NEUROPSYCHOLOGICAL AND MATHEMATICAL PERFORMANCE IN CHILDREN AND ADOLESCENTS WITH BRAIN INJURY: A MULTIPLE-CASE STUDY

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ABSTRACT

Many students have struggled with mathematics along school years. The achievement of mathematical competences depends not only upon the acquisition of knowledge on numerical concepts, calculation procedures and arithmetical rules, but also upon the development of specific cognitive skills, such as those related to problem-solving and visuospatial processing. Such functions are often impaired in cases of brain damage during childhood, depending on variables such as the extent and location of cerebral lesions. Discussions regarding possible associations

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between mathematical performance and cognitive processes may contribute to a better understanding of the neuropsychological expressions of low mathematical achievement showed by brain damaged students. In this multiple-case study, five male children and adolescents between ages of 12 and 15, suffering from brain damages of different etiologies, and varying location and extent of injuries, with normal intellectual performance and with complaints of difficulties in math, were submitted to mathematical achievement tests (including a Brazilian educational exam, the SARESP), and to neuropsychological assessment. The results indicated that difficulties in consolidating concepts of numbers, operations, arithmetical problem solving skills as well as visuoconstructive and executive functioning deficits – were predominant in all cases. Based on these observations, some reflections are raised regarding the relationship between neuropsychological deficits and low mathematical performance, considering Cognitive Psychology and Neuropsychology models.

Keywords: mathematical skills; brain injury; neuropsychology.

INTRODUCTION

The quality of the educational system is one of the major social problems in developing countries such as Brazil. When referring to mathematics, particularly, Brazil ranked 57th out of a total of 65 countries evaluated by the Programme for International Student Assessment (PISA), in 2009. Results from the Sistema de Avaliação da Educação Básica [Elementary Education Evaluation System] (SAEB), a national program that evaluates Portuguese and mathematics performance among private and public school children every two years, revealed a drop in math performance during the period between 1995 and 2005. In the Sistema de Avaliação e Rendimento Escolar do Estado de São Paulo [Evaluation and School Performance System of the State of São Paulo] (SARESP - 2009), despite widespread improvement in results from previous years, the performance of the students evaluated also proved to be under their level of education. The search for a better understanding of the cognitive factors possibly related to low mathematics achievement is a challenge for teachers and health professionals (psychologists, speech therapists) in finding education and rehabilitation alternatives to overcome children´s difficulties.

Mathematical performance depends upon the acquisition of skills (for example, knowledge of the four operations), the interpretation of arithmetic problems and knowledge of procedures used in performing calculations (Weinstein, 2010). Such skills become more complex along with progress through the school years. For example, medium and high complexity skills development – such as solving an elementary-level equation or even the comprehension of an elementary-level function and its applications – depends upon the acquisition of problem-solving skills that imply the use of the basic operations in the initial grades of elementary education.

The development of mathematical skills has been investigated in different areas of knowledge, as in Cognitive Psychology and Cognitive Neuropsychology. In the Psychology field, Vergnaud's theory of conceptual fields (2009) deserves notice, since it broadens and redirects the Piagetian focus from logical operations and general thinking structures to studying cognitive functions of the "subject in action".

This author takes as reference the content of knowledge itself and its conceptual analysis. A conceptual field, in this theory, is defined as a set of problems and situations in which the treatment demand concepts, procedures, and representations of different, but strongly related, types. For example, the conceptual field of multiplicative structures consists of all situations that may be analyzed as problems of simple and multiple proportion, in which normally a multiplication or a division is needed, or a combination of these operations (Vergnaud, 2009). Various types of mathematical concepts are involved in situations which constitute the conceptual field and multiplicative structures in thinking needed to control such situations. Among such concepts are linear function, nonlinear function, vector space, dimensional analysis, fraction, reason, rate, rational numbers, multiplication and division. In turn, the conceptual field of additive structures comprises situations whose domain requires addition, subtraction or a combination of such operations (Vergnaud, 2009).

In Cognitive Neuropsychology, the focus is on the description of the mental processes involved in the treatment of numbers and calculation procedures. One of the most relevant models is the one developed by McCloskey, Caramazza and Basili (1985). This model is based on the distinction between a system of numerical processing and a system of calculation. The first refers to the comprehension and production of numbers based on Arabic (e.g. 17) and verbal (e.g. seventeen) codes, and represented in phonological terms (oral) and writing (spelling), configuring the set of semantic representations that expresses the translation of the codes in terms of magnitude of quantities they represent. The system of written and mental calculation covers the numerical facts, comprehension of arithmetic symbols and of mathematical operations (addition, subtraction, multiplication and division).

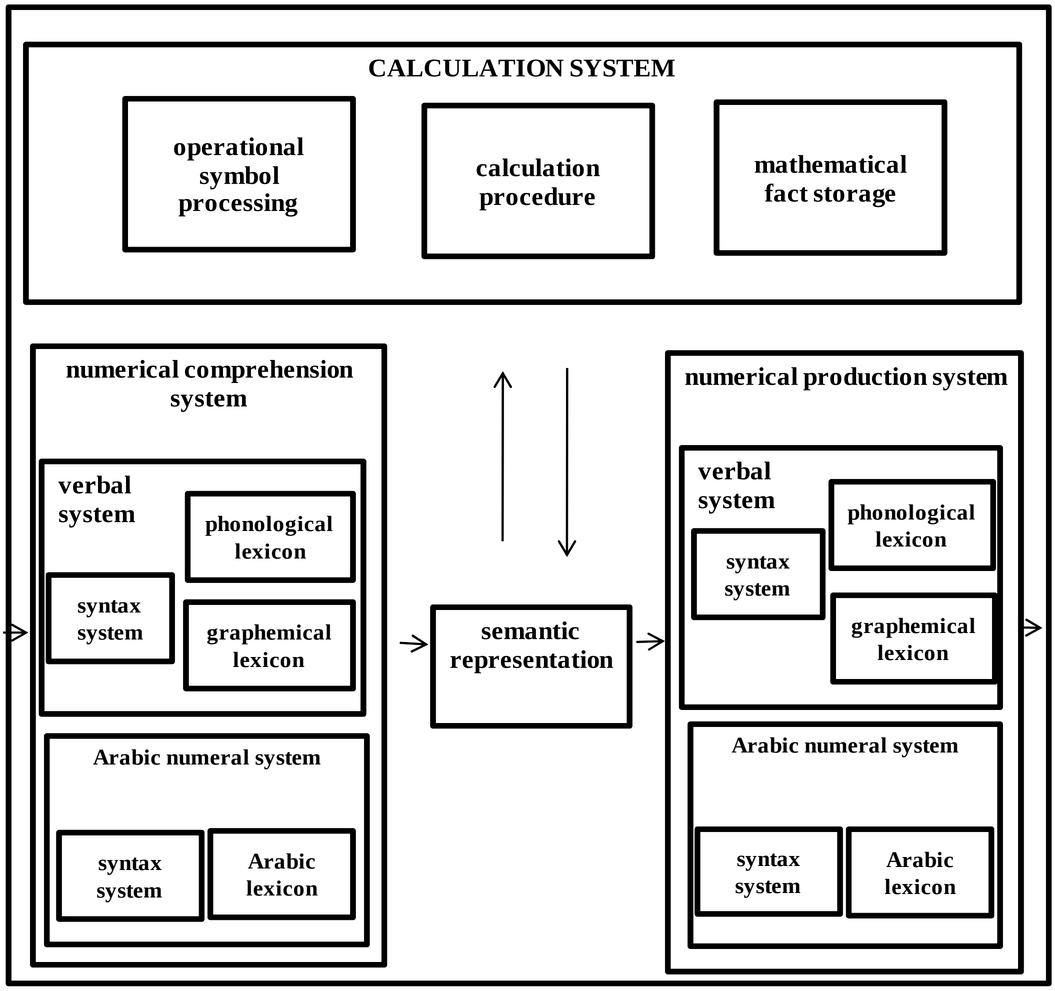


Figure 1 – Model for Processing Numbers and Calculation according to McCloskey et al (1985)

Such models, described as a functional architecture (see Figure 1), therefore allow the understanding of cognitive processes involved in comprehension and expression of numbers, as well as in the procedures of calculation. Based on this description, specific tasks have been outlined to evaluate these processes separately, and such tasks have been proven fundamental in identifying more precisely the nature of calculation dysfunctions showed by adults with acquired brain injuries. For example, the ETC301 battery (Deloche, Dellatolas, Vendrell, & Bergego, 1996) includes tasks such as transcoding alphabetical versus Arabic (e.g. reading numbers in Arabic code), reading and writing numbers in different codes, comparison of numbers in Arabic writing, serial ordering and cognitive estimate of quantities. One version for children is the ZAREKI-R, which has been employed in investigating the mathematical skills profile in children with dyscalculia (Santos, Paschoalini e Molina, 2007).

Developmental dyscalculia is a specific learning disorder, which compromises normal acquisition of numerical and calculation skills. According to DSM-IV (2002), Mathematics Disorder may be identified when *the mathematic ability, as measured by individually administered standardized tests is significantly below the expected level, considering chronological age, measured intelligence, and appropriate schooling for the individual's age. Different skills that may be impaired in this disorder include "linguistic"skills (e.g., understanding or naming mathematical terms, operations or concepts and decoding written problems into mathematical symbols), "perceptual"skills (e.g., recognizing or reading numerical symbols or arithmetic signs, and clustering objects in groups), "attention"skills (e.g. copying numbers or figures correctly, remembering to add the "carried" numbers, and observing operational signs) and mathematical "skills" (eg. following sequences of mathematical steps, counting objects, and learning multiplication tables).*

The estimated prevalence of developmental dyscalculia in school population is 5 to 6%, and it is as common in girls as in boys (Shalev, 2004). The term has been used to refer to both acquired as developing disorders (Kosc, 1974; Lucchelli & Renzi, 1993; Rourke, 1993). As with other learning disabilities, its etiology is associated with neurobiological basis (Geary, 2010). Neuroimaging studies have shown that the main areas in the brain involved with numerical processing are located in the parietal lobe, more specifically in intraparietal sulci (Kadosh et al, 2011). Other cortical reasons are situated in the pre-frontal lobe, temporal lobe and the cingulate cortex, as well as in sub-cortical regions. Since the neural network of both hemispheres contain the substrate of normal arithmetic skills, dyscalculia can result from bilateral dysfunctions, although the left parietotemporal area has a particular importance. However, poor schooling and cultural privation are also implied in its manifestation (Shalev, Manor, & Gross-Tsur, 2005). Dyscalculia has been frequently reported in premature and low birth weight children, as well as in a variety of diagnoses or neurological disorders such as Attention Deficit and Hyperactivity Disorder, language disorders, epilepsy and Fragile X Syndrome (Shalev, 2004). In Non-Verbal Learning Disability, in particular, it constitutes one of the main characteristics, in addition to the difficulties in social cognition and visuoconstructive dysfunctions (Hardanek and Rourke, 1994). The prognosis of long-term dyscalculia and recovery possibilities are still under investigation (Shalev, 2004).

Difficulties in numerical processing and calculation may also be present in several clinical conditions associated with neurological dysfunctions. For example, in children with brain damages, a poor performance in arithmetic tasks is not sufficient to point out dyscalculia, since it can reflect broader cognitive deficits, mainly involving memory or executive functioning. Hence, in these conditions, difficulties of this nature must be more carefully analyzed (Novick and Arnold, 1988,APUD Capovilla and Capovilla, 2007). Particularly for children, a brain injury acquired at early developmental stages may interfere in the maturation of cognitive functions essential to learning, including math skills (Ciasca, Moura-Ribeiro, & Tabaquim, 2006). However, little research has been made on how math skills are developed in these conditions.

Studies aiming to investigate associations between neuropsychological dysfunctions and mathematical learning disabilities in children with neurodevelopmental disorders or brain injury have shown the involvement of attention, visual memory and executive functions (Miranda & Llario-Gil, 2001). For example, Korkman, Kirk and Kemp (2002) investigated a sample of children aged 8 to 12 years diagnosed with specific mathematical disabilities, and identified attention, executive functions, visual memory and spatial processing deficits; by the other hand, language, sensory-motor function and social perception were preserved. Working memory deficits have been observed particularly in developmental dyscalculia (Nöel, 2005). The involvement of working memory in performing mathematical operations seems to be explained in terms of demands for temporary maintenance of information necessary for calculation, for attention control and for updating relevant information stored in long-term memory (Adams & Hitch, 1997). Recent reviews, however, have pointed out that the extent of this involvement is not yet fully understood (Geary, 2010).

In this article, results from a multiple case study that aimed to describe and analyze possible associations between neuropsychological deficits and poor mathematical performance showed by children with brain injuries will be described, looking to contribute to new interpretations in regards to neuropsychological bases for mathematical abilities.

A better understanding of difficulties in mathematical performance showed by children with brain injuries may, as we understand, contribute so that the school may offer all students an education that respects and integrate the differences among them. Additionally, it is expected that the discussion herein proposed proves to be useful in encouraging health and educational professionals to reflect, if possible in multidisciplinary teams, about alternative education and rehabilitation programs that aim a more adequate approach to learning difficulties associated to complex neuropsychological dysfunctions.

STUDY DESCRIPTION

Methods

Participants

Participating in this study were five children and adolescent males, ages ranging from 12 to 15 years old, diagnosed with brain injuries of different etiologies (malformations of the corpus callosum, cerebral palsy with right hemiparesis, ischaemic stroke), enrolled between grades 6 and 9 of elementary school, in private schools in São Paulo state, Brazil. The parents' level of schooling varied between complete secondary and complete higher education. The presence of psychiatric comorbidities or intellectual, sensory or motor deficiencies – all of which could compromise the tests' applicability - was not detected in any of the participants.

The subjects were selected at the clinic of the Children's Neuropsychological Interdisciplinary Center (NANI) [Núcleo de Atendimento Neuropsicológico Infantil Interdisciplinar (NANI)], one of the units of research and care of the Paulista Center of Neuropsychology (CPN) [Centro Paulista de Neuropsicologia (CPN)], where neuropsychological evaluations and mathematical performance were assessed. All subjects were submitted to a Magnetic Resonance Imaging (MRI). The image was performed without the use of sedation or contrast; all exams were paid for with funds from sponsorship from a national agency fostering research (CNPq - 475146/2008

5), under approval from the Comitê de Ética em Pesquisa da UNIFESP [Ethics in Research Committee of UNIFESP] (protocol 1086/09). Analysis of the MRI and description of information concerning the location and extent of brain damages were performed by a neuroradiologist, co-author of this research. The research was approved by the Comitê de Ética em Pesquisa da PUC/SP [Ethics in Research Committee (118/2010). Guardians signed an informed consent form, allowing children to participate. A summary description of each case follows.

Case 1 - 15 years and 9 months of age, monitored at NANI since 2005. He was diagnosed with Corpus Callosum agenesis (ACC).
History: The baby was born full term by cesarean section, weighing 3,200 g and measuring 49 cm. In the 5th month of pregnancy an arachnoid cyst was identified through ultrasound. At 11 months old he underwent surgery to implant a ventriculoperitoneal shunt. The major benchmarks of neuropsychomotor development were reached within normal standards for his age. At the time of this study, he had completed the 9th grade of elementary school, with learning difficulties focused mainly in mathematics.
Neuroimaging Data: Corpus Callosum agenesis; Cingulate gyri missing; Anterior commissure hypertrophy; Frontal interhemispheric hypertensive cyst (star) shunting (black arrow); Posterior displacement of lamina rotralis (White arrow). (see Figure 2)

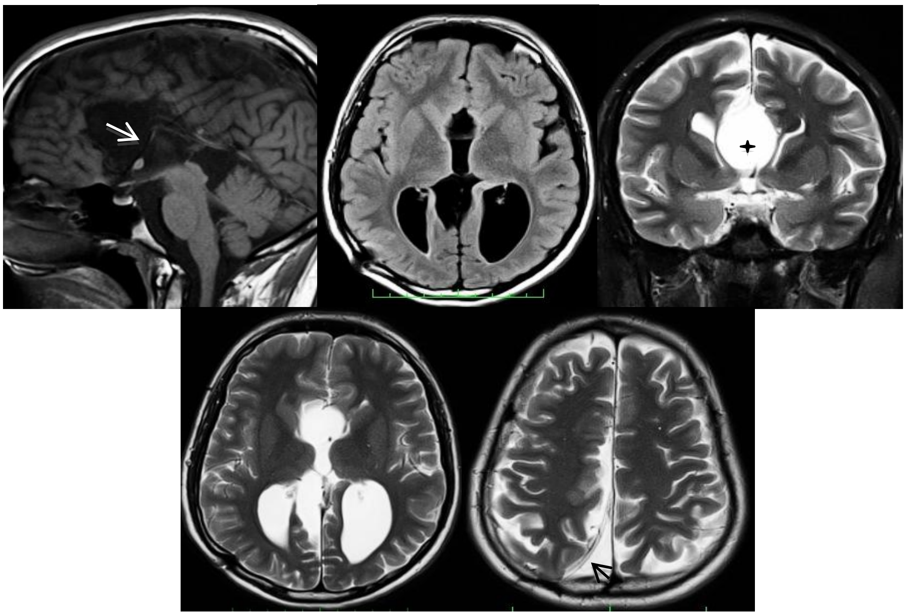


Figure 2 - MRI Case 1

Case 2 – 14 years and 11 months of age, monitored at NANI since 2004. He was diagnosed with Corpus Callosum agenesis (ACC).
History: Uneventful pregnancy. The child was born at 38 weeks of gestation, by cesarean section, and weighed 3,700 g and measured 51.5 cm. There was report of

neonatal anoxia with good evolution in a maternity document. Neuropsychomotor developmental benchmarks were within standards. Starting at pre-school, oral and writing difficulties were observed, which were corrected by pedagogical reinforcement and speech therapy monitoring.
Neuroimaging data synthesis: Corpus Callosum agenesis; Cingulate gyri missing; Anterior commissure hypertrophy; Left frontoparietal heterotopic gray matter; Left Schizencephaly type I (fused lips). (see Figure 3).

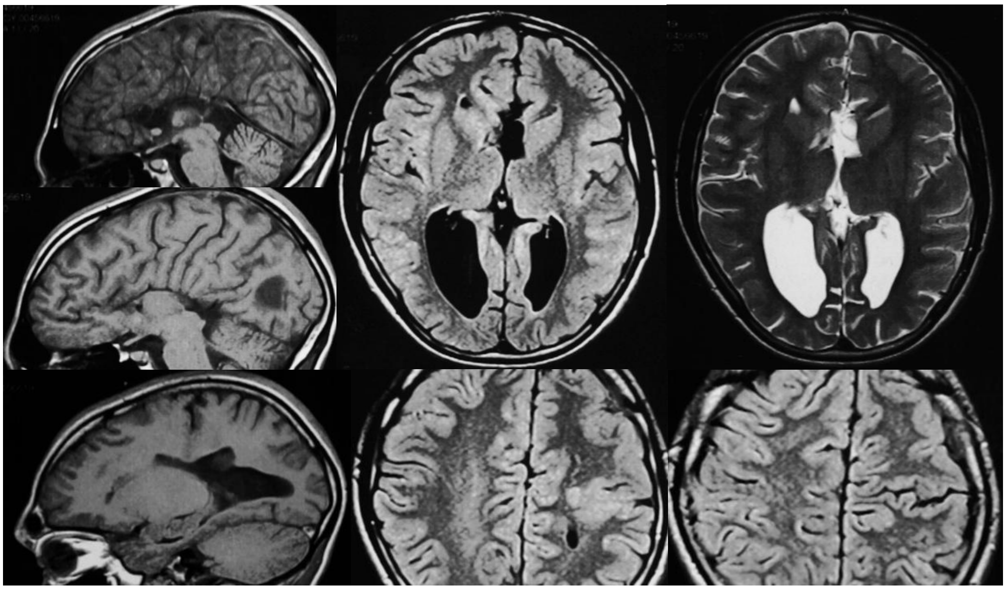


Figure 3 - RNM Case 2

Case 3 – 13 years and 11 months of age, monitored at NANI since 2010. He was diagnosed with cerebral palsy with right spastic hemiparesis.
History: Born full term, weighing 4,300g and measuring 53 cm. Clinical reports include anoxia and seizures at birth, as well as being hospitalized for ten days due to difficulties in sucking maternal breast. At 4 months, he was diagnosed with West syndrome due to the presence of seizures. Right hemiparesis was detected as soon as 2 months of age, having then begun physiotherapy treatment. Started walking at 15 months. At the time of this study, he was in the 8th grade of elementary school, in private school, and showed difficulties in reading comprehension and in mathematics.
Neuroimaging data: Left internal bone skull remodeling; Small left cerebral peduncle; Left middle fossa arachnoid cyst; Hypertensive left porencephalic temporal cyst; Desctrutive left basal ganglia injuries; Small left thalamus. (Figure 4).

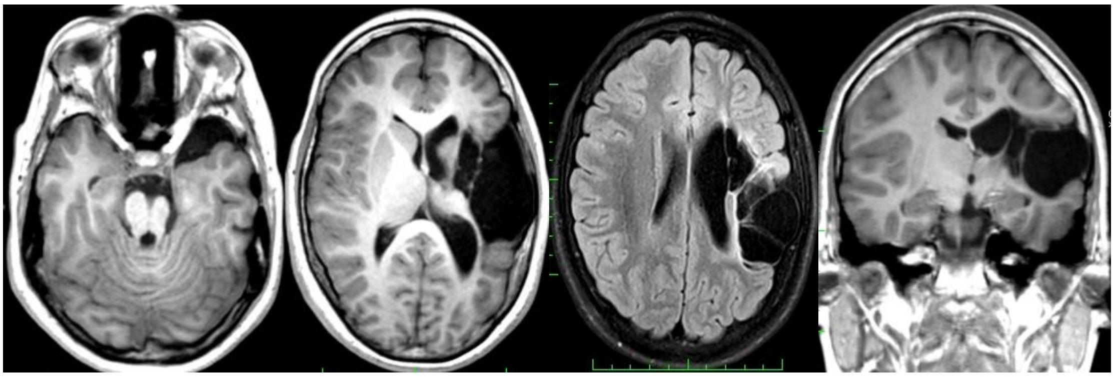


Figure 4 - RNM Case 3

Case 4 – 13 years and 4 months of age, monitored at NANI since 2005. He was diagnosed with cerebral palsy with right hemiparesis, associated with partial-symptomatic epilepsy. **History**: Born at 38 weeks and developed well until 1 year and 3 months, age at which he acquired the ability of independent walking. Episodes of febrile seizure started at 9 months of age, followed by signs of spasticity, predominantly in the lower right limb. Evolved with intermittent crises of seizures until 9 years of age. At 7 years he underwent surgery to lengthen the Achilles tendon in his right foot. Currently he presents visual difficulties predominantly in the right eye (40% visual acuity in this eye). At the time of assessment he attended the 6th grade of elementary school, with poor academic performance, specifically in mathematics.

Data from neuroimaging exam: Periatrial bilateral gliosis; Bilateral thalamic gliosis; Small left caudate nucleus (black arrows). (Figure 5).

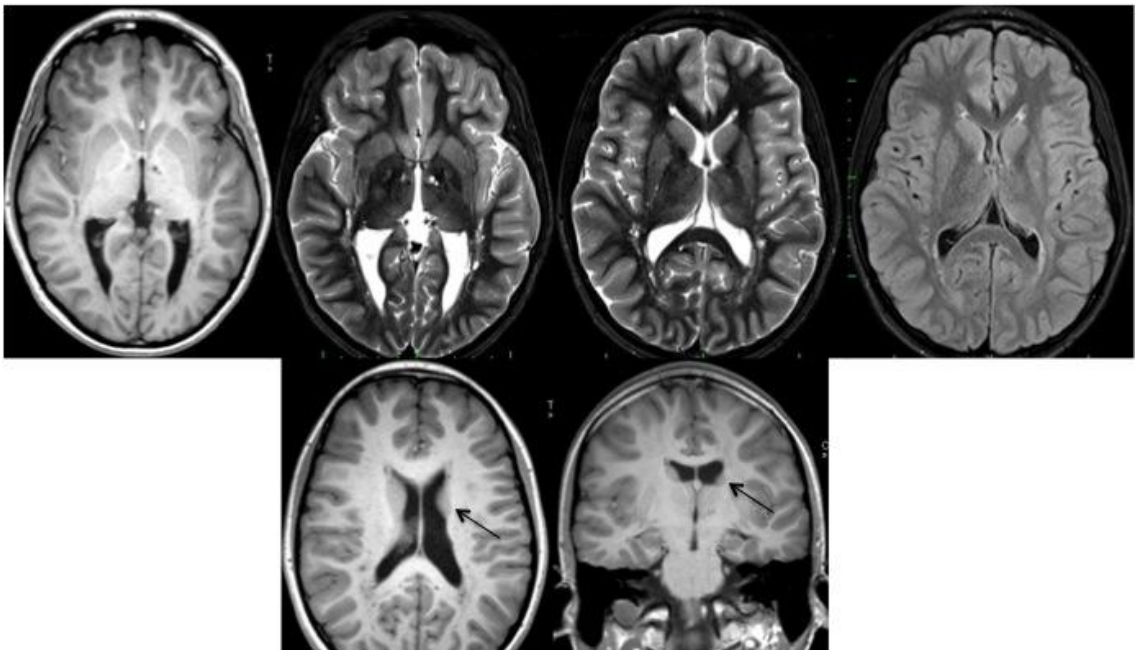


Figure 5 - RNM Case 4

Case 5 - 12 years and 8 months of age, monitored at NANI since 2010. He was diagnosed with brain injuries caused by a ischaemic stroke (IS)
History: He was born at term by cesarean section, weighing 4,100 kg. The main developmental benchmarks were met within normal standards. At nine months of age he showed crises of seizure associated with a fever, at which point a ischaemic stroke was detected, which resulted in localized lesions in the left hemisphere. At the time of assessment, he attended the 6th grade of elementary school. He showed difficulties in concentrating and other academic problems, mainly in Portuguese and mathematics.
Data from neuroimaging exam: Small left hemicranium; Cerebelar atrophy; Frontal, temporal and parietal left destructive cortical and subcortical injuries. (Figure 6).

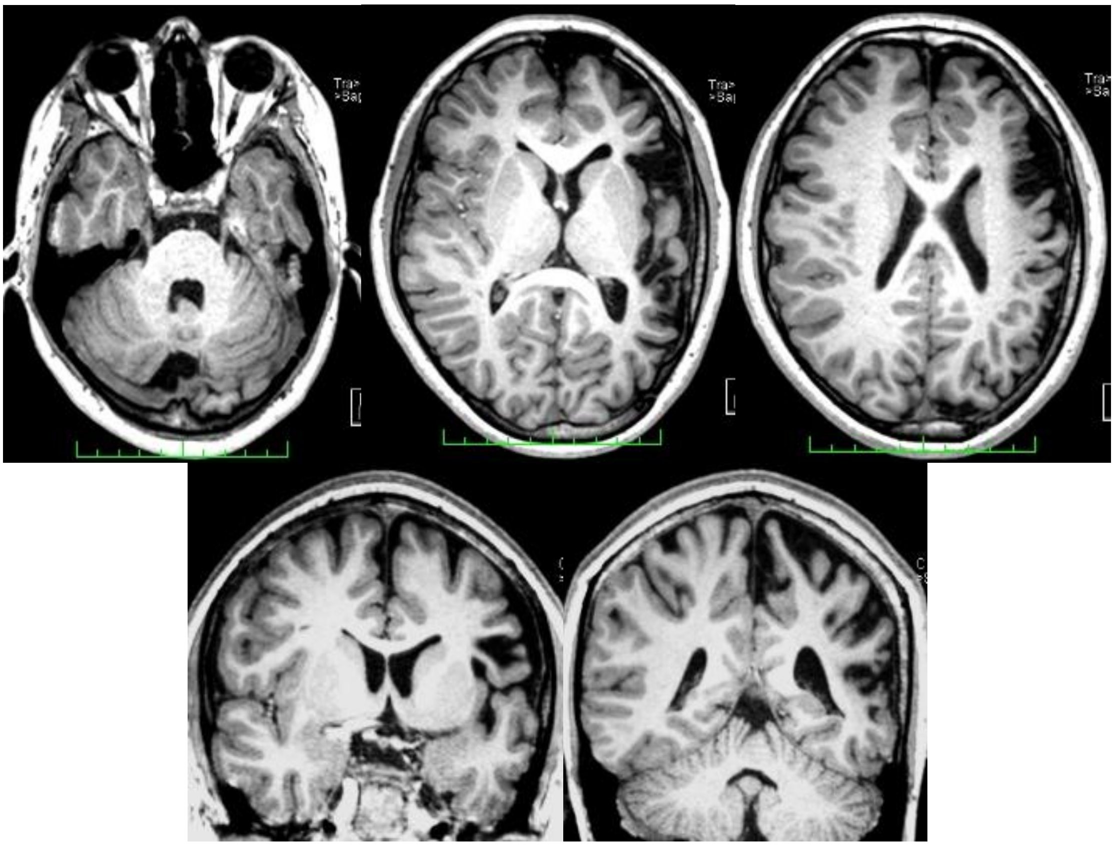


Figure 6 - RNM Case 5

VARIABLES OF INJURY DEFINITION
Region Frontal (F): brain damage involving frontal lobe • Extra-frontal (EF): cerebral damage involving parietal-temporal-occipital lobes • Subcortical (SC): cerebral damage involves the corpus callosum, thalamus or basal ganglia • Posterior Fossa: cerebral damage involves the brain stem or cerebellum

Laterality • Left (L): brain damage restricted to the left hemisphere • Right (R): brain damage restricted to the right hemisphere • Bilateral (B): brain damage in both hemispheres
Extension • Focal Lesion (F): brain damage restricted to one region • Multifocal (MF): brain damage involving two or more regions • Diffused (D): damages in the whole brain

Table 1 – Summary of demographic data and clinical variations of the participants

	PARTICIPANTS				
	1	2	3	4	5
Age	15y 9m	14y 11m	13y 4m	13y 4m	12y 8m
Educational Level	9th grade	9th grade	8th grade	6th grade	6th grade
Main Diagnosis	ACC	ACC	CP-RH	CP-RH	IS
Predominant Region	SC	SC	EF/SC	SC	F/EF/SC
Laterality	B	B	L	L	L
Extent	D	D	MF	F	MF

(ACC: Corpus Callosum agenesis; CP: Cerebral Palsy, Right Hemiparesis; IS: Ischaemic Stroke)

Procedures

Participants were submitted to an evaluation of mathematical performance and neuropsychological assessment, which included an exam of the global intellectual performance. The procedures were applied individually, in appropriate classrooms, and took around three of four sessions, each lasting 90 minutes. A description of the procedure used in these evaluations follows.

Assessment of academic mathematical performance

Mathematical performance was investigated considering knowledge of mathematical concepts and execution of algorithms, focusing on analysis of the nature of errors made by participants. The following procedures were used: Mathematics achievement test, as used in the Sistema de Avaliação de Rendimento Escolar do Estado de São Paulo [São Paulo State's Academic Performance Evaluation System] (SARESP, 2007) and the Protocol for Calculation and Mathematical Reasoning (adapted from Boller and Faglioni, by Bastos, 2003).

In the Mathematics Achievement test (SARESP, 2007) participants performance was compared to that expected by their grade or age group. For children evaluated at the beginning of the school year, the test applied was from the grade immediately below the one attended. These procedures allowed us to verify the academic performance of participants in terms of learning of concepts and skills development, identifying also the factors that affect performance. Participants performance was analyzed in comparison to mathematical matrices, structured by years and grades evaluated. For each of these schooling levels descriptors are defined in order to indicate a particular skill that must have been developed. These descriptors are grouped by themes that relate one set of educational goals. They are:

- **Numbers and Operations / Algebra and Functions** – This descriptor comprises the abilities to compare, organize and represent whole, rational, positive and negative numbers; solve a problem-situation and perform calculations, comprehending different meanings of the operations, involving whole and rational numbers; relate fraction and decimal representations in a same rational number; solve situation-problems that involve rational numbers in situations that indicate part-whole, quotient and reason; use exponentiation features to simplify calculations; solve problem-situations involving the concept of percentage; use algebra representations to express regularities observed in numeric sequences; calculate the numeric value of simple algebra expressions, among others.
- **Space and Shape** – This descriptor refers to spatial perception skills, knowledge of angles (side measures, measures of the angles), location / moving of object in maps, sketches and other graphical representations, to

establish relationships between different units of measurement of time, mass length and capacity, among others.

- **Quantities and Measures** – includes skills related to the identification of measurement procedures; the notion of surface measurement and equivalence of one-dimensional figures through composition and decomposition of images; calculate the area of one-dimensional images by decomposition and / or composition in images of known areas; calculate the volume of containers; interpret data in various and adequate visual aids (flow charts, tables and graphs) to understand the meaning of the arithmetic mean as an indicator of a trend in research; read and interpret data shown in tables, among others.
- **Treatment of Information** – related to reading and interpreting data shown in tables; solving problems using data shown in tables and charts, among others.

The performance levels have a pedagogical interpretation based on the reference matrix of SARESP and the suggested curriculum in São Paulo State. The points on the scale used to measure the proficiency of students in 4th, 6th and 8th grades of elementary school range from 150 to 500.

The SARESP scale is organized in levels of performance (see Table 2), defined from learning expectations (concepts, competences and abilities) established in each grade and subject in the curriculum proposal from the State of São Paulo.

Table 2 – Classification criteria for academic mathematical performance – SARESP 2007

LEVELS	4th grade	6th grade	8th grade	12thgrade
Below Basic	< 175	< 200	< 225	< 275
Basic	Between 175 and 225	Between 200 and 225	Between 225 and 300	Between 275 and 350
Adequate	Between 225 and 275	Between 225 and 300	Between 300 and 350	Between 350 and 400
Advanced	Above 275	Above 300	Above 350	Above 400

Students at each of above described levels demonstrate:

- **Below Basic** – insufficient knowledge of concepts, competences and abilities expected for their grade.

- **Basic** –partial development of contents, competences and abilities expected for their grade.
- **Adequate** –knowledge of concepts, competences and abilities expected for their grade.
- **Advanced** –knowledge and mastery of concepts, competences and abilities required in the above grade level.

The protocol for calculation and mathematical reasoning (Bastos, 2003) covers measurements for students who have completed the first cycle of elementary school (4th grade), ranging in age from 9 to 14 years. The protocol is composed of four items, in order to assess:

- **Lexical and syntactic skill:** in this task students are asked to read numbers (e.g. 7), in increasing difficulty levels (ones, tens, hundreds, thousands);
- **Skill to recognize quantities:** involve identifying quantities (ones, tens, hundreds, and thousands);
- **Calculation skill:** covers calculations in all operations, each one of them involving 7 calculations (except division, involving 6 calculations), always increasing in complexity;
- **Mathematical reasoning skill**: solution of 8 problems, again involving increasing levels of complexity.

The final scores correspond to the number of correct responses, ranging from a skill to the other. Performance is therefore classified into categories, ranging from unsatisfactory to fully satisfactory. Criteria for classifying performance were divided into five groups, as described in Table 3.

Table 1 – Performance rating criteria in calculation and mathematical reasoning protocol, according to the number of correct answers

Hits	Efficiency
Group 1: 0 a 19	Unsatisfactory
Group 2: 20 a 39	Slightly Satisfactory
Group 3: 40 a 59	Regular
Group 4: 60 a 79	Satisfactory
Group 5: 80 a 100	Fully Satisfactory

- **Unsatisfactory:** this classification refers to answers that involve: a) numbers copied out of the problem, without evidence of understanding the problem; b) incorrect answers, in which the direction given to solve the question presented cannot be traced; c) answers in blank, when nothing can be inferred regarding the participant's performance;
- **Slightly Satisfactory:** this classification involves answers that right from the beginning employ inappropriate strategies and, therefore, do not reach the solution of the problem; b) the approach used is identified, but it does not succeed; c) they start with a wrong approach, then the participant realizes that the answer will not be reached, but he gives up without trying to use a different approach; d) they indicate an unsuccessful attempt to reach a sub-goal, which implies they are giving up the task;
- **Regular:** this classification refers to answers that involve: the use of a) appropriate strategy, however, without finding the answer; b) the fact that a sub-goal has been reached, however, without being able to complete the problem and find its answer; c) the use of an inadequate strategy, which reveals, meanwhile, some understanding of the problem; d) the correct answer, but without showing what was the strategy used to achieve it;
- **Satisfactory:** this classification refers to answers that involve: a) the use of a correct strategy, without being able to find the answer to the problem: its conditions were ignored; b) incorrect answer, due to lack of clarity when using the current strategy.
- **Fully satisfactory:** this classification refers to answers which express adequate solutions, compatible with the strategies used and with the understanding of the problem.

In summary, the results of the achievement and mathematical skills evaluations were analyzed according to the rules of each procedure employed. Thus, we sought to identify the mathematical content assimilated and the level of math skills developed by the participants.

Neuropsychological research

Intellectual performance investigation was based on the Weschsler Intelligence Scale for Children - WISC-III (Wechsler, 2003). Neuropsychological tests adopted were traditionally used in clinical practice (Lezak, Howieson, & Loring, 2004). The following procedures were used:

- **Semantic Verbal Fluency.** Tasks of verbal fluency involve the generation of as many words as possible from one category (e.g. animals) or letter (e.g. F) in 60 seconds. It provides information about the ability to retrieve information stored in long term memory. The performance is evaluated considering the number of words generated. In this study, the “animals” category was used.
- **Phonological Verbal Fluency.** In this task, the subject is asked to generate as many words beginning with a given letter, in 60 seconds. It allows for the evaluation of executive functions, especially those concerning the organization and the strategies used in the word search. We used the letters F, A and S., as used in neuropsychological assessment (Lezak, Howieson & Loring, 2004). The participants’ performance was evaluated considering the average of words generated in each letter.
- **Digit Span**– WISC-III. In this task, increasing sequences of digits are orally presented by the examiner, and the subject is asked to immediately recall the sequences, initially in direct (forwards) and after in reverse (backwards) order. It allows evaluating the temporary storage (phonological loop) and the mental manipulation (central executive) components of verbal working memory.
- **Corsi’s Blocks Test**. The Corsi’s Blocks Testconsists of a board with nine numbered blocks arranged randomly. The examiner touch increasing sequences of blocks and the subject is asked to repeat the same sequences, in direct (forwards) and in reverse (backwards) order. The test evaluates temporary storage (forwards) and the ability to mental

manipulate (backwards) visual-spatial information (non-verbal working memory).

- **Rey Auditory Verbal Learning Test - RAVLT** (Malloy-Diniz et al, 2000). The test measures auditory-verbal episodic memory. A list of 15 words (List A) is presented orally by the examiner in five consecutive trials, and the subject is asked to recall all the words in each trial. Subsequently, a interference list (list B) is presented with 15 other words. The subject must recall the words from this alternative list and immediately recall once again the first list. After 20 minutes, he is asked to recall once again the first list (A) without it being repeated. The scores represent the total words of list A recalled in the serial recall (A1-A5), recall after interference (A-6) and delayed recall (A7).
- **Continuous Performance Test – CPT** (Conners, 2004). This computerized visual test measures sustained and selective attention and impulsivity. It requires discrimination between the targets (letter X) and non-targets (non-X) stimuli, which are presented in the center of a computer screen with varying inter-stimuli time intervals. The subject is asked to press the spacebar on the computer every time the non-target stimuli appears (any letter), and inhibit the motor response to the continuous appearance of the target (X), during 14 minutes. Analysis of performance allows identify the presence of clinical profile of an attention deficit disorder, including a confidence index.
- **The Wisconsin Card Sorting Test – WCST**. It is a classic test used to investigate executive functions, associated with the frontal lobe, such as inhibition of impulsive responses, ability to develop and maintain a strategy to solve a problem despite contingencies changes, cognitive flexibility, and the ability to categorize. The scores include the number of established categories, perseverative errors and failures in maintaining the pattern of response, among others.
- **Rey Complex Figure Test**– The subject is exposed to a complex figure and asked to copy and later on to reproduce it again without seeing the

model (immediate memory). Visual-constructive abilities, visual-spatial perception and graphic planning can be analyzed based on performance on the copy. Visual memory skills are analyzed in the immediate recall task.

Participants' performance was compared to Brazilian norms (averages and standard deviations by age groups), obtained in the test manuals or in previous studies with samples of subjects of similar age and educational level (Mello, 2003). We calculated the Z score for classify performance and then observed the corresponding percentile ranges. Thus, we have tried to identify specific neuropsychological deficits (in one or more functions in isolation) or global (presence of deficits in all functions examined). Performance below the 10th percentile was considered as sign of a deficit.

Finally, the data obtained in the mathematics performance evaluation and in neuropsychological assessment was compared, seeking to identify possible links between the mathematical difficulties and specific neuropsychological deficits that might be associated with low mathematical achievement of the children evaluated.

RESULTS

Neuropsychological assessment

Neuropsychological assessment was initiated with the investigation of the global intellectual performance (IQ) as well as in verbal (VIQ) and performance (PIQ) domains, based on the Brazilian version of the WISC-III. The results of each participant considering IQ and scaled scores in each subtests are described in Table 4.

Table 2 - Results of the Global Intellectual Performance (IQ and scaled scores)

	Participants				
Tests	**1**	**2**	**3**	**4**	**5**
IQ	109	97	91	87	108
VIQ	102	113	95	95	104
PIQ	115	79	87	81	109
Picture Completion	13	10	6	11	18

Coding	11	**7**	**6**	**5**	**7**
Picture Arrangement	15	9	10	**2**	8
Block Design	10	8	11	9	12
Vocabulary	10	12	**7**	10	11
Similarities	13	13	13	**7**	14
Arithmetic	**5**	11	9	**4**	**6**
Information	13	12	12	11	8
Comprehension	11	8	11	9	11

The results showed, therefore, that all participants had average intellectual performance. A significant discrepancy between VIQ and PIQ, i.e., when there is difference of more than 15 points (Simões, 2002), was found in only one case (participant 2). Four of the five participants had a performance below average (scaled score equal to or less than 7) in the subtests =, and three in the Arithmetic subtest.

Regarding the evaluation of higher cortical functions, performed by means of neuropsychological tests, there was wide variation among participants and individually (see Table 5).

Table 3 – Neuropsychological Assessment Results (Percentile)

	Participants				
Tests	**1**	**2**	**3**	**4**	**5**
CPT– omissions	68	50	41	10	84
CPT– reaction time	4	45	45	99	72
CPT-Block change reaction time	3	41	19	98*	89*
RAVLT-total	53	69	42	16	**<1**
RAVLT-after interference	66	90	**<1**	27	**<1**
RAVLT-delayed recall	42	93	84	12	**<1**
Rey Complex Figure Test - copy	**<1**	**<1**	**<1**	**<1**	76
Rey Complex Figure Test - memory	**<1**	16	31	58	**<1**
Digit Span (forwards)	98	98	27	27	27
Digit Span (backwards)	99	42	50	**<1**	16
Corsi (forwards)	93	58	73	**<1**	73
Corsi (backwards)	73	73	42	12	88
Semantic Verbal Fluency	76	50	62	62	84
Phonological Verbal Fluency (FAS)	58	**5**	27	12	**<1**
WCST-total of errors	76	24	58	27	69
WCST-perseverative errors	16	**<1**	**7**	**<1**	**1**

CPT: Continuous Performance Test; RAVLT – Rey Auditory Verbal Learning Test; WCST: Wisconsin Card Sorting Test; * clinical profile of attention deficit.

The functions that were generally more impaired, considering the presence of low performance in four of five participants were visual-constructive (copy of Rey Complex Figure Test) and executive functions (considering number of perseverative errors on the WCST). Other functions were also impaired in the group (deficit present in at least one participant) included attention (CPT), auditory-verbal episodic memory (RAVLT), long-term visual memory (Rey Complex Figure Test memory) and the component associated with executive functioning self monitoring (FAS). No participant showed difficulties in the measures related to the temporary storage component of verbal working memory test (digits span forwards) or to the component of mental manipulation of non-verbal working memory (CORSI forwards).

Mathematical performance evaluation

The analysis of performance on the SARESP (2007) exam revealed that competencies in Numbers and Operations stood at the basic level for all participants, indicating partial domain of the concepts and abilities required for the grade in which they are in. The most common problems involved algorithmic calculations, with failures in those which execution required the completion of a series of steps. There were problems both in solving arithmetic calculations and problem resolution, what should have already been acquired. Participants also demonstrated conceptual difficulties, such as base 10 in arithmetic and also in the field of rules and strategies to borrow and carry values, a problem of procedural nature.

Table 4 – Results of mathematical performance evaluation (SARESP 2007)

	Participants				
Tests	**1**	**2**	**3**	**4**	**5**
Numbers and Operations	**B**	**B**	**B**	**B**	**B**
Space and Form	AD	AD	AD	**BB**	AD
Quantities and Measures	AD	**B**	AD	AD	**BB**
Treatment of Information	**B**	AD	AD	AD	**BB**

BB – below basics; B – basics; AD – adequate

In the evaluation of Bastos' protocol (2003), all participants showed adequate performance on the questions related to recognition of quantities and had more difficulties in Multiplication, followed by Problems Resolution (see Table 7).

Table 5 – Results of mathematical performance evaluation (Bastos, 2003)

	Participants				
Tests	**1**	**2**	**3**	**4**	**5**
Writing of numerical symbols	FS	FS	FS	**SS**	FS
Writing of numerical words	FS	FS	FS	S	FS
Recognize quantities	FS	FS	FS	FS	FS
Sum	S	FS	FS	**RE**	FS
Subtraction	S	FS	S	**UN**	**RE**
Multiplication	**SS**	**RE**	**SS**	**IN**	**IN**
Division	S	FS	**RE**	**UN**	**UN**
Problem Resolution	**SS**	PLS	S	**UN**	**SS**

UN- unsatisfactory; SS- slightly satisfactory; RE- regular; S- satisfactory; FS- fully satisfactory

A summary of the findings in the various evaluations is described in Table 8.

Table 6 – Summary of findings from neuropsychological evaluations and mathematical performance

Participants	Neuropsychological Deficits	Low results on SARESP	Difficulties observed on Bastos' Protocol
1	Visual-construction Visual memory	Numbers and operations Information Treatment	Multiplication and problem solving
2	Visual-construction Executive functions	Numbers and operations Quantities and Measures	Multiplication
3	Visual-construction Executive functions	Numbers and operations	Multiplication and Division
4	Visual-construction Executive functions Attention	Numbers and operations Space and Form	Writing of numerical symbol All basic operations Problem Resolution
5	Executive Functions Attention Verbal memory Visual memory	Numbers and operations Quantities and Measures Information treatment	Subtract Multiplication Division Problem Resolution

A better description of the nature of the difficulties presented by the participants is proposed in some examples. Participant 1 showed a good performance in the questions concerning mathematical concepts related to quantities and measures, and also in those referring to space and form. The contents involving concepts of numbers and operations and treatment of information were the most deficient. For example, while trying to resolve the seventh question (figure 7), which required finding the roots of the equation “x^2 + 10X +16”, the participant initiated the question setting up the correct equation for its resolution, but did not conclude it adequately, for he made mistakes in basic multiplication and subtraction operations (in the 4x16 multiplication operation, which result is 64, he wrote 34, and in the subtraction operation 100-34, which result is 66, he wrote 76).

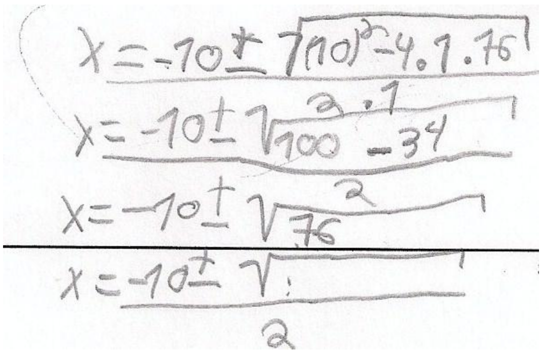
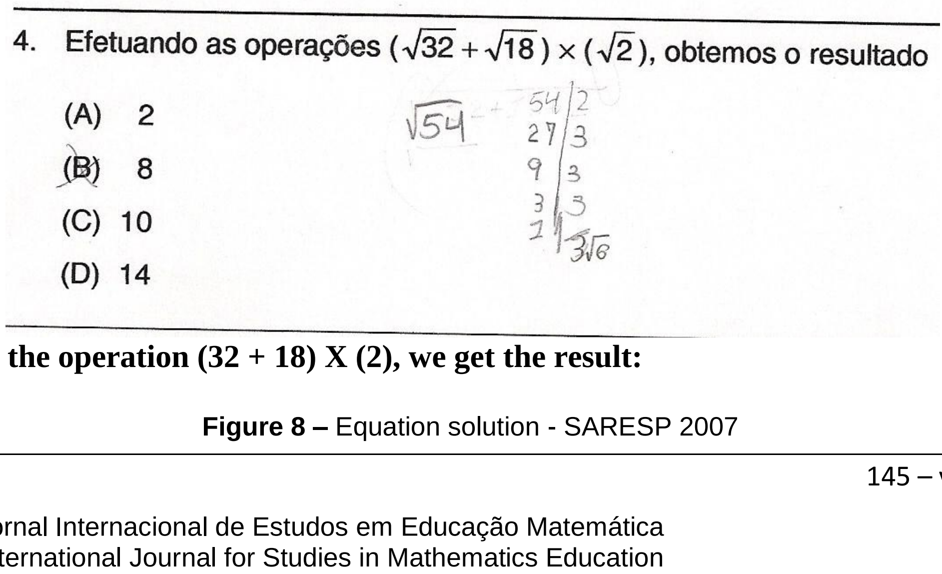


Figure 7 – Equation solution - SARESP 2007

As he made mistakes in the operations involved, he reached a wrong number and could not extract the square root. In general, it was observed that the major difficulty faced by the participant was to solve problems, as noted throughout the test.

Participant 2 had more difficulties regarding the concepts related to numbers and operations. The questions in which he did not succeed involved irrational numbers, algebraic expressions and second-degree -equation as can be seen in Figure 8.

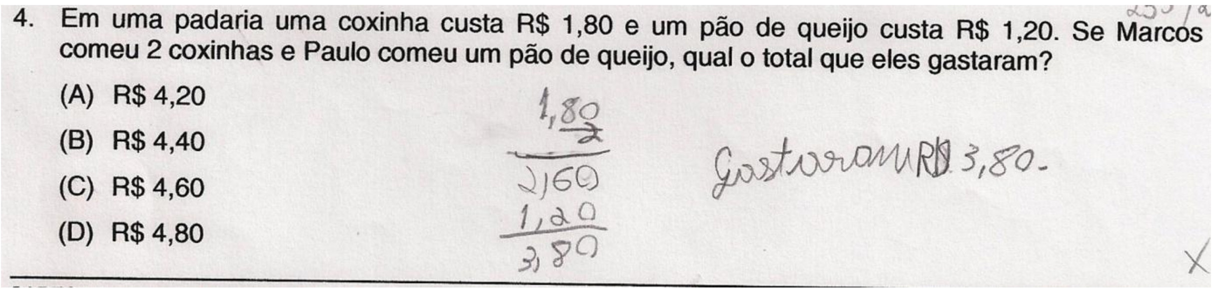


4. Solving the operation (32 + 18) X (2), we get the result:

Figure 8 – Equation solution - SARESP 2007

When asked to identify an irrational number, to solve the problem-situation involving irrational numbers, to perform algebraic operations or to solve second-degree-equations, it is clear that as operations become more complex, involving the knowledge of rules and symbols, participant 2 no longer can solve the exercises. Considering possible associations with expressions of neuropsychological deficits, the mathematical difficulties seem to be related with little cognitive flexibility and self-monitoring failures (executive functions).

The domain in which participant 3 obtained the worst performance was also the one regarding numbers and operations. It can be noticed that he did not understand what was being asked: knowledge on how to do operations and how to answer problems which involve whole and rational numbers, exponentiation, percentages and simple algebra expressions, as demonstrated on Figures 9 and 10.

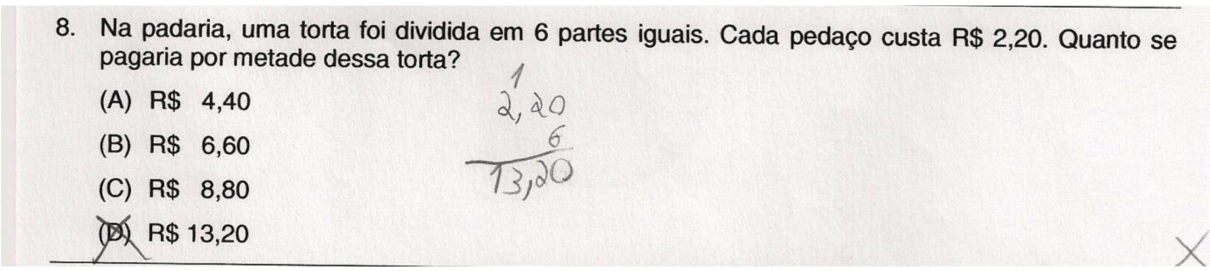

4. Em uma padaria uma coxinha custa R$ 1,80 e um pão de queijo custa R$ 1,20. Se Marcos comeu 2 coxinhas e Paulo comeu um pão de queijo, qual o total que eles gastaram?

(A) R$ 4,20
(B) R$ 4,40
(C) R$ 4,60
(D) R$ 4,80

In a bakery, a Brazilian pastry called *coxinha* costs R$1,80 and a Brazilian type of bread made of cheese called *pão de queijo* costs R$1,20. If Marcos ate 2 *coxinhas* and Paulo ate one *pão de queijo*, how much did they spend?

Figure 9 – the answer of a problem SARESP 2007

The problem above (fig. 9) requires for two calculations to be made: one to multiply and one to add. Participant 3 uses the correct strategy to answer the problem, but makes a mistakes when he multiplies, which leads him not to obtain success in his answer.


8. Na padaria, uma torta foi dividida em 6 partes iguais. Cada pedaço custa R$ 2,20. Quanto se pagaria por metade dessa torta?

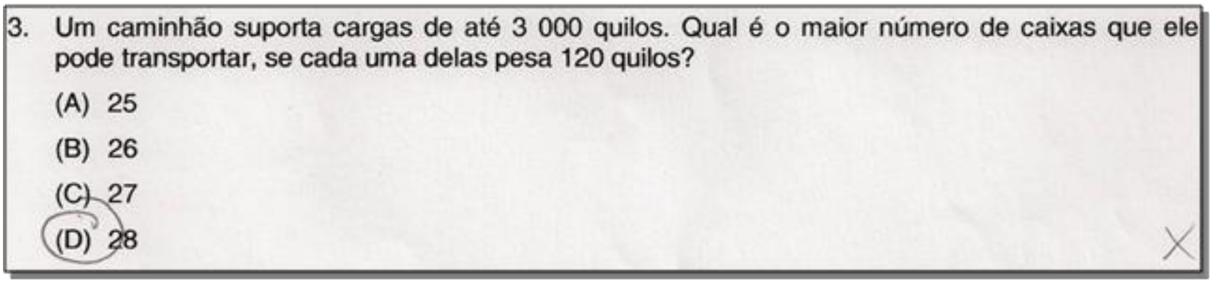
(A) R$ 4,40
(B) R$ 6,60
(C) R$ 8,80
(D) R$ 13,20

8. In a bakery, a pie was divided into six equal pieces. Each piece costs R$2,20. How much would you pay for half of this pie?

Figure 10 – the answer to a problem SARESP 2007

Another type of mistake can be noticed here: after reading the problem (fig. 10) participant 3 believes that all he should do is multiply. Such poor understanding suggests that he did not identify all the pieces of information, for he did not comprehend the question, nor did he identify the relationship between the pieces of data of the problem and the most adequate strategy for its solution. Instead of answering to the question: “How much would you pay for half of this pie”, which answer is “6.60”, he indicated that the total amount would be “13.20”. In this sense, he did not realize that there were two operations to be made in this problem: the multiplication (which he executed) and the division operation. Such question, like the previous one, was not resolved by this participant. Both require two kinds of operations and both involve operations with rational numbers.

In the mathematics domain, in the SARESP test (2007), the areas in which participant 4 attained the worst performance were those relative to numbers and operations, space and form, and in the questions involving space and form he did not present domain of any of the abilities evaluated (geometric constructions, plane figures, angles, triangles congruency). With regard to questions involving numbers and operations, this participant presented conceptual difficulties, and he did not understand the rules of the decimal number system. In tasks of problem resolution involving natural numbers, whether whole or rational, he could not develop an adequate strategy to conclude the exercises and be successful. He had difficulties in defining which arithmetical operations should be used for the resolution of the problems and draw them on paper, which could have aided him in the resolution, as illustrated in figures 11 and 12.


3. Um caminhão suporta cargas de até 3 000 quilos. Qual é o maior número de caixas que ele pode transportar, se cada uma delas pesa 120 quilos?

(A) 25

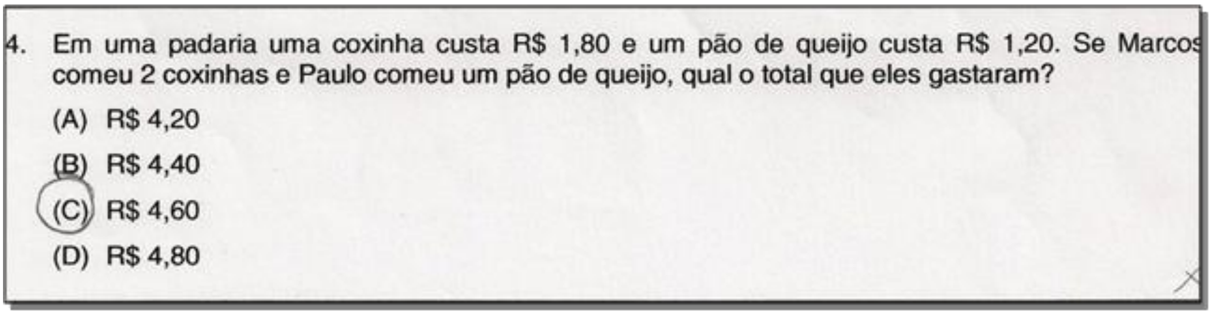
(B) 26

(C) 27

(D) 28

3- A truck can support loads of up to 3000kg. What is the biggest amount of boxes it can carry, if each one weights 120kg?

Figure 7 – the answer to a problem SARESP 2007



4. Em uma padaria uma coxinha custa R$ 1,80 e um pão de queijo custa R$ 1,20. Se Marcos comeu 2 coxinhas e Paulo comeu um pão de queijo, qual o total que eles gastaram?

(A) R$ 4,20

(B) R$ 4,40

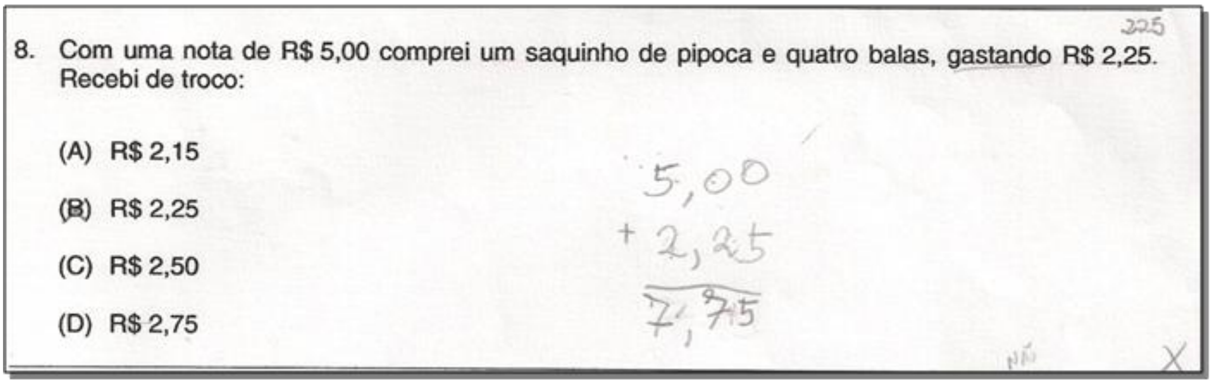
(C) R$ 4,60

(D) R$ 4,80

4. In a bakery, a Brazilian pastry called *coxinha* costs R$1,80 and a Brazilian type of bread made of cheese called *pão de queijo* costs R$1,20. If Marcos ate 2 *coxinhas* and Paulo ate one *pão de queijo*, how much did they spend?

Figure 8 – the answer to a problem SARESP 2007

The questions in which participant 5 had more difficulties were the ones that involved answering problems such as the ones seen on figure 13.



8. Com uma nota de R$ 5,00 comprei um saquinho de pipoca e quatro balas, gastando R$ 2,25. Recebi de troco:

(A) R$ 2,15

(B) R$ 2,25

(C) R$ 2,50

(D) R$ 2,75

8. With a 5 real Bill, I bought a bag of popcorn and four candies, spending R$2,25. I got as change:

Figure 9 – the answer to a problem SARESP 2007

This question, as can be verified, requires for problems to be resolved using the decimal writing of bills and coins in the Brazilian monetary system. It is a question of adding structure, involving subtraction. Participant 5 could not define what was the algorithm to be used. Better yet: he defined the wrong algorithm, for he could not understand the verb used in the question – "spending". Because of that, instead of subtracting, he added. When he did not reach an acceptable answer, he chose the amount of purchase, which was already described in the question. He insisted in the initial approach without choosing another alternative for the resolution of the problem.

The theme in which participant had the worst performance was the one regarding "Quantities and Measures", which emphasizes the skills that allow someone to estimate different measures: time, space, weight, load capacity and the ones connected to the monetary system.

DISCUSSION

In this study we have sought to analyze, in a group of children and adolescents with brain injuries, who had in common normal intellectual development and low achievement in mathematics, predominant neuropsychological deficits and in what domains of mathematical performance would appear their greatest weaknesses. The strong clinical variability related to the brain injuries, typical of these cases, and the reduced number of participants imply restrictions for broader conclusions regarding possible association among the deficits identified and aspects of mathematical performance. However, some reflections can be proposed, considering Cognitive Psychology and Neuropsychology models.

The findings suggest that, regardless of clinical variables like location or extension of the brain damages, children with brain injuries and difficulties in mathematics tend to present visual-constructive and executive functioning alterations. The acquisition of competences related to the concepts related to the domain of Numbers and Operations, such as proposed in the SARESP test, seems to be more impaired in these cases. With regard to the development of mathematical skills, as proposed by Bastos (2003) protocol, the most important difficulties seem to involve the domain of multiplication, followed by problem resolution.

Mathematical ability related to the domain defined as Problem Solving may be related, within the scope of neuropsychological assessment, to the procedures associated to Executive Functions. Indeed, the children were not able to adequately comprehend logical relationships of each problem presented and, as such, could not relate the pieces of information among themselves and could not define the operations required for an adequate answer. In general, we can state that the most important difficulties they have presented were: (a) they use less sophisticated problem resolution strategies or, as generally described by teachers, “immature” strategies; (b) they take a longer time to reach the result; (c) they make many calculation and memory recover mistakes, without realizing it. Another possible association among the areas of neuropsychological functioning and mathematical performance would be between the domain of Space and Form and visual-constructive functions. Participant 5 was the only one among the evaluated cases who did not present visual-constructive deficits, and also did not have difficulties in the items related to Space and Form, suggesting that the preservation of this neuropsychological function favors the acquisition of such competence.

A particular discussion regards the results attained by participants 4 and 5. Both presented, when compared to the others, the greatest number of neuropsychological deficits, including clinical profile of attention deficit, and also difficulties in the two procedures of evaluation of mathematical performance. The clinical variables related to the injury, in these two boys, are very different in each of them, which does not indicate justifications related to the areas affected or to the extension of the brain damages. Therefore, it is possible to consider that the environmental variables, related to pedagogic aspects, to the kind of stimuli they receive or to social interaction better justify the differences in the mathematical performance of these children.

Although the evidences of neuropsychological deficits associated with difficulties in the consolidation of mathematical abilities are frequent, as in the Non-verbal Development Disorder, our findings were not consistent with the concept of a neuropsychological profile in cases of broader injuries associated with mathematical difficulties. However, such findings lead us to consider that the visual-constructive abilities and the executive functioning constitute, to a greater or lesser degree, substantial indicators of greater efficiency for mathematical performance. Such functions possible share neural circuits in common, which integrate frontal and parietal areas, and that would be involved in the manipulation of visual-spatial information and in the resolution of problems, essential cognitive procedures for mathematical development. Finally, the results obtained by the patients do not support the idea of a primary involvement of operational memory in mathematical difficulties, such as highlighted by Geary (2010).

Other considerations concern the interpretation of data obtained with the evaluations based on theoretical models of Cognitive Psychology and

Neuropsychology. For example, a relevant discussion would involve considering what competences would be more essential for the consolidation of the conceptual domains associated with Mathematics, such as proposed by Vergnaud (2009). The results obtained by the participants in mathematical tests particularly suggest that the competences related to the conceptual subject of multiplicative structures (Multiplication) seem to depend essentially upon the consolidation of basic concepts of numbers and algebra notions (Numbers and operations). The acquisition of spatial perception abilities (Space and Form) seems less relevant. Considering the numerical treatment model by McCloskey, Caramazza and Basili (1985), low performance in the item related to Numbers and Operations suggest that the difficulties of the child with brain injuries involve more basic deficiencies related to cognitive procedure involved in semantic representations (comprehension and production of numbers), and not only complex procedures associated to calculation proceedings (multiplication operations). One can thus consider that the learning or pedagogical strategies aiming the stimulation of the mental processes required to dominate different situations related to the domain of Multiplication should also favor the acquisition of these basic concepts.

In summary, the observations made about these five boys with complex brain injuries who experienced various difficulties in learning mathematics lead us to consider the importance of an evaluation of the nature of the difficulties they find in the performance in this subject on a neuropsychological basis. The search for more specific investigation parameters, as well as the development of broader and more comprehensive protocols, based on neuropsychology knowledge, may be relevant both in the context of cognitive rehabilitation and pedagogic intervention.

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Submitted: September 2011

Accepted: June 2012