A friendly technique to study the child neurocognitive development in the school environment

Fábio T. Rocha, Armando F. Rocha and Eduardo Massad

Medical Informatics – LIM 01 HCFMUSP

Faculty of Medicine

State University of São Paulo – Brazil

Address for correspondence:

A. F. Rocha

Rua Maria Inez Carletti, 26

Jundiaí – SP

CEP 13201-813

Brazil

Abstract

Learning disabilities (**LD**) is experienced by 10% of the school aged children and are important causes of school evasion. Modern techniques of brain imaging allow neuroscientist to better comprehend human cognition and to study neurocognitive development. The most popular among these techniques is fMRI, but it requires special facilities and is unfriendly to the children. The development of the microcomputers turned EEG recording very portable and allows it to be used at the school associated with very friendly computer games (**CG**) specially designed to study children neurocognitive development. Here, we describe an EEG brain mapping technique developed for such a purpose. The study of the brain activity during word and phrase reading by normal and learning disabled children is presented as an example of its application. The developed **CG**s were very effective in distinguishing children with a normal school development from those experiencing difficulties in reading.

.

Introduction

Learning disabilities (**LD**) is experienced by at least 10% of the school aged children and they are important causes of school evasion[1,2,3,,4]. Among the major learning disabilities are language specific impairment (**SLI**); dyslexia; attention deficit and hyperactivity disorder (**ADHD**); specific arithmetic impairment; etc. Modern techniques of brain imaging allow neuroscientist a better comprehension of the human cognitive functions. The most popular among these techniques is fMRI, which requires special facilities and is unfriendly to the children. The electroencephalogram (EEG) on the contrary is an easy to use and transportable technique that has been widely used to record the brain activity of disabled children and adults. E.g., delta and theta waves were correlated with **ADHD** and dyslexia[5,6,7]. However, in many (if not all) of these studies the EEG has been recorded in unfriendly environments and the tests used were not specifically designed to study the school progress of **NO** (normal) and **LD** children.

The development of the microcomputers turned EEG recording very portable and allows it to be used at school, networked with another microcomputer used to present very friendly computerized games (**CG**) designed for studying children neurocognitive development at school environment. If **CG**s are programmable to explore language and arithmetic according to the school program, a powerful technique is provided to study the neurocognitive development of **NO** or **LD** children in a very natural setting. Here, we describe ENSCER a computerized technology developed under these guidelines. The imaging of the brain activity during word and phrase reading by **NO** and **LD** children are presented as examples of application of this technology.

Methods

Enscer® has a data base of 5.057 different educational **CG**s developed taking into account the Ministry of Education Guidelines, and aimed to teach and evaluate the

Kindergarten and Elementary School student (Figs. 1). Infantile themes were used to develop **CG**s and a set of infantile characters were created to turn **CG**s more interesting. Enscer® has being now in use for more than 6 years to test and to teach kids in normal or special programs at public or private schools, and it has been considered very friendly by the students. The student solves the problem posed by specific **CG**s while his/her EEG (10/20 system; impedance smaller than 10 Kohm; low band passing filter 50Hz; sampling rate of 256 Hz and 10 bits resolution) is recorded (Fig. 1). Statistical analysis of his/her performance and of the recorded EEG provides data to study a defined cognitive function (Fig. 2). This technique was tested before to study neural plasticity[8] and arithmetic brain processing[9].

The beginning ($\mathbf{t_0}$) of each event **EVE** of a given **CG**; the moment a decision ($\mathbf{t_d}$) is made about it; the type (**DEC**) of this decision; the response time $\mathbf{RT = t_d - t_0}$ and the recorded EEG are saved in the Performance (**PDB**) and the Entropy (**EDB**) Data Bases, respectively (Fig. 3). Bad EEG recordings and the associated performance data were discarded. The linear correlation coefficients $\mathbf{r_{i,j}}$ for the recorded activity by each electrode $\mathbf{e_i}$ referred to the recorded activity by each other of the remaining 19 $\mathbf{e_j}$, were calculated for the EEG epoch associated to each **CG'**s event **EVE** and each volunteer **VOL** (Fig. 2). The entropy $\mathbf{h(r_i)}$ of $\mathbf{r_{i,j}}$ for each recording electrode $\mathbf{e_i}$ was calculated as proposed by Rocha et al (Foz et al, 2001; Rocha et al, 2004; Rocha, Rocha and Massad, 2004).

ENSCER® was used to evaluate the cognitive development of 600 children enrolled in 5 elementary schools: 400 of them considered **LD** by their teachers, and 200 (from the same classrooms) of them considered as mastering the school program (**NO** students). All students were tested on reading (Fig. 4) and arithmetic capabilities; but because of space limitation, only the results concerning to reading will be presented and discussed here.

The results confirmed (with rare exceptions) teacher's evaluation of the students as **NO** or **LD**. The EEG was recorded from 123 of the **LD** children and 61 of the **NO** students. Four experimental groups of 20 (10 males and 10 female) students were constituted according to their language and arithmetic skills (see fig. 4). The first group (**NO1**) was composed by students attending the second grade and beginning to master word reading and one digit addition and subtraction. The second group (**LD1**) was composed by children from the second to the fourth grades and having great difficulties to read a small set of words and to do elementary arithmetic. The third (**NO2**) group was composed by students attending the third degree and mastering phrase reading, and beginning their training on multiplication and division. The fourth group (**LD2**) was composed by children from the third and fourth grades having an acceptable word reading capability and having great difficulties to read a phrase and to do elementary arithmetic. These students have also a story of word reading difficulty in the first two school years.

Results and Discussion

The set of implemented **CGs** was very effective in distinguishing children with a normal school development from those experiencing difficulties in reading and arithmetic. With few exceptions, the tests confirmed teachers´ classification of 400 **LD** students and of 200 **NO** students from the same classrooms. Most of **LD** children were unable to understand the meaning of the tested words and the totality of them had great difficulties in understanding a simple SOV (subject-verb-object) phrase. Their arithmetic capabilities were restricted to manipulated addition and subtraction.

We selected 2 learning disabled (**LD1** and **LD2**) experimental groups from the entire set of 400 **LD** students for the EEG study and 2 control (**NO1** and **NO2**) groups from the 200 **NO** students. The selection aimed to organize homogenous **LD** groups and comparable **NO** groups concerning the neurocognitive development. Age was not taken into consideration because learning disability definition implies **LD** children older than **NO** student. The **LD1** group was composed by children from the 2^{nd} to 4^{th} grades being able to visually compared words but having great difficulties in accessing their meanings. The **LD2** group was composed by children from the 3^{th} and 4^{th} grades being able to access word meaning but having great difficulties in accessing phrase meaning and a story of word reading difficulties in the first school years. The arithmetic **LD1** and **LD2** capabilities were restricted to very simple illustrated one digit addition and subtraction. In contrast to **LD1**, the **NO1** students were able to access the meaning of the majority of the tested words and were able to solve illustrated one digit addition and subtraction. In contrast to **LD2**, the **NO2** students were able to understand the majority of the tested phrases; to master two digit addition and summation and one digit multiplication and division.

Both **WR** and **WM** tasks involved:
a) to load the target word in working memory;
b) to scan the possible matching words and/or figures;
c) in the **WR** case to visually compare the target and the scanned matching words; or in the **WR** and **WM** cases to access the verbal meaning of the target word;
d) to recode the scanned matching visual images into verbal meaning and to compare with the target word meaning, and finally,
e) to select the best matching.

Thus, our **WR** and **WM** tasks require the intervention of the so called executive functions[20,21] (e.g. working memory; visual scanning control, etc.); a verbal to visual or visual to verbal semantic recoding[22,23,24], and the selection of the most acceptable solution.

NO1 word reading (both **WR** and **WM**) was associated with 3 different patterns of brain activity as disclosed by the Factorial Cognitive Brain Mappings (**FCBM**s on Fig. 5). **NO1–F1–FCBM** shows a bilateral high correlated activity at the anterior brain that may be associated with the reading executive functions[10,11]: e.g., target word loading in the working memory and the temporal and spatial eye scanning control of the possible matching words or figures. **NO1–F2**-**FCBM** shows a high bilateral correlated activity at the posterior brain that may be associated with both the visual recognition of words and figures and the associated meaning processing[12,13,14]. Finally, the **NO1–F3**-**FCBM** shows a strong correlation between the entropy calculated for the left and right temporal lobes in the **WR** case, and between the entropy calculated for the right and left temporal and parietal electrodes lobes in the **WM** case. We may assume that **NO1–F3**-**FCBM** discloses the brain activity associated with the final decision about the most acceptable solution. Bilateral association disclosed by all 3 **NO1–FCBM**s is in accordance with the fact that our wording reading tasks involves both visual (a preferential right hemisphere function) and verbal (the left hemisphere specialization) processing and association of these results.

WR in the **LD1** group was associated with 3 different patterns of brain activity as disclosed by the **LD1–WR–FCBM**s (Fig. 5) that keep some similarity with those **NO1–WR–FCBM**s. The most important differences are observed for the **F2-FCBM**s and **F3-FCBM**s. Accepted that **F2–FCBM** disclose those activities involved in semantic decoding and recoding, then the fact that **LD1–F2–FCBM** shows $\mathbf{h(r_i)}$ correlation for a small number of electrodes if compared to **NO1–F2–FCBM** may indicate less involvement of word meaning access by the **LD1** compared to the **NO1** students in **WR** solution. This is in agreement with the fact that **LD1–F3–FCBM** involves a number of electrodes higher than that for **NO1–F3–FCBM**. This may imply that **LD1–WR** solution depended mostly on a more complicated visual analysis of word lettering, rather than on a word meaning assignment. In addition, factorial analysis disclosed only two patterns of brain activity for **WM** solution in **LD1.** **LD1–F1–FCBM** discloses a high correlated bilateral anterior activity that may be correlated with the executive functions discussed above and **LD1–F2–FCBM** shows a strong $\mathbf{h(r_i)}$ covariation at the posterior brain that may be correlated with unsuccessful attempt to associate meaning to the target word from the visual analysis of the possible matching figures.

NO1–RCBMs (Fig. 6) shows that **NO1–RT** correlated with **h(r$_i$)** calculated for most of the electrodes disclosed by **NO1–F1–FCBM** and perhaps involved with the reading executive functions, and with some of the electrodes of **NO1–F2–FCBM** that are perhaps involved with verbal and visual semantics analysis. In addition, **NO1–RT** was positively correlated with **h(r$_i$)** associated with some electrodes and inversely related with that calculated for other electrodes. This means that the activity at some sites delayed and at some other sites accelerated decision making. In contrast with these results**, LD1–RT** is correlated mostly with **h(r$_i$)** calculated for the right hemisphere, and **LD1–RCBM**s are not very similar to **LD1–FCBM**s, corroborating the hypothesis that **NO1** and **LD1** differed in the strategies used to solve the **WR** and **WM** games[5].

The **LD2** children have an acceptable **WM** performance but they experienced in the past the same **LD1** difficulty in accessing word meanings. **WM–LD2** is associated with 3 patterns of activities that are completely different for those patterns disclosed for **NO1–WM-FCBM**s. There is no **WM–LD2–FCBM** that may be correlated with anterior brain executive functions and posterior brain semantic activities. Instead, all 3 **WM–LD2–FCBM**s show **h(r$_i$)** covariations that are mostly unilateral and involving both anterior and posterior electrodes. Two of these mappings disclose different left hemisphere patterns of activity, while the third one shows a pattern that involves mostly the right hemisphere electrodes. In addition, **LD2–F2–RCBM** is very similar to **LD2–F2–FCBM.** It seems, therefore, that **WM** mastering in the case of **LD2** children is supported by a different neural processing than that normally used by **NO1** students[5].

PM task involved first to listen to the oral text and to see the figures of the illustrated story about environment preservation, and later to read phrases about this story and to correlate it to one of five previously sawn scenes or animals (see Fig. 1). The test required, therefore, a) to read a phrase; b) to recall both verbal and visual information from the listened story; c) to identify the part of the story associated with the phrase and d) to scan the possible figures for the best matching. Factorial analysis disclosed 3 patterns of brain activity associated to **NO2–PM** understanding (Fig. 6). **NO2–PM–F2–FCBM** discloses a correlation among left hemisphere electrodes that may be correlated with the phrase reading and decoding[16,17]. **NO2–PM–F1–FCBM** in turn shows an association among right hemisphere and left anterior electrodes, that may be associated with recalling the listened story and identifying the visual elements associated with the decoded phrase[10,11]. Such activities involve the frontal executive areas and right visual processing systems. Finally, **NO2–PM–F3–FCBM** may disclose the brain activity correlated conflict solving and selection of the best **PM** understanding. Once again, the unsuccessful attempt in phrase reading by **LD** students is associated with two brain activity patterns and it is quite different from the **NO** children[18]. **LD2–PM–F1–FCBM** discloses a strong $\mathbf{h(r_i)}$ covariation for 18 of the 20 recording electrodes, and **LD2–PM–F2–FCBM** shows a bilateral association of the posterior brain. It seems that **LD2** students are unable to organize their brain activity to decode the phrases.

We may conclude from the above that the Educational Computer Games and the EEG technology described here are useful tools to study the neurocognitive development of normal students and children experiencing learning difficulties in the very natural school environment.

References

1- Bakley (2003) Attention/Hyperactivity Disorder In Child Psychopathology. (Eric J. Mash and R. A. Bakely. eds). The Guilford Pres. New York. 75-143

2 - Biederman, J. and S. V. Faraone (2005) Attention-deficit hyperactivity disorder *The Lancet*, *Volume 366: 237-248*

3 - Bush. G. Valera.E. M. and Seidman. L. J (2005) Functional Neuroimaging of Attention-Deficit/ Hyperactivity Disorder: A review and suggested future directions. Biol Psychiatry 57:1273-1284

4 - Rocha, A. F., E. Massad and A. Pereira Jr. (2004) The Brain: From Fuzzy Arithmetic to Quantum Computing, Springer Verlag

5 - Harmony, T, T. Fernández, J. Silva, J. Bernal, L. Díaz-Comas, A. Reyes, E. Marosi, M. Rodríguez and M. Rodríguez (1996) EEG delta activity: an indicator of attention to internal processing during performance of mental tasks. Int. J. Psychophysiology 24:161-171

6 - Klimesch, W., M. Doppelmayr, H. Wimmer, J. Schwaiger, D. Röhm, W. Bruber and F. Hutzler (2001) Theta band power changes in normal and dyslexic children. Clinical Neurophysiology 113:1174-1185

7 - Rippon, G. and N. Brunswick (2000) Trait and state EEG indices of information processing in developmental dyslexia. Int. J. of Psychophysiology, 36:251-265

8- Foz, F. B., Luchini; Palmeri, S., Rocha, A. F., Rodela. E. C.; Rondó, A. G., Cardoso, M. B. Ramazzini, P. B.; Leite, C. C. (2001) Language Plasticity Revealed by EEG Mapping. *Pediatric Neurology* 26:106-115

9 - Rocha. F. T., A. F. Rocha, E. Massad and R. Menezes (2004) Brain mappings of the arithmetic processing in children and adults. . Cognitive Brain Res. 22: 359-372

10 – Baddeley, A. (2003) Working memory and language: an overview. J. Communicaiton Disorders, 26:189-208

11 – Faw, B. (2003) Pre-frontal executive committee for perception, working memory, attention, long-term memory, motor control and thinking. A tutorial review. Consciousness and Cognition 12:83-109

12 - Trauzettel-Klosinski, S, Dürrwächter, U. , Klosinski, G. and Braun, C. (2006) Cortical activation during word reading and picture naming in dyslexic and non-reading-impaired children Clinical Neurophysiology, 117: 1085-1097

13 - Naghavi, H. R. and Nyberg,L. (2005) Common fronto-parietal activity in attention, memory, and consciousness: Shared demands on integration? Consciousness and Cognition, 14 390-425

14 - Wallentin, W. , Roepstorff, A., Glover, R. and Burgess, N. (2006) Parallel memory systems for talking about location and age in precuneus, caudate and Broca's region NeuroImage, 32:1850-1864

15 - Ramus, F. (2003) Developmental dyslexia: specific phonological deficit or general sensorimotor dyfunction? Current Opinion in Neurobiology, 13:1-7

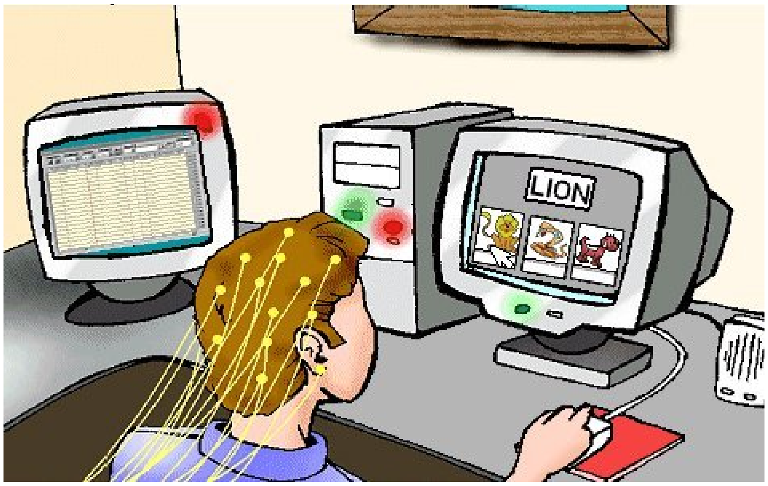
16 - Kuperberg,G. R Lakshmanan, B. M, Caplan, D. N. and Holcomb, P. J (2006) Making sense of discourse: An fMRI study of causal inferencing across sentences NeuroImage, :343-361

17- Xu, J. Kemeny, S., Park, G. , Frattali, C. and Braun, A. (2005) Language in context: emergent features of word, sentence, and narrative comprehension NeuroImage, 25: 1002-1015

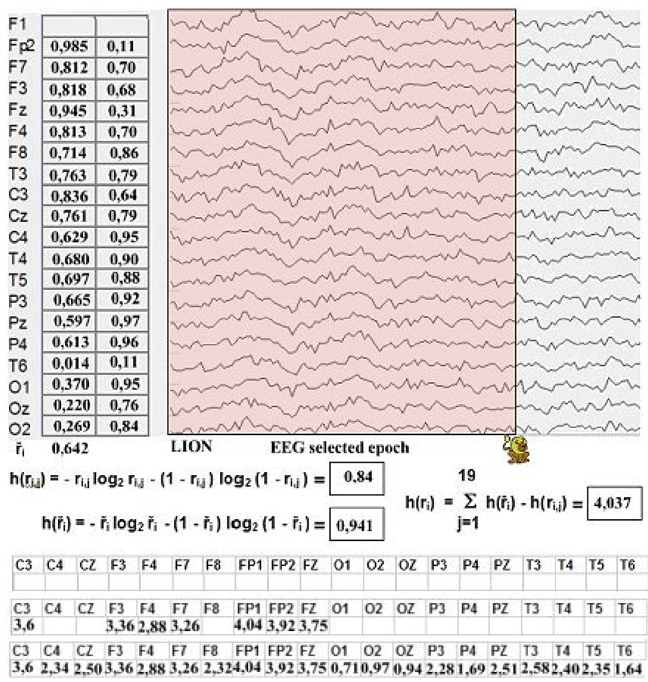
18 - Oren, R. and Breznitz, Z. (2005) Reading processes in L1 and L2 among dyslexic as compared to regular bilingual readers: behavioral and electrophysiological evidence. J.Neurolinguistics, 18:127-151

Fig. 1 – Language activities

Stories are presented to the child frame by frame or as a flash-movie. Both the oral and written texts are provided. For each story, different sets of games (**CG**) are developed to teach or test semantic reading or writing of words or phrases. Reading **CG**s require the child to select the best picture matching to a selected word or phrase from the story text. The pictures are either scenes or refer to elements or characters of the illustrated story or movie. Writing **CG**s, require the child to solve a crossword game or to write a small phrase about a character or scene. In each recording session, the child first sees the illustrated story or movie and after that plays the reading/writing **CG**s..



Two networked microcomputers are used to record the EEG activity (10/20 system) while the individual is solving a specific cognitive task. The beginning of each task and the moment a decision is made are saved in the database together with the type of decision-making (DEC) and time required (response time RT) to achieve such decision.



The linear correlation coefficients $r_{i,j}$ for the recorded activity at each recording electrode e_i referred to the recorded activity for each other 19 recording sites e_j are calculated for each event EVE of a given CG performed by a given volunteer VOL. These $r_{i,j}$ are used to calculated the correlation entropy $h(r_i)$ for each recording electrode e_i . In this way, $h(r_i)$ is calculated for all 20 recoding electrodes.

Fig. 2 – The EEG recording and pre-processing

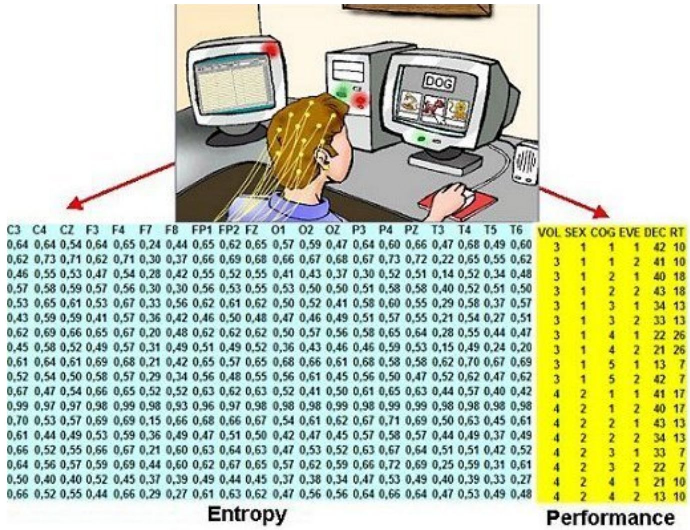
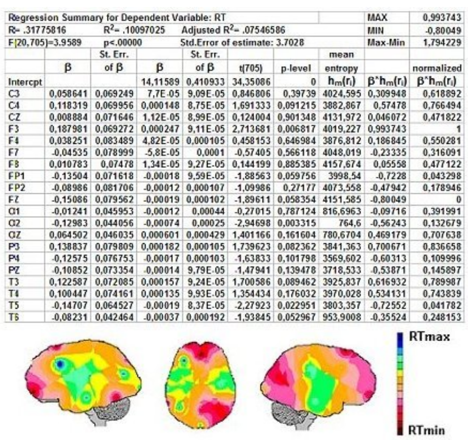
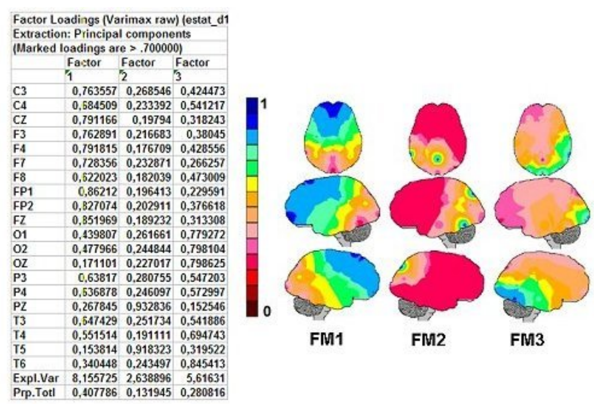
<table>
<tr><td colspan="2">
</td></tr>
<tr><td colspan="2">Decision-making DEC and the response time RT for each Entropy, for each event EVE and each volunteer VOL are saved in the Performance Data Base (PDB). Other pieces of relevant information (e.g. Sex) are also part of PDB. The corresponding values of $h(r_i)$ constitute the Entropy Data Base (EDB).</td></tr>
<tr><td>Regression Analysis</td><td>Factorial Analysis</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Regression Cognitive Brain Mapping</td><td>Factorial Cognitive Brain Mapping</td></tr>
<tr><td>Regression analysis between a given Performance Index (e.g., RT or DEC) and $h(r_i)$ is used to build the Regression Cognitive Mapping (RCBM). Each RCBM shows the contribution $\beta_i\ h_m(r_i)$ of each electrode e_i to RT or DEC. $h_m(r_i)$ is the average of $h(r_i)$ calculated for all volunteers.</td><td>Factorial Analysis is used to build the Factorial Cognitive Brain Mappings (FCBMs) showing how the regression entropy $h(r_i)$ of all electrodes covaried in a given task. In general, 3 loading factors account for more than 60% of $h(r_i)$ covariation.</td></tr>
</table>

Fig. 3 – The EEG Mapping procedures

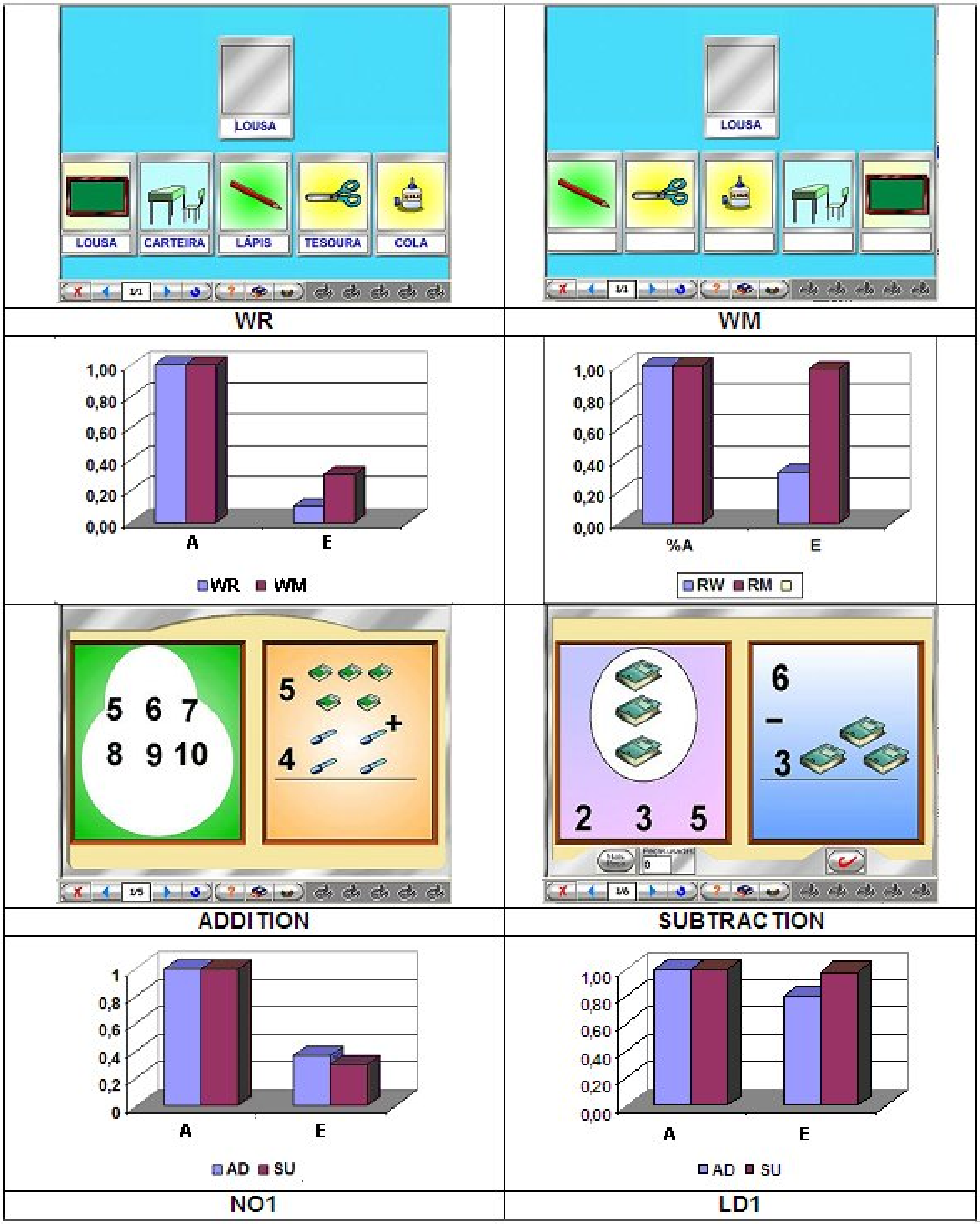


Fig. 4 –The cognitive tests and group performance

RW – Word Recognition; RM – Word Meaning Recall; AD – Addition; SU – subtraction; A – Percentage of children completing the task; E – Percentage of errors; NO – Normal children; LD – Learning Disabled children.

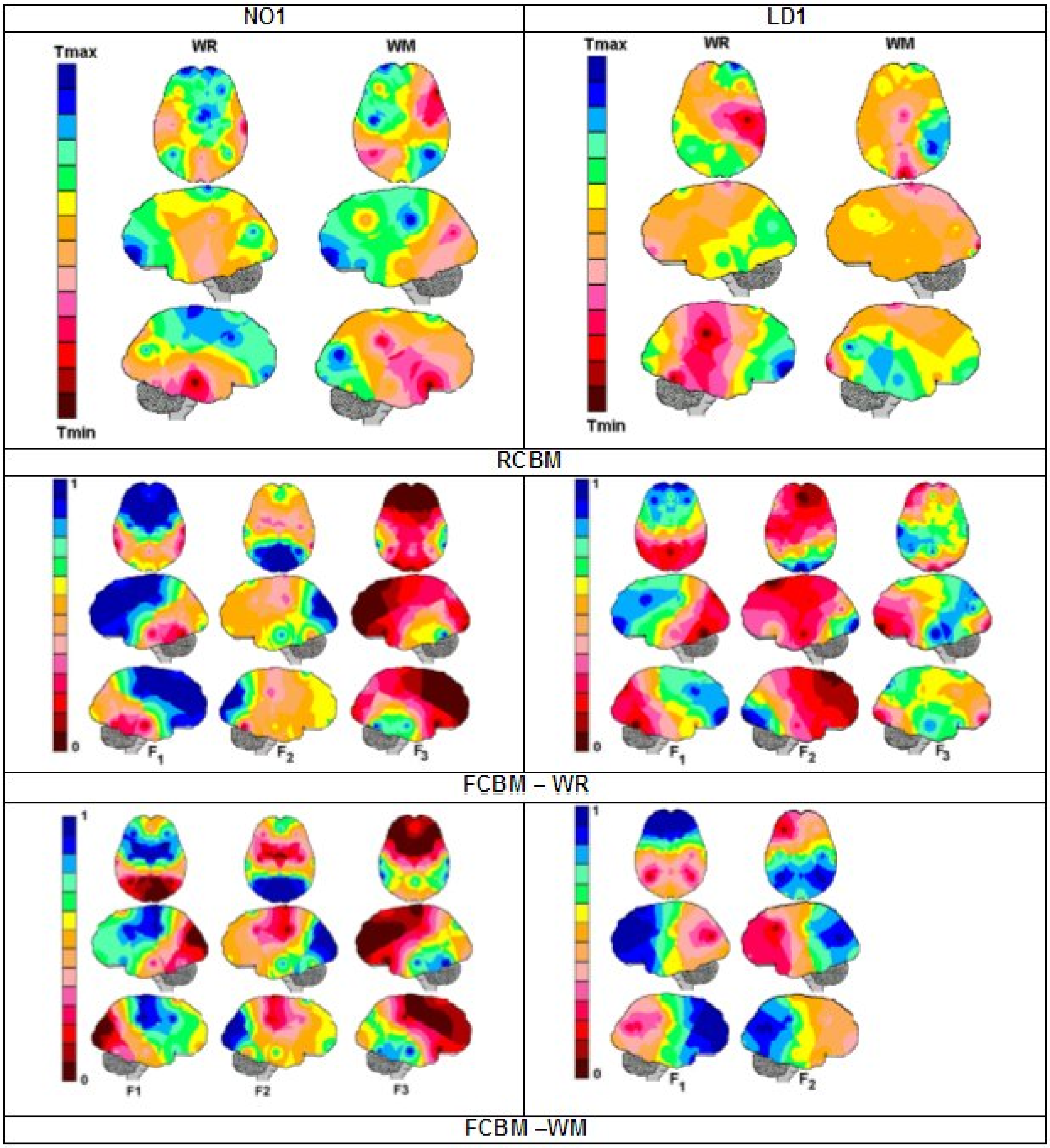


Fig. 5 – Word reading

Factorial Cognitive Brain Mappings (FCBM): display the loading (varying from 0=red to 1=blue) for each recording electrode r_i for each of the three different factors (F_1 to F_3) explaining 80% $h(r_i)$ of covariance. Regression Brain Mappings (RCBM): display the the contribution of $h(r_i)$ to the regression $RT = A + b_i\ h(r_i)$. Blue electrodes contribute to increase RT and red electrodes contribute do decrease RT. NO1 – normal students, LD1 –

Learning disabled students; WR – word recognition; WM – word meaning recall

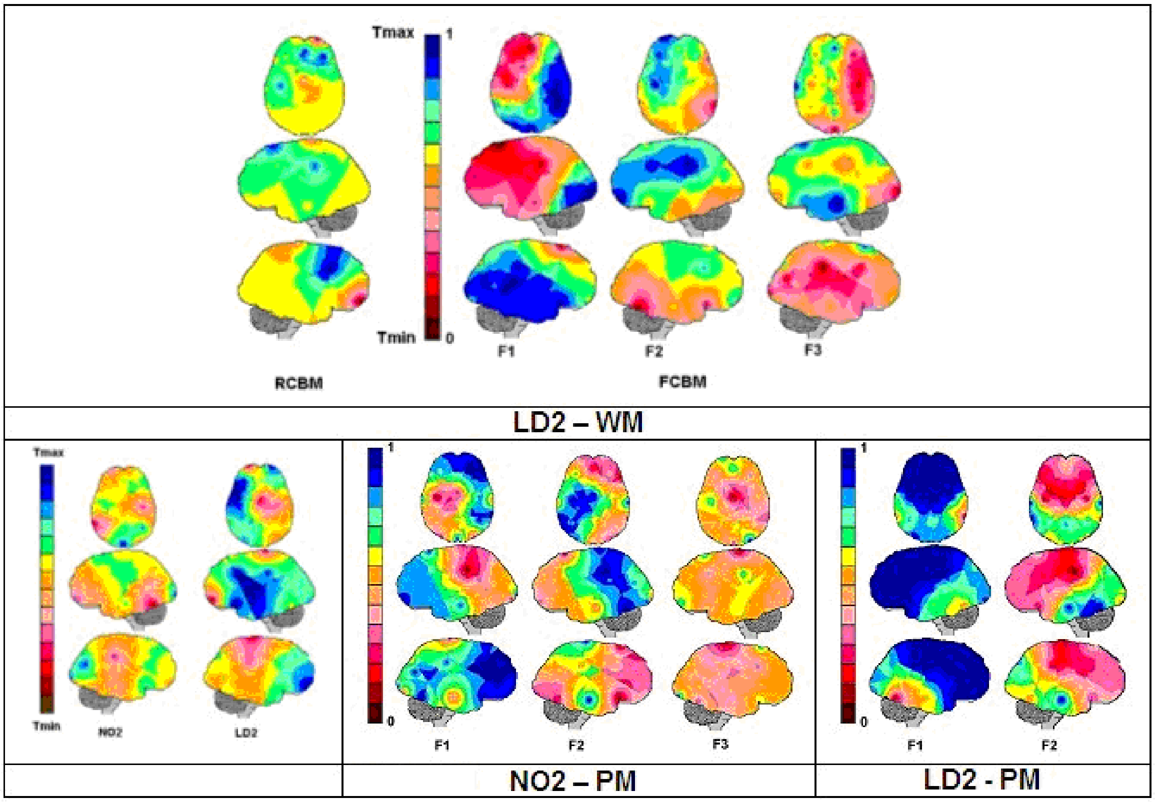


Fig .6 – Word and phrase reading

FCBM and RCBM as in Fig. 5. NO2 – normal students. LD2 – learning disabled children. WM – word meaning recall. PM – phrase meaning recall

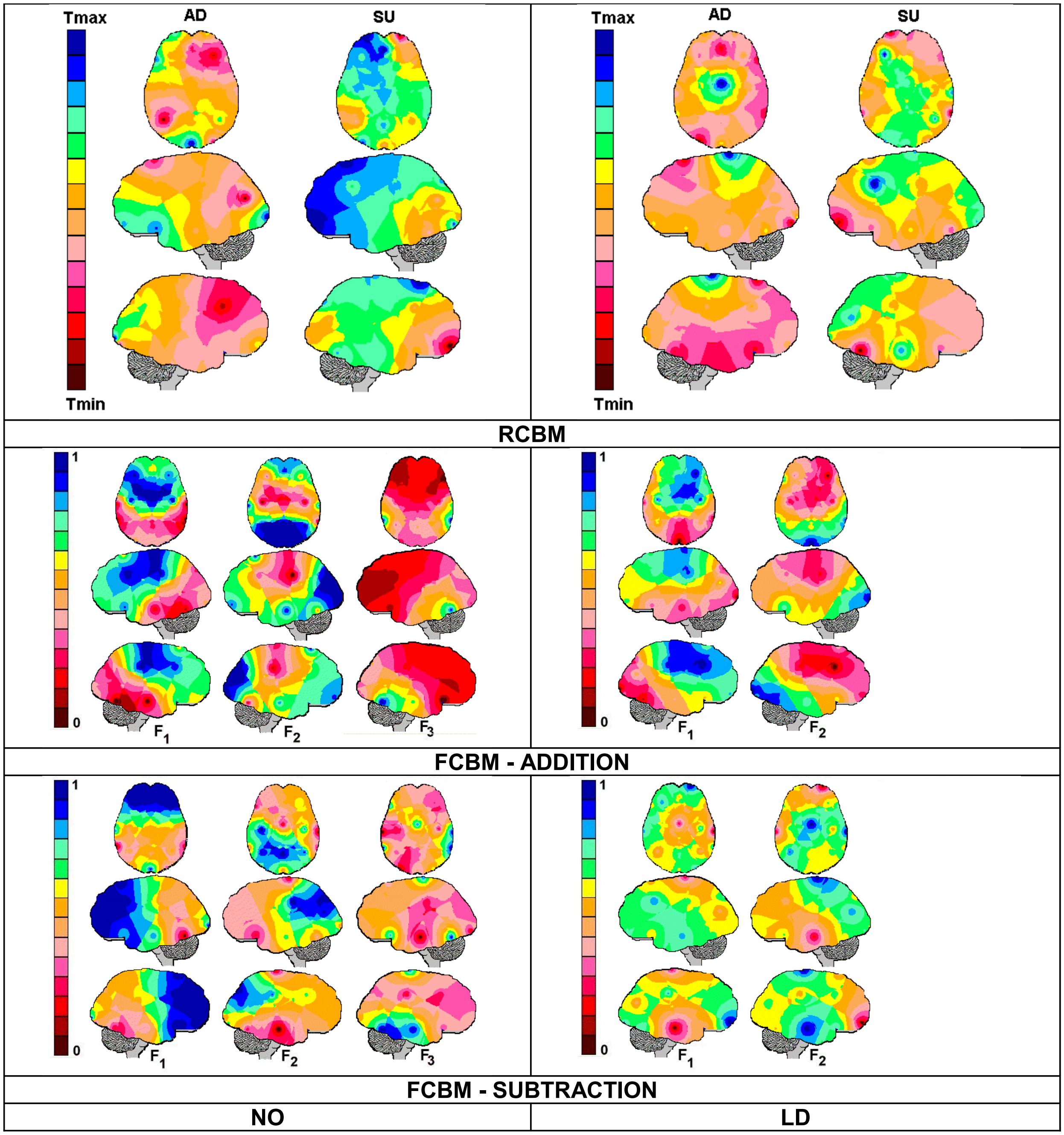


Fig. 8 – Arithmetic