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Math anxiety – When the emotional brain paralyzes the thinking brain**

Summary

Math anxiety as a mental and even physiological condition that occurs when confronted with math problems may be associated with a negative attitude towards math and difficulties in performing math activities. It manifests itself as an emotional response to a perceived threat in the form of mathematical stimuli, resulting in a state comparable to that experienced in the other forms of anxiety disorders. Over the last years, math anxiety as an issue in education attracts increased attention from both educators and researchers, emphasizing the importance of emotions in the learning process. This review article presents a literature study that aims to provide an overview of the research of the field, ranging from the initial studies of the concept of math anxiety to the latest research exploring the mechanisms of manifestation of math anxiety in the example of studies of brain activity under mathematical stimuli. Moreover, the review describes the most studied family, school, and social factors that have been claimed to play an important role in the origin of math anxiety, also the tools used to measure the level of math anxiety in different age groups. Finally, it examines the main proposed explanations of the relations between math anxiety and students' math achievement.

Keywords: math anxiety, emotions, working memory, gender stereotype, brain activity, math achievement

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Introduction

Emotions play an important role in the learning process influencing students and teachers (Pekrun et al., 2010); research pay more attention to negative than positive emotions since they are implying a negative impact on academic performance. Experiencing strong, upsetting emotions is often accompanied by a feeling of being unable to think clearly. Therefore, when an individual experiences constant emotional distress, this can lead to the “paralyzation” of learning abilities. Not always is intellectual potential decisive for academic achievement; if the control over emotions is impaired, it can lead to crucial problems for learning. One of the most studied emotions in the context of education is anxiety (Pekrun et al., 2002). Moreover, researchers have begun to describe anxiety associated with a variety of subjects such as chemistry, foreign language, etc. (Horwitz, 2010; Kurbanoglu & Akin, 2012). However, most of the research is devoted to math anxiety, since math is often considered the most strenuous subject in the curriculum that can cause strong emotions (Ashcraft & Ridley, 2005).

Math anxiety is a mental and even physiological condition that occurs when confronted with mathematical stimuli, accompanied by a negative attitude towards math (Dowker, Bennett & Smith, 2012; Kucian et al., 2018) and difficulties in performing math activities (Hembree, 1990; Ma, 1999; Zhang, Zhao, & Kong, 2019). Research claims that worrying during performing math tasks uses up the brain’s energy for processing negative emotions, loading up working memory and leaving little place for thinking about tasks regardless of math abilities (Ashcraft & Kirk, 2001; Ashcraft & Krause, 2007). Some studies suggest that inherently weak math abilities such as abstract thinking, visuospatial processing, and “number sense” may be the cause of the subsequent development of anxiety when interacting with math (Eden, Heine, Jacobs, 2013; Ferguson et al., 2015; Maloney, Ansari, & Fugelsang, 2011). Conceivably, the weakness of these abilities can be a genetically determined factor. Nevertheless, math anxiety as an affective factor can also be contributed to or facilitated by external conditions.

Evidently, research indicates that math anxiety is negatively correlated with academic outcomes (Hembree, 1990; Ma, 1999; Zhang et al., 2019). Moreover, it is not only associated with immediate negative affective reactions influencing math achievement but also has harmful long-term consequences for career choice and professional success (Ashcraft, 2002; Eispino et al., 2017). However, research indicates that math anxiety may differently impact math achievement across individuals varying in their intrinsic math motivation (Wang et al., 2015). For instance, lack of motivation coupled with math anxiety can cause avoidance

behavior that is, avoiding any situations related to mathematics. Conversely, high motivation can help overcome negative emotions associated with math.

The current literature study addresses the concept of math anxiety and discusses the mechanisms of manifestation of math anxiety in the example of studies of brain activity under mathematical stimuli. The article describes the most studied possible causes of the development of math anxiety, also the measurement instruments used for different age groups. Finally, it examines the main proposed explanations of the relations between math anxiety and students' math achievement.

The phenomenon of math anxiety

Research on math anxiety began in the 1950s when Gough (1954) first used the concept of “mathemophobia” to describe conditions similar to a phobia but related exclusively to mathematics (Gough, 1954). The first definition of math anxiety dates back to 1957 – “the presence of a syndrome of emotional reactions to arithmetic and mathematics” (Dreger & Aiken, 1957, p. 344). Currently, several definitions of math anxiety can already be distinguished. For instance, “feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic settings” (Richardson & Suinn, 1972, p. 512), “the panic, helplessness, paralysis and mental disorganization that arises among some people when they are required to solve a mathematical problem” (Tobias, 1978, p. 65), “a general fear of contact with mathematics” (Hembree, 1990, p. 45), or “a feeling of tension, apprehension or fear that interferes with math performance” (Ashcraft, 2002, p. 181).

In general, all these definitions can be divided into two types: (1) some emphasize academic performance (feelings of tension, apprehension, or fear that affect performance); (2) others focus on experienced feelings (a state of distress that a person experiences when interacting with math) (Chinn, 2009). It is also worth paying attention to the fact that some definitions indicate that math anxiety is not a problem that manifests itself only in students during learning math at school or university. Often people in adulthood may experience anxiety about math or numbers in ordinary life, in situations when there is a need to perform any arithmetic calculations, for instance, calculating a change in a store or a utility bill, etc. As the study has shown, adults who had completed graduate school or had a STEM (science, technology, engineering, and mathematics) career had significantly lower levels of math anxiety than did those with less education, or non-STEM careers (Hart & Ganley, 2018). It can be assumed that study participants

suffering from math anxiety, initially, at the beginning of formal schooling, chose to have less interaction with math.

Manifestation mechanisms

Nowadays, the math anxiety phenomenon has attracted the attention of not only researchers but also of teachers and parents, sometimes students themselves show an interest in understanding the causes of excessive anxiety or difficulties in math classes. In this regard, the question often arises: how to distinguish math anxiety from just a dislike toward math or a negative attitude toward math that can arise, for instance, when math seems rather abstract. The main difference can be explained in the specific type of response, since anxiety as an affective factor may cause feeling restless and tense, sweating, having a rapid heartbeat, etc. As for the attitude toward math, it is to a greater extent based on motivation and cognition (Dowker, Sarkar, & Looi, 2016). However, these indicators have a strong correlation (Hembree, 1990; Hoffman, 2010). Similarly, as with math performance, it is difficult to establish a causal relationship: does anxiety lead to a negative attitude to math or vice versa?

How do we understand if it is real anxiety? The measures for assessing math anxiety include questionnaires and rating scales. Studies have shown that these tools have good psychometric properties for determining math anxiety. However, any survey in the form of self-reports may have its limitations, often respondents are not entirely accurate in their self-perception and these tools are not the realtime assessment of situational anxiety responses, this affects the overall assessment of the presence of such a state as anxiety. Studies of the neurobiology of math anxiety allowed us to understand better what exactly happens to a person suffering from math anxiety.

One of the most discussed studies has shown that the expectation of a math problem increased activation in the pain perception network, including the bilateral dorso-posterior insula and mid-cingulate cortex, in adults with high levels of math anxiety (Lyons & Beilock, 2012). The authors of this functional MRI study point out that the reaction to the experience of pain was observed precisely during the anticipation of the upcoming math task, but not during the execution of this task. These results may indicate that the affective component, such as anticipating a dreaded event, is a real manifestation of anxiety, in this case, caused by math.

Another functional MRI study, in which the participants were children aged from 7 to 9 years old, showed that high math anxious individuals showed hyperactivity and abnormal effective connectivity in the right basolateral amygdala (Young, Wu, &

Menon, 2012). The amygdala is a brain area related to processing negative emotions and frightened or fearful inputs (Phelps & LeDoux, 2005). Moreover, it is studied in the context of the pathological processes of anxiety disorders (Rauch, Shin, & Wright, 2003). The authors also found that children with high math anxiety showed reduced responses in cortical and subcortical areas that are associated with mathematical and numerical reasoning. Notably, these results also point to a parallel between math anxiety and other specific types of anxieties and also emphasize that fear about math is a specific form of situational anxiety. A recent study has shown that math anxiety is even linked to changes in brain structure and, as the author points out, it is proof that math anxiety in children is real (Kucian et al., 2018). The structural changes have been detected in the amygdala, which is characterised as a key area in the brain for negative emotional processing such as fear, stress, and anxiety. Directionality between reduced amygdala volume and stress was shown in previous studies (Roosendaal, McEwen, & Chattarji, 2018). However, the study has a limitation – lack of assessment of general anxiety or test anxiety among children, since the reduced amygdala volume could be related to anxiety in general, rather than math anxiety in particular.

Another research that involved children was the interventional study with brain imaging that also demonstrated activation of brain circuits that are related to negative emotional processing in children experiencing math anxiety (Supekar et al., 2015). The main idea of this study was to test how successful eight weeks of cognitive tutoring could be in reducing high levels of math anxiety. The results showed that children with high levels of math anxiety experienced significant reductions in anxiety after tutoring. Besides, math tutoring normalized hyperactivity and functional connectivity of the amygdala in highly anxious children to the level of their less anxious peers.

The results of these studies give grounds to consider math anxiety as a separate psychological feature that manifests itself directly when interacting with math. Moreover, math can cause real anxiety, specifically the state when a person experiences emotional discomfort associated with the expectation of some danger that similarly to anxiety disorders most often occurs without the presence of real threatening conditions.

Possible reasons for math anxiety

The question of the possible reasons for the development of math anxiety remains open. Numerous studies are devoted to identifying the causes of its occurrence. As for math ability, some researchers associate math anxiety with