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Neuroeducation in the classroom: using multimodal neuroimaging to predict mathematical learning[1]

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Abstract

Mathematical learning difficulties are frequent in the classroom. The lack of early intervention can have serious educational consequences, and these math difficulties can even continue into adulthood. This article briefly reviews BEHAVIORAL and neuroimaging research on both dyscalculia and the mathematical learning process. It concludes that longitudinal studies using multimodal neuroimaging techniques are the key to studying individual variability in children with a low level of mathematical performance and the brain areas that predict improved learning. The results of these studies will make it possible to implement suitable evidence-based interventions in educational settings. Thus, neuroeducation will help to achieve better teaching and learning in the classroom.

Keywords: Mathematical learning, neuroeducation, dyscalculia, cerebral plasticity, magnetic resonance imaging.

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Neuroeducación en el aula: uso de neuroimagen multimodal para predecir el aprendizaje matemático

Abstract

Las dificultades en el aprendizaje de las matemáticas son frecuentes en el aula y pueden continuar hasta la edad adulta si no hay una intervención temprana. Este es un artículo de revisión donde se muestran estudios conductuales y de neuroimagen sobre discalculia y procesos de aprendizaje matemático. Concluye que los estudios longitudinales con técnicas de neuroimagen multimodal son la clave para estudiar la variabilidad individual en niños/as con un bajo nivel de rendimiento matemático y las áreas del cerebro que predicen la mejora del aprendizaje, permitiendo así implementar intervenciones en entornos educativos basadas en la evidencia. Por tanto, la neuroeducación ayudará a lograr una mejor enseñanza-aprendizaje en el aula.

Palabras Clave: aprendizaje matemático, neuroeducación, discalculia, plasticidad neuronal, imágenes de resonancia magnética.

1. INTRODUCTION

Like other animal species, humans have evolved the basic capacity to quantify the elements that make up their environment. This "number sense", or "numerosity", is innate, allowing us to better adapt to our environment and acquire preverbal skills to distinguish quantities of elements (FEIGENSON, DEHAENE, & SPELKE, 2004). Numerosity allows us to perceive the approximate number of objects that make up a group and distinguish between “a lot” and “a little”. Studies conducted with babies have observed that they are capable of distinguishing up to three elements in the first months of life (Izard, Dehaene-Lambertz, & Dehaene, 2008; Piazza, Izard, Pinel, Le Bihan, & Dehaene, 2004). However, this basic number sense does not explain the complexity of mathematical knowledge in adults. In fact, we develop most of our knowledge and skills at school and with language participation.

In today's society, about 20% of the population is estimated to have poor numeracy skills (EACEA/Eurydice., 2011).Therefore, there is a pressing need to help these students to achieve a level of mathematical knowledge that allows them to adequately perform their future work. Recent studies on developmental dyscalculia (DD), or mathematics learning disability (MDL), a term used as a synonym of DD, appear to shed some light on the path to follow. The neurodevelopmental disability, DD, is a structural disorder that affecting mathematical skills that may stem from a genetic or congenital disorder in the brain parts that make up the direct anatomo-physiological substrate of the development of age-appropriate mathematical skills, and it does not simultaneously affect general mental functions (Kosc, 1974). However, the lack of social awareness about DD is reflected in the scant public investment in investigating it, compared to other neurological developmental disorders such as dyslexia or attention deficit hyperactivity disorder (ADHD) (BISHOP, 2010). Lack of mathematical skills is associated with poor academic performance and difficulties in daily life activities that require the ability to calculate, such as counting, locating, measuring, designing, playing and explaining (BISHOP, 1991), or difficulties at work

(RIVERA-BATIZ, 1992). Therefore, research about the neural bases underlying mathematical learning in DD is needed in order to obtain evidence-based intervention methods.

Although the past decade has seen more research on DD, not everyone with mathematical difficulties has DD; even today, the criteria used to define and diagnose DD are still ambiguous (MAZZOCCO & MYERS, 2003). DD and other mathematics difficulties may be associated with other learning disorders (i.e., dyslexia) or with various neuropsychiatric and pediatric disorders (e.g., ADHD, epilepsy), but they are also fostered by environmental factors. In other words, one study might refer to DD, whereas another study might conceptualize the same symptoms as another form of mathematical impairment; thus, heterogeneity is considered a characteristic of DD research(KAUFMANN et al., 2013). The most recent studies have used an approach that differentiates between children with a persistent deficiency in mathematics(DD) and those with moderately low mathematics achievement (LA) (GEARY, HOARD, BYRD-CRAVEN, NUGENT, & NUMTEE, 2007; MAZZOCCO & MYERS, 2003; MURPHY, MAZZOCCO, HANICH, & EARLY, 2007).

Some authors have estimated that approximately7% of children and adolescents will be diagnosedwithDD in at least one area of mathematics before graduating from high school, and an additional 10% of children and adolescents will be identified as LA(BARBARESI, KATUSIC, COLLIGAN, WEAVER, &

JACOBSEN, 2005; LEWIS, HITCH, & WALKER, 1994; SHALEV, MANOR, & GROSS-TSUR, 2005). Lack of early intervention may have serious consequences that can even continue into adulthood (DOUGHERTY, 2003; MURNANE, WILLETT, & LEVY, 1995). For example, students with mathematical difficulties may not acquire the mathematical competences they need to study a university science and technology degree (GEARY, 1994; MA, 1998). In addition, children with mathematical difficulties might avoid anything that has to do with math, which might even lead to anxiety and phobias (ASHCRAFT & MOORE, 2009; ASHCRAFT, 2002; GINSBURG, 1997). However, early intervention is infrequent because learning difficulties are not well defined and might present comorbidity with other developmental disorders and so detecting them in the educational setting is not an easy task.

The calculation capacity of pupils with DD is considerably worse than what would be expected for their chronological age, IQ, and typical schooling for their age. Although some preschool students already show confusion about numerical concepts or are unable to count accurately, mathematical impairment is rarely diagnosed before the end of grade 1 (6-7-year-olds), and its diagnosis is more likely in grade 3 (8-9-year-olds) (MOLINA & GARCÍA, 1984). Even thoughlearning difficulties in mathematics can be associated with a high IQ, children can perform similarly to classmates in the first years of primary education, and it might not be until grade 5, or even later, when this disorder becomes evident(MIRANDA, FORTES, & GIL, 1998).One longitudinal study (GEARY, 2010; GEARY, HOARD, NUGENT, & BAILEY, 2012)shows the mathematical development of children with DD and LA from grades 1 to 5 (6 to 10-year-olds)compared to TA children and a group of children with low intelligence scores (Low-IQ, Mean IQ = 78). The children in the DD group had low-average IQ scores (M = 91), and the LA (M = 101) and TA (M = 103) children had average scores. The results revealed that the mathematical performance of children with DD lags behind that of the Low-IQ children after third grade (8-9-year-olds), whereas the mathematical performance of children with LA and a low IQ overlapped, despite the 23-point difference in mean IQ. In all these grades, the advantage of TA children over the DD and LA groups was greater for math, but no differences were found in their reading skills(GEARY, 2011). GEARY (2011) concluded that the poor mathematics achievement of the DD and LA groups could not be attributed to low intelligence or reading skills.

Research in the neuroscience field has sought patterns or subgroups in learning disorders because complex cognitive skills, e.g., calculation, language, etc., imply an overlapping of the neuronal networks involved in math and reading. This overlapping indicates that more than one particular function may be affected (RAPIN, 1988). SIEGEL and RYAN (1989) suggested that one of the problems in DD is due to a specific difficulty in maintaining numerical information in the working memory. This difficulty, in turn, would explain the poor knowledge of "numerical facts” in this group, e.g.: problems in rapidly recognizing numbers after hearing or viewing them, difficulties memorizing and reproducing the graphology of each number, not being able to remember a temporal series of numbers, and difficulties in counting (determining what number goes before or after a given number), performing mental calculations and remembering several steps involved in problems with several levels or processes.

The aim of this review is to draw attention to the need to take Neuroeducation into the classroom. Educational neuroscience researchers investigate the neural mechanisms of reading, numerical cognition, and attention, as well as their resulting difficulties, including dyslexia, DD and ADHD, and their relation with education (ANSARI & COCH, 2006; GOSWAMI, 2006; MELTZOFF, KUHL, MOVELLAN, & SEJNOWSKI, 2009). Hence, the experimental findings from cognitive neuroscience can be interpreted or generalized to suggest possible implications for learning, cognitive development, and pedagogy in formal educational settings. Thus, neuroscience must be understood as a tool that offers opportunities to develop strategies to be adopted in the area of education. One fundamental link between education and neuroscience involves obtaining knowledge about the brain's capacity to learn and the way changes in the brain are related to learning processes. Understanding how the brain processes mathematical concepts will make it possible for teaching interventions to focus on important conceptual activities. To do so, we must find a good evidence-based instruction method that has been validated by behavioral evaluations, but also by structural and functional changes in the brain after the intervention. Consequently, this article shows the need to close the neuroscience-education circle and carry out longitudinal mathematical learning studies associated with interventions, in order to predict the possibilities that children with DD, LA and typical achievement (TA) will acquire mathematical skills. Its ultimate aim is to indicate how this methodology should develop in the future with the objective of creating a possible classification of these groups based on the biomarkers obtained from multimodal neuroimaging data and behavioral variables. Note that for the purpose of this review, neuroscience is essentially equated with magnetic resonance imaging (MRI), as MRI based approaches currently constitute mainstream research in this field of study according to our understanding.

1.1. Neuroimaging Contributions

ROURKE (1993) observed that high manipulative IQ scores and low verbal IQ scores characterize children with both DD and dyslexia and those with dyslexia alone, whereas high verbal IQ scores and low manipulative IQ scores characterize children with DD alone. Therefore, the comorbidity of dyslexia and DD has a greater effect on verbal mathematical tasks, whereas DD alone has a stronger effect on nonverbal mathematical tasks. Based on these findings, we deduce that the difficulties observed in the first two groups are due to verbal impairments, and that the problem basically consists of a dysfunction in the left brain hemisphere. We can also expect a dysfunction in the right brain hemisphere in children with DD due to impaired visuospatial mathematical skills. To support this theory, anatomical studies have employed MRI using voxel-based morphometry (VBM), and they have found reduced gray matter (GM) volume in the right Intraparietal Sulcus (IPS) (ROTZERet al., 2008). Rykhlevskaia, Uddin, Kondos, and Menon (2009) found the same reduced GM, but they also encountered differences in the white matter (WM) volume in the right temporo-parietal cortex, along with structural deficits in the hippocampus and the entorhinal cortex. These authors also conducted a structural connectivity study using diffusion tensor imaging (DTI). This study showed reduced fractional anisotropy (FA) in the region with reduced WM volume, which indicated microstructural deterioration in the right hemisphere. The FA in this region also correlated with numerical operations, but not with verbal mathematical reasoning or reading words. Tractography with DTI also suggested that the influence of the WM fibers that connect the right fusiform gyrus to the temporo-parietal cortex acts as a specific source of vulnerability in DD. All of this information led to considering right parietal dysfunction to be the main cause of DD. However, other studies have also indicate da decrease in grey matter density in the left IPS in premature children with DD(ISAACS, EDMONDS, LUCAS, & GADIAN, 2001).

Functional MRI (fMRI) has been essential in acquiring knowledge about the neural substrate of numerosity, as it allows us to non-invasively view which brain areas are active while performing a task inside the scanner. Research using fMRI has noted bilateral IPS, left angular gyrus (AG),and bilateral posterior superior parietal lobe (PSPL) activation during number tasks performed by healthy participants (DEHAENE, PIAZZA, PINEL, & COHEN, 2003).

Dehaene and colleagues postulated that these three parietal circuits play a significant role in mathematical skills. The bilateral IPS has been associated with a core quantity system, and it is activated during number detection on a number comparison task (greater right than left IPS), and when performing mental arithmetic. A region in the left AG has been associated with the verbal processing of numbers and storing arithmetic facts (e.g. arithmetic skills such as multiplication tables) and a bilateral PSPL system of spatial andnon-spatial attention, which may contribute to the visual processing of numbers.

The first study in DD children compared to TA children showed less activation in the left IPS, the right inferior frontal gyrus and the middle frontal gyrus during an approximate addition task. Additionally, this study found no differences between the arithmetic networks of TA and DD, as both activated the same frontoparietal network (KUCIAN et al., 2006). Price and colleagues (2007) demonstrated that children with DD do not modulate the right IPS in response to magnitude processing demands during a non-symbolic numerosity task. These neuroimaging studies suggest that the IPS shows atypical recruitment in DD. However, more recent studies of DD have posited that the disorder must involve a distributed network of brain regions,such as the bilateral posterior parietal, prefrontal, andventral occipito-temporal areas. These areas are known to serve multiple cognitive functions necessary for successful numerical problem solving (BUTTERWORTH, VARMA, & LAURILLARD, 2011; FIAS, MENON, & SZUCS, 2013).

However, very little is known about what actually happens in the brain of a child with or without mathematical difficulties during the mathematical learning process, that is, what brain area(s)is(are) associated with and/or favor(s) the development of numerical learning, and what the best intervention method would be. Previous studies on learning in adults (DELAZER et al., 2005; ISCHEBECK et al., 2006),using a series of multiplication problems,have demonstrated that the bilateral frontoparietal network is activated while doing untrained multiplications inside a scanner (including the IPS, and inferior frontal gyrus associated with executive function and verbal working memory). These studieshave associated this network with a simple arithmetic problem-solving strategy. However, when subjects performed previously trained multiplications, the brain activation changes from a frontoparietal network to left AG. These studies discovered that through direct instructions (the transmission or traditional model), a change in multiplication problem-solving processes takes place, suggesting a shift from the strategy-based process to the memory-based process, specifically retrieval of verbally coded arithmetic facts, which creates automatisms. ISCHEBECK et al. (2006) also examined the effects of practicing subtractions, and they found that doing both trained and untrained problems activated the frontoparietal network, which is associated with strategy-based processes. Their study also showed that repetitively practicing subtraction problems did not make this arithmetic operation automatic, but it increased efficiency during the strategic process. Basically, these studiessuggest that learning-related neural changes depend on the mathematical concept and on choosing the most appropriate classroom interventions.

Brain activity patterns in 4-year-olds and adults have shown overlapping areas in the bilateral parietal lobe when these areas respond to a change in numerosity on non-symbolic numerical tasks(CANTLON, BRANNON, CARTER, & PELPHREY, 2006). This study showed that one noteworthy difference between the number-related brain activity of children and adults is that adults showed robust bilateral activation in the IPS, whereas4-year-old children with limited experience using symbolic numbers, on average, showed number-related IPS activation predominantly in the right hemisphere. CANTLON and colleagues (2006)provide evidence that there is an important neurobiological link between symbolic and non-symbolic numerical cognition in adults. Most importantly, they further demonstrated that the IPS is recruited for non-symbolic numerical processing early in development, before formal schooling has begun. Furthermore, the RIVERA and colleagues (2005) study also demonstrated that the inferior parietal region, including the left IPS, shows increasing brain activity during symbolic mathematical operations between 8 and 19 years old, whereas the right IPS is equally active at all ages.

Nevertheless, there is a path followed in the organization of more complex arithmetic skills during development. With age, the organization of the changes in routine numerical activity goes from frontal areas (associated with executive function and verbal working memory) and medial temporal areas (associated with declarative memory, that is, consciously remembering facts and events, including the hippocampal region) to parietal areas (Three parietal circuits

(DEHAENE et al., 2003)), and ventral occipito-temporal areas (associated with processing symbolic forms) (Ansari, 2008) (see Figure 1). The link between the parietal and ventral occipito-temporal areas is required for mapping number symbols to numerosity representations. This path indicates the possibility of neuronal specialization for arithmetic processing, which may stem, at least in part, from a developmental interaction between the brain and experience (ANSARI& KARMILOFF-SMITH, 2002; JOHNSON, 2001). Additionally, it is clear that working memory (particularly the central executive), processing speed, and other cognitive skills play a key role in learning mathematics, and that this role can vary with development. Therefore, one approach to DD posits that the typical school environment may not always provide the right kind of experiences to enable the dyscalculic brain to develop normally to learn arithmetic (BUTTERWORTH et al., 2011).

Some theories about DD should address the differences between DD and LA and the individual differences in arithmetic in the general population (KAUFMANN et al., 2013), in order to identify the nature of the relations between the cognitive domain and numerical processing. It is necessary to study these individual differences in groups of children with DD, LA and TA, given the range and heterogeneity of the clinical manifestations of DD. Despite the usefulness of both cross-sectional and longitudinal studies for describing concurrent cognitive profiles and correlates of DD within or across age groups, only longitudinal studies can reveal the trajectories of the acquisition of mathematics and related skills without potential confounds and cohort effects (MAZZOCCO & RÄSÄNEN, 2013). The longitudinal study by SUPEKAR et al. (2013), who used VBM and Resting-State MRI (RS-MRI, fMRI with no task), focused on predicting mathematical improvement through computer program tutoring. This study showed a significant increase in both speed and arithmetic problem-solving in children with TA (with individual differences found among sample members). It also demonstrated that none of the behavioral variables, including IQ, working memory, or mathematical skills, predicted the improvement in arithmetic problem-solving performance. These authors also found that the pre-tutoring GM volume in the hippocampus (associated with declarative memory) was able to predict improvements in individual performance. Moreover, RS-fMRI has shown that the greater functional connectivity between the hippocampus and the dorsolateral and ventrolateral prefrontal cortices and basal ganglia also predicted this improved performance. These areas are associated with cognitive control, and they facilitate coding and memory recovery. Another longitudinal study that has employed prediction to evaluate the neural bases associated with a mathematical learning process is the recent study by EVANS et al. (2015) using multimodal imaging. They demonstrated the feasibility of forecasting long-term gains in children's numerical ability based on structural and intrinsic functional brain measures acquired at age 8. They found that higher GM volume in the ventral occipito-temporal (including left fusiform gyrus), the posterior parietal cortex (including left IPS), and prefrontal cortex (including dorsolateral and ventrolateral prefrontal cortex) specifically predicted long-term gains in numerical skills. Intrinsic connectivity analysis provided strong evidence that the ventral occipito-temporal, posterior parietal cortex, and prefrontal cortex form a network that works in concert to promote successful numerical-skill acquisition. Despite the known importance of the IPS in quantity processing, its whole-brain connectivity pattern identified the least number of voxels that predicted growth in numerical skills. By contrast, intrinsic functional circuits associated with the left fusiform gyrus, within the ventral occipito-temporal, had the most extensively connected network that was predictive of gains in numerical ability. Left fusiform gyrus links with posterior parietal areas are particularly noteworthy, as numerical problem solving requires dynamic interactions among ventral occipito-temporal areas that support number-form recognition and posterior parietal areas that support semantic aspects of quantity processing and manipulation. Crucially, behavioral measures of mathematics, IQ, working memory, and reading did not predict children's gains in numerical abilities. This study identifies brain regions and functional circuits that scaffold the development of numerical skills, and it highlights potential biomarkers for identifying children at risk for learning difficulties. Both studies were carried out with a TA sample, and both considered individual differences.

1.2. Intervention

In the past two decades, several mathematics tutoring programs have been designed to improve basic arithmetic fluency. This fluency provides a basis on which to construct more complex skills (FUCHS

ET AL., 2006; KAUFMANN & DANNENBERG, 2002; MCCLOSKEY, HARLEY, & SOKOL, 1991). Individualized tutoring has helped to develop and evaluate tutoring programs in classrooms (Beirne-Smith, 1991; Butterworth, 2011; Fuchs et al., 2008; Johnson & Bailey, 1974; Rittle-Johnson & Koedinger, 2009).

Some behavioral research has used tutoring programs. By performing prevention activities in early childhood education, KINDERGARTEN (3-year-olds) (GRIFFIN, CASE, & SIEGLER, 1994) and Preschool (3-5-year-olds) (Clements & Sarama, 2007), or in Primary Education (6-11-year-olds) (FUCHS, FUCHS, YAZDIAN, & POWELL, 2002), these studies have shown that it is possible to substantially improve mathematical learning. For instance, a study by Fuchs et al. (2005) identified 169 students from 41 first-grade classes (6 to 7-year-olds) who had begun to show mathematical impairment. The study randomly assigned these children to a control group or to a group that received tutoring 3 times/week for 16 weeks. The results revealed that development in the first grade was much better on calculations, concepts and mathematical problem-solving in the tutored group than in the control group. The number of students with mathematical difficulties declined substantially by the end of the academic year, and this reduction continued one year after the tutoring had ended. The children who were evaluated in the tutoring programs showed individual differences in mathematical learning (FUCHS, FUCHS, & COMPTON, 2012). We know very little about the behavioral and cerebral mechanisms that lead to these individual differences. Studying individual differences in a learning process can help to understand variability in responding to a given instruction or in solving a mathematical problem, thus increasing the possibility of identifying which children require different approaches or interventions in mathematical learning. Therefore, identifying the behavioral and cerebral mechanisms related to mathematical learning could greatly increase our understanding of general cognitive development (POSNER & ROTHBART, 2007) and help to adapt instruction to students' needs and their 'zone of proximal development' (ZPD; VYGOTSKY & COLE, 1978).

Scientific research still has to show whether calculation skills can improve through appropriate early intervention in children with DD. The longitudinal study by Kucian et al. (2011)with a sample of DD children used fMRI to compare DD with TA before and after mental number line training. The brain activation was measured using an fMRI number line task. Both groups determined whether three numbers were ascending or descending in order, compared to a control condition, where they determined whether the digit "2" was present. Before training, the DD group showed less bilateral parietal activation, which reflects neuronal dysfunction in pivotal regions for number processing, but more frontal activation (related to working memory and attentional control to solve the numerical task). The effects of the training revealed reduced activation in the frontal areas in both groups, but more so in the DD group. This finding suggests that they performed the task more automatically after training, thus being more dependent on parietal areas, and they adopted fewer strategies related to frontal areas. This effect indicates that the children with DD exhibited a more typical behavioral and neural activity pattern after training, coinciding with studies on learning in dyslexia, but they did not reach the post-training level of the TA group. A recent study (IUCULANO et al., 2015) found that 8 weeks of one-to-one math tutoring focused on strengthening conceptual and procedural knowledge can effectively improve arithmetic problem-solving skills in primary-school children with DD (ages 7,5 to 9,6 years). This study demonstrated that one-to-one math tutoring elicits extensive functional brain changes in the DD group, normalizing their brain activity to the level of the TA group. Before tutoring, the differences in brain activation between the DD and TA groups were in the prefrontal, parietal, and ventral occipito-temporal cortex, but these differences were absent after tutoring. Neuroplasticity manifests as normalization of aberrant functional responses in these distributed networks that support successful numerical problem solving. Notably, machine-learning algorithms revealed that brain activity patterns in the DD group are significantly discriminable from those of the TA group before tutoring, but not after it, suggesting that behavioral gains are not due to compensatory mechanisms. Finally, children with DD who displayed greater tutoring-induced functional brain plasticity also exhibited larger performance gains. Unfortunately, no further scientific evidence is available to confirm whether the pattern found in these two studies is maintained.

Therefore, these studies seem to indicate that a possible intervention in children with DD would involve training to stimulate the learning of number sense with didactic material or suitable software. Special needs teachers employ manipulative games or materials, such as Cuisenaire rods, multibase blocks, abacus or card games, among others, to teach number sense to students with DD. This manipulative material is used to introduce abstract mathematical concepts and develop mathematical comprehension (MONTESSORI, 1966) prior to introducing formal algorithms. These materials facilitate learning through the discovery and construction of a solution, which, in turn, allows students to compare their solutions with the correct one and, if necessary, adapt their solution. This has been shown to be an efficient mechanism for learning with comprehension (PAPERT, 1980; PIAGET, 1952). All of these activities require teachers' individual attention to students or working in small student groups for a limited time during school hours. Brian Butterworth (2011) recommends a promising new training approach for these children that involves two software packages based on neuroscience findings in DD: *Number Race* and *Graphogame-Math.* These are games that adapt to and address basic numerosity processing, and they have been shown to be effective in previous studies (RÄSÄNEN, SALMINEN, WILSON, AUNIO, & DEHAENE, 2009). These two software packages are based on an approach that emulates the task performed with manipulative materials, which are so important in constructivist learning. They allow the children to build a response, provide them with feedback, and offer methods to compare the student's solution with the correct one.

In a sample of nine 7 to 9-year-olds with DD, the study by WILSON, REVKIN, COHEN, COHEN, AND DEHAENE (2006) showed that behavioral training with *The Number Race* provided promising behavioral results. These authors suggested that training with this software increased the children's number sense after a short study period (5 weeks). Nevertheless, no longitudinal studies are available on the changes in cognitive functioning associated with this learning.

All this evidence seems to indicate that one of the key points in mathematical neuroeducation research is to study cerebral plasticity in association with the mathematical learning process, combining educational software designed for learning basic mathematical skills with longitudinal observation and multimodal neuroimaging techniques.

1.3. Learning-Related Cerebral Plasticity

The cerebral plasticity concept has been vastly modified in recent years. Far from the former conception of cerebral plasticity as a process that occurs only during the so-called "critical periods" of brain development, we now know that the brain is constantly being modeled throughout life (DRAGANSKI & MAY, 2008; DRIEMEYER, BOYKE, GASER, BÜCHEL, & MAY, 2008; MAY, 2011; PASCUAL-LEONE, AMEDI, FREGNI, & MERABET, 2005). Cerebral plasticity refers to the structural or functional changes that take place in the brain as an adaptation to changes in the environment, physiological alterations, or experience. Cerebral plasticity is, therefore, a fundamental phenomenon that occurs not only in brain development, but also during adaptation to a given setting, e.g., through learning effects (DRAGANSKI ET AL., 2004; MAGUIRE ET AL., 2000; SCHOLZ, KLEIN, BEHRENS, & JOHANSEN-BERG, 2009), or if cerebral lesions are produced (Ballantyne, Spilkin, Hesselink, & Trauner, 2008; Yogarajah et al., 2010).

Studying learning-related cerebral plasticity is fundamental to understanding the factors that determine the brain’s flexibility in adapting(MAY, 2011; PASCUAL-LEONE et al., 2005), and to find out whether the brain is capable of varying in structure and function with certain types of learning. The evidence obtained to date on structural and/or functional reorganization as a result of learning stems from animal studies that have been conducted with primates and non primates. Currently, neuroimaging techniques allow us to study these processes in the human brain noninvasively and *in vivo*. Thus, knowledge about cerebral plasticity can help us to design applications capable of compensating for deficits associated with various pathologies and optimize learning in a given population (MAY, 2011; PASCUAL-LEONE et al., 2005), for example, by studying mathematical learning in primary school children through an educational intervention program.

The literature offers studies on mathematical processing that have employed cross-sectional approaches. However, there are doubts aboutwhether such designs are suitable for studying a possible structural or functional brain modification with specific types of learning. According to this paradigm, elucidating whether structural and/or functional brain differences are due to learning or to other unrelated genetically or environmentally determined factors is a difficult task (DRAGANSKI & MAY, 2008). Some correlations have been made with exposure times or level of proficiency in an attempt to solve this question, but this must be done by investigating the characteristics of cerebral plasticity through longitudinal studies (DRAGANSKI & MAY, 2008).

Recent cerebral plasticity research using longitudinal studies has analyzed changes in functional connectivity and in cerebral networks with RS-fMRI. This new scanning methodology offers interesting results about how the brain works when active, but not when it performs a task. This is a new form of scanning based on studying the information that the brain provides when it does nothing, which is a lot of information. The longitudinal study in adults by VENTURA-CAMPOS et al. (2013)showed that individual variability in functional connectivity conditions people's learning capacity; in turn, the learning process produces a modification in the cerebral networks associated with trained areas. This study concluded that it is possible to predict the human brain's learning capacity by studying the brain's initial spontaneous functional connectivity, that is, the connection or synchronization of activity between two or more brain areas, through RS-fMRI. Thus, studying cerebral plasticity with RS-fMRI gives us the opportunity to know the state of the brain before starting a task, and it can provide information about how much will be learned; in other words, it provides us with a predictive element about how we will respond to a learning task. Ventura-Campos et al. (2013) went a step further than the methodology ofLEWIS, BALDASSARRE, COMMITTERI, ROMANI, and CORBETTA (2009) and BALDASSARRE et al. (2012), by studying learning through a combination of task-related fMRI and RS-fMRI. This was the first learning prediction study based on trained brain areas. Hence, these longitudinal studies on changes in cerebral connectivity are probably one of the most relevant methodological sources to study cerebral plasticity due to learning processes.

We believe that studying the neural bases that underlie individual differences in children with DD and LA is of great interest in cerebral plasticity studies. Cerebral plasticity processes are not always associated with behavioral benefits. Hence, completely comprehending the functional changes that occur after certain training includes understanding which processes optimize performance. Consequently, knowledge about these plasticity processes in association with teaching-learning interventions opens up a new research area between the fields of education and neuroscience, where neuroimaging methods seems to play an essential role.

2. CONCLUSION

The children with mathematical learning difficulties have a problem that limits their school lives. The complexity of diagnosing DD and its subtypes means that the samples used in some studies are not homogeneous. Thus, various classifications exist, making it difficult to compare and replicate studies. These studies reveal a common phenomenon in children with DD: a core deficit in number sense. We found other studies that have also reported a deficit in different cognitive domains, including working memory, attention, memory, and processing speed, among others. Furthermore, the question of whether the origin of this disorder lies in the absence of a basic numerical concept, or whether it is a problem that affects several cognitive domains, is still a matter of debate and requires further research. Additionally, much of the research to date has focused on arithmetic operations, and little is known about algebra, geometry, probability, mathematical problem-solving, etc. We also need to understand the neural bases of abstract mathematical thinking and apply this knowledge to mathematics education in the future.

We based this review on the mathematical learning disorders line of research, and we propose new research lines accompanied by longitudinal studies that use behavioral variables along with MRI multimodal variables. We can obtain these variables by combining different neuroimaging methodologies with MRI, e.g. task-related fMRI, RS-fMRI, VBM and DTI, which will be essential for showing the cerebral plasticity processes associated with the mathematical learning process after intervention. These brain plasticity processes will allow us to understand individual variability in children with DD, LA and TA by helping to perform evidence-based educational interventions with them. Future research with longitudinal studies should provide biological markers, which, along with behavioral data, will be able to predict mathematical learning and better diagnose DD and its subtypes.

To date, knowledge from Neuroscience has not been presented to teachers so that they can apply it to children with or without learning difficulties. A better understanding of the neuronal bases involved in the mathematical teaching-learning process can play a decisive role in improving mathematical education. Neuroeducation is the science that will show teachers the way to teach and, therefore, help to reduce the academic failure of students with mathematical learning difficulties. This new approach, which may promote a reform in education, is currently the focal point of contemporary teaching circles where the Neuroeducator as a new professional figure is reinforced (MORA, 2013).

3. REFERENCES

ANSARI, D. 2008. "Effects of development and enculturation on number representation in the brain." **Nature Reviews. Neuroscience**, Vol. 9,No.:4, 278–291.

ANSARI, D., & COCH, D. 2006. "Bridges over troubled waters: education and cognitive neuroscience." **Trends in Cognitive Sciences**, Vol. 10,No.:4, 146–151.

ANSARI, D., & KARMILOFF-SMITH, A. 2002. "Atypical trajectories of number development: a neuroconstructivist perspective." **Trends Cogn Sci**, Vol. 6,No.:12, 511–516.

ASHCRAFT, M. H. 2002. "Math anxiety: Personal, educational, and cognitive consequences." **Current Directions in Psychological Science**, Vol. 11,No.:5, 181–185.

ASHCRAFT, M. H., & MOORE, A. M. 2009. "Mathematics Anxiety and the Affective Drop in Performance." **Journal of**

Psychoeducational Assessment.

BALDASSARRE, A., LEWIS, C. M., COMMITTERI, G., SNYDER, A. Z., ROMANI, G. L., & CORBETTA, M. 2012. “Individual variability in functional connectivity predicts performance of a perceptual task.” **Proc Natl Acad Sci U S A**, Vol. 109,No.:9, 3516–3521.

BALLANTYNE, A. O., SPILKIN, A. M., HESSELINK, J., & TRAUNER, D. A. 2008. “Plasticity in the developing brain: intellectual, language and academic functions in children with ischaemic perinatal stroke.” **Brain**, Vol. 131,No.:Pt 11, 2975–2985.

BARBARESI, W. J., KATUSIC, S. K., COLLIGAN, R. C., WEAVER, A. L., & JACOBSEN, S. J. 2005. “Math learning disorder: incidence in a population-based birth cohort, 1976-82, Rochester, Minn.” **Ambulatory Pediatrics : The Official Journal of the Ambulatory Pediatric Association**, Vol. 5,No.:5, 281–289.

BEIRNE-SMITH, M. 1991. “Peer tutoring in arithmetic for children with learning disabilities.” **Except Child**, Vol. 57,No.:4, 330–337.

BISHOP, A. 1991. **Mathematical Enculturation: A Cultural Perspective on Mathematics Education**. Netherlands: Kluwer Academis Publishers.

BISHOP, D. V. M. 2010. “Which neurodevelopmental disorders get researched and why?” **PLoS ONE**, Vol. 5,No.:11, e15112.

BUTTERWORTH, B. 2011. “Foundational Numerical Capacities and the Origins of Dyscalculia.” In *Space, Time and Number in the Brain* (Vol. 14, pp. 249–265).

BUTTERWORTH, B., VARMA, S., & LAURILLARD, D. 2011. “Dyscalculia: from brain to education.” **Science (New York, N.Y.)**, Vol. 332,No.:6033, 1049–1053.

CANTLON, J. F., BRANNON, E. M., CARTER, E. J., & PELPHREY, K. A. 2006. “Functional imaging of numerical processing in adults and 4-y-old children.” **PLoS Biol**, Vol. 4,No.:5, e125.

CLEMENTS, D. H., & SARAMA, J. 2007. “Effects of a Preschool Mathematics Curriculum: Summative Research on the ‘Building Blocks’ Project.” **Journal for Research in Mathematics Education**, Vol. 38,No.:2, 136–163.

DEHAENE, S., PIAZZA, M., PINEL, P., & COHEN, L. 2003. "Three parietal circuits for number processing." **Cognitive Neuropsychology**, Vol. 20,No.:3, 487–506.

DELAZER, M., ISCHEBECK, A., DOMAHS, F., ZAMARIAN, L., KOPPELSTAETTER, F., SIEDENTOPF, C. M., … FELBER, S. 2005. "Learning by strategies and learning by drill - Evidence from an fMRI study." **NeuroImage**, Vol. 25,No.:3, 838–849.

DOUGHERTY, C. 2003. "Numeracy, literacy and earnings: Evidence from the National Longitudinal Survey of Youth." **Economics of Education Review**, Vol. 22,No.:5, 511–521.

DRAGANSKI, B., GASER, C., BUSCH, V., SCHUIERER, G., BOGDAHN, U., & MAY, A. 2004. "Neuroplasticity: changes in grey matter induced by training." **Nature**, Vol. 427,No.:6972, 311–312.

DRAGANSKI, B., & MAY, A. 2008. "Training-induced structural changes in the adult human brain." **Behav Brain Res**, Vol. 192,No.:1, 137–142.

DRIEMEYER, J., BOYKE, J., GASER, C., BÜCHEL, C., & MAY, A. 2008. "Changes in Gray Matter Induced by Learning—Revisited." **PLoS ONE**, Vol. 3,No.:7, e2669.

EACEA/Eurydice. Mathematics Education in Europe: Common Challenges and National Policies; 2011

EVANS, T. M., KOCHALKA, J., NGOON, T. J., WU, S. S., QIN, X. S., BATTISTA, X. C., & MENON, V. 2015. "Brain Structural Integrity and Intrinsic Functional Connectivity Forecast 6 Year Longitudinal Growth in Children ' s Numerical Abilities."**Journal of Neuroscience**, Vol. 35,No.:33, 11743–11750.

FEIGENSON, L., DEHAENE, S., & SPELKE, E. 2004. "Core systems of number." **Trends Cogn Sci**, Vol. 8,No.:7, 307–314.

FIAS, W., MENON, V., & SZUCS, D. 2013. "Multiple components of developmental dyscalculia." **Trends in Neuroscience and Education**, Vol. 2,No.:2, 43–47.

FUCHS, L., COMPTON, D., FUCHS, D., PAULSEN, K., BRYANT, J., & HAMLETT, C. 2005. "Prevention, identification and cognitive determinants of math difficulty." **Journal of Educational**

Psychology., Vol. 97, 493–513.

FUCHS, L. S., FUCHS, D., & COMPTON, D. L. 2012. “The early prevention of mathematics difficulty: its power and limitations.” **J Learn Disabil**, Vol. 45,No.:3, 257–269.

FUCHS, L. S., FUCHS, D., HAMLET, C. L., POWELL, S. R., CAPIZZI, A. M., & SEETHALER, P. M. 2006. “The effects of computer-assisted instruction on number combination skill in at-risk first graders.” **Journal of Learning Disabilities**, Vol. 39,No.:5, 467–475.

FUCHS, L. S., FUCHS, D., YAZDIAN, L., & POWELL, S. R. 2002. “Enhancing first-grade children’s mathematical development with peer-assisted learning strategies.” **School Psychology Review.**, Vol. 31, 569–584.

FUCHS, L. S., POWELL, S. R., HAMLETT, C. L., FUCHS, D., CIRINO, P. T., & FLETCHER, J. M. 2008. “Remediating Computational Deficits at Third Grade: A Randomized Field Trial.” **J Res Educ Eff**, Vol. 1,No.:1, 2–32.

GEARY, D. C. 1994. **Children’s Mathematical Development: Research and Practical Applications**. Washington, DC: Association American Psychological.

GEARY, D. C. 2010. “Missouri longitudinal study of mathematical development and disability.” **British Journal of Educational Psychology**, Vol. 2,No.:7, 31–49.

GEARY, D. C. 2011. “Consequences, characteristics, and causes of mathematical learning disabilities and persistent low achievement in mathematics.” **Journal of Developmental and Behavioral Pediatrics : JDBP**, Vol. 32,No.:3, 250–263.

GEARY, D. C., HOARD, M. K., BYRD-CRAVEN, J., NUGENT, L., & NUMTEE, C. 2007. “Cognitive mechanisms underlying achievement deficits in children with mathematical learning disability.” **Child Development**, Vol. 78,No.:4, 1343–1359.

GEARY, D. C., HOARD, M. K., NUGENT, L., & BAILEY, D. H. 2012. “Mathematical cognition deficits in children with learning disabilities and persistent low achievement: A five-year prospective study." **Journal of Educational Psycholog**y. Vol. 104, No.:1, 206–223.

GINSBURG, H. P. 1997. "Mathematics Learning Disabilities: A View From Developmental Psychology." **Journal of Learning Disabilities**. Vol. 30, No.:1, 20-33

GOSWAMI, U. 2006. "Neuroscience and education: from research to practice?" **Nature Reviews. Neuroscience**, Vol. 7,No.:5, 406–411.

GRIFFIN, S. A., CASE, R., & SIEGLER, R. S. 1994. "Rightstart: Providing the central conceptual prerequisite for first formal learning of arthmetic to students at risk for school failure." **McGilly, K.Editor. Classroom Lesson:Integrating Cognitive Theory and Classroom Practice. Cambridge, MA: MIT Press.**, 25–50.

ISAACS, E. B., EDMONDS, C. J., LUCAS, A., & GADIAN, D. G. 2001. "Calculation difficulties in children of very low birthweight: a neural correlate." **Brain : A Journal of Neurology**, Vol. 124,No.:Pt 9, 1701–1707.

ISCHEBECK, A., ZAMARIAN, L., SIEDENTOPF, C., KOPPELSTÄTTER, F., BENKE, T., FELBER, S., & DELAZER, M. 2006. "How specifically do we learn? Imaging the learning of multiplication and subtraction." **NeuroImage**, Vol. 30,No.:4, 1365–1375.

IUCULANO, T., ROSENBERG-LEE, M., RICHARDSON, J., TENISON, C., FUCHS, L., SUPEKAR, K., & MENON, V. 2015. "Cognitive tutoring induces widespread neuroplasticity and remediates brain function in children with mathematical learning disabilities." **Nature Communications**, Vol. 6, 8453.

IZARD, V., DEHAENE-LAMBERTZ, G., & DEHAENE, S. 2008. "Distinct cerebral pathways for object identity and number in human infants." **PLoS Biol**, Vol. 6,No.:2, e11.

JOHNSON, M., & BAILEY, J. S. 1974. "Cross-age tutoring: fifth graders as arithmetic tutors for kindergarten children." **J Appl Behav Anal**, Vol. 7,No.:2, 223–232.

JOHNSON, M. H. 2001. "Functional brain development in humans." **Nat Rev Neurosci**, Vol. 2,No.:7, 475–483.

KAUFMANN, A. F., & DANNENBERG, A. L. 2002. "Age as a risk factor for cutaneous human anthrax: evidence from Haiti, 1973-1974." **Emerg Infect Dis**, Vol. 8,No.:8, 874–875.

KAUFMANN, L., MAZZOCCO, M. M., DOWKER, A., VON ASTER, M., GÖBEL, S. M., GRABNER, R. H., … NUERK, H.-C. 2013. "Dyscalculia from a developmental and differential perspective." **Frontiers in Psychology**, Vol. 4, 516.

KOSC, L. 1974. "Developmental Dyscalculia." **Journal of Learning Disabilities.**, Vol. 7, 167–177.

KUCIAN, K., GROND, U., ROTZER, S., HENZI, B., SCHÖNMANN, C., PLANGGER, F., … VON ASTER, M. 2011. "Mental number line training in children with developmental dyscalculia." **NeuroImage**, Vol. 57,No.:3, 782–795.

KUCIAN, K., LOENNEKER, T., DIETRICH, T., DOSCH, M., MARTIN, E., & VON ASTER, M. 2006. "Impaired neural networks for approximate calculation in dyscalculic children: a functional MRI study." **Behavioral and Brain Functions : BBF**, Vol. 2,No.:1, 31.

LEWIS, C., HITCH, G. J., & WALKER, P. 1994. "The prevalence of specific arithmetic difficulties and specific reading difficulties in 9- to 10-year-old boys and girls." **Journal of Child Psychology and Psychiatry, and Allied Disciplines**, Vol. 35,No.:2, 283–292.

LEWIS, C. M., BALDASSARRE, A., COMMITTERI, G., ROMANI, G. L., & CORBETTA, M. 2009. "Learning sculpts the spontaneous activity of the resting human brain." **Proc Natl Acad Sci U S A**, Vol. 106,No.:41, 17558–17563.

MA, X. 1998. "A Meta-Analysis of the Relationship between Anxiety toward Mathematics and Achievement in Mathematics." **Journal for Research in Mathematics Education**, Vol. 30,No.:5, 520–540.

MAGUIRE, E. A., GADIAN, D. G., JOHNSRUDE, I. S., GOOD, C. D., ASHBURNER, J., FRACKOWIAK, R. S., & FRITH, C. D. 2000. "Navigation-related structural change in the hippocampi of taxi drivers." **Proceedings of the National Academy of Sciences of the United States of America**, Vol. 97,No.:8, 4398–4403.

MAY, A. 2011. "Experience-dependent structural plasticity in the adult human brain." **Trends Cogn Sci**, Vol. 15,No.:10, 475–482.

MAZZOCCO, M. M. M., & MYERS, G. F. 2003. "Complexities in identifying and defining mathematics learning disability in the primary school-age years." **Annals of Dyslexia**, Vol. 53,No.:1, 218–253.

MAZZOCCO, M. M. M., & RÄSÄNEN, P. 2013. "Contributions of longitudinal studies to evolving definitions and knowledge of developmental dyscalculia." **Trends in Neuroscience and Education**. Vol. 2, 65-73

MCCLOSKEY, M., HARLEY, W., & SOKOL, S. M. 1991. "Models of arithmetic fact retrieval: an evaluation in light of findings from normal and brain-damaged subjects." **J Exp Psychol Learn Mem Cogn**, Vol. 17,No.:3, 377–397.

MELTZOFF, A. N., KUHL, P. K., MOVELLAN, J., & SEJNOWSKI, T. J. 2009. "Foundations for a new science of learning." **Science**, Vol. 325,No.:5938, 284–288.

MIRANDA, A., FORTES, C., & GIL, M. D. 1998. **Dificultades del aprendizaje de las matemáticas. Un enfoque evolutivo.** Edidiones Aljibe. Malaga, España

MOLINA, S., & GARCÍA, E. 1984. **El éxito y el fracaso escolar en la EGB. Laia.**Barcelona, España

MONTESSORI, M. 1966. **The Discovery of the Child**. Madras: Kalakshetr.

MORA, F. 2013. **NEUROEDUCACIÓN, solo se puede aprender aquello que se ama**. Alianza Editorial.España

MURNANE, R. J., WILLETT, J. B., & LEVY, F. 1995. "The Growing Importance of Cognitive Skills in Wage Determination."**Review of Economics and Statistics,** Vol. IXXVII, No. 2, 251- 266

MURPHY, M. M., MAZZOCCO, M. M. M., HANICH, L. B., & EARLY, M. C. 2007. "Cognitive characteristics of children with mathematics learning disability (MLD) vary as a function of the cutoff criterion used to define MLD." **Journal of Learning Disabilities**, Vol. 40,No.:5, 458–478.

PAPERT, S. A. 1980. **Mindstorms: Children, Computers, And Powerful Ideas**. Brighton, UK: Harvester.

PASCUAL-LEONE, A., AMEDI, A., FREGNI, F., & MERABET, L. B. 2005. "The plastic human brain cortex." **Annu Rev Neurosci**, Vol. 28, 377–401.

PIAGET, J. 1952. **The Child's Conception of Number**. London: Routledge & Kegan Paul.

PIAZZA, M., IZARD, V., PINEL, P., LE BIHAN, D., & DEHAENE, S. 2004. "Tuning curves for approximate numerosity in the human intraparietal sulcus." **Neuron**, Vol. 44,No.:3, 547–555.

POSNER, M., & ROTHBART, M. K. 2007. **Educating the human brain.**American Psychological Association, Washington, DC., 263.

PRICE, G. R., HOLLOWAY, I., RÄSÄNEN, P., VESTERINEN, M., & ANSARI, D. 2007. "Impaired parietal magnitude processing in developmental dyscalculia." **Current Biology**.

RAPIN, I. 1988. "Disfunción cerebral en la infancia." **Neurología, Cognición, Lenguaje y Conducta. Barcelona. Martinez Roca.**

RÄSÄNEN, P., SALMINEN, J., WILSON, A. J., AUNIO, P., & DEHAENE, S. 2009. "Computer-assisted intervention for children with low numeracy skills." **Cognitive Development**, Vol. 24,No.:4, 450–472.

RITTLE-JOHNSON, B., & KOEDINGER, K. 2009. "Iterating between lessons on concepts and procedures can improve mathematics knowledge." **Br J Educ Psychol**, Vol. 79,No.:Pt 3, 483–500.

RIVERA-BATIZ, F. L. 1992. "Quantitative Literacy and the Likelihood of Employment among Young Adults in the United States." **Journal of Human Resources**, Vol. 27,No.:2, 313–328.

ROTZER, S., KUCIAN, K., MARTIN, E., VON ASTER, M., KLAVER, P., & LOENNEKER, T. 2008. "Optimized voxel-based morphometry in children with developmental dyscalculia." **Neuroimage**, Vol. 39,No.:1, 417–422.

ROURKE, B. P. 1993. "Arithmetic disabilities, specific and otherwise: a neuropsychological perspective." **Journal of Learning**

Disabilities, Vol. 26,No.:4, 214–226.

RYKHLEVSKAIA, E., UDDIN, L. Q., KONDOS, L., & MENON, V. 2009. "Neuroanatomical correlates of developmental dyscalculia: combined evidence from morphometry and tractography." **Frontiers in Human Neuroscience**, Vol. 3, 51.

SCHOLZ, J., KLEIN, M. C., BEHRENS, T. E., & JOHANSEN-BERG, H. 2009. "Training induces changes in white-matter architecture." **Nat Neurosci**, Vol. 12,No.:11, 1370–1371.

SHALEV, R. S., MANOR, O., & GROSS-TSUR, V. 2005. "Developmental dyscalculia: a prospective six-year follow-up." **Developmental Medicine and Child Neurology**, Vol. 47,No.:2, 121–125.

SIEGEL, L. S., & RYAN, E. B. 1989. "The development of working memory in normally achieving and subtypes of learning disabled children." **Child Development**, Vol. 60,No.:4, 973–980.

SUPEKAR, K., SWIGART, A. G., TENISON, C., JOLLES, D. D., ROSENBERG-LEE, M., FUCHS, L., & MENON, V. 2013. "Neural predictors of individual differences in response to math tutoring in primary-grade school children." **Proc Natl Acad Sci U S A**, Vol. 110,No.:20, 8230–8235.

VENTURA-CAMPOS, N., SANJUÁN, A., GONZÁLEZ, J., PALOMAR-GARCIA, M. A., RODRÍGUEZ-PUJADAS, A., SEBASTIÁN-GALLÉS, N., … ÁVILA, C. 2013. "Spontaneous brain activity predicts learning ability of foreign sounds." **Journal of Neuroscience**.Vol. 33, No.: 22, 9295-9305

VYGOTSKY, L. S., & COLE, M. 1978. **Mind in society**. Cambridge, MA: Harvard University Press.

WILSON, A. J., REVKIN, S. K., COHEN, D., COHEN, L., & DEHAENE, S. 2006. "An open trial assessment of 'The Number Race', an adaptive computer game for remediation of dyscalculia." **Behavioral and Brain Functions : BBF**, Vol. 2,No.:1, 20.

YOGARAJAH, M., FOCKE, N. K., BONELLI, S. B., THOMPSON, P., VOLLMAR, C., MCEVOY, A. W., … DUNCAN, J. S. 2010. "The structural plasticity of white matter networks following anterior temporal lobe resection." **Brain**, Vol. 133,No.:Pt 8, 2348–2364.

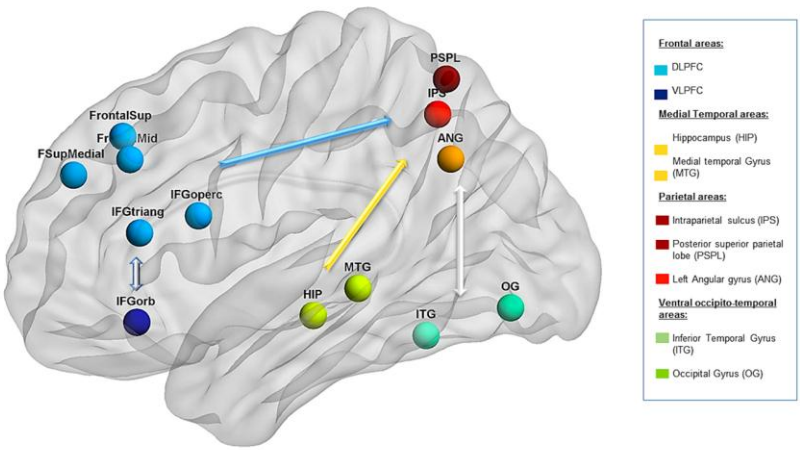

Figure 1. Brain reorganization of changes in routine numerical activity with age. Organization goes from the frontal areas and medial temporal areas to parietal areas and ventral occipito-temporal areas. Frontal areas are associated with executive function, where the prefrontal cortex is important for abstract mathematical thinking, the dorsolateral prefrontal cortex (DLPFC) is associated with verbal working memory and cognitive control, and the ventrolateral prefrontal cortex (VLPFC) is related with attention control. The medial temporal areas (MTG), which include the hippocampus (HIP), are associated with declarative memory. Parietal areas, especially the bilateral intraparietal sulcus (IPS), are associated with numerosity representation, the left angular gyrus (AG) is involved in the retrieval of learned number facts, and the bilateral posterior parietal lobe is associated with mediation of the visuospatial task, attention, eye orientation, and spatial working memory . The ventral occipito-temporal areas with the inferior tempotal gyrus (ITG), involved in number recognition, are connected to the occipital lobe (OG) via the fusiform gyrus, where the right fusiform gyrus is associated with processing the visual form of mathematical symbols.

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