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Review Paper

A literature review on math anxiety and learning mathematics: A general overview

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Abstract. Learning mathematics has become a necessity in today's world since success in everyday life requires mathematical knowledge and because mathematics is the basis for science and technology. However, a large number of individuals in the population experience difficulties performing mathematical tasks, which generates feelings of frustration, anxiety and rejection when performing activities that involve mathematical thinking. In this literature review, concepts such as number sense and mathematical thinking, math anxiety, the possible reasons for math anxiety, and options for diagnosis and therapeutic alternatives to address and overcome this problem are analyzed. If these problems are not solved, they could affect the personal development of those affected by them and the society to which they belong.

Keywords: Anxiety, educational psychology, school phobia.

INTRODUCTION

Mathematics, the result of cognitive mental processes, is a key communication language among human beings (Ansari, 2008; Chochon *et al*., 1999; Shum *et al*., 2013; Vargas, 2013). Numbers are used daily for various activities that go beyond academic and scientific activities and that are performed by people without a higher level of training but who have had adequate encouragement and experience to master the use of numbers. However, several myths around mathematical thinking create barriers within individuals and impede individuals' understanding and application of numbers (Phelps-Gregory *et al*., 2020). A large number of individuals in the population experience difficulties performing mathematical tasks, which generates feelings of frustration, anxiety and rejection. Given the importance given to mathematics education, measured through various international tests (PISA, Programme for International Student Assessment; TIMSS, Trends in International Mathematics and Science Study), as an indicator of a country's development, it is important to know the various factors (and anxiety can be one of those factors) that influence the low scores reported in this area, clinical presentation, diagnostic strategies and possible interventions aimed at improving performance in mathematics (Andrews *et al*., 2014; Carnoy *et al*., 2016). For the present review, a bibliographic search was carried out in the PubMed and Academic Google databases. The terms used for the search were anxiety, mathematics, mathematical anxiety, and numerophobia. Articles in the English language available in the full text were selected.

NUMBER SENSE AND MATHEMATICAL THINKING

Since mathematics is part of daily life and is considered a universal language, various authors have argued that all individuals naturally develop an intuitive mathematical sense called number sense (Ansari, 2008; Ashcraft, 1992; Dehaene, 2011). This number sense is not exclusive to human beings, since experiments in different animal species show that fish, birds, and rodents, among other animals, have a sense of numbers.

Number sense

Number sense is defined as a set of skills that allow the individual to work with numbers and develop concepts, such as more, less, greater and fewer; understand the order of the numbers in a list, such 1st, 2nd, 3rd, etc.; and come up with possible simple solutions for numerical tasks (Dehaene, 2011). Fish, birds and mammals have this sense, which possibly allows them to identify quantities of elements that make up a group, such as number of prey, number of grains, number of fruits, etc.; this ability is a key factor in their survival (Davis and Bradford, 1986; Matsuzawa, 1985; Uller *et al*., 2003). In humans, this sense of number develops in early stages, reaches its maximum development at the age of 30 and is the basis of formal logical thinking (Dehaene, 2011; Vargas, 2013). The anatomical and functional substrates of number sense are in the intraparietal sulcus and the sensorimotor areas, respectively.

Number sense requires an adequate development of sensory perception (vision, hearing, and touch) and motor ability that includes gross and fine motor control (movement of the hand, fingers and facial muscles that determine phonation) and a sense of laterality and body position. These skills are key in the development of number concepts (integers, decimals, and fractions) and mathematical operations (addition and subtraction). Poor sensorimotor development and number sense can make it difficult to perform simple mathematical procedures such as counting, addition, subtraction, multiplication, or division (Maldonado Moscoso *et al*., 2020; Barroso *et al*., 2021). In the same way, poor sensorimotor development can affect one's ability to understand measurement systems related to distance, time, speed, acceleration, force, etc. In addition to optimal sensorimotor development, adequate working memory is required for proper number sense (Pelegrina *et al*., 2020).

Working memory

Working memory is a process in which the brain stores information and requires a set of brain structures and neural processes that allow the temporary storage of information. This memory is also called operational memory. The pertinent anatomical substrates are the prefrontal cortex (executive function), the temporal lobe (auditory or verbal memory) and the occipital lobe (visual and spatial memory). These zones are activated when current information is used to process the new information; these zones are also involved in the development of behaviors and complex cognitive processes that include decision making and mathematical calculation (Passolunghi *et al*., 2016). The working memory system requires various components: a central component that fixes attention, a verbal component that maintains vocal information, a visuospatial component, and a multimodal component that associates information from various sources and allows working memory to be linked to long-term memory.

Emotions and math

Although mathematics is one of the most objective, logical and practical academic disciplines, learning mathematics and solving mathematical problems also involves emotional components: motivation, attention, interest, and concentration. These processes are generated in the limbic system and are responsible for the emotional behavior of the individual and determinants of learning (Hannula, 2006; Pina *et al*., 2021).

Attention and concentration are linked to instinctive survival behaviors, but they also participate in cognitive processes, which depend on motivation and interest (Passolunghi *et al*., 2020). The limbic system participates in these emotional processes and encompasses several key anatomical components: the amygdala, the insula lobe, the hippocampus and the hypothalamus, among others (Hannula, 2006; Pina *et al*., 2021). The amygdala is responsible for responses related to attention, fear, anguish, and aversion, and its activation is reflected in adaptive responses to threats from the environment: fear, anger, and aggressiveness. The opposite of these responses are the sensations and responses that reflect security, well-being, pleasure, confidence, and joy. In general, the individual oscillates between emotional states of comfort or well-being and states of discomfort. States of discomfort generate avoidance or rejection behaviors, which are accompanied by involuntary physiological responses produced by the sympathetic system that include tachycardia, tachypnea, sweating, coldness, and tremor; together, these responses characterize states of emotional stress. The limbic system not only mediates adaptive responses to stressful situations but also imprints an emotional tone on the rational or cognitive behavior displayed by an individual in processes such as memory, learning, and mathematical thinking. Performing a mathematical calculation can generate pleasure or joy (Di Martino and Zan, 2011; Hannula, 2006). However, cognitive processes that demand effort can generate reactions of frustration and stress. Persistent stress responses constitute a so-called anxiety disorder (Caviola *et al*., 2017; Passolunghi *et al*., 2016).

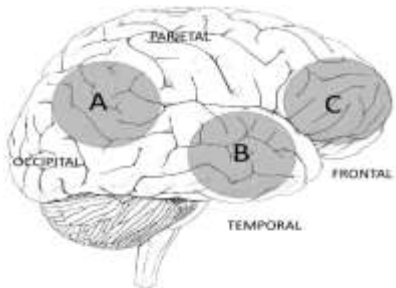

Figure 1. Representation of brain areas related to mathematical thinking. A. Posterior parietal area. B. Temporal area. C. Frontal area. Author´s image.

NUMBER ANXIETY OR MATH ANXIETY

Mathematical anxiety is defined as a condition in which negative emotions (aversion, stress, and fear) and even feelings of pain and suffering predominate individuals' responses when it is necessary for them to solve a mathematical problem (Ashcraft, 2016). This anxiety could have varying degrees of severity ranging from simple anxiety to states of phobia. Numerical phobia or numerophobia is defined as an irrational fear of real or imaginary situations related to numbers (Gough, 1954). Numerous studies have shown that emotional factors can play an important role in math performance with math anxiety playing a particularly important role (Ashcraft, 2016; Buratta *et al*., 2019; DeCaro and Rittle-Johnson, 2012). Questionnaires used to assess mathematical anxiety are negatively correlated with scores on mathematical aptitude tests, whereas they generally do not show a significant correlation with tests of knowledge and verbal aptitude (McLeod, 1992; Miller and Bichsel, 2004; Barroso *et al*., 2021). One possible reason for the negative association between math anxiety and performance is that people who have higher levels of math anxiety avoid activities and situations that involve math; therefore, they have less practice (Ashcraft *et al*., 2007; Barroso *et al*., 2021). Math anxiety could also influence academic performance by overloading working memory (Ashcraft, 2016; Skagerlund *et al*., 2019; Pelegrina *et al*., 2020). Anxiety, in general, has been found in many studies to be associated with working memory deficits (Caviola *et al*., 2017; Eysenck and Calvo, 1992). Therefore, the burden that math anxiety and associated reflections place on working memory could explain the decline in math performance (Engle, 2016; Maloney *et al*., 2013).

Determinants of math anxiety

Mathematical anxiety is a problem that depends on factors internal and external to the individual. On the internal side are the biological factors, such as genes that determine the development of the nervous system and external environment and sociocultural factors.

Internal factors affecting math anxiety

Internal factors that participate in the generation of math anxiety include neurobiological factors, genes and age.

Neurobiological factors related to math anxiety

Mathematical thinking ability is determined by the following mathematical skills: 1) ability to solve simple arithmetic tasks, 2) ability to compare values and symbols, 3) ability to calculate verbally, and 4) ability to solve more complex mathematical tasks (geometry and spatial synthesis). Currently, mathematical skills are considered to be achieved mainly through the functioning of the hippocampus and the parietal and temporal lobes. In some studies (Jolles *et al.*, 2016; Supekar *et al.*, 2015; Uddin *et al.*, 2010), it has been reported that mathematical abilities in children are correlated with the size of the hippocampus and are correlated with the size of the posterior and temporal-parietal lobes in adults (Figure 1). It has also been reported that children with math anxiety show activation of the amygdala and medial prefrontal cortex and decreased interparietal sulcus activity (Qin *et al*., 2014).

Genes and math anxiety

It is suggested that genetic factors are associated with mathematical cognition and anxiety in general. The results of studies in twins show mathematical disabilities in monozygotic twins with a concordance of 70% and dizygotic twins with a concordance of 50% (Hart *et al.*, 2016; Wang *et al.*, 2014). Alterations in groups of genes related to the expression of neuronal proteins, neurotransmitters, working memory and synaptic plasticity have been postulated as determinants of mathematical anxiety. Genes involved in working memory participate in the development of excitation and inhibition systems in the prefrontal cortex, which includes glutamatergic pyramidal neurons and GABAergic inhibitory interneurons. Alterations in the expression of genes involved in synaptic plasticity have also been proposed to be responsible for mathematical anxiety. Included here are molecules such as neurexins, neuregulin, brain-derived neurotrophic factor (BDNF), and DISC protein; these molecules play a key role in neurogenesis and synaptic plasticity. The role of neuronal cell adhesion molecule (NRCAM), which is part of the group of immunoglobulins responsible for cell adhesion, has also been studied (Carey *et al.*, 2016; Malanchini *et al.*, 2017; Moustafa *et al*., 2017).

Age and math anxiety

In general, math anxiety seems to increase with age, as studies suggest that severe math anxiety is rare in children (Barroso *et al.*, 2021; Szczygiel, 2020; Ashcraft, 1992; Carey *et al.*, 2016; Gough, 1954; Hembree, 1990). One reason is that general anxiety increases with age, and the onset of clinical anxiety disorders peaks in early adolescence (Barroso *et al.*, 2021; Szczygiel, 2020; Egger and Angold, 2006; Kilts *et al.*, 2006). In adolescents, arithmetic with larger numbers that place a greater demand on working memory and more abstract numerical aspects in mathematics can increase anxiety.

External factors affecting math anxiety

External factors that participate in the generation of math anxiety include gender, nationality and environment.

Gender and math anxiety

Research indicates that men and women, in countries with equity in education, show little or no difference in math achievement. However, they do indicate that women tend to rate themselves lower and express more anxiety about mathematics (Beilock *et al.*, 2007; Baird and Keene, 2019; Barroso *et al.*, 2021). One possible explanation for greater math anxiety in women than in men is the threat of stereotype (Beilock *et al.*, 2007; Buratta *et al.*, 2019; Dowker *et al.*, 2016; Geary *et al.*, 2019; Merritt, 2020). This explanation for anxiety generally refers to women remembering the stereotype that men are better at math than women, although anxiety can also occur with respect to other stereotypes: racial, economic, religious, nationality, age (Phelps-Gregory *et al.*, 2020; Merritt, 2020). Increased anxiety can come from several sources, including self-confidence, exposure to stereotypes, and the influence and social transmission of anxiety by family, friends, and teachers who are anxious about math (Phelps-Gregory *et al.*, 2020). Some studies suggest that men have better visuospatial memory and women have verbal working memory and that math anxiety affects verbal memory more than visuospatial working memory (DeCaro and Rittle-Johnson, 2012).

Nationality and math anxiety

Some aspects of attitudes towards mathematics appear to be common to many countries and cultures, for example, the tendency of young children to appreciate mathematics. However, there are differences related to performance, interest in mathematics, mathematical ability, and the social importance attributed to mathematics. Children in high-achieving Asian countries, such as Korea and Japan, tend to show great math anxiety, whereas children in high-performing Western European countries, such as Finland, the Netherlands, Liechtenstein and Switzerland, show low math anxiety (Dowker *et al*., 2016; Suárez-Pellicioni *et al.*, 2016; Maloney *et al.*, 2013; Stoet *et al.*, 2016). There is important evidence that both the socioeconomic status of individuals and the economic position of countries have a very large influence on participation in mathematical programs and mathematical achievement (Dowker *et al*., 2016). Several studies have suggested that ethnic minority students express more positive attitudes towards mathematics than white students in both the United States and the United Kingdom (Aldous, 2006; Baird and Keene, 2019; Lubienski, 2002; McGraw *et al.*, 2006; Nguyen *et al.*, 2020).

Environment and math anxiety

According to studies of twins, problems learning mathematics are caused by hereditary factors (40-70%) and environmental factors (10 to 70%). Such a wide range in values is explained by the heterogeneity of the groups studied (Hart *et al.*, 2016). One theory assumes a decreasing role for environmental factors and an increasing role for genetic factors with age; genetic factors with respect to age are as follows: 20% in newborns, up to 40% in children, and approximately 50% in adolescents (Ashcraft, 1992; Ashcraft, 2016; Ashcraft *et al*., 2007). Environmental factors include parental education level, family environment, parenting style and place of residence, technical teaching material, grading system, and teacher education level (Phelps-Gregory *et al.*, 2020). On the other hand, socioeconomic status, including educational level, is very important and is a strong predictor of early mathematical achievement (Dowker *et al.*, 2016). Also, environmental factors, such as nutrition, and environmental stress that includes the presence of toxins, radiation, pollution, among others, can alter the function of internal structures, such as the nervous system (Malanchini *et al.*, 2017).

There are three theories to explain causal directions between learning mathematics and math anxiety, the deficit theory, the debilitating anxiety model and the reciprocal theory, however, no model can explain this relationship because the scientific evidence is inconsistent and exhaustive research is required at various levels (Carey *et al*., 2016).

DIAGNOSIS OF MATH ANXIETY

To study and treat math anxiety, it is necessary to find proper ways to assess and measure it. Currently, two types of tests are used: cognitive and physiological.

Cognitive measures: Questionnaires and scales

Most of the measures for assessing math anxiety involve questionnaires and rating scales and are predominantly used with adolescents and adults. Known scales include the Mathematical Anxiety Research Scale or MARS, the Fennema-Sherman Mathematics Attitude Scale, the Mathematics Attitude and Anxiety Questionnaire, and the Infant Mathematics Attitude Scale (Skagerlund *et al*., 2019; Suárez-Pellicioni *et al*., 2016; Suinn and Winston, 2003). However, there are potential problems with questionnaire measures, which include the veracity of the answers and the self-criticism capacity of the respondents. Some studies have tried to address this problem by using physiological measures of anxiety (Lyons and Beilock, 2012; Suárez-Pellicioni *et al*., 2016).

Physiological measures: Cortisol secretion

Cortisol secretion is a physiological response to stress (Levine *et al*., 2007). Some studies have explored the level of cortisol in response to stress-induced by a statistical test and the relationship between these changes and real test performance (Pletzer *et al*., 2010). Cortisol appears to rise before the test, which would indicate an anticipatory response.

Physiological measures: EEG/ERP (event-related potential) or evoked potentials

Evoked potential (ERP) tests and number processing behavior measures were performed in people with high and low math anxiety, as measured by the MARS questionnaire. The ERP measures showed that those with high math anxiety showed greater activity in the frontal areas associated with numerical processing (Suárez-Pellicioni *et al*., 2016).

Physiological measures: Functional magnetic resonance imaging

There is evidence that stress affects the activation levels of the regions of the prefrontal cortex (Qin *et al*., 2014). These effects are greater in people with high levels of general anxiety (Lyons and Beilock, 2012). Some functional brain imaging studies have indicated that 7- to 9-year-olds already display some of the same neural correlates of math anxiety as adults (Vukovic *et al*., 2013). Children with high math anxiety showed greater activity in the amygdala and areas in the ventromedial prefrontal cortex before the math task than children with low math anxiety (Lyons and Beilock, 2012).

POSSIBLE TREATMENTS FOR MATH ANXIETY

There are no clear criteria for how math anxiety can be treated or, ideally, how to prevent it. Early interventions for children with math difficulties can likely help prevent a vicious cycle in which math difficulties cause anxiety, leading to greater difficulties with math. One strategy is for parents and teachers to show positive attitudes towards math. Additionally, the media can further promote mathematics as interesting and important. Treatments for established math anxiety include:

Mathematical interventions

Cognitive tutorials. Interventions with intensive 8-week math tutoring programs have been evaluated to improve math skills in children aged 7 to 9 years (Sokolowski and Necka, 2016; Supekar *et al*., 2015). Studies show that tutoring reduces math anxiety levels.

Treatments for anxiety

Expressive writing consists of writing negative emotions and concerns before taking a test. Studies show that performance improves, especially in individuals with high anxiety. People with low anxiety did not experience any particular benefit from expressive writing (Park *et al*., 2014).

Interventional treatments

Transcranial electrical stimulation (tES) has become a painless technique in which mild electrical currents are applied to the scalp to regulate cortical neuronal activity. The brain region usually in focus is the dorsolateral prefrontal cortex (dlPFC), which is involved in working memory and affect regulation and is closely involved in stress responses and control (Dowker *et al*., 2016). It is suggested that dlPFC tES could alleviate the stress associated with math anxiety, thereby improving math performance.

CONCLUSION

Mathematical anxiety represents a complex, multifactorial problem caused by the influence of biological and environmental factors. This problem is probably underdiagnosed and has to do with the fact that society, through the school system, generates and perpetuates the problem by establishing myths and stereotypes about mathematics. Generation after generation, the idea of mathematics is presented as a difficult task to tackle; also, there is little practical application of the concepts taught, and the differences in mathematical skills between men and women, among other aspects, are perpetuated. This creates in the individual and collective unconscious an idea of incapacity before learning-related tasks.

Scientific information on math anxiety: causes, signs, symptoms, diagnostic and treatment is not sufficient, inconsistent, and require extensive research. Several questions in this field remain open, and neurobiological studies could help in the search for answers. The use of new techniques will allow, for example, the detection of genes that participate in the development of mathematical disabilities. Identifying the causes and differences in mathematical learning would help, for example, in the design of an individual approach to mathematical learning from an early age to maximize individual capacities. This brief review aimed to show that this is a promising field that requires much research at various levels, including studies to clarify causes and mechanisms, studies to validate diagnostic methods, and studies to support treatments and interventions.

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