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Discalculia: manifestaciones clínicas, evaluación y diagnóstico. Perspectivas actuales de intervención educativa *Dyscalculia: Clinical manifestations, evaluation and diagnosis. Current Perspectives of educational intervention*

Dyscalculia: Clinical manifestations, evaluation and diagnosis. Current Perspectives of educational intervention

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Abstract

Learning difficulties and learning disorders are very frequent in schools nowadays, and they have been increasing in the field of mathematics. Such difficulties tend to be associated with other disorders such as dyslexia or Attention Deficit Hyperactivity Disorder (ADHD). The present article aims at deepening our understanding, definition and detection of dyscalculia, along with reviewing current educational treatments. Since 1990, concerns about learning difficulties in the classroom have been made explicit in policies such as the Spanish Law on the General Ordering of the Education System (LOGSE). Likewise, the indicators, symptoms, and prevalence of dyscalculia have been gathered since the publication of the DSM-IV and the ICD-10. Nonetheless, its detection, identification and intervention are below expectation. Features such as the knowledge of its underlying neurobiological basis are fundamental for a posterior psychopedagogical approach. We conclude, first, that we can only rely on a few specific tools for its detection. Second, we highlight the relevance of the detection of its risk factors. Finally, regarding current perspectives of treatment, early detection and the interdisciplinary nature of the interventions are supported

Keywords: Learning difficulties, dyscalculia, Early years education, Primary education, Secondary education, detection, educational intervention.

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Resumen

Actualmente, son numerosas las dificultades y trastornos del aprendizaje en el ámbito escolar, con un incremento en el área de las matemáticas. Tales dificultades suelen aparecer asociadas a otros trastornos como la dislexia o el Trastorno por Déficit de Atención e Hiperactividad (TDAH). Este artículo tiene como objetivo profundizar en la definición y detección de la discalculia, así como revisar las perspectivas actuales para su tratamiento desde la educación. Desde 1990 se explicita la problemática de las Dificultades de Aprendizaje en el aula con la publicación de la Ley de Ordenación General del Sistema Educativo español (LOGSE). Así mismo, desde la publicación del DSM-IV y el CIE-10, se han recogido los signos, síntomas y prevalencia de la discalculia. Sin embargo, su detección, identificación e intervención están por debajo de lo deseado. Aspectos como el conocimiento de las bases neurobiológicas subyacentes son fundamentales para el posterior abordaje psicopedagógico. Concluimos, en primer lugar, que existen muy pocos instrumentos específicos para la detección. En segundo lugar, destacamos la importancia de la detección de sus factores de riesgo. Finalmente, respecto a las perspectivas actuales de tratamiento se aboga por la detección temprana y el carácter interdisciplinar de las intervenciones.

Palabras clave: Dificultades de aprendizaje, discalculia, Educación Infantil, Educación Primaria, Educación Secundaria, detección, intervención educativa.

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Many children are unable to classify objects by size, match them, to understand arithmetic language or to assimilate the concept of rational calculation (Gracia-Bafalluy &

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Escolano-Pérez, 2014). Several authors have pointed out that the subject of mathematics is amongst those with a high failure rate (Fernández & Llinares, 2014; Sans, López-Sala, Colomé, Boix & Sanguinetti, 2013). The current review aims at clarifying and delimits what is understood as dyscalculia, along with presenting its types, clinical manifestations, neurological bases and evaluation, including also current perspectives of educational intervention.

Learning disorders were firstly described towards the end of the XIX century, focusing on reading and acknowledging its independence of level of intelligence, instruction, motivation and sensory deficits (Carboni-Román, Del Río Grande, Capilla & Maestú, 2006). In 1962, Kirk and Bateman coin the term "Learning Disabilities" (LD):

> a *learning disability* refers to a retardation, disorder, or delayed development in one or more of the processes of speech, language, reading, writing, arithmetic, or other school subjects resulting from a psychological handicap caused by a possible cerebral dysfunction and/or emotional or behavioral disturbances. It is not the result of mental retardation, sensory deprivation, cultural or instructional factors.

From this perspective, linguistic, visuospatial, reasoning and mathematical abilities are linked to LD. In 1978, the Secretary of State for Education and Science (UK) publishes the Warnock Report, introducing the term "Special Educational Needs" (SEN) and substituting "Special Needs" (SN) (SEN, 1978). This report proposes changing to an integration model, where children should preferably be educated in mainstream schools, thus constituting a radical change in how SN were considered (Coronado Hijón, 2008).

From this moment on, along with the publication of the DMS-IV (APA, 1993), a relative consensus is obtained regarding the defining features of students with LD. Firstly, his or her achievement would be substantially below the individual's expected level, given his or her chronological age, measured intelligence and age appropriate education. On second place, difficulties would be observed in one or more of these seven areas: oral expression, listening comprehension, written expression, mechanical reading, reading comprehension, mathematical calculations and mathematical reasoning. In addition, the LD would be related to other difficulties in basic psychological processes such as attention, memory, auditory perception, visual perception, visuomotor coordination and oral language. Finally, such difficulties are not primarily the result of visual, hearing or motor disabilities, mental retardation, emotional disturbance, or of environmental, cultural, or economic disadvantage (APA, 1995, 2003, 2013). In the latest version of the DSM-5 (DSM-5, 2013), specific learning disabilities (SLD) are included within the diagnostic category of neurodevelopmental disorders. Given the variety of processes that can be affected, and the high comorbidity between disabilities, it is fundamental to perform a differential diagnosis (Millá, 2006; Serra-Grabulosa, 2014). SLD have a chronic nature, and those suffering from it normally show other problems not just at the cognitive level (Gross-Tsur, Manor, & Shalev, 1996), but also at the emotional level (Artigas-Pallarés, 2002; Serra-Grabulosa, 2014).

In the scientific literature, there are many studies on LD, especially about dyslexia and ADHD (Artigas-Pallarés, 2002; Balaguer & Tárraga, 2014; González-Castro et al., 2014; Martínez Zamora, Henao López & Gómez, 2009). However, other learning disabilities such as the "non-verbal learning disorder" (NVLD), or dyscalculia, have been less studied (González-Castro et al, 2014). In Spain, the publication of the Warnock Report (SEN, 1978) encourages a model of SE articulated in the Spanish Law 13/1982, Social Integration of Disabled People, which specifies the constitutional right to education and integration of individuals with disabilities. This model establishes the principles of normalisation, sectorisation, integration and individualisation, both from a social and an educational point of view, while establishing guidelines in accordance with the rights established at a constitutional level and the Spanish Royal Decree 334/85 for the Arrangement of Special Education. Both laws consider LD as a subcategory belonging to a wider category, that is, SEN (Coronado Hijón, 2008).

In 1990, with the publication of the Spanish Law of General Ordering of the Educational System (LOGSE), general educational aims were established for all students, and the adaptation of teaching to the characteristics of students with or without SEN was prescribed (LOGSE, Article 2.5). Subsequently, the Organic Law of Education (LOE, 2006), and currently the Organic Law for Quality Improvement of Education (LOMCE, 2013), include students with LD within the term "Specific Learning Difficulties" (SLD). This fact means that LD are considered as those emerging from the interaction between pupil and his or her teaching/learning context, where the school has to give an efficient educational answer from the curriculum, taking into account students' diversity (Mora & Aguilera, 2000).

Towards a definition of dyscalculia

Loss of ability to perform calculation tasks resulting from a brain pathology is known as *acalculia* (Ardilla & Rosselli, 2002). *Dyscalculia* is a specific learning difficulty affecting arithmetic, independent of intelligence and instruction, and with a neurobiological, and tentatively genetic, basis. (Sans et al., 2013). In 1908, Lewandowsky and Stadelmann published for the first time reports on calculation disorders, differentiating them from language disorders. In 1925, Henschen coins the term acalculia to explain the loss of the capacity to perform calculations because of brain damage. This led Henschen to propose an anatomical substrate for arithmetic operations, differentiated to that of language and musical ability (Ardila & Rosselli, 2002). In 1926, Berger introduced the distinction between primary and secondary acalculia, acknowledging that calculation disorders can be associated to others such as verbal, spatio-temporal or reasoning disorders. In 1940, Gerstmann proposed that primary acalculia was linked to agraphia, right-left disorientation and finger agnosia, forming a neurological disorder known as "Gertsmann syndrome".

In 1974, Kosc proposed the term "dyscalculia" for the first time. Kosc defined dyscalculia as a disorder differentiated from other mathematical impairments, highlighting its heritability and/or congenital affection of the brain areas responsible for mathematical functions. Henceforth, different types were established (see Table 1).

Table 1. *Types of dyscalculia* (adapted from Kosc, 1974)

TYPE	IMPAIRMENT
Verbal	To name quantities, numbers, terms, symbols and relationships.
Practognostic	To mathematically enumerate, compare and manipulate objects.
Lexical	To read mathematical symbols.
Graphical	To write mathematical symbols.
Ideognostical	To perform mental operations and understanding mathematical concepts.
Operational	To perform numerical operations and calculations.

As part of her initial contributions, Badian (1983) found that dyscalculic children show frequent numerical difficulties of a spatial nature, impairments in calculation, and attention-sequencing impediments with a low incidence of alexia for numbers and agraphia (Ardila, Rosselli & Matute, 2005). In 1993, Geary established a classification of dyscalculia based in three types of errors: 1) visuo-spatial, 2) linked to semantic memory, and 3) procedural. Rourke (1993) distinguished between dyscalculia linked to language problems, and dyscalculia linked to spatio-temporal difficulties, sequential problems and number inversions (Spreen & Strauss, 1995). Currently, the term dyscalculia is used in various ways, covering from a mathematics or arithmetic learning difficulty, to an impairment in calculation (Rebollo & Rodríguez, 2006). Therefore, even though there is some consensus about its diagnostic criteria, discrepancies are found on its definition, hampering dyscalculia's evaluation and intervention.

Following the DSM-IV-TR (APA, 2000), dyscalculia is defined as a learning disability where mathematical ability is substantially below the individual's expected level, given his or her chronological age, intelligence quotient and age appropriate education, where such difficulties significantly interfere with academic performance. In its latest version, the DSM-5 (APA, 2013), learning disorders become a more general subcategory, namely, specific learning disorders. Within ICD-10 (WHO, 1992), dyscalculia is found within the specific developmental disorders of scholastic skills. It refers to a specific disorder of arithmetic skills, where there is a specific alteration in the learning capacity of arithmetic that cannot be explained by neurodevelopmental disorders or by inadequate schooling. Within the most recent ICD-11 (WHO, 2018), which will come into force in 2022, dyscalculia is no longer classified as a scholastic learning disorder (this is also the case for disorders such as reading), but as a developmental learning disorder with mathematical difficulties, within the general classification of developmental learning disorders. In spite of sharing exclusion features with ICD-10 (WHO, 1992), it adds that it cannot be explained either by lack of competence in the language of instruction or by psychosocial adversities. Either way, both the DSM and the ICD highlight the need of using standardised tests as assessment tools for calculation or reasoning.

The origin of dyscalculia has also not been clearly established. Rourke (1989) considers dyscalculia as a brain disorder genetically determined, while authors such as Fergusson, Horwood, and Lawton (1990) propose that the causes of dyscalculia are found in the child's environment and his or her social context. For acalculia, as opposed to dyscalculia, the mathematical disorder is consequence of a brain injury. However, the cognitive dysfunction of the underlying processes of both acalculia and dyscalculia could be the same, as the errors showed by those affected are similar.

Typical development of calculation abilities

Quantity manipulation is an innate capacity that allow us to quantify everything around us (Ardila & Rosselli, 2002; Barrachina, Serra-Grabulosa, Soler Vilageliiu & Tolchinsky, 2014; Sans et al., 2013). Throughout recent history, several reports (Calpadi & Miller, 1988; Koehler, 1951; Mechner, 1958) have argued that some animals can use numerical concepts and perform arithmetic operations at least up to a certain quantity. However, the given answers tend to be approximate (Dehaene, 1997). This capacity to recognise quantities is also found in small children (Fuson, 1988; Wynn, 1990, 1992). Following Geary (2004), basic competences are classified between innate quantitative abilities, such as numerosity, pre-counting and ordinality, and acquired arithmetic abilities, later developed upon innate abilities, such as the concept of number and counting. Therefore, we are referring to a basic capacity that is found in the early stages of development, such as claimed by Piaget, (1959) where the development of mathematical reasoning takes place during Primary Education (see Lievegoed, 1999). Human babies are able to recognise between 3 and 6 items (Antell & Keating, 1983), but their capacity to build correspondences between number and quantity emerges during the second year of life (Langer, 1986). The child starts using some tags for numbers and develops the capacity to count up to 3. In this way, the following are acquired: the one-to-one principle (each object in a collection is matched with just one number tag), the stable order principle (the tags must be ordered in a permanent position in the list). Also, the cardinality principle (the last tag used in a count sequence represents the group) is observed at the age of 3 (Gelman & Meck, 1983), where children can generally count up to 10. During this period, the child is also learning how the numeric system works and memorising number words (Ardila & Rosselli, 2002).

The first and second year of Primary education are characterised by the handling of addition and substraction, using procedures such as finger counting, counting out loud, and memorisation of additions and substractions with small amounts (Ardila & Rosselli, 2002). From the third to the fifth year of Primary education, children manipulate the principles of multiplication and division. From 10 to 13 years of age, the use of finger counting begins to disappear, but counting out loud remains as a strategy (Grafman, 1988; Siegler, 1987).

Methods

1. Aims of the review

It is intended to review the relevant scientific literature concerned about aspects such as the definition and types of dyscalculia, prevalence and neurobiological bases, assessment and detection tools and current treatment perspectives.

2. Search terms

Dyscalculia, mathematical learning, learning disorders, difficulties in learning mathematics, intervention and identification, mathematics disorder, calculation and arithmetic disorders, early difficulties in mathematics, neurological bases of dyscalculia, , acalculia, number processing, didactic intervention, developmental neuropsychology, early detection, early attention to mathematical difficulties and mathematical competence.

3. Inclusion/ exclusion criteria.

a. Publication date between 2000 and 2018, including previous manuals and articles that we considered essential.

b. Articles both in English and Spanish language have been included.

c. An educative perspective has been adopted (Early Years, Primary and Secondary Education).

d. No studies with an adult population have been included.

e. Only articles of a scientific, not divulgative, nature have been considered.

f. Primary sources have been used, such as original articles and theses, and secondary sources such as databases.

4. Search strategies

The following databases and documentary sources have been consulted: PubMed, Dialnet, ERIC, Google Scholar, Revista de Neurología and PsycINFO.

5. Strategy for selecting studies

Once keywords were defined, articles were chosen by following the specified criteria. The contents of this review are directly linked to the general aim defined at the beginning of this section. As it can be seen in Table 2 (and in Table 3 below), the majority of the consulted articles focus on basic research, followed by assessment and diagnosis, and finally treatment. The specific-1 topic refers to those articles in which calculation disorders are treated in detail, whereas specific-2 articles mention dyscalculia in a secondary manner.

Table 2. *Consulted bibliography*

MAIN TOPIC	SPECIFIC TOPIC-1	SPECIFIC TOPIC-2	N
Basic research	Children		12
	Learning difficulties and learning disorders		7
	Prevalence and neurobiological basis		9
	Cognitive and information processing models		20
	Comorbidity	ADHD	2
		Dyslexia	1
	Educational psychology		9
Assessment and diagnosis			18
Treatment			16
TOTAL NUMBER OF REVIEWED ARTICLES			94

Table 3 below shows bibliographical references, outlining those pieces of work of a theoretical or empirical type, along with their topic (basic research, assessment and diagnosis, and treatment). As it can be seen in the table, the majority of the consulted articles focus on basic research, followed by assessment and diagnosis, and treatment .

Table 3. *Bibliographic record of the references included in the review*

Authors/year	**Type**	**Topic**
Alonso Cánovas (2009)*	Empirical	Basic Research
Antell and Keating (1983)	Empirical	Basic Research
Ardila and Rosselli (2002)*	Empirical	Basic Research
Ardila, Rosselli and Matute (2005)	Empirical	Basic Research
Arribas, Santamaría, Sánchez- Sánchez and Fernández- Pinto (2015)*	Empirical	Assessment and Diagnosis
Artigas-Pallarés (2002)*	Empirical	Basic Research
Ausubel (1968)	Theoretical	Treatment
Badian (1983)*	Empirical	Basic Research
Balaguer Rodríguez and Tárraga Mínguez (2014)	Theoretical	Basic Research
Barrachina, Serra-Grabulosa, Soler Vilageliiu and Tolchinsky (2014)*	Theoretical	Basic Research
Berger (1926)	Empirical	Basic Research
Boix et al. (2001)*	Theoretical	Basic Research
Bryant, Bryant, Gersten, Scammacca, and Chavez (2008)*	Empirical	Treatment
Bryant, Bryant, Porterfield, Dennis, Falcomata, Valentine, Brewer and Bell (2014)*	Empirical	Treatment
Butterworth, Reeve, Reynolds and Lloyd (2008)*	Empirical	Basic Research
Butterworth and Yeo (2004)*	Empirical	Treatment
Callaway (2013)*	Empirical	Treatment
Calpadi and Miller (1988)	Empirical	Basic Research
Carboni-Román, Del Río Grande, Capilla and Maestú (2006)	Empirical	Basic Research
Cipolotti and Butterworth (1995)*	Empirical	Basic Research
Cohen (1971)*	Empirical	Basic Research
Coronado Hijón (2008)	Empirical	Basic Research
Davis, Bryson and Hoy (1992)	Empirical	Basic Research
Dehaene (1997)	Empirical	Treatment
Dehaene and Cohen (1995)*	Empirical	Basic Research
Dehaene, Molko, Cohen and Wilson (2004)*	Empirical	Basic Research
Dowker (2005)*	Empirical	Treatment
Elliot, Smith and McCulloch (1996)*	Empirical	Assessment and Diagnosis
Estévez Pérez, Castro Cañizares and Reigosa Crespo (2008)*	Empirical	Basic Research
Faramarzi and Sadri (2014)*	Empirical	Treatment
Fernández and Llinares (2014)	Theoretical	Basic Research
Fergusson, Horwood and Lawton (1990)	Empirical	Basic Research
Fuson (1988)	Empirical	Basic Research

Table 3. *Bibliographic record of the references included in the review (continuation)*

Authors/year	**Type**	**Topic**
Garrido (2014)*	Theoretical	Treatment
Geary (1993)	Empirical	Basic Research
Geary (2004)	Empirical	Basic Research
Gelman and Meck (1983)	Empirical	Basic Research
Gerstmann (1940)	Empirical	Basic Research
Ginsburg and Baroody (1983)*	Empirical	Assessment and Diagnosis
González-Castro, Rodríguez, Cueli, Cabeza and Álvarez (2014)	Empirical	Basic Research
Gracia-Bafalluy and Escolano-Pérez (2014)	Empirical	Basic Research
Grafman (1988)	Empirical	Basic Research
Grégoire, Nöel and Van Nieuwenhoven (2015)*	Empirical	Assessment and Diagnosis
Gross-Tsur, Manor and Shalev (1996)	Empirical	Basic Research
Gillum (2014)*	Empirical	Basic Research
Henschen (1925)	Empirical	Basic Research
Jacubovich (2006)*	Empirical	Basic Research
Käser et al. (2013)*	Empirical	Treatment
Kirk and Bateman (1962)*	Empirical	Basic Research
Koehler (1951)	Empirical	Basic Research
Kosc (1974)*	Empirical	Basic Research
Kucian et al. (2011)*	Empirical	Basic Research
Langer (1986)	Empirical	Basic Research
Lewandowsky and Stadelmann (1908)	Empirical	Basic Research
Lewis, Hitch and Walker (1994)	Empirical	Basic Research
Lievegoed (1999)	Theoretical	Basic Research
Loveland, Fletcher and Bailey (1990)*	Empirical	Basic Research
Manga and Campos (1991)*	Empirical	Assessment and Diagnosis
Martínez Zamora, Henao López and Gómez (2009)*	Empirical	Basic Research
McCloskey, Caramazza and Basili (1985)*	Empirical	Basic Research
Mechner (1958)	Empirical	Basic Research
Millá (2006)*	Empirical	Treatment
Miranda Casas, Meliá de Alba, Marco, Roselló and Mulas (2006)	Empirical	Basic Research
Mora and Aguilera (2000)	Theoretical	Basic Research
Nelwan, Vissers and Kroesbergen (2018)*	Empirical	Treatment
Olea, Ahumada and Líbano (1986)*	Empirical	Assessment and Diagnosis
Palomino and Crespo (2005)*	Empirical	Assessment and Diagnosis
Pérez, Arias and Mateos (2000)*	Empirical	Assessment and Diagnosis
Piaget (1959)	Theoretical	Basic Research
Portellano, Mateos and Martínez-Arias (2012)*	Empirical	Assessment and Diagnosis
Räsänen, Salminen, Wilson, Aunio and Dehaene (2009)*	Empirical	Treatment
Re, Pedron, Tressoldi and Lucangeli (2014)*	Empirical	Treatment
Rebollo and Rodríguez (2006)	Empirical	Basic Research
Rourke (1987)	Empirical	Assessment and Diagnosis
Rourke (1988)	Empirical	Assessment and Diagnosis
Rourke (1993)	Empirical	Basic Research
Santamaría, Arribas, Pereña and Seisdedos (2005)*	Empirical	Assessment and Diagnosis
Sans, Boix, Colomé, López-Sala and Sanguinetti (2012)*	Theoretical	Basic Research
Sans, López-Sala, Colomé, Boix and Sanguinetti (2013)*	Theoretical	Basic Research
Serra-Grabulosa (2014)*	Theoretical	Basic Research
Siegler (1987)	Empirical	Basic Research
Shalev, Auerbach and Gross-Tsur (1995)	Empirical	Basic Research
Shalev, Weirtman and Amir (1988)	Empirical	Basic Research
Spreen and Strauss (1991)*	Empirical	Assessment and Diagnosis
Strang and Rourke (1985)*	Empirical	Evaluation and Diagnosis
Temple (1997)*	Empirical	Basic Research
Thurstone (1938)*	Empirical	Evaluation and Diagnosis
Thurstone and Thurstone (2004)*	Empirical	Evaluation and Diagnosis
Vygotsky (1931)	Empirical	Treatment
Weschler (2012)*	Empirical	Evaluation and Diagnosis
Wilson et al. (2006)*	Empirical	Treatment
Wynn (1990)	Empirical	Basic Research
Wynn (1992)	Empirical	Basic Research
Yuste, Martínez and Galve (2005)*	Empirical	Evaluation and Diagnosis

Note: The articles marked with an asterisk (*) are those of central importance found after the review. Those articles without an asterisk are used as a complement in the introduction/discussion.

Results

Prevalence and neurobiological bases of dyscalculia

The prevalance of LD in the school population ranges between 5% and 15% (Sans et al., 2013), and between 2,27% and 6,4% in the case of dyscalculia (Estévez Pérez, Castro Cañizares & Reigosa Crespo, 2008). In addition, there is approximately a 25% of comorbidity between dyscalculia and other developmental disorders (Gross-Tsur et al., 1996). The issue of gender distribution in dyscalculia has not been free of controversy, although some authors consider that its incidence is similar for both genders (Lewis, Hitch & Walker, 1994; Gross-Tsur et al., 1996). However, caution is needed, as dyscalculia has been significantly less studied tan other LD, and therefore there is much to know (Ardila & Rosselli, 2002).

Regarding its neuroanatomical basis, Cohen (1971) proposed that the difficulties with arithmetic can be explained by short term memory (Shalev, Weirtman & Amir, 1988). The relationship between dyscalculia and attention difficulties has also been widely studied (Badian, 1983; Davis, Bryson & Hoy, 1992, Shalev, Auerbach, & Gross-Tsur, 1995; Strang & Rourke, 1985). Several models have been put forward to account for numerical processing and calculation and their neurobiological bases. Of special importance are McCloskey's model of numerical cognition (McCloskey et al., 1985), Cipolotti and Butterworth's multiroute model (1995), and Dehaene and Cohen's triple code model (1995).

McCloskey and collaborators (1985) propose a cognitive model of numerical cognition to explain the errors made by patients with acalculia. Temple (1997) used this model to study dyscalculia. It is a modular model where different subcomponets can be selectively impaired as a consequence of a brain lesion (see Figure 1).

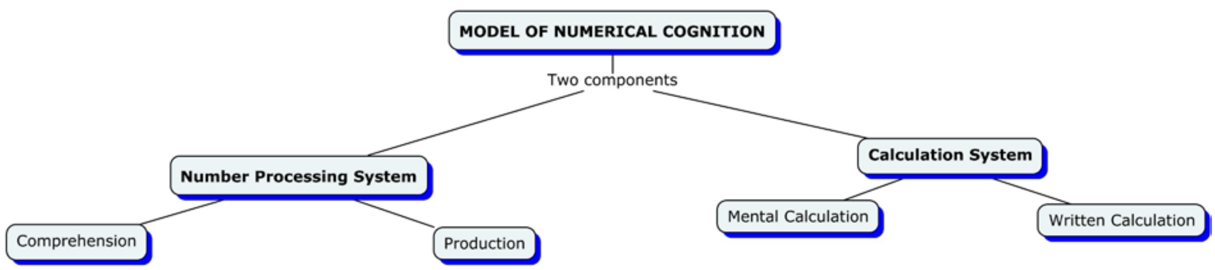

Figure 1. McCloskey et al.'s model of numerical cognition (adapted from Jacubovich, 2006)

It consists of a number processing system with an entry and exit subsystem, which provide with separate modules for the processing of the arabic and verbal codes in their phonological (oral) and written (orthographic) modalities. Also, the model has a semantic representation system which works as a mediator in the translation of codes from an input to an output, through the coding of magnitudes that would act as an intermediary during the resolution of the arithmetic calculation (Serra-Grabulosa et al., 2010). Finally, we find a calculation system divided into two independent subsystems, mental calculation and written calculation.

McCloskey et al.'s model (1985) is extended by Cipolotti and Butterworth (1995), in their multiroute model. They added additional asemantic processing pathways allowing for conversion between codes without accessing to the semantic representation of number. The use of one or other route depends on task demands, where those routes not being at use would be inhibited. For their part, Dehaene and Cohen (1995) developed the triple code model, composed of three mentally manipulable modules that contain numerical information. Three functional hypotheses are proposed. First, numerical information can be manipulated in three codes: analogical (bilateral inferior parietal region) verbal-auditory (left perisylvian areas) and arabic (bilateral fusiform gyrus). On second place, they propose that information can be translated from one code to another through asemantic routes. Finally, choosing a certain code depends on the type of mental operation to be performed. By using neuroimaging techniques on healthy adults, Dehaene and Cohen (1995) pointed out that the neural circuits concerned with numerical processing are mostly localised in the parietal lobe, although there are other areas involved, such as the prefrontal cortex, the posterior part of the temporal lobe, the cingulate cortex, and several subcortical regions (see Serra-Grabulosa et al, 2010). Following this model, arithmetic proficiency is probably due to the continuous exchange of information between visual, verbal and quantitative number representations. Thus, dyscalculia can originate in several ways: due to damage in any of the three modules, a poor development, or because the connexions between modules have not been adequately developed (Alonso Cánovas, 2009).

Assessment and Diagnosis

Following Strang and Rourke (1985), the errors made by children with dyscalculia can be classified in: 1) spatial organisation of quantities, 2) visual attention, 3) procedural errors in arithmetic, 4) motor errors when writting quantities by hand, 5) related to numerical judgement and reasoning, 6) errors in memory for quantities, and 7) perseverance in solving arithmetic operations and number problems. Clinical manifestations of dyscalculia differ by age and schooling level (Sans, Boix, Colomé, Lopez & Sanguinetti, 2012). In Early Years education, difficulties are observed when having to classify objects by their features, in understanding concepts such as “more than” and “less than”, sorting objects by size, in one-to-one correspondences, counting up to 10, or copying arabic numbers (Sans et al., 2012). In Primary education, difficulties are associated to numeracy (Boix et al., 2001; Sans et al., 2012, Sans et al., 2013; Serra-Grabulosa, 2014). These students, therefore, fail in aspects such as telling the time or counting money, confuse mathematical signs, perform transpositions when writing numbers, show difficulties to memorise mathematical concepts and to understand place value, barely automatising mathematical facts.

In Secundary Education, difficulties arise relation to understanding abstract concepts, students show poor abilities to apply mathematical skills, calculation errors are made, problem solving strategies are scarce, and there is a lack of automatisation for arithmetic facts (Barrachina et al., 2014; Boix et al., 2001; Sans et al., 2012, Sans et al., 2013). Associated neuropsychological difficulties are also found, such as in the tactile analysis of objects and deficiencies when interpreting facial and emotional expressions (Rourke, 1987), inadequate prosody in verbal language (Rourke, 1988) and difficulties when interpreting non- verbal events (Loveland, Fletcher & Bailey, 1990).

The diagnosis of dyscalculia (as happens with other LD) is clinical (APA, 2000, 2013). This requires gathering data about the clinic history of the student, as well as school reports and contacting the school’s guidance service. In parallel, a neuropsychological evaluation will be performed by using standardised tests (see Table 4), in order to establish what the difficulties are, to assess the preserved and altered cognitive functions, to detect the possible associated deficits and to perform a differential diagnosis. Therefore, this evaluation will include tests that assess the intelligence quotient, reading and writing processes and basic psychological processes (Barrachina et al., 2014), as the calculation capacity is multifactorial (Ardila et al., 2005). All these data will be evaluated in order to establish the best educational treatment. Currently, there are just a few standardised instruments to detect and diagnose calculation disorders in Spain, mostly for Secondary and High School education. Some of the available tests to detect and diagnose calculation disorders are gathered in Table 4 below, which results from the literature review performed in the current article. It is important to highlight that in some cases (as in tests of academic aptitude and intellectual performance), subtests belonging to more general scales are used (for instance, in the WPPSI-IV).

Table 4. *Standardised tests to assess dyscalculia*

TEST	NAME	SCALE	AUTHORS
TEDI-MATH	Test for the Diagnosis of Basic Skills in Mathematics	3-8 years	Grégoire, Nöel, & Nieuwenhoven, 2015 (adapted to Spanish by Sueiro & Pereña, 2015)
TEMA-3	The test of early mathematics ability	3-8 years	Ginsburg & Baroody, 1983 (adapted to Spanish by Núñez & Lozano, 2007)
Calculation and Mathematical Level Test		7-12 years	Palomino & Crespo, 2005
Mathematical Aptitude and Performance Test		7-12 years	Olea, Ahumada & Líbano 1986
WPPSI-IV	Weschler Preschool & Primary Scale of Intelligence	2-7 years	Weschler, 2012 (adapted to Spanish by the R&D Department of Pearson Clinical and Talent Assessment, 2014)
BADyG-R	Battery of Differential and General Aptitudes- Renewed.	From Early Years to High School	Yuste, Martínez & Galve, 2005
LURIA-DNI	Neuropsychological Battery-Children's	7-10 years	Manga & Ramos, 1991
CUMANÍN	Child Neuropsychological Maturity Questionnaire	3-6 years	Pérez, Arias & Mateos, 2000
CUMANES	Neuropsychological Maturity Questionnaire	7-12 years	Portellano, Mateos & Martínez- Arias, 2012
BAS II	British Ability Scales	2-17 years	Elliot, Smith & McCullouch, 1996 (adapted to Spanish by Arribas & Corral, 2011)
PMA	Primary Mental Abilities	From 10 years old	Thurstone, 1938
TEA	Test of Educational Ability	8-18 years	Thurstone & Thurstone, 2004
BAT-7	TEA Abilities Battery	From 12 years old	Arribas, Santamaría, Sánchez-Sánchez & Fernández –Pinto, 2013
EFAI	Factorial Assessment of Intellectual Abilities	From 7 years old	Santamaría, Arribas, Pereña & Seisdedos, 2005

Current perspectives in educational intervention.

Attention to LD should be subjected to early detection and intervention in order to prevent the possible students' school failure (Millá, 2006). The child with dyscalculia requires of a more intensive and explicit teaching in regards to number sense, a more practical education when using the number system and concrete experiences with large and small numbers (Serra-Grabulosa, 2014). The notably early detection of mathematical problems suggests the need to implement individualized re-education programmes during childhood, which will facilitate their effectiveness (Serra-Grabulosa, 2014). This re-education needs to be quite targeted complying with the minimum objectives and basic standards of the school curriculum. These programmes will improve the student's achievement both in general and in the area of mathemathics, making him/her feeling more competent (Boix, Colomé, Lopez & Sanguinetti, 2013).

In order to elaborate an effective re-education programme, the objectives should vary depending on the student's prior knowledge (Ausubel, 1968), placing him/her on the Zone of Proximal Development (Vygotsky, 1931). Among the re-education objectives, we would like to highlight: 1) understanding place value and how each number relates to the others 2) understanding the composition/decomposition of numbers, 3) counting in a precise and flexible manner, 4) understanding the use of multiples of 10, 5) to automatise what is learnt, 6) increasing confidence in numbers and mathematics and 7) apply what is learnt to real life.

Barrachina et al. (2014) suggest a few guidelines for an effective re-education. First of all, to strengthen the recreational aspect of re-education in order to offer successful experiences in children who normally fail at school. Furthermore, the student needs to be positively reinforced in order to increase confidence. This is why objectives must be set in the short term, work must be highly structured and materials needs to be varied, enhancing multisensoriality (Serra-Grabulosa, 2014). Considering the student's low numerical processing speed, the sessions should not be constrained by time and will have to maintain a minimum periodicity of two per week. The student's monitoring should be carried out in all subjects and families should get involved in the treatment. To give an adjusted educational answer implies to develop an Individual Work Plan containing a Curricular Adaptation adjusted to the needs and interests of the student. It will provide meaningful and functional learning, coordinate all the agents involved in the child's development and adapt the evaluation process to avoid harming the student. (Garrido, 2014).

Although limited, there are a handful of available re-education options for dyscalculia and/or mathematical difficulties. Fortunately, as Gillum (2014) points out, recently we can observe a growing interest in the development of several interventions to treat dyscalculia. The focus of such interventions is varied. It can deal with mathematical fact knowledge, the ability to carry out mathematical procedures, or to understand how to use mathematical principles, amongst others (Dowker, 2005). However, we would like to emphasise that the most important aspect of re-education is to identify and act over the first signs of difficulties in mathematics (that is, early intervention) Interventions can take place in the classroom (either as part of the educational curriculum or as an extra) and may follow a traditional approach or use Information and Communication Technologies (ICT). On first place, we will review those proposals of a more "traditional" nature (that is, not using ICT) to focus then on ICT.

Butterworth and Yeo, pioneers on dyscalculia research, published *Dyscalculia Guidance* in 2004, a manual with a ludic approach to guide the teaching of mathematics in Primary education both individually and in groups. The manual gathers proposals for understanding the numerical system and consolidating the mental number line, working with large numbers and improving calculation strategies.

Re, Pedron, Tressoldi, and Lucangeli (2014) performed a successful individual training in order to improve the concept of number, automaticity in retrieving and using arithmetic facts, mental and written calculation and writing. Other approaches propose group intervention during regular class time, focusing in improving the learning of the concept of number, operations, and quantitative reasoning (see Bryant, Bryant, Gersten, Scammacca, & Chavez, 2008; Bryant et al., 2014). Also, we can find interventions that have adopted a neuropsychological approach in students with dyscalculia.

In Faramarzi and Sadri's study (2014), their intervention focused on strengthening auditory and visual memory, reinforcing attention, training executive functions, developing visuospatial perception and reinforcing language. Those students who completed the neuropsychological intervention showed a significant improvement in their mathematical performance compared to the control group. Another recent study (Nelwan, Vissers, & Kroesbergen, 2018) implemented a working memory training for children with attention and/or math difficulties, where one group received the intervention with a high level of training, another group received the same intervention with less training, and the control group did not receive any intervention.

Measures were taken of both visual and verbal working memory and mathematical skills. The group that received more training improved more than the group with less training, in visual working memory and mathematical skills, and maintained the improvement in mathematics over time, showing the relevance of motivation and of using a good training in interventions.

Focusing now on the use of ICT, these enhance the ludic aspect of learning mathematics. Some examples are the software created by Dehaene, called *The Number Race* (2004), based on his cognitive model, and *Rescue Calcularis* (2011) created by Kucian et al. (2011). *The Number Race* is a software designed mostly for children between 4 and 8 years of age, aimed at learning basic mathematical concepts and arithmetic. The game intends to strengthen the cerebral circuits involved in the manipulation and mental representation of numbers (Dehaene, Molko, Cohen, & Wilson, 2004; Wilson et al., 2006). In 2009, Räsänen, Salminen, Wilson, Aunio and Dehaene reported that *Number Race* improved the ability of 15 dyscaculic children in pre-school age when performing number comparison tasks, with no effect on counting or arithmetic. The software *Rescue Calcularis* is a computer-based training programme based on Calcularis' software (Kucian et al, 2011), designed on the basis of typical and atypical development of mathematical skills. The most notable improvements were observed in substractions and numerical representation (Käser et al., 2013). Another available option is *Number Sense*, a webpage developed by the team of Butterworth and Laurillard at the London Institute of Education (http://low-numeracy.ning.com), see also *Number Catcher* http://www.thenumbercatcher.com/nc/home.php), which has been used by numerous schools in London, and is expanding all over the world in countries such as Cuba, China and Singapore. Although the original games of *Number Sense* are not available as of 2019, the new website is frequently updated, and links to new games (such as "NumberBeads") can be found, as well as publications of interest on dyscalculia. The intention of the games included in *Number Sense* is to nourish those abilities that are, following Butterworth, in the roots of numerical cognition and at the hearth of dyscalculia: to manipulate precise quantities. Despite plans to evaluate the software through controlled studies at the Cuban Neuroscience Center, we still need scientific articles evaluating the effectiveness of Number Sense (see Callaway, 2013). Other studies, however, have not found an advantage in the administration of ICT interventions compared to instruction by teachers using cognitive modelling techniques with explicit instructions and immediate and corrective feedback (see Leh & Jitendra, 2013).

Discussion

Throughout this review article. we have collected information regarding the definition and types of dyscalculia, prevalence and underlying neurobiological bases, tools and instruments for the detection of dyscalculia and current perspectives on educational intervention. To do so, it has been necessary to go deeper into issues such as what we understand by LD and what their characteristics are. Therefore, it can be said that dyscalculia is a chronic disorder in the area of mathematics, affecting all ages, where performing its detection and diagnosis as early as possible is of vital importance (Ardila & Rosselli, 2002; Millá, 2006). In Spain, the Organic Law for Quality Improvement of Education (2013), and previously the Organic Law of Education, LOE (2006), frame dyscalculia within SLD considering students with this disorder as Students with Additional Educational Support Needs. Such students are likely to benefit from a range of educational measures that do not increasingly alienate them from the mainstream curriculum and provide them with an effective educational response tailored to their needs.

This calculation disorder has been poorly studied compared to other neurodevelopmental disorders, as currently classified by the DSM-5 (2013). Undoubtedly, in the scientific literature there is a greater number of research articles relating to dyslexia or ADHD (Artigas-Pallarés, 2002; Martínez Zamora et al., 2009; Miranda Casas, Meliá de Alba, Marco Taverner, Roselló & Mulas, 2006), given its comorbidity. From this derives the need to establish clear criteria for the detection and differential diagnosis of dyscalculia. We have observed that the DSM, both in its fourth and fifth edition (APA, 1994, 2000, 2013) shows the need and obligation of use specific standardized tests. Again, we find very little research in this regard, which means that we do not have specific instruments for calculation, being then forced to use subtests of more general scales (Weschler Scales (Weschler, 2012), Cumanin (Pérez et al., 2010), PMA (Thurstone, 1938), EFAI (Santamaría et al. 2005), amongst others).

A controversial issue is that of the Intellectual Quotient (IQ) which, as established by the DSM diagnostic manuals and the WHO classification, ICD-10 and ICD-11 (1992, 2018), must be within normality. However, as we already know, not only the area of mathematics is affected in dyscalculia, but also processing speed, executive functions and even linguistic abilities (Badian, 1983; Millá, 2006; Strang & Rourke, 1985; Shalev et al., 1995) which in most intelligence tests are part of the total IQ, as occurs in the Weschler Scales (Weschler et al., 2012). This overlap of difficulties means that the IQ is perhaps not an adequate exclusion criterion. Parallel to the use of standardized tests, and, as it is a clinical disorder, a neuropsychological clinical assessment is necessary. At this point, in addition to the examination of the clinical history, it will be necessary to deepen into aspects such as working memory, processing speed or executive functions that are so closely related to calculation disorders (Badian, 1983; Strang & Rourke, 1985; Shalev et al., 1995).

Once the causes of the difficulty and the neuropsychological profile have been determined, as well as the available resources (both human and material), an intervention plan will be established. The early identification of calculation disorders should be done, if possible, during the very first years of Primary Education. It will be at this moment when the teaching staff will have to develop an adapted mathematics teaching programme, based on the encountered difficulties, so students can be as close as possible to the level of the rest of their classmates. Early intervention has important short-term effects on children at risk and those born with disabilities by preventing or minimizing developmental delays (Millá, 2006). This approach will be carried out from an interdisciplinary perspective in both diagnosis and intervention. In this way, we propose to focus on four main areas: a) health: at the level of neurologist, neuropsychologist, psychologist and paediatrician, fundamentally, b) social: many students who suffer from dyscalculia show low levels of self-esteem and are often very frustrated, c) family: coordination and commitment of parents in the re-education of their children is needed and d) educational: implementing individualised resources and programmes (see also Millá, 2006). From this perspective, it can be said that the student with dyscalculia has specific needs for educational support associated with SLD. In the educational field, we highlight the work of the Early Childhood Intervention Teams, the Educational and Psychopedagogical Guidance Teams and the Guidance Departments. Although acting on these difficulties represents a very effective measure to reduce their effects on later learning, we do not have protocols in this regard.

As stated in the current Spanish Organic Law for Quality Improvement of Education (LOMCE, 2013), providing an effective educational response involves adapting the fundamental elements that compose the curriculum (Article 6). That is, the objectives of each teaching and educational stage, competencies, or capacities to apply the contents of each teaching and educational stage in an integrated manner, in order to achieve the adequate performance of activities and the effective resolution of complex problems, contents, or sets of knowledge, abilities, skills, and attitudes that contribute to the achievement of the objectives of each teaching and educational stage, and to the acquisition of competencies, didactic methodology, assessable learning standards and results, and evaluation criteria for the degree of acquisition of competencies and the achievement of the objectives of each teaching and educational stage.

In a nutshell, it can be said that, despite there being a long history in the topic of LD, the terminology that defines them and the diagnostic criteria that we currently use are still not clear. There are very few specific tools and instruments for the detection of dyscalculia and the educational treatments are still very far from the reality of the classroom, which being extremely complex and diverse, requires a multidisciplinary intervention. The aim of our review is to provide a general overview, albeit exhaustive and scientific, of such an unknown learning disability as dyscalculia. Given the scarcity of studies on this subject (especially in comparison with other learning disorders), there are still many unknowns to be resolved. Therefore, in addition to the disorders that we have identified in the current review, we consider that relevant areas for future research are the exploration of which risk factors are influencing the development of this disorder, on the one hand, and on the other hand, the development of standardised tests or that would detect not only whether a student has dyscalculia or not, but its comorbidity with other little-known disorders as NVLD.

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