DEALING WITH DYSCALCULIA OVER TIME

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Abstract

Although several surveys related to dyscalculia have proceeded so far, research seems to fail till now to develop a clear concept map referring to the features of dyscalculia classified according to age. Dyscalculia can be recognized by some specific features that are noticed through all stages of the individual's development. In this paper a classification of features is proposed, according to individuals' age as well as several screening methods, in order to ensure efficiency of the screening procedure. Dyscalculia's features evaluation during different stages of age is crucial since diagnosis is relevant to the age considering that math's learning difficulties arising in early ages are likely to be remitted since this status is possible to be temporary. An innovative aspect in this work is the citation and analysis of algorithmic thinking difficulties encountering in older ages under the range of learning difficulties in mathematics and dyscalculia.

Introduction

This paper deals with dyscalculia as a specific disorder of managing and conceiving mathematical concepts. The features of dyscalculia are going to be analyzed and classified according to the age of the individuals who display this specificity. Dyscalculia can be diagnosed even at an early age by difficulties noticed in the direct estimation of quantities, in counting and in the recognition of numerical symbols, as well as in the perception of spatial concept. When dyscalculia arises in primary school aged children, it is identified by difficulties in the visual perception, in the spatial number organization, in basic mathematical operations, in mathematical problem solving and in the algorithmic thinking ability. Adults facing dyscalculia present problems namely in the mathematical induction logic, in Euclidean and non-Euclidean geometry concepts, in algebra and in calculus, which are to be further analyzed. Additionally, incomplete capabilities in solving an algorithmic problem are observed both in children and in adults, when these problems need design, description and application of algorithmic steps. Although dyscalculia's features are classified according to all stages of individual's development, there are some common characteristics, which occur irrelatively to the individual's age. It would be hard to get a strict and absolute classification of dyscalculia features, because individual development, educational opportunities and perception level differ in each case.

Related Work

According to Shalev et al., (2008) developmental dyscalculia has been sub-typed according to the presence or absence of coexisting reading disorder neuropsychological profiles or different components of the areas of mathematics. However, sub-typing has not yielded consistent domain-specific differences among children with dyscalculia and has not proved useful in understanding or treating the disorder. Authors also notice that dyscalculia should be evaluated over time but this classification is not cited in their work (Shalev et al., 2008).

According to Geary's (2009) classification in relation to preschoolers at risk of math difficulties, dyscalculia features are focused on three basic pillars. Dyscalculia is inferred initially as a persistent difficulty in the learning or understanding of number concepts, i.e. knowing basic number names and discriminating the larger/smaller number. Additionally, it is inferred to counting principles difficulties, like in cardinality of a set and in basic counting sequence. Finally, difficulties in arithmetic are sub-typed, for instance troubles noticed while solving simple arithmetic problems such as finger counting or recalling an answer (Geary 2006).

Karagiannakis et al., (2014) used a multi-deficit neuro-cognitive approach and proposed a classification model describing four basic cognitive domains for mathematical learning difficulties, within which specific deficits may reside. Within the cognitive psychology frame Karagiannakis' and co-authors' classification included the core number deficits, the memory (retrieval and processing) inefficiency, the reasoning shortage and the visual-spatial perception difficulties. (Karagiannakis et al., 2014)

Semantic Approach of Dyscalculia Term

Individuals display a mathematics disability when their performance on standardized calculation tests or on numerical reasoning tasks is comparatively low, given their age, education and intellectual reasoning ability (Munro, 2003). Low performance due to a cerebral trauma is called "acquired dyscalculia" (Munro, 2003). Mathematical learning difficulties with similar features but without the evidence of a cerebral trauma are referred to as "developmental dyscalculia" (Munro, 2003). According to the definition that Kosc (1974) proposed as "developmental dyscalculia", dyscalculia is a structural disorder of mathematical abilities which has its origins in a genetic or congenital disorder of those parts of the brain that are the direct anatomico-physiological substrate of the maturation of the mathematical abilities adequate to age, without a simultaneous disorder of general mental functions (Kosc, 1974). Summing up the results from valid research and taking into consideration possible typical error and divergence, the prevalence of people with difficulties in mathematical concepts is 5% - 6%, referring to school aged children (Rosselli, 2006).

Features of People Dealing with Dyscalculia

Like most learning disabilities, dyscalculia can be recognized through some specific features that are noticed through all stages of individual development. Those features could be classified according to the individual's age, although there are some common characteristics occurring irrespectively to the individual's age. In particular, features of dyscalculia referring to preschool and school aged children, teenagers and adults are classified as follows.

Children up to 6 Years Old

The evidence of dyscalculia could be noticed even during early age, due to several difficulties noticed in general. In particular, problems in perception of pre-math concepts are noted in preschoolers. Pre-math skills is a term used to refer to math skills learned by preschoolers and kindergarten students, including learning to count numbers (usually from 1 to 10, but occasionally including 0), learning the proper sequencing of numbers, learning to determine which shapes are bigger or smaller, and learning to count objects on a screen or book. Pre-math skills are also tied to literacy skills, meaning that young children face difficulties in pronouncing the numbers correctly (Kikasab et al., 2009).

A problem related to the number concept, is having difficulties in connecting the number concept (i.e. number six) to the quantitative and symbolic form (six objects). More specifically, the quantitative form is related to the recognition and direct quantities estimation often described by the term “subitizing” (Clements, 1999). The term “subitizing” is referred to the ability of finding a sets’ cardinality status, which is an inherent property and evolves significantly over time (Burr et al., 2010). In particular, infants up to three weeks old are able to recognize automatically sets that contain up to three elements (Xu et al., 2010). This ability is improving over time and subitizing ability referring to adults reaches the automatic recognition of sets cardinality which contains up to five components (Xu et al., 2010). Another feature usually noticed is difficulty in learning and recognizing numbers symbols, as well as conceiving the value of numbers especially referring to real life subjects (Cipolotti et al., 1991). This is mostly related to incomplete memory ability related to the number concept (Geary et al., 2007). Additionally, the children have troubles with understanding and recognizing cardinality in sets of objects and difficulties in connecting numbers with their names and symbols to the quantities they represent (Richardson, 2008).

Furthermore, difficulties in counting, especially referring to numbers bigger than ten (10), as well as counting down are noted in these ages (Shalev et al., 2000). In addition, this difficulty leads to problems in the visual perception of numbers, i.e. troubles discriminating and registering numbers in series (Cipolotti et al., 1991). In other words, they face troubles in counting orally or even more in writing the number (Richardson, 2008). This is also reflected in time management difficulties in everyday life. They tend to face problems in perceiving facts in series. For instance, temporal concepts such as today, yesterday, tomorrow etc, are often confused (Cappelletti, 2001).

Moreover, children dealing with dyscalculia are often not familiar with basic number names (e.g. 9 = nine) and face difficulties in discriminating which number is larger or smaller. They are typically aware of the fact that the value of number three (3) is greater than the value of number two (2), but they face troubles in figuring out that the value of number nine (9) is greater than thevalue of number eight (8). However, many of these children catch up in these areas of number understanding, at least for simple numbers (Geary, 2006). Furthermore, this ability is related to difficulties in conceiving conservation principles i.e. the perception that the quantitative value of an object or the number of elements of a set remains unchanged, regardless the spatial organization (Pordodas, 2003). This difficulty basically concerns visual perception but it is also related to difficulties in space perception. These difficulties in space perception are also known by the term ageometria or ageometresia (Berg, 1997). Ageometresia or ageometria is a term used to describe a form of dyscalculia, a disability that prevents students from understanding geometry (Shekhar, 2012).

Additionally, among difficulties in spatial concept, difficulties in space organization can be noticed, too, in early aged children, such as problems in classifying a number of sets of objects in series, starting from the smaller and ending to the larger set of items (Perikleidakis, 2003). Referring to the development of geometrical perception in early ages, identification level is the initial level in Van Hiele's learning model, where the enhancing of children's ability in perceiving shapes such as entities/totalities, without conceiving their features, is involved. Children begin forming concepts of shape long before they enter school

. They may first learn to recognize shapes by their overall appearance, stating the name of the shape (Clements et al., 2000). However, dyscalculic children appear to have difficulties in perceiving and representing shapes as a whole, although in this stage they don't consider that the shape is made up of separate components. In addition to this, they are face difficulties in naming and distinguishing shapes between similar looking shapes (Levenson et al., 2011). This is related to deficit in spatial experience, which prevents them from knowing how shapes fit together when dealing with puzzles, blocks and boxes (Richardson, 2008).

This deficit leads to difficulties in critical aspects of mathematical learning and thinking. There are two aspects about learning a sequence of information and using the sequence effectively (Munro, 2003). Children are not able to link pieces of information in a sequence or to move through the sequence to identify the item that 'comes next' (Munro, 2003). For instance, they deal with difficulties in recognizing the link between quantities that have five, six and seven items, in learning the names of the places in order, as well as learning a set of arithmetic actions or steps in order (Munro, 2003). That is also related to lack of pattern experience, meaning that they face troubles with figuring out which pattern comes next (Richardson, 2008). This is also referred to the sequence of numbers or to an algorithmic procedure, where the next step should be figured (Richardson, 2008).

School Aged Children

Dyscalculia as a specificity is more clearly identified in primary school children age. School aged children present several difficulties referring to visual perception (Groffman, 2009). Initially, problems arise while children are reading and writing numbers (Shalev, 2004), where confusion and replacement of visual similar digits is noticed (Shalev, 2004). Mistakes referring to the omission of number digits or incorrect replacement of number digits are usually noticed (Cappelletti et al., 2001). Not only that, but also children dealing with dyscalculia are not familiarized with mathematical vocabulary (Landerla et al., 2004). Additionally, difficulties appear in comprehension and distinction of math operations symbols (+, -, x, /), as well as in math and numerical symbolism in general (Munro, 2003 - Shalev, 2004 Geary, 2006).

Spatial number organization problems are also commonly encountered. For instance, inversions in number symbols are noted, i.e. number six (6) is written instead of nine (9). Occasionally, numerical digits are inversed i.e. number twelve (12) is displayed as twenty one (21) (Ardila et al., 2002), as well as spatial digits are omitted, i.e. the number 8221 is written as 821 (Ardila et al., 2002). Another deficit noticed is having troubles in visual conception of arithmetic quantities, as well as in placing digits in the proper position, according to their value (Porpodas, 2003).

Respectively, confusion in array of numbers, troubles putting numbers in sequence, difficulties linked to memorization and automatic recall are noted (Shalev, 2004 - Piazza et al., 2010). Additionally, weakness in both written and mental arithmetic operations is noticed, as well as troubles in perceiving definitions and types and learning them by heart (Cipolotti et al., 1991). Problems in memorization and learning of mathematical concepts, such as trigonometry concepts and types are also detected. Generalizing, the above mentioned features are linked to inadequate long-term and short-term memory related to mathematical functions (Periklidakis, 2003). Especially, difficulties in calculations are expressed in problems related to short-term memory and lead to inability to calculate (Rosselli et al., 2006). These problems are linked with limited capability to make calculations and with difficulty in memorizing and recalling simple arithmetic operations (Rosselli et al., 2006). Difficulties in recalling number facts and using algorithms in order to add, subtract, multiply and divide are noticed. In addition to this, troubles appear in the correct use of arithmetic signs and memorizing math facts, such as arithmetic and time tables (Munro, 2003). Therefore, difficulties are noticed in adding/subtracting/multiplying/dividing two-digit numbers, three-digit numbers, decimals or fractions (Munro, 2003).

Dyscalculic children also show difficulties when they deal with math problems (Mccloskey et al., 1985), due to incomplete long-term memory (Shalev, 2004). Additionally, dyscalculic children usually avoid strategy games, where algorithmic thinking ability is required (Porpodas, 2003). “Algorithmic thinking ability” is a term which describes the capacity needed in order to complete a task using a series of default actions, aiming at completing a process (Futschek, 2006 - Cooper, 2000). “Algorithmic thinking” is an ability evolving over time and more severe problems are displayed and noticed in older ages even more clearly.
In reference to spatial and geometry cognition, several difficulties are noticed. According to Van Hiele’s learning model, descriptive and theoretical abstraction level is linked to school aged children. “Descriptive level” or “analysis level” is the one where children are able to identify, recognize and cite the features of shapes (Olkun et al., 2005 - Mason, 2002). Children are able to classify logically the properties of figures, such as class inclusion, definitions and logical implications to gain a meaningful aspect. However,

dyscalculic children face difficulties in perceiving the above mentioned concepts and terms (Smith et al., 1989). Initially, dyscalculic students are not capable of acquiring the necessary vocabulary to describe the properties (Smith et al., 1989). Therefore, they show difficulties in perceiving and using terminology having to do with geometrical concepts (Gutierrez et al., 1998) as well as in describing verbally figure properties (Gutierrez et al., 1998). The theoretical abstraction (informal deduction) level is referred to the stage where rational layout of shapes is processed according to their features and the significance of well given definitions is conceived (Gutierrez et al., 1998). Dyscalculic children in this stage of geometrical cognition development are not able to make logical arguments about the attributes themselves or relations among attributes (Olkun et al., 2005).

Additionally, time related difficulties appear, such as identifying and distinguishing time concepts i.e. hours, days, months etc (Cappelletti et al., 2001).

Adolescents and Adults

While referring to older ages, geometrical thinking according to Van Hiele's model is the formal logic (deduction) level (Crowley, 1987). This perception stage is related to the ability to conceive and to use mathematical induction logic, as well as definitions, axioms, theorems and proofs related to the conception of the Euclidean geometry sufficiently. In the case of dyscalculic students, they encounter problems in applying geometrical methods in order to solve problems (Yazdani, 2008). Thus, the role of deduction is not sufficiently conceived (Smith, 1989) and similar difficulties are noticed due to incomplete logical perception (Gutierrez, 1998). Finally, referring to the academic students, Van Hiele's fifth level is referred to the stage where students are sufficient in studying non Euclidean geometry, as well as unrealistic assumptions and definitions. The students analyze various deductive systems with a high degree of rigor, being able to understand the geometric methods and generalize the geometric concepts (Smith, 1989). In case of dyscalculic adults, non Euclidean geometry's assumptions, axioms and theorems, where three-dimensional perception is required, are not efficiently conceived.

Referring to problems of high school students', difficulties in algebra are observed. Under the term "algebra", mathematical concepts such as main math concepts, math visualization and math applications are included (Fradkin, 2010). Under this prospective, difficulties in distinguishing the concepts of integer/real/complex numbers, as well as difficulties in perceiving variables are noticed (Fradkin, 2010). Additionally, troubles are noted in mathematical operations with variables, not only in addition/subtraction/multiplication /division, but also in integer power root and non-integer power log (Fradkin, 2010). Referring to math visualization, problems are noticed in regard to perceiving number concepts in number axle or complex plane (Argand diagram) or concepts related to Venn diagram (Fradkin, 2010). Finally, referring to math applications, difficulties appear in solving algebraic equations i.e. in advanced mathematics, science, engineering, business, finance (Fradkin, 2010).

Referring to problems related to dyscalculia during academic ages, severe difficulties to calculus are observed (Latorre et al., 2007). “Calculus” is the mathematical study of change. It refers to any method or system of calculation guided by the symbolic manipulation of expressions and several math procedures are included (Latorre et al., 2007). Calculus has two major branches, the differential calculus (concerning rates of change and slopes of curves), and the integral calculus (concerning accumulation of quantities and the areas under curves) (Latorre et al., 2007). While dealing with calculus, students are confronted with the concept of limit, involving calculations that are no longer performed by simple arithmetic and algebra, and infinite processes that can only be carried out by indirect arguments (Tall, 1992). In particular, some of the calculus basic topics are hard to be conceived by adults suffering from dyscalculia, such as limits, differential and integral calculus lists and tables, as well as multivariable functions. Especially, the concept of limit creates a number of several cognitive difficulties, including difficulties embodied in the language; terms like “limit”, “tends to”, “approaches”, “as small as we please” have powerful colloquial meanings that conflict with the formal concepts (Tall,1992). Additionally, the idea of “N getting arbitrarily large”, implicitly suggests conceptions of infinite numbers (Tall, 1992). This implies that there is confusion over the passage from finite to infinite, in understanding “what happens at infinity”, a concept hard to be conceived from dyscalculic people (Tall, 1992).

Adults dealing with dyscalculia have mainly troubles with algorithmic thinking (Vlamos, 2010) expressed by limited ability in the algorithmic processing of stimuli (Porpodas, 2003). “Algorithmic thinking” term is referred to a group of skills, concerning the way that an algorithm is conceived, designed and applied. The term “algorithm” describes a finite sequence of actions, which describe how to solve a given problem. Additionally, “algorithmic thinking” is referred as the ability of conceiving, creating, implementing and evaluating an algorithm. Basic algorithmic principles contribute to the development of logical thinking and learning methodologies, which are needed to solve problems (Plerou et al., 2013). Basic algorithmic principles contribute to the development of logical thinking and learning methodologies, which are needed to solve problems. Some of the basic principles needed are: the ability to conceive the given problem and the ability to use techniques to describe the problem briefly (Futschek, 2006). Moreover, the application of techniques which separates a problem into smaller pieces, as well as the design, the description and the application of strategies are needed in order to solve a problem (Futschek, 2006). Difficulties in algorithmic thinking are probably caused due to problems of long-term memory, thus inefficiency while conceiving and solving a complex problem is noticed (Swansona et al., 2001). Specifically, there are problems in serial memory and memorization procedures and therefore difficulty in applying algorithms in which sequential and analytical approach is needed (Periklidakis, 2003). Additionally, difficulties are noticed in the process, the memorization and the organization of information, which appears some weakness in the mental representation of the problem. That occurs due to dysfunction in the long-term memory, concerning mathematical procedures, resulting in difficulties in understanding and solving complex problems

(Munro, 2011). This means incomplete solving capabilities in order to solve an algorithmic problem in which the implementation and the revocation of algorithmic steps are needed. (Futschek, 2006).

Dyscalculic adults also encounter problems in realistic contexts in every day issues, particularly in conceiving the value of money, in using change or in estimating the cost of a product properly (Purohit et al., 2008 - Trott et al., 2006)

Additionally, poor sense of direction is noticed, expressed with troubles in managing space, i.e. in orientation and in giving directions, in turning left or right or in perceiving the points of the horizon (Ardila et al., 2002). Additionally, troubles in perceiving and managing time are noticed, such as estimating the time required in order to accomplish an assigned task and dealing with deadlines (Trott et al., 2006). Furthermore, difficulties with time concepts are noted, such as following a schedule and recalling sequences of past or future events (Butterworth, 2005 - Purohit et al., 2008). Moreover, weaknesses in memorization are noticed. This is the reason they tend to avoid games which require strategic thinking (Porpodas, 2003 - Periklidakis, 2003), This is also the reason they avoid keeping score during games and they lose track of whose turn it is during board games and card games (Purohit et al., 2008).

Diagnostic Screening

To our knowledge, research orientates mainly towards the difficulties in numerical symbolism and calculus, for which diagnostic approach has been materialized. There are quite many cases where several methods or games have been used in order to identify dyscalculia features. In particular, Purohit's et al. (2008) work is related to the detection of math difficulties in early ages. He has proposed a classification of dyscalculia features, focusing to seven pillars. The screening test procedure suggested (CrAFT) works on simple geometrical shape recognition, on the ability of discriminating objects or the size of sets, on set classification and number perception, on counting abilities (association of quantity with numerals), on auditory-visual number and symbol association capability (digit place value perception) and on basic computing skills, such as addition and subtraction (Purohit et al., 2008).

Additionally, the Mathematics Education Centre at Loughborough University has developed a diagnostic test, known as "Dyscalculium", in order to improve the screening process to identify dyscalculia. It is designed for undergraduate students and for employees facing problems in mathematics. Dyscalculium" controls the perception level of basic arithmetic concepts and the relationship between several numbers, as well as the problems of applying mathematics on everyday issues (Trott et al., 2006).

An additional screener is "Dyscalculia Screener' which is also a computer based test that assesses dyscalculia tendency for children from six to over fourteen years old. "Dyscalculia screener" comprises four computer-controlled, item-timed tests. In particular, the abilities checked through the

"Dyscalculia screener" are as follows: simple time reaction, dot enumeration, number comparison and arithmetic achievement, such as addition and multiplication (Butterworth, 2004)

Discussion

Developmental changes and school-related changes are reviewed in basic number, counting, and arithmetic skills from infancy to old age. Research in dyscalculia is still in its emergent stage, lagging behind other learning disabilities. The diagnosis of dyscalculia using innovative information technology is a field studied basically in regards to preschool and school ages as well as in adults. In each case, algorithmic thinking difficulties are not evaluated and there is not yet an overall diagnostic screener dealing with the range of dyscalculia. Future directions include the suggestion of a screener, in order to deal with dyscalculia's' total evaluation, in respect to the proposed feature classification and additionally emphasizing on algorithmic thinking difficulties.

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