Emotional and behavioral disorders	Estimation of costs

As a rule, affected children are presented in clinical practice from the 2nd and 3rd grade onwards in appropriate institutions (Jacobs et al., 2009). On the one hand, this is due to the fact that the first decisions for attending secondary schools are made at this time, on the other hand, affected children can hardly compensate for any deficits in arithmetic with increasing school requirements by other (neuropsychological) skills, such as ability to learn and memorize (in connection with ADHD See also Petermann ,Toussaint (2009) and Tischler et al. (2010)). Mathematics performance drops and often it happens due to initial emotional and behavioral problems (e.g.

examination anxiety, F40.2, adjustment disorder, F43.2, disorder of social behavior with oppositional, defiant behavior, F91.3).

A. level 1

The first anamnestic initial interview with the parents or other primary caregivers usually shows to what extent deficits in language, motor skills or visual information processing (milestones in early childhood development) have already occurred in kindergarten. School certificates, written samples, exemplary class work as well as development reports from kindergarten and school time, but also examination booklets and (consultative) medical reports provide information about possible causes and development of the computing disorder. It is not uncommon for affected children to be given speech therapy or occupational therapy treatment at pre-school age. The exploration also provides information about possible family resources and the social conditions in which the child is located (family accumulation, homework conflicts, funding opportunities).

B. Level 2

Answering problem checklists by parents and other primary caregivers as well as teachers and educators provides information about the child's socio-emotional status. Motivational aspects should also not be neglected in relation to work and learning behavior.

The implementation of a complex intelligence test (such as WISC-IV; (2011)) allows statements on the cognitive performance level of the child based on a differentiated performance profile and gives first indications of possible partial performance disorders (such as attention deficit disorder, working memory disorders and the ability to learn and remember). The mosaic test is particularly suitable as a screening tool for disorders of visual information processing (visual-cognitive, spatial-perceptive, spatial-cognitive and spatial-constructive disorder; see Petermann et al. (2010); AWMF (2012).

Careful observation of behavior when carrying out the examination procedures is essential. It provides information about the child's work behavior and psychological status:

1) Does the child show an open mind to the examination situation and the diagnostician or does he appear to be insecure, scared or oppositional?

2) Does the child work in a motivated and focused manner or can it be easily distracted by irrelevant environmental stimuli or internal impulses and does it have to be attributed to the task more frequently?

A single test procedure is recommended to check the computational skills (such as ZAREKI-R (2009), RZD 2–6 (2005)); Group test procedures (e.g. in a class association) are primarily suitable for identifying children who may have a computing problem. When selecting the individual test procedure, it should be noted to what extent the in. Task types listed in Tab. 1 are covered. Many methods (Jacobs & Petermann, 2005) alone enable a quick diagnosis according to ICD-10 (impairment in basic arithmetic operations), but do not give any indication of the underlying causes or provide any information that can be used for any therapy planning. The additional implementation of a more differentiated procedure, which suggests the impairment of basic mathematical skills (such as quantity formation, transcoding performance, counting, visual-spatial skills), remains unaffected by this. A clear comparison of current test procedures can be found at Jacobs & Petermann ((2012).

In the context of clinical dyscalculia diagnostics, class-level standardized individual test procedures are most suitable, which include both basic mathematical skills and the actual arithmetic skills (basic arithmetic, understanding of rules). It is important to ensure that the procedures include enough items per task type to ensure meaningful results and that the standards are as up to date as possible. A reading and spelling performance check should always be carried out for differential diagnostic clarification.

If the basic diagnosis (level 2) gives indications of possible partial performance disorders or emotional and behavioral disorders, then an in-depth diagnosis (level 3) takes place.

C. Level 3

The previous test results and the information collected can contain indications of further neuropsychological, emotional and behavioral disorders (related to the computing disorder). In addition to the use of disorder-specific questionnaires, neuropsychological diagnostics (attention, ability to learn and remember and visual information processing [15, 25, 26, 27, 28]) are particularly recommended (AWMF,2012).

D. Level 4

The discussion of the findings with parents or other caregivers includes the interpretation of the test results and a detailed explanation of the diagnosis made. Furthermore, the parents are informed about the possibilities of intervention and the costs of any dyscalculia therapy. With regard to the school, the possibility of compensating for disadvantages is discussed in order to counteract any further psychological stress on the child.

LIMITATION OF STUDY

This study was conducted as an overview rather than an exhaustive review of Dyscalculia. Also the guideline of DSM-V was not explicitly taken into account for diagnosis in this review. There are many articles that do not use the Term mentioned in this article and were not included in this review.

CONCLUSION

Dyscalculia is a defect with a high prevalence that can extend from childhood to adulthood. The discrepancy between intelligence and computing power or, according to DGKJP, the double discrepancy criterion should be used as the diagnostic criterion for diagnosing a computing disorder. Visual information processing is a basic competence on which the computational skills are based. The diagnosis of suspected arithmetic disorder can be displayed in a dynamic process over 4 levels: After anamnesis and exploration, the 2nd level is followed by the basic and the 3rd level by the differential and in-depth diagnostics. A single test procedure (class level standardized and standardized) is recommended to check the arithmetic skills, group test procedures are primarily suitable for the identification of children who may have arithmetic problems. Careful behavior monitoring is essential during the testing process. The fourth level includes the consultation, in which the test results and findings are discussed with the affected person and possibly their parents and the necessary or possible therapy is planned. The advice should be specific to the disruption and should also include cost considerations and the possibility of using social law support.

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