A Cognitive-Driven BCI-Based E-Learning Platform For Learning Disorders: A Preliminary Study

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Abstract. E-learning represents a consolidated practice in education, as a support to traditional classroom-based lessons, in distance, blended and continuous education and, in more recent times, increasing enough as a mean for self-assessment and self-training to maximize learning results. Despite of this overall interest, however, little attention has been devoted to adopting advanced technology-based e-learning approaches in developing specific platforms to support students experiencing Learning Disorders (LDs) difficulties. Among all, cognitive technologies could be integrated in advanced training platforms to empower students' abilities, especially in case of LDs. Indeed, several studies focuses on LDs, especially analyzing: correlations among them, theories about their intern relationships and certain biological models on their basis. Also, computer-aided supports have been studied as a booster in learning process, to compensate individuals' difficulties. Despite of this, few studies focus on the use of cognitive technology to trace a possible integration of these latter with pedagogical approaches to enhance learning processes.

The present article focuses on experimenting a prototype of a web-based e-learning environment, preliminarily focused on helping students with dyslexia, considering some results obtained with priming and BCI from our previous researches.

The preliminary results are reliable enough to allow future developments, studying deeper the potentiality of learning empowerment through cognitive technologies integrated in e-learning environments.

Keywords: Brain Computer Interface, Learning Disorders, e-learning.

1 Introduction

Learning Disability indicates a neurological disorder affecting specific areas of learning such as, specifically, these recognized types: Dyslexia, that affects reading skills, Dysgraphia, damaging writing abilities, Dysorthography, that involves problems in spelling in writing, and Dyscalculia, causing problems in mathematics skills. LDs occur in a situation of normal intelligence, and in the absence of neuromotor, sensitive and pre-existing psychopathological disorders.

In the Italian students' population, these disorders affect about the 4% of the learners in developmental age, and they are usually diagnosed in co-occurrence with two or more LDs rather than in a single form. As a consequence, we can state that LDs represent a complex topic and it is not easy to provide effective instruments to help such kind of learners in overcoming the related problems in studying scholastic disciplines, in which all depends on writing, reading and calculus abilities. Also, often these disorders are associated with easy loss of attention and concentration, due to the great effort and work load these learners must put on commonly easy learning activities, causing them a great stress, discomfort and discouragement in studying. Moreover, notwithstanding the progress in neuro and cognitive technology, current ICT technologies are mostly used to provide compensation or dispensation tools for students and not to help them to recover from these difficulties.

Recently, thanks to Artificial Intelligence-based (AI based) algorithms adopted for the analysis of the large quantity of data collected during the experimental sessions, technological tools such as Brain Imaging open a wide scenario of opportunities to study and analyze relationships among Learning and Technology. The main improvement that these technologies brought to the research in the education field is due to the possibility of observing the brain "in action", that is the observation and analysis of brain functions such as memory, language and perceptive task of an individual response to a specific stimulus. Several non-invasive Brain Imaging techniques currently allow to verify in real time the brain response of an individual under stimuli: MEG (Magnetic Electroencephalography), EEG (Electroencephalography), fMRI (functional Magnetic Resonance), PET (Positron Emission Tomography). Among them, EEG is the most used technique to investigate mechanism such as learning abilities, due to its low invasiveness and high time resolution, which make it particularly suited to measure increase in learning abilities. We identified in BCIs (Brain Computer Interfaces) the EEG-based cognitive technology most suited for the described purposes. Being a simplification of EEG medical equipment [2], the BCI headsets allow to detect and collect the cerebral rhythms from an individual, then analyzed by AI and signal analysis methods. BCIs are currently widely used in research, thanks to their high accuracy, perfectly comparable to the medical EEG devices, and also to their low cost and high portability. They are completely non-invasive and present the advantage to keep in comfort the individual wearing them. Moreover, most of them are wireless, within a range of some meters, and allow the individual to a wider movement freedom in the experimental environment. BCI devices allow to collect different brain frequencies, grouped in rhythms reflecting the frequency range they belong. Following literature [6, 8], alpha waves (7 Hz – 14 Hz) are associated to meditation, relaxation, contemplation; beta rhythms (14 Hz – 30 Hz), are related to attention, active thinking, concentration; the delta band (3 Hz – 7 Hz), have been registered in children and associated with continuous attention activity, as in [23]; the theta rhythm (4 Hz – 7 Hz), are generally related to emotional engagement [10]; the gamma signal (30 Hz – 80 Hz), are usually related to the cognitive interpretation of multi-sensory signals. Thanks to the possibility to collect the brain rhythms described above, BCIs allow to investigate the mechanisms of learning, memory and attention, isolating reactions to specific stimuli. Due to their flexibility, BCI devices have been widely used in research to register the response to musical and visual stimuli and recognize the emotional valence [15,19, 20, 21, 39], but also to reveal the mechanism of visual creativity [17]. The aim of past and current researches, is to evaluate the emotive and cognitive response to stimuli, in order to understand what are the mechanisms that triggers these processes or characterizes them in terms of brain rhythms. The headsets have also been used in some experiments aiming at evaluating the response to colors [16, 18], to stereoscopy and monoscopy [9] and also the cognitive response to visual-perceptive stimuli [4], based on the concept of priming [5, 33, 38].

Currently, the research focuses on the comprehension of the cognitive mechanisms at the basis of learning, emotional intelligence and expression. Considering the potentiality of these technological, cognitive tools we evidently have the possibility to verify, as Vygotskij stated [36, 37], how the human ontogeny is strongly influenced by cultural tools available in this historical and social context and, at the same time, how to adopt such technologies to empower learning skills.

2 A technological model based on priming

In their research, Vygotskij [36, 37] and Piaget [29, 30] underlined how the interaction between objects and subjects stimulates the constitution of superior psychic processes, as well as how the cognitive evaluation is subjective because it is also influenced by social factors and the cultural context of each individual. They stressed how this process can influence education and their thought can be easily applied also to advanced technology. Indeed, e-learning, being based on computer fruition, is particularly suited for studying activities performed by individuals experiencing LDs. In this context, the potentiality provided by new cognitive tools could have a strong impact on this individual learning empowerment. Starting from this consideration, we state that observation of the brain in action jointly with consolidated teaching methods and technological devices could allow to design effective learning environments to overcome learning difficulties, especially if considering priming techniques.

Priming is an automatic cognitive mechanism according to which the exposition to a certain kind of stimulus can modify the response to a subsequent stimulus. Priming refers to an increased sensitivity to certain stimuli based on information previously stored. This is considered an unconscious phenomenon. When exposed to a stimulus this may influence the response to a subsequent stimulus thus generating a priming effect based on implicit memory. It can occur following perceptual, semantic or conceptual stimulus repetition. This way, our brains keep track about what we encounter in order to interact efficiently with the world around us.

Some studies [1, 28] recorded event-related potentials (ERP) during semantic priming tasks with pairs of words. The results showed that evoked potentials have a late component called N400, which was significantly related to semantic anomalies.

It seems that N400 priming effect is produced by processes that are involved in integrating semantic information into context. The easier it is for new information to be incorporated into immediate context, the smaller is the amplitude of the N400 component [25]. Automatic and controlled semantic priming are critical for changes in activation of distinct parts of anterior cingulate cortex (ACC). Putamen and hippocampus both react differently to semantically related and unrelated words. Matsumuto, Haneda, Okada & Sadato [24] found changes in the anterior cingulated cortex, and also, changes in various regions of temporal cortex and inferior frontal cortex activity. Decreased activity was usually observed for semantically related pairs of words.

Despite in literature scholars have widely dealt with this phenomenon, still few experiments analyze the effects of priming in learning and their neural correlates. We hypothesized that the learners, which received a semantic priming, would show behavioral patterns faster than those who do not receive the same stimulus, and that the priming effect would result in a lower general cognitive load correlated to a lower engagement of anterior cortical areas, saving, in this way, the ability to keep concentrate during a learning session. Hence, a possible learning environment specifically designed for LDs and based on the priming concept and on the use of BCIs, has been proposed.

Our research addresses the following question:

- Is it possible to improve learning abilities using new cognitive technologies, such as, for example, priming-based systems and Brain-Computer Interfaces?

A key challenge in this scenario is to identify science-based methodological frameworks and validate new tools, methods and teaching paths suitable to grant more effectiveness, in order to assess the impact of tools aimed at strengthening cognitive learning abilities [16, 18].

2.1 Priming and e-learning Platform as triggers for self-repairing LDs

In order to develop a first concept of an e-learning platform based on priming, from 2012 to 2016 several workshops were made in primary and secondary schools.

We involved about 500 students and more than 50 teachers and educators in about 200 hours of stages and laboratories working on "Augmented Didactics" [12, 13] in order to design new learning tools and techniques, able to engage all students in defining a 'self-learning process'.

These workshops were driven by the following aims [11]:

- Help all students succeed through customized learning;
- Meet the demand for new technology, especially Wi-Fi and tablet, in student-centric classrooms;
- Help students get ahead, not only using digital technologies (mobile devices, APPs and e-Learning Platforms) but also using their social attitudes: collaboration, sharing and trust.

Since consolidated studies in neuroscience [31] reveal the way we learn doesn't always match up with the way we are taught especially when we consider Learning Disorders [34], we started working on the following questions: if each of us learns differently (in terms of: pace, style, speed) why do we have to use a single teaching program and a single evaluation method? What kind of stimuli do we have to use for engaging students' curiosity? How can we make learning an experience that everyone wants to repeat?

During the first set of workshops we started proposing to teachers and students a range of topics and issues without a precise pre-established order: complexity, change, digital technologies, evolution, collaboration, conflicts were the first stimuli we primed in this school eco-systems.

This had the advantage of stimulating exploration, investigation and learning, in order to placate the impulse to collect information from the environment to interact with it. Each learner chose different digital media, designed different solutions, provided different deliverables, working alone or in team, and then they shared results with others. All girls and boys involved were attentive, engaged, and focused on the same subject. [12].

A second set of workshops was based on purpose and methods of evaluation process.

Traditional evaluation models are based on getting good performances, where 'good' means 'based on a unique standard scale'. The focus on competence assessment rather than on the discipline cuts off the desire to experience new things, to learn and to evolve, especially in students with LDs.

Leaving evaluation standards, we returned the responsibility for personal and professional growth to learners, giving them the choice of timing, steps and ways to learn [12] and [13].

During our workshops we never used standard evaluation criteria, and this has unleashed in the students a sort of self-evaluation and self-repair process. During our laboratories, students with specific learning problems were able to completely customize the experience of learning and did not show any substantial difference in the attainment of a knowledge or a competence.

3 Methods

We developed a prototype of an e-learning platform implementing priming stimuli, accessed by students while wearing a BCI device. Our aim was to collect and then analyze the registered rhythms, as we hypothesized that during tasks primed by semantic-related cues beta and gamma frequency bands will show a lower activation with respect to non-primed ones.

3.1 The experimental platform

The platform prototype has been developed using HTML5 and php. In this phase, it has been only used in order to present the three experimental tasks described above. Moreover, it has been designed according to the general final structure, with the aim to test it in a future development direction. Indeed, the e-learning environment, we will develop in a future step of this research, will be designed to consider the results collected in this phase.

Also, the 15 principles related to dyslexia-friendly test and several principles related to website design have been implemented [3], such as a clear presentation of the text, avoiding the use of italics and capitalization, justification, abbreviations and long periods, improve the readability of a web page both for dyslexics, as expected, and for non-dyslexics as well. Also, background colors have been chosen carefully, avoiding excessive contrast or brightness and the presence of images behind the text. Currently, the web pages are not designed to be compatible with screen reader technology, as needed by dyslexics using text-to-speech tools, but we aim to implement this feature in a future step.

The current version of the e-learning environment is composed by a main page (home), where a student can access to the registration form, also taking a preliminary test aiming at evaluating his/her preferred learning style. On the registration form, the student is also asked to describe his/her learning difficulties. In this phase, this part is not presented to the user, because it will be included in the final version of the website, since it is not functional to this study. The same is for other features of the platform, such as "choose the subject", "improve your skill", "help", "contact", that will be working on the final version. On the main page also a "login" button will be present, allowing registered users to access to their personal profile page, where they can control their learning and personal skills progress.

In our study, the platform has been used to present to the participants the task described in the following paragraph devoted to the procedure, that will be part of the section "improve your skills" in the final version of the e-learning environment.

3.2 The experimental procedure

Three conditions have been implemented and a Neurosky Mindwave B.C.I. device was used to collect frontal EEG data. The Neurosky Mindwave B.C.I. device mounts a single dry sensor located in the frontal area of the scalp (that is enough for our aims) and it collect all the EEG rhythms listed in the previous paragraphs. It is connected to a personal computer through a Bluetooth connection.

We designed three tasks: the first and the second were inspired by literature in order to confirm the semantic priming effects using a not yet used technology (Neurosky Mindwave). The third one, due to its complexity, was planned on purpose to evaluate if semantic priming can actually be considered as a method to enhance some cognitive performances. In all tasks, a group received related primes and a group received unrelated primes before a stimulus-target, which varies according to the task. A group did not receive any prime.

Task 1 (Letter): participants were asked to read the stimulus shown on the computer monitor in front of them in order to accomplish a delayed letter-search task [26]. The sequence of the stimulus is the following: fixation cross (1800 ms), prime word (110 ms), blank screen (850 ms), target word (110 ms), one letter (250 ms) and a fixation cross until the subject answer. During the last fixation cross the subjects had to report if the letter was part of the last word they saw.

Task 2 (Word Recognition): participants were asked to read the stimulus displayed on the monitor in front of them, to perform a word recognition task. Subjects had to spot if the target stimulus was an actual real world (i.e. existing in Italian vocabulary) or a fake word. The sequence of the stimulus is the following: fixation cross (1800 ms), prime word (110 ms), blank screen (850 ms), target word (300 ms), fixation cross until the subject responds.

Task 3 (Definition): This last exercise brings a higher level of difficulty than the experiments that are usually proposed in literature and because of this it is useful to evaluate if semantic priming can be considered as a good way to improve cognitive performances of subjects.
Subjects were asked to spot the name of an object that was described by a definition taken from the Italian dictionary. Before the definition, the subjects of the prime-related group saw a list of words, most of which were semantically related to the definition, while the prime-unrelated group received semantically extraneous words. The sequence of the stimulus is the following: fixation cross (1800 ms); a list of words, shown one by one (each one for 1500 ms); pop up window containing the description of the object and the prompt box to be filled by the subject.

Each condition had 50 trials. Each subject underwent the three experimental conditions in three different sessions (randomly sequenced). In the following sections, we will refer to "related group" intending the subjects who received words semantically related to the stimulus target.

3.3 Participants in the experiment

Twenty-eight right-handed volunteers (age range 18-29) with normal or corrected to normal visual acuity and without neurological illness, but with certified learning disabilities participated in the study. We focused on disorders related to text reading (dyslexia).

4 Results and discussion

The outcomes were promising, since we found significant differences in all conditions. The first task consisted in Letter recognition. In this test, the related group reported an average reaction time (RT) of 1.51 seconds while the other two groups (unrelated prime and no-prime) reacted slower (respectively, 1.82 s and the 1.81 s).
In Word recognition, the related-group RTs had an average of 1.29 seconds vs 1.56 and 1.55 of the other groups.
In the third task (Definition), the prime-group answers took an average of 6.51 seconds to respond, versus 7.71 and 7.95 of other 2 groups.

In addition, looking at the correctness of the answers (accuracy), subjects in the related-group gave more corrected answers than the others. In particular, for the Letter task accuracy was 94% for related, 91% and 93% for no-prime. For the Word task, the accuracy was 92% for related, 81% for unrelated and 84% for no-prime. Finally, for the Definition task the accuracy was 90% for related, 82% for unrelated and 81% for no-prime. This first analysis suggests that the priming effect has an important role, not just in speeding up, but also in optimizing the responses to a specific task.

We also used the Matlab's tool EEGLab to analyze EEG correlates of behavior resulting from the data recorded by the B.C.I. Following our hypotheses, primed-participants reported a less average activation of Gamma rhythms, registered immediately before and after the onset of the stimulus. As expected, the EEG data showed that in the frontal area the priming effect appears to be correlated to a reduced activity, consequently revealing a cognitive discharge (see Fig. 1).

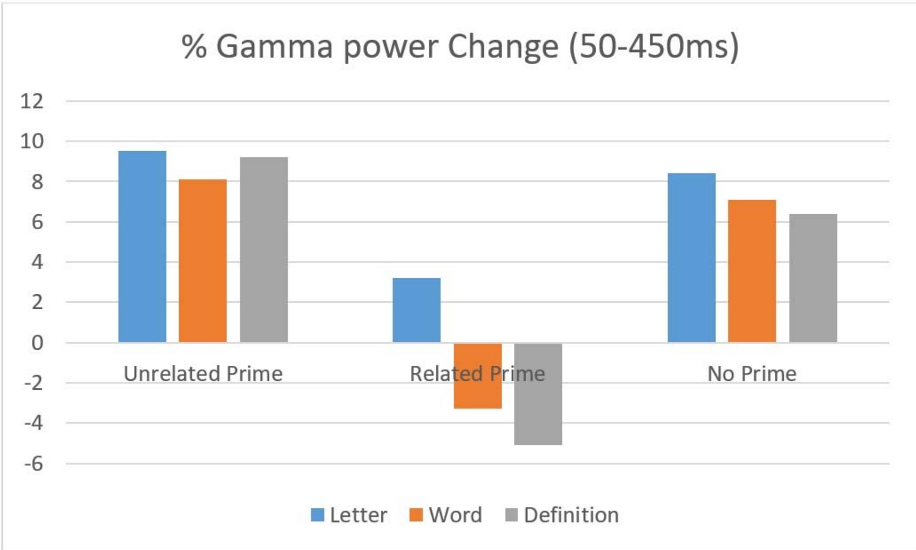

Fig. 1. Priming effect detected by the analysis of Gamma rhythm power.

In particular, focusing on the third task the gamma, the power decrease in the related group, and this effect may suggest a focused activation due to the activation of a related semantic representation and the automatic spreading activation, which accompanies priming stimuli.

The gamma power difference at the single front electrode may reflect local networks in this area thought to be involved in top-down semantic processing. Gamma frequencies are thought to transiently bind together cell assemblies [7, 14, 22] and work on a more local scale [35]; thus, they are a likely mechanism for dynamically forming local networks involved in semantic processing. It is possible that priming has the role of stimulating the semantic representations which are used to perform a semantic task, before the presentation of the task itself. This way, when individuals have to give an answer, their brain needs less effort than those who do not receive any prime.

The obtained results suggest that education material including priming stimuli effectively modulates the cognitive load of participants during specific tasks implying the working memory functioning. Though, we have not data directly indicating an increase in learning performance it is well known that a major problem for dyslexics is working memory functioning, with a negative impact on learning when it is overloaded (Beneventi et al., 2010). Consequently, a strategy aimed at reducing cognitive load during reading and studying might have a positive effect for dyslexics, especially in demanding tasks. Furthermore, this strategy might be helpful also to approach learning activities that implies much information to be learned in a short time for all students.

In our experiment, we used a BCI device to collect EEG data, but this device might also be used to assess the cognitive load providing specific feedback when excessive, less-functional level of cortical activity is reached. This latter use of a BCI might be a valid self-assessment tool for learners, to improve their own learning skills. We believe, indeed, that a systematic use of BCI devices will foster the implementation of cognitive-driven education and enhancement programs. Additionally, other experiments could concern EEG response from dyslexic people, including not only semantic, but also visual, textual and audio stimuli. This comes from our previous works, in which we have already analyzed EEG signals, collected by BCI devices to investigate the response of users to sounds and music [20, 21], to visual stimuli [4], to video [9], and the engagement of cognitive and memory processes in learning [16]. As an example, in neuroscience studies a considerable interest is devoted to the cognitive empowerment obtained thanks to music learning [16, 27, 37] suggests that a cognitive-driven design of the artificial illumination and of colors used in working and didactic materials should strongly improve learning performance. This might be particularly important in case of learning disorders, allowing to use colors and illumination priming to further improvements in the learning process.

5 Conclusion and further developments

In order to produce a prototype of a Technological and Cognitive platform oriented to LDs (TCLD) able to fulfil the above stated requirements, we have experimented methods and tools from the fields of Psychology, Pedagogy and Cognitive Sciences, using new technologies of Brain Imaging that allow the cognitive impact on the individual to be assessed [3].

As a starting point, we have developed a prototype of a cognitive technology-based platform, including some semantic priming stimuli, and we experimented it on individuals with LDs disorders in the University learning environment.

Our study outcomes replicated the results of a previous study on subject without reading problems [32], showing that the semantic priming is effective in helping individuals in reinforcing their learning abilities and, also, that BCI devices represents an important feedback tool allowing learners to regulate their workload and, as a consequence, their effectiveness in learning. Differently by the previous experiment, we did not find any effect of the priming on beta modulation, but only on Gamma. If replicated in future studies, this datum could suggest that BCI driven intervention for dyslexics could target higher EEG frequency ranges.

The obtained results allow us to argue that the use of priming and BCI tools could be useful within a pedagogical program in order to contribute improving users' ability to focus attention on abstract cognitive tasks and in translating abstract thinking in concrete operations. Furthermore, the use of BCI regulates attention levels, improves the ability to stay focused and keep attention on mental tasks and may contribute to the development of multitasking abilities, now considered particularly important in different contexts. BCI-based tools, differently from other techniques or method to improve attention and concentration requiring specific skills, may be enjoyed by everyone, without any prerequisite both in stand-alone and in group settings.

Our future aim consists in improving our research, introducing feedback mechanisms and more priming stimuli, such as those based on colors and sounds. The presented study is innovative insofar because it promotes cross-fertilization among several disciplines and in the joint use of EEG-based Brain Imaging technologies, allowing us to observe learners' cerebral reaction to educational stimuli and methods within a web-based e-learning platform. This approach represents an innovation not only in education, but especially in the perspective of future job placement of LD-affected people, who can acquire skills useful to improve their productivity as socially well-introduced members of society. This is a vital outcome for children and youth worldwide, because the number of LD students is dramatically increasing.

The spread of mobile technologies and online communities means that digital natives communicate in a very different way from ours and they required customized paces, times and ways to maintain a high involvement in culture and knowledge evolution. It is necessary to create different styles and levels of communication between teachers, students and parents: they are a real community, and social networks are their "augmented place" to share, spread and imitate.

A new e-learning Platform, based on augmented formats give us a possible way to highlight talents, skills and attitudes that often remain latent, because levelled in a unique model.

New technologies allow teachers to broaden the field of observation and evaluation of learners. Through digital data collected in social profiles teachers can verify the evolution of talent and the peculiarities of each 'young person'. They can open the diaphragm to focus on individual learning solutions and progress.

Opening new channels of expression, girls and boys with specific learning disorders have definitely excelled in making original solutions, showing their skills in unconventional disciplines. It is therefore important to consider that through new technologies they will be able to learn with passion, selecting by themselves channels and alternative methods of communication.

We have a great opportunity to join forces to improve the educational system and cultural development of future generations, based on cooperation, reciprocity, fairness and transparency, focusing continuous improvement of the process of learning and cultural evolution of our whole society.

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