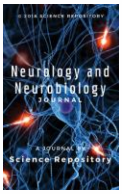

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Research Article

A Neurological View for Mathematical Learning Disabilities

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ABSTRACT

The present article is a literature review of recent researches that have to do with children with mathematical learning disabilities especially dyscalculia and ageometria. Our focus is on researches regarding neurosciences, mainly on the brain structure and the areas where various mathematical processes are performed. In addition, we present researches that show the role of hippocampus during arithmetic problem solving.

General Issues

Learning difficulties in Mathematics have been studied by many researchers over time and some common features have been formulated such as [1, 2]:

i. They have visual-spatial deficits.
ii. They confuse mathematical symbols and as a result, they perform wrong actions.
iii. They confuse some symbols of numbers (e.g. 6 and 9).
iv. They find it difficult to speak numbers with more than one digit (e.g. 47890).

In the present article special learning difficulties in mathematics that are known as "dyscalculia" and "ageometria" will be analyzed. The term "Dyscalculia" is composed of the Greek" dys" which means without or with difficulty and the Latin term "calculia" which means count and is used to describe difficulties that people have with numbers [3]. The term "ageometria" refers to the visual- spatial difficulty that someone has and it relates to difficulties in perceiving space and understand geometry [4]. As Cohen Kadosh et al. (2007) refer the term dyscalculia is sometimes mistakenly used to describe those who perform poorly in mathematics, on the contrary dyscalculia must be used to describe someone that has specific arithmetic disorders [5].

From the earliest studies that tried to identify the causes of learning disabilities, scientists have turned to neurological functions [6, 7]. Many of them believe that the problem is due to the structure of the brain. The brain's cerebral cortex is divided into the cerebral hemispheres, each of which has been divided into frontal, parietal, temporal and occipital lobes. Brian functions are performed in many different regions of the brain that are working in conjunction, but each lobe carries out the major burden of a certain function [8]. The processing of sensory information is performed in the temporal lobe. Certain areas in the temporal lobe are responsible for visual processing; the media temporal lobe contains the hippocampus which is important for memory, learning and emotions. The primary auditory cortex receives auditory information and processes sound information. The occipital lobe is the visual processing center, the primary visual cortex receives visual information from the eyes and this information is transmitted to secondary visual areas, which interpret depth, distance, location and identity of the object being seen. So, we can conclude that any damage to the brain can cause a variety of difficulties in Geometry and Mathematics.

Arsalidou and Taylor (2011), with the help of ALE (Activation Likelihood Estimate) analysis, using quantitative meta analyses of fMRI researches they looked into brain areas that were used for number and calculation tasks. Numerical processing was correlated with areas in the parietal lobes (the inferior and superior parietal lobules). In calculation

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task activity in parietal areas was also observed for arithmetic operations. However, in calculation tasks, more prefrontal areas such as the middle and superior frontal gyri were activated. In particular, during addition problems, visual areas of the brain were involved as well as parietal areas, frontal and prefrontal regions, bilateral thalamus, right insula, right claustrum and bilateral cerebellum. In subtraction tasks occipito-temporal visual regions, parietal areas, frontal and prefrontal regions, bilateral insula and right cerebellum were activated. In the end, during multiplication tasks occipitotemporal visual regions, parietal areas, temporal regions, frontal and prefrontal regions, bilateral cingulate gyrus, bilateral thalamus, left claustrum, right insula, right caudate body and right cerebellum were activated. They described the two neural activity networks that perform mathematical calculations. The lower cerebral area of the two hemispheres (first network) is responsible for semantic knowledge (the individual perceives quantities and sizes) [9].

The second network is responsible for verbal coding of numbers, storing arithmetic sequences, optically recall. To sum up, they found that [10]:

i. Although there was a great overlap between important ALE regions during the numbers and calculation tasks, the areas of the prefrontal cortices were the areas that differed.
ii. Calculation problem solving enabled more areas in the prefrontal areas than numerical task solving. This difference indicates that solving calculation tasks needs more cognitive resources, such as working memory, than numerical tasks.
iii. Actions of addition, subtraction and multiplication activated the prefrontal and parietal areas in the left and right hemispheres: Specifically, during addition, the left hemisphere was mostly energized, in subtraction it was bilateral or mostly left and primarily right hemisphere in multiplication.

In the next figure (Figure 1), we can see the areas of the brain activated by numerical tasks (Figure 1a), calculation tasks (Figure 1b) and the brain regions that are activated when performing arithmetic operations such as addition, subtraction, multiplication (Figure 1c).

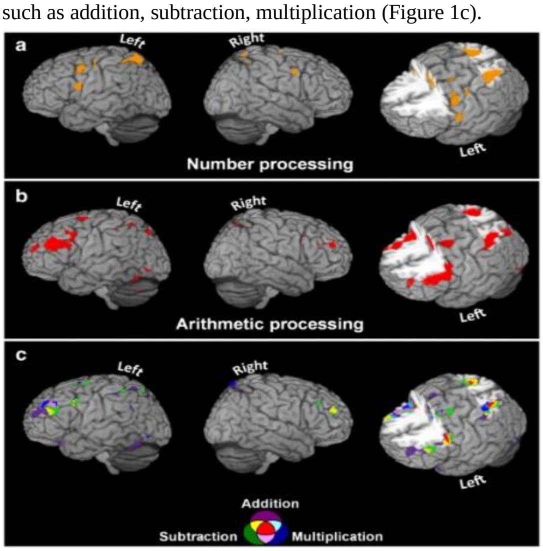

Figure 1: Brain activities by mathematical calculation (Arsalidou & Taylor, 2011).

Figure 1c depicts brain regions that are activated during processes of addition (purple), subtraction (green) and multiplication (blue). Red indicates areas used in all three actions (addition, subtraction, multiplication). Yellow indicates common areas for addition and subtraction; light blue shows areas common for addition and multiplication, while pink depicts brain regions common to subtraction and multiplication [10].

Mathematics and Brain Activities

Children with learning disabilities have difficulties in mathematics. This is expected since solving a problem requires language processing in which children with dyslexia are lagging behind. Besides, these children present problems in phonological processing and short-term memory [11, 12]. Literature reviews of the past two decades assign mathematic learning disabilities to genetic causes or malfunctions of certain areas of the brain responsible for processing numbers, quantities, mathematical symbols and numerals [13-16]. According to studies the cause of dyscalculia is located in the parietal lobe and more specifically in the intraparietal sulcus in the two hemispheres of the brain. Researchers argue that dyscalculia is due to a brain dysfunction involving the left intraparietal sulcus (IPS), while others the right intraparietal sulcus (IPS) [17, 18].

Gruber and colleagues (2001) using functional magnetic resonance imaging (fMRI), mapped human brain activity in six healthy humans performing numerical procedures and other controlled activities that affect visual-constructive, linguistic, attention and mnemonic functions. Specifically, they investigated two regions of the brain during calculation and non-mathematical tasks. They concluded that similar cortical networks consisting of bilateral prefrontal, premotor and parietal regions were activated, while in parietal sub-regions different areas were involved in the above tasks. In particular, the superior parietal lobules were activated during non-arithmetic number or letter substitution tasks whereas calculation activated the left dorsal angular gyrus and the medial parietal cortices. Another finding was that the left inferior frontal areas were activated during complex calculating tasks. These areas are also involved in working and linguistic memory functions [19].

Kadosh and his colleagues (2007) conducted an experiment to identify which of the intraparietal sulcus is responsible for DD. The experiment involved two groups nondyscalculic and dyscalculic. The first group consisted of 5 persons (four males, mean group age = 28.6 years, standard deviation = 4.5), with normal vision and without neurological or psychiatric disorders. The second consisted of 5 persons (three males, mean group age = 27.2 years, standard deviation = 4.8) who were diagnosed with DD via an age-standardized battery of numerical tests based on McCloskey neurocognitive model and did not have other learning difficulties [20]. The procedure was performed with the help of fMRI-guided transcranial magnetic stimulation (TMS) neuronavigation. The results showed that both intraparietal sulci are involved in automatic size processing, but only the right IPS is significantly necessary for automatic magnitude activation. However, they argued that this is not in contradiction with previous studies which argued that the left hemisphere has a possible role in numerical processing, they suggested that these findings are caused by inefficient verbal processing of numbers [17, 21].

Rosenberg Lee et al. (2015) researched brain circuits on children aged 7-9 during addition and subtraction problems in San Francisco. Two groups were selected after a long process, one with typically development (TD) and one with DD. These groups had similar age, IQ, reading ability and working memory and differed in mathematical abilities. The final groups consisted of 16 with DD (10 girls, 6 boys) and 20 TD children (11 girls, 9 boys). Results showed that children with DD found it more difficult to solve subtraction than addition problems. In addition, hyper-activation during addition and subtraction problems was present in multiple frontal, parietal and visual areas. Another finding was that DD children even if they solved addition and subtraction problems correctly or incorrectly showed high levels of hyper-activation in the parietal cortex. Also, children with DD showed hyper-connectivity of the IPS to prefrontal and parietal cortices. In the end they could say that children with DD have difficulties in problem solving because of inappropriate task modulation and hyper-connectivity, rather than under-engagement and under-connectivity. It is worth mentioning that during addition, the bilateral hippocampus showed greater activation than in subtraction in both groups [22].

Hippocampus

Researches in children have shown higher brain activity in the right hippocampus, parahippocampal gyrus (PHG) and other areas of the brain, during arithmetic problem solving. In addition, further analysis has shown interactions between the hyppocampus and other areas of the brain. Also, the right hippocampus showed a large scale of connectivity with bilateral ventrolateral (VLPFC) and dorsolateral prefrontal cortex (DLPFC) [23]. Other researchers support that when children solved arithmetic problems, they used mainly the hippocampus and VLPFC and DLPFC while adults use other areas of the brain [24].

Conclusions

The exploring of research led us to the conclusion that the causes of dyscalculia and ageometria are multifactorial. In this article we focused mainly on the brain structure and the areas where various mathematical processes are performed which has been proven to be dysfunctional in children with specific learning disabilities. Studies vary and are not all consistent, so we can conclude that number processing involves many complex processes and neuron systems located in different brain regions that also change with age [25, 26].

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