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NEUROTECHNOLOGIES FOR EDUCATION IMPROVEMENT: SELF-KNOWLEDGE AFTER OPENING THE BLACK BOX

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Abstract: *In the framework of new neurotechnologies available for education improvement, a general referential conceptual model of brain operation and functioning, together with some different ways to visualize brain processing, in terms of functional architectural activity patterns, during basal and cognitive tasks, are presented. The model proposed is based on a general description of interacting modules in the brain, acting as coordinated and mutually regulated units, assembled in terms of temporal synchrony and tuning correlations measured between EEG channels, recording cortical brain activity during different tasks. An exploratory method to allow data gathering for channels spectral map visualization and functional EEG architectural patterns of basal brain activity and cognitive tasks is presented to determine inter- and intra-individual differences and the potential of individual identification based on this approach. Results obtained in this way support the idea that it is possible to extract distinctive individual characteristics coming from cortical brain activity and that different tasks and performances can be potentially correlated with different functional and structural architectures that arise as indicative of different ways to process information during cognitive and resting state. A final reflection is made about how this investigative approach can be used to education in terms of didactic and educative paradigms´ testing and as a bridge to communicate and involve students in their own process of cognitive change during learning.*

Keywords: *EEG, channels spectra and maps, brain synchrony and tuning, functional architectures, coordination and self-regulation, brain activity assembles maps.*

Introduction

Actually, one of the main problems in education has its roots in the lack of proper and up to date knowledge concerning to the neurocognitive domain implied in any learning process. This inner, and hitherto hidden domain, has been traditionally treated as a black box, a way of knowing where the only information we can have from it arise as a contingent correlation that we can make between inputs and outputs. Though it has been a useful procedure to understand mechanical systems (Kabiri 2002; Witters and Swevens 2010) it could not necessarily be a good strategy to grasp dynamic and complex systems where outputs vary through time and especially when this is exactly what you are expecting of them to occur, that they change in time because of learning. During the last 10 years neuroscience has started to influence many fields related with human behavior (Zhang 2003) but there is no real impact in one of the most important activities of human culture yet: the education system (Howard-Hones 2007). Even though we may have increased our knowledge in many of the cellular and molecular mechanisms implied in learning processes (Kandel 2000) we still are far to translate these micro-scale knowledge to the macro-scale phenomena where human education occurs. The context we call educational is a complex domain of human social behavior where we found a plethora of variables interacting to give raise to multiple and coexisting particular and specific systems interacting with many other of similar makeup. Here, we can distinguish several aspects that come together in such a way that any of them can be as important as any other, depending on the particular trajectory of the implied system under study. Taking a bit of distance from the technical jargon hitherto used, we are going to refer to this system under study as a student, a boy or a girl immersed in a set of rules that are supposed to guide them by a path of increasing knowledge and abilities to face the future. But what we see today in many countries is an educative crisis that explicitly manifests in social phenomena as exhaustion of the used methodology or vision, probably because we continue applying a method and practice invented more than a century ago without considering the huge changes that society and knowledge has experienced and accumulated during this time. One of these changes has occurred almost recently with the rise of audiovisual revolution. It started with electronics and TV invention andtoday has reached unexpected frontiers with an amazing offer of audiovisual devices and computer games that are light years ahead of any teacher trying to capture the attention of his audience. In this respect maybe one of the big mistakes carried out by educational psychologists from some decades ago was to believe that stimulation (and overstimulation) has as good results in children as in experimental rats. In a number of classic papers (Diamond et al. 1964, 1991) experimental psychologists and neurobiologists showed that rats reared in an enriched environment produce more neuron connections in their brain than similar rats reared in a poorly stimulated environment. These results allow assuming immediately that stimulation is good for the brain. Probably it is, but as any other kind of stimulation it depends on the dosage. For years has been known that excess of any stimulant trigger first a habituation response without a significant effect of the stimulant after many stimulations, and after that what it is obtained is a reverse consequence of the desired effect. That is the reason because psychiatrists prescribe methylphenidate (an amphetamine derivatepsychostimulant) to diminish hyperactivity and treat attention deficit disorders. More than 50 years before to the rats research, in 1908 Yerkes and Dodson showed that almost all drug treatments based on a stimulus-response paradigm rules under an inverted U-shaped plot that represent three phases of the phenomena (Fig. 1). First, there is an almost linear relationship between stimulus and effect, resulting in a bigger response with a bigger stimulus; second, there is a plateau zone where no significant effect is seen with dosage increments, and then there is a negative correlated part of the curve where the more the stimulus the worst (or the contrary) is the effect.

Probably, at the time of the results coming from the environmental enriched experiments with rats, nobody took notice of the Yerkes-Dobson findings to put some regulation to the enthusiasm to transfer these results directly to humans. Or maybe nobody could effectively stop the avalanche of overstimulation that started the color TV and that has reached our present days. Whatever be the case this is only an example of what can happen when we do not know enough about the system in which we want to add an improvement based on scientific findings. The case now is that we still do not know enough about what happen in several biological domains intertwined in the framework of education process. We still do not know what happen in the brain of the students when they learn something, or when they have difficulties to learn something, or when they have to spend a significant time learning something that requires several steps of increasing difficulty.

The Model

For our purposes here, we choose to think about the brain as an always working system of processes, built up by a number of operational units. Most of these units have specific localization, but others work as a disaggregated net, not necessarily in any specific place or area of the brain. There is a functional modulation of processes that operates like a parallel activity of stimulatory and inhibitory interplay, maintaining a balance between two forces: approach and retreat. All the operation units of this net are communicated, in the sense that any part of the system can be tuned and synchronized with any other. Tuning and synchronization are the expression of the actual "synchrony-tuned" working state of the system. And it must be a defined parameter that characterize synchrony-tuning (S~T) state for any different task (action). We will associate S~T with the degree of efficient focused attention that the system have during a task and relates directly with the degree of order within the quasi-stable and almost chaotic (quasi-predictable) background activity. S~T have a value that comes from evaluate the net configuration that the system have during a period of time. Net configurations have five principal parameters: the degree of interconnectivity, the degree of synchronicity and tuning, net strength and complexity. The system has been evolutionary designed for predicting, so it is always gambling about the future, the more the experience (knowledge) it has, the fewer mistakes it makes. At the same time, the system is always running in a tilted plane, or rather, it is always running down and cannot stop this falling unless it dies (or stop working). As the system is in a kind of free fall it is always obligated to take decisions. The system can take three kinds of decisions: to slow down, to accelerateand/or to change direction. To slow down means to inhibit the working process of some specific units. To turn, or change direction, means to start with a new pattern of functional connectivity which results in a different output. In an always ongoing working system, all the implied units are mutually regulated, activating or inhibiting each other. It is necessaryto count on a reference plane against to make sensible comparisons, but this is not an absolute referencebecause it varies between some limits, changing the relative value of the ongoing parameters and, consequently, the following outputs. Any operating unit, or a configuration of them, can constitute a reference plane to contrast with. In a sense, this reference acts as a threshold, changing the character and the relative value of the ongoing activity that can also be, for example, an ongoing evaluation process. So the system is self-relative because uses itself as a reference to evaluate and gamble into the future (Fig. 2). During its development the system acquires two characteristics: it develops preferences and abilities. Preferences are attractor states, manifested as specific net configurations of tune and synchronicity between operating units, where the system "likes" to be; and abilities, as particular and specific net configurations (of tune and synchronization) that makes the things easier for the system and from where it can profit gaining or saving energy. It can happen that an abilitycan be, at the same time, a preference or vice versa. To work more efficiently (using less energy and/or time) the system must be able to make use of its resources in a way that it uses the minimum necessary operating units and the minimum necessary intercommunication between them. So the process runs easier and faster using only the minimal necessary elements during the required time. To do this, the system may have specialized units for specialized tasks, such specializations comes from some evolutionary constraints and from a history of recurrent interactions and co-adjustment that ends in a specific stable (strange) attractor configurations for solving specific tasks or problems. With this model in mind we are going to start to evaluate some of the parameters above described with the purpose to have a better characterization of a system in terms of its ongoing activity state and predominant attractors.

Neuroexploratory Method

EEG channel recordings of human subjects were taken under basal (resting state) and problem solving conditions and they were characterizedand compared in terms of spectral activity maps, tuning and synchronicity, to determine inter- and intra-individual differences in the way student's brains rests in a default (basal) state (Fig. 3) or process information during a task (Fig. 4 & 5). Maps were compared to establish common preferences and descriptive functional attractor for some activities and a comparative index, during task solving or basal state, were derived from the analysis. One task solving experiment consisted in the resolution of an abbreviated version (15 questions) of the Raven test (Fig. 4), and a second test were performed to compare intra-individual brain co-channels correlation patterns consisting in the task of drawing 4 consecutive motifs: human face, human body, abstract figures and common objects (Fig. 5). EEG sample rate was 128 Hz and the electroencephalogram device was a brain-computer interface (Emotiv-EpocTM). Signals were cleaned of artifacts by visual inspection and software based on ICA and subsequent component rejection. The signal was filtered using a FFT noise estimation filter to extract the upper 25% of signal intensity. Channel spectra and maps (Fig. 3 and Fig. 4) were generated with EEG-LAB on a MatLab platform. Image analysis of the FFT channels 2D spectrograph maps were performed with ImageJ and ImageDiffto estimate tune similarity and a Spearman linear correlation analysis gave us values of synchronicity between pairs of EEG channels. Both parameters were combined to obtain an idea of synchrony and tuning between paired electrodes. High values of linear correlations and high tune similarity resulted in high strength electrodes inter-correlation, represented by the width of a black line connecting couples of electrodes. Dashed lines indicate anti-synchronic or negative correlations (Fig. 5).

Figure 3 shows intra- and inter-individual differences in the spectral maps activity of ten subjects (S1 to S10) during 3 minutes of EEG recording in basal conditions (resting state, awake with closed eyes). Maps represent channel activation and spectral predominance

FIGURES

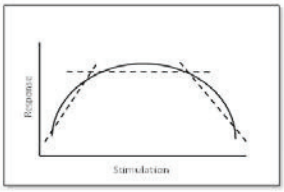

Figure 1

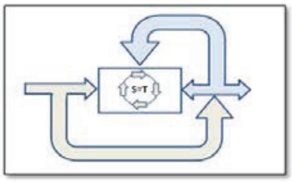

Figure 2

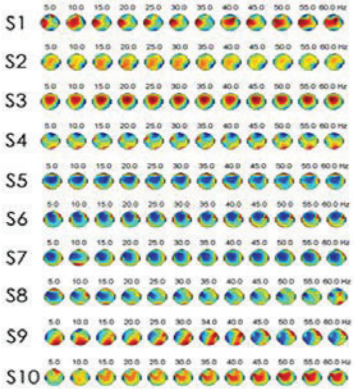

Figure 3

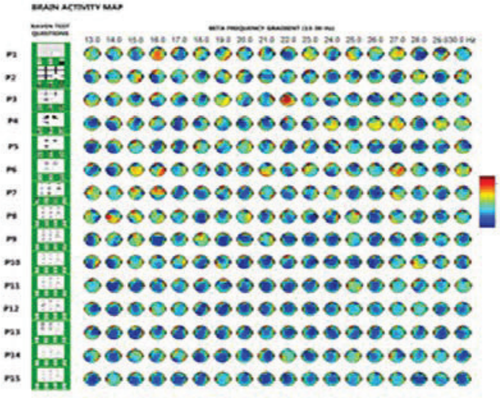

Figure 4

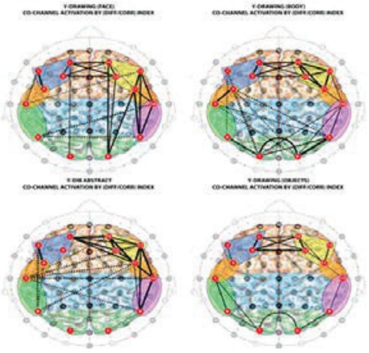

Figure 5

for EEG data range from 5 to 60 Hz, in 5 Hz increasing steps. High inter-individual and low intra-individual differences are evident allowing obtaining good identity characteristics from all of them. Figure 4 shows intra-individual EEG beta range (1 Hz steps) EEG spectral maps variation during the resolution of the Raven test. Maps reveal evident changes in information processing strategy related to increasing task difficulty (questions P10 to P15). Figure 6 shows intra-individual variation of the synchrony-tuning maps during a task of drawing four consecutive artistic motifs: human face, human body, abstract figures and common objects, during a time length of 3 minutes for each drawing in a wholeEEG range: 0.5 Hz(delta) to 60 Hz(gamma). White numbers in red circles represent electrode locations over the 10-20 EEG standard system background reference map. Color areas indicate frontal, temporal and parietal zones. Obtained maps reveal different clusters of EEG electrodes signal correlation expressed in high synchrony and tuning. Dashed lines represent inverse (negative) correlations.

Discussion and Conclusions

Nowadays neurotechnologies can allow researchers and educators to have new ways to represent and see the processes involved in the brain during different situations of interest (Díaz et al. 2011, Díaz et al. 2012). In some way this is equivalent to start opening the black box of the brain to reveal individual differences, tendencies and in-developing long-term processes,and start to know about the way brain use information to solve problems in learning tasks. This powerful tool can be applied, for example, to compare results coming from applying alternative educative paradigms. Actual neuroscience technologies allow for the first time to have a better comprehension and detail of what makes a difference between individuals with different performances and how different tasks and body-mind states trigger different ways to be or to solve problems, according these individual constitutive, but malleable, disparities. They also allow following brain dynamics changes during long-term learning processes and to relate these changes to behavior. At the same time, a long-term monitoring can facilitate teachers guiding learning processes by means of the use of alternative didactics that can be evaluated accordingly, and more important, to share this information with the students, that can have new and novel manners to have access to what is happening in his or her brains and associate this with its own ongoing or developing behavior or way of thinking. This new feedback loop that now can be established can be used volitionally to strengthen new ways of thinking-acting motivated by the interest of seeing what will happen the next time their brains are confronted with new challenges. With these new tools we, as researchers, can start to test hypothesis concerning if there are specific and recognizable (repetitive or regular) patterns of cortical brain areas coordination and connectivity that correlates with differential inter-individual performances or if any different brain finds their own and optimal way to solve imposed cognitive challenges. Using these technologies to test and explore these and many other questions, together with sharing the resulting findings with the testing subjects (the students) will allow establishing a new nexus between educators, parents and students, a bridge that every day is less used in a number of developed and developing countries and that heavily calls for attention because is this nexus which ensures big part of cultural trans-generational transmission.

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