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Analysis of brain activity and response to colour stimuli during learning tasks: an EEG study

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ABSTRACT

The research project intends to demonstrate how EEG detection through BCI device can improve the analysis and the interpretation of colours-driven cognitive processes through the combined approach of cognitive science and information technology methods. To this end, firstly it was decided to design an experiment based on comparing the results of the traditional (qualitative and quantitative) cognitive analysis approach with the EEG signal analysis of the evoked potentials. In our case, the sensorial stimulus is represented by the colours, while the cognitive task consists in remembering the words appearing on the screen, with different combination of foreground (words) and background colours.

In this work we analysed data collected from a sample of students involved in a learning process during which they received visual stimuli based on colour variation. The stimuli concerned both the background of the text to learn and the colour of the characters. The experiment indicated some interesting results concerning the use of primary (RGB) and complementary (CMY) colours.

Keywords: EEG, colours, brain activity, cognitive science

1. AIMS AND MOTIVATION

Every day we navigate in a coloured world. Our sensorial units are continuously stimulated by the physical properties of particles and radiations. Colours, being intrinsically part of our objective and subjective experience, are among the richest characteristics of the sensorial world. Consequently our mind and behaviour are constantly modulated by the colours we see. Indeed, colour vision probably evolved because it contributed to survival. In fact, many studies suggest that colour often serves as signal function for animals, facilitating the production and repetition of adapting behaviour[23,24]. Other studies concern how the different colour impact affect cognition and behaviour.

Indeed, starting with the pioneer studies (based on observations of psychiatric patients) of Goldstein[25], the most accepted conceptual model posits that the colours red and (to a lesser degree) yellow forse meglio dire "have a stimuation effect", whereas the colours green and (to a lesser degree) blue are experienced as quieting. Consequently, red and yellow relative to green and blue was posited to impair cognitive tasks in which accuracy is required[25]. Although a lot of research has been conducted to support Goldstein's conceptualization, data are not convergent[7,26].

For instance, in very well-articulated study, Elliot and colleagues[27] showed that the perception of red prior to an achievement task, relative to the perception of green or an achromatic colour (white, black or grey), evokes avoidance motivation, as indicated by participants' choice of easier and less demanding tasks with respect to subjects primed by green items. The same study reported a greater right, relative to left, frontal cortical activation in subjects perceiving red signals prior to the task. The authors considered this datum as a biological marker of the de-activation of the motivational system due to the perception of a red-coloured (intrinsically negative-valenced) inputs.

At the opposite, a study by Hill & Barton[28] on Olympic athletes indicated that red enhances performance, since athletes being dressed in red showed better performances than blue-dressed ones. Furthermore, a recent study[29] reported that blue (relative to green) light increased responses to emotional stimuli in the voice area of the temporal cortex and in the hippocampus. These results support the view that ambient blue light promotes affective arousal and associated mnemonic processing, probably favouring a rapid behavioural adaptation to the environment.

Even though further research is clearly needed to understand the complex relationship between colour and cognitive processes in different contexts, it is well established that cognitive, emotional and motivational systems are highly

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responsive to subtly stimulation (such as colour modulation) ant that they can operate subtly as well. Indeed, people generally do not exhibit any conscious awareness of the influence of colour on their performance. In particular, negative-valenced (e.g. a red-coloured signal) have a strong impact on the human mind, triggering involuntary physiological as well as psychological responses, i.e. activating avoidance behaviour even when it is not required nor beneficial. Furthermore, colours have also a significant impact on attention mechanisms, naturally linked to physiological arousal and motivational drivers.

Generally speaking, attention is activated when one or more sensory receptors return a sensation to the brain for the processing of information received. If we focus on the stimuli affecting attention, we have to consider some visual characteristic reinforcing or not the stimulus itself, such as size, intensity, colour, movement, position and contrast.

Many experiments confirm that attention is reinforced when colours are used in educational material and during lessons, and several studies[19] showed that children remember colour cues better than verbal cues. Additionally, other works show that observers can use colour as discriminant to select the appropriate set of visual stimuli, improving search performance[5, 20, 22]. Even if data are not always convergent, we can argue that blue-coloured stimuli should enhance attention tasks, while red could impair them.

Our objective has been to test colours' power in the reinforcement of attention in learning processes, through the analysis of EEG signals collected during the experiments.

In our experiments we aimed to verify two hypotheses:

1. different colours have different impact on attention during a learning task, independently by the learners;
2. whether is it possible to individuate one or more colours, or a gamma of colours particularly suited to stimulate attention and consequently reinforce learning and concept permanence.

This work is organized into five sections: the first is the introduction to aims and motivation of our research; the second presents the outcoming from previous research taken into account in designing the experiments and supporting our hypothesis; the third describes the methodology adopted, followed by the fourth section in which we report the results of our investigation. In the last section, conclusions and further perspectives are presented.

2. RESULTS FROM PREVIOUS RESEARCHES

In previous works, we have investigated means and methods to collect, analyse and interpret data[2, 6] from people accessing art to find a way to enhance the visitors' experience visiting a museum. Our studies have been conducted attempting to jointly use methods from technology, pedagogy and psychology with the aim to enhance the public's experience when observing artworks, focusing on colour stimuli to elicit cognitive reactions.

In order to get conscious and unconscious feedback from users, we chose to use EEG-based BCI (Brain-Computer Interface). The reason for this choice lies in their extensive use in the entertainment and in the scientific communities due to their reliability in collecting EEG data with a high time resolution and to their portability and low-cost. BCIs[1] commercial devices consist in a simplification of the medical EEG equipment, communicating an EEG response to stimuli by WI-fi or bluetooth connection, allowing people to feel relaxed, reduce anxiety and move freely in the experimental environment or in the game. BCIs collect several cerebral frequency rhythms: the Alpha band (7 Hz – 14 Hz), related to relaxed awareness, meditation, contemplation; the Beta band (14 Hz – 30 Hz), associated with active thinking, active attention, solving practical problems; the Delta band (3 Hz – 7 Hz), frontally in adults, posteriorly in children with high amplitude waves, detected during some continuous attention tasks[10]; the Theta band (4 Hz – 7 Hz), usually related to emotional stress, such as frustration and disappointment; the Gamma band (30 Hz – 80 Hz), generally related to cognitive processing of multi-sensorial stimuli.

We performed our studies using BCI devices with particular focus on users' emotional and cognitive response to musical[9] and visual stimuli, with the aim to transfer our result not only to enhance users experiencing of art but especially, as will be clarified in the following, to enhance users ability in performing cognitive-oriented tasks.

We previously implemented specific experiments to evaluate the possibility to use two selected BCI commercial devices, namely the Neurosky Mindwave[a] and the Emotiv Epoc[b] for research purposes. Indeed, despite the reduced number of sensors, we argue that such devices may be suitable to effectively and efficiently detect any user's mental

[a] http://www.Neurosky.com
[b] http://www.Emotiv.com

state. This preliminary step was necessary to take any further step. We designed these pilot experiments' protocol with the aim to test the reliability of both the Emotiv Epoc and the Neurosky Mindwave. We based the considered mental state/emotion labels on the 2D valence/arousal model originating from cognitive theory of emotions. In this model, valence is represented on the X axis from highly negative to highly positive, and arousal is on the y axis, from calming/soothing to excited/agitated[16]. This model has been used to determine the apparent mood of music in several works[11, 12] .

To test the generalization ability of the chosen EEG features patterns and associated labels, we elicited physiological emotional responses using music stimuli and sound stimuli from the International Affective Digitized Sounds (IADS) database[c]. In particular, we designed the experiments according to[17], because the two dimensions of emotion mainly considered by researchers are valence and intensity, but there are, in fact, few models related to brain activity taking into account both dimensions. Self-assessment of valence/arousal was therefore performed in the study by each participant and for each sound, using a simplified version of the Self-Assessment Manikin scale[14]. In this way, we could correctly identify the correspondence of the hypothesized mental state response to each sound with the subjective self-reported mood state.

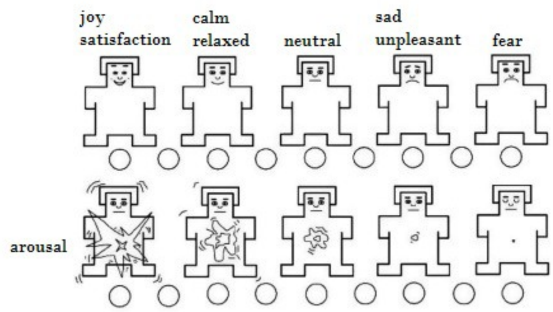

Figure 1. The simplified version of the Self-Assessment Manikin (SAM) used in the experiments.

Results showed that brain activity measured at the anterior part of the scalp distinguished the valence of musical emotions both using the Emotiv Epoc and the Neurosky Mindwave. The activity increased during the presentation of positive-valenced musical excerpts, while it decreased when negative-valenced items were delivered. The overall frontal activation is related to the intensity of emotions elicited by music[8, 9]. In fact, it decreases with sounds related to fear and increases with happiness or satisfaction. No gender patterns are detected.

Considering these results, we decided to use the Neurosky Mindwave in subsequent experiments to refine the approach, sacrificing a greater precision for a long-lasting data detection without decay of the users' involvement level. In further experiments we used the same approach to investigate the exposure to a visual-perceptual, semantic, or conceptual stimulus influences response to a later stimulus in the context of a Museum of fine Art[3].

Priming is a kind of implicit memory (a sort of tacit memory that is not consciously retrieved or observed, but able to modulate attention mechanisms). While the performance of episodic memory based on explicit tasks initially improves with age and declines with advancing age, priming remains relatively stable from age 3 to 80. Visual-perceptual priming[20, 21] is defined by enhanced processing of previously seen visual material, relative to novel visual material. The purpose of our research consisted in developing a priming-based tool, taking into account the most relevant experimental and physiological findings and applies them in general to cognitive-driven environments.

Students and lay public are often unskilled visual onlookers. They do not know that an image or an artistic item may be read just as a book. They lack proper education in visual language and communication[15]. Therefore people first need to develop or improve visual skills. Besides, people should learn a method. This fact is evident if we consider Art, for which people need to have perceptual as well as conceptual knowledge to fully comprehend an artistic object. For this reason we started our investigation in detecting response to colour stimuli focusing on artworks. In order to achieve our aims we applied a priming protocol to a museum environment. The final purpose was to test if using primed stimuli (colours, lines, shapes, and so forth) enable subjects to improve their artistic experience and the appreciation of artworks .To evaluate the subjective experience, an ad-hoc questionnaire was used at the end of the experimental session.

[c] http://csea.phhp.ufl.edu/media/iadsmessage.html

During the experiment, we submitted individuals to a museum tour where they individually watched priming stimuli on a screen, under a researcher's supervision. We then obtained encouraging results both from the analysis of the questionnaire and from the investigation performed on the EEG signals collected by the BCI device. In fact, participants who received the visual primes showed a greater engagement of memory as reported in questionnaires, thus indicating an increase in the attention level. Also beta and gamma rhythms, related to thinking and attention, presented regular tracks on the same questions, while theta brainwaves did not show frustration symptoms and, correspondingly, alpha values confirmed the relaxed attention state of the subjects. These studies represent part of a wider interdisciplinary research project[3, 4, 6, 8, 9] aimed to evaluate the response of humans to visual, auditory and perceptual stimuli, measured with classical methods used in Psychology and Cognitive Science and with innovative brain imaging methodologies, such as, in our case, the EEG.

In other works we tested the user reaction to visual stimuli using ambiguous images from monoscopic and stereoscopic movies[4] and colours[7]. Also in this case, using both classical questionnaires-based measures and EEG-signal analysis, we obtained interesting results, confirming the importance of specific colours, shapes and sound, on the one hand to make priming really effective and, on the other hand, to have guidelines to use appropriately 3D Virtual Environments[13] to engage visitors. We also applied the same concepts and methodology in the context of e-learning environments for dyslexic users. All the obtained results are functional for current experiments, focused on the analysis of brain activity and response to colour stimuli during learning tasks.

3. INSTRUMENTS AND METHODS

With the aim of testing colours' power in the reinforcement of attention in learning processes, we measured the EEG signals related to attention stimulation in a controlled experimental setting. EEG signals have been collected by a BCI device, namely the Neurosky Mindwave. Indeed, results from our previous works and from other studies confirmed that this BCI device represents the best choice for our purpose.

The Mindwave provides just one sensor positioned in the frontal area of the scalp. Despite of this apparent disadvantage, the Mindwave BCI is more comfortable for users, both for the easiness of positioning the device on the scalp, and because it uses a dry sensor, while other BCIs implement wet ones. The limitation of a single electrode implies that the possible analysis of the brain activity relates to very general phenomena, and cannot be used easily to identify ERPs or to associate a specific brain activity with a specific brain area. This registering method, hence, reduces the accuracy of the neurophysiological interpretation of results. What we can measure, in other words, is an average of the activity of the whole brain, with a stronger contribution of the frontal lobes. This is not a strong disadvantage, since we are interested to analyse highly cognitive brain activity, mainly recordable in frontal regions, rather than elementary stimulus related activity. Another advantage, convincing us in using Mindwave, consists in the wireless communication between the BCI device and the computer during the collection of data. This feature, in fact is particularly appreciable since it provides to subjects a comfortable experience, thus enhancing the ecological validity of experiments.

We have decided to use all the recorded brainwaves. On the collected EEG data, we performed a signal analysis, in which we have been looking for a greater brain activation corresponding to colour/learning stimuli, measured by the general signal intensity. We also measured brain activation for each band, to detect which of them was more involved in cognitive tasks and the relationship between colours and brain activity.

Additionally, we verified the actual memory effect of priming stimuli using a memory task after the experimental test. In this way, we were able to search for association between EEG effects and memory measures. On collected data we also performed a cognitive-based analysis. Specifically, we performed a frequency analysis of results obtained from the questionnaire, to detect what combination of colours has a greater impact on cognitive tasks. These results have been subsequently compared with those obtained from the signal analysis on collected EEG data. The details of the performed analysis are shown in next paragraphs.

In the experiments we concentrated on contrast of the colour of selected words with the colour of the background, excluding to consider other visual constancy factors. We chose the contrast between couples of colours combining primary (red, greeb, blue - RGB) and complementary (cyan, magenta, yellow - CMY) ones.

To test the impact of colours on cognitive performance, we organized four experimental sessions:

1. in the first one, we submitted participants with a sequence of black words put on coloured backgrounds. We delivered black words on primary colour (RGB) backgrounds and black words on complementary colour (CMY) backgrounds.
2. In the second experiment we put primary colour words and complementary colour words on a white background.

3. In the third experiments we put primary colour words on primary colour backgrounds and complementary colour words on complementary colour backgrounds, showing all the possible combinations.
4. In the fourth and last experiment, we put primary colour words on complementary colour backgrounds and complementary colour words on primary colour backgrounds, showing all the possible combinations.

After each session, participants have been asked to write the words they remembered (in descending order). To be sure that participants' attention and cognitive tasks could be colours-related, words have been chosen among unusual obsolete words or they have been meaningless. In the following table, we show the words used in the four experiments.

Table 1. Words used for each experiment. The mispelled or meaningless words have been underlined.

experiment	**shown words**
black words on coloured backgrounds	panzana; abbirivio, atramento, imbolsito, enfiteusi, bastajo
coloured words on white backgrounds	plenaria, indulgere, misogino, crotalo, avulso, andito
primary coloured words on primary coloured backgrounds	grafomane, tolemaico, quinci, pedalino, mielite, ribattino
complementary coloured words on complementary coloured backgrounds	cagione, glimpa, frida, soverchio, inopia, scardio

The experiments were conducted among undergraduate students of the University of Milan, Italy. The population consisted of 19 males and 19 females, aged in the range 21-56. All had normal or corrected-to-normal vision.

During the experiment, the following procedure was followed for each session: 1) participants were asked to read the consent form, specifying the objectives of the study and prompted to either agree or disagree, 2) participants were instructed on the following experiments, 3) the participants did the experiments, 4) the participants were asked to answer a post-test consisting of a cognitive questionnaire to assess their attention levels and the impact of colours.

All the individuals agreed to participate in the experiment but in some cases (N=3) the data was discarded since the BCI did not produce readings for these participants. Cases with missing data were not considered in the analysis.

The participants sat at a distance of 50 cm from a screen, wearing the Mindwave device. They were asked to sit in a comfortable position, and avoid as possible to talk or move during the observation of the test images, in order to avoid the influence of Electromyography (EMG) signals in the collected data. No specific task (like e.g., counting or searching for particular features) was assigned to the users: they were simply asked to stay concentrated reading the words.

To manage the connection with the device, and to synchronize the recording of EEG data with the test images used in the experiments, we used the OpenVibe software[d], an open source platform for designing and performing BCI and neurosciences experiments.

The data collected have been analysed using different software tools, based on EEGLAB and *ad hoc* implemented MATLAB™ code. We recall that the signal transmitted by the device is already filtered to remove the 50 Hz frequency band related to electric power equipment. Moreover, it detects eye blinks, thus avoiding a specific filtering work. Other motion related activities should be detected with ad hoc signal analysis, that it has not been considered, since from a visual inspection the signal in general did not show these typical features.

4. RESULTS

The research project intends to demonstrate how EEG detection through BCI device can improve the analysis and the interpretation of cognitive processes through the combined approach of cognitive science and information technology methods. To this end, firstly it was decided to design a research project based on comparing the results of the traditional cognitive analysis approach with the EEG signal analysis of the evoked potentials. We define Evoked Potential (EP) or Evoked Field (EF) the variations in EEG or MEG signals associated to a sensorial stimulus. More generally, they are called Event-Related Potential (ERP) or Event Related Field (ERF) the variations induced by an event (a sensorial stimulus, a motor act or an endogenous event). ERP/Fs are the result of an adjustment of the phase of the cerebral rhythms related to the event ad of an increment of the power of the signal.

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[d] http://www.openvibe.org

In our case, the sensorial stimulus is represented by the colours chosen among primary (RGB) and complementary (CMY) ones, while the cognitive task consists in remembering the words appearing on the screen, with different combination of foreground (words) and background colours.

The experiment indicated some interesting results concerning the use of primary and complementary colours. The observed data and the following analysis indicated some variation depending on the choice of the colours (primary or complementary).

The analysis of the collected data was divided into two stages:

1) the Behavioral data analysis , based on the findings deriving from the questionnaire submitted to participants-
2) the EEG signal analysis conducted to confirm (or confute) the previous findings.

Before analysing the EEG signal, here is already possible to highlight the really interesting results of the post-experiment survey, described in the next paragraph.

4.1 Behavioural data analysis

From the statistical analysis performed on the answers given by participants we obtained interesting results.

Concerning the first experimental session, during which participants observed a sequence of six obsolete or nonexistent words written in black on primary and complementary colour backgrounds, the most remembered word has been the one put on a yellow background (26 individual on a total of 35), followed by that written on a cyan background (10 on 35). The word written on a green background has been the most difficult to remember (only 3 participants on 35). However, we have to observe that the word on the yellow background was the last presented one, so it is important to underline the result obtained with the cyan background, also considering the results obtained in the following experimental session and from the following pure EEG signal analysis.

The sequence of colour backgrounds was provided in the following order: red, green, blue, cyan, magenta, yellow. In figure 1 we show the numbers of successful cases in remembering words, related to corresponding colour backgrounds.

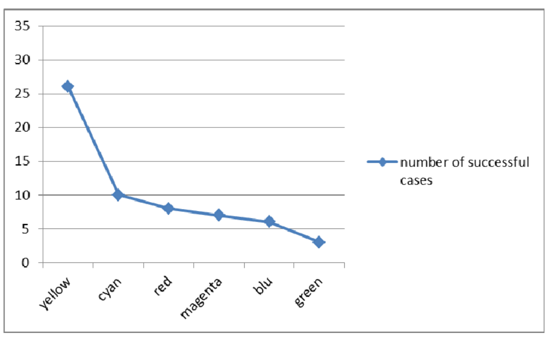

Figure 2. Number of words successfully remembered with respect to coloured backgrounds.

During the second experimental session, participants were submitted with obsolete or meaningless words written in primary and complementary colours on white backgrounds. The sequence of colours has been the following: green, blue, red, magenta, yellow, cyan. The most remembered word has been the one written in blue (26 participants on 35), followed by the green one (24 on 35). The worst result has been registered for the word written in red (7 on 35).

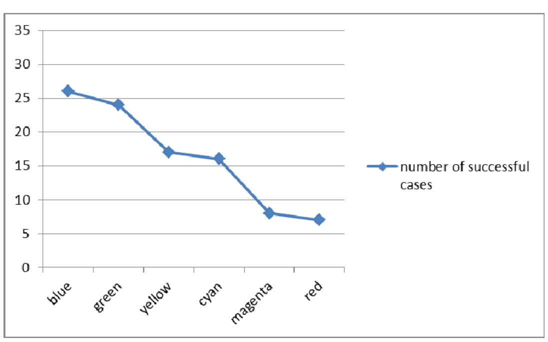

Figure 3. Number of words successfully remembered with the respect to corresponding text colour on withe background.

In the third session the stimulus used was composed by a word written in a primary colour on a primary colour background. The colour combinations have been presented following the order: red/blue, red/green, blue/red, blue/green, red/green, green/blue, green/red. The most successful combinations were red/blue and blue/red (in both cases 21 participants on 35). The blue/green combination was the less remembered (6 on 35). Note that the opposite combination green/blue has registered a success rate of 17 individuals on 35.

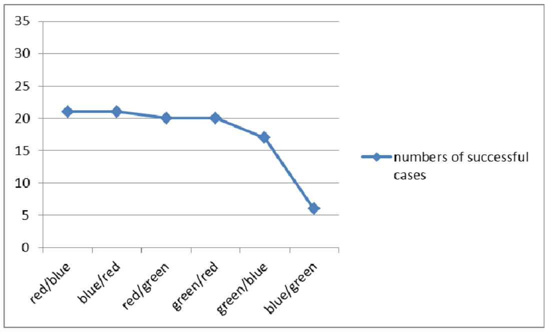

Figure 4. Number of words successfully cases remembered related to corresponding combination text/background primary colours.

In the fourth and last session, participants observed words written in complementary colours on complementary colours backgrounds using the following text colour/background colour presentation order: magenta/yellow, magenta/cyan, yellow/magenta, yellow/cyan, cyan/yellow, cyan/magenta.

The most remembered word was the one corresponding to the combination cyan/magenta (12 participants on 35), while the most confusing combination was the yellow/magenta (0 individuals on 35), jointly with the combination yellow/cyan (1 on 35). Generally speaking, the combinations containing yellow as foreground colour registered the worst performance, jointly with the combination containing yellow as the background colour (indeed, cyan/yellow registered 4 successes on 35, while magenta/yellow registered 8 successes on 35).

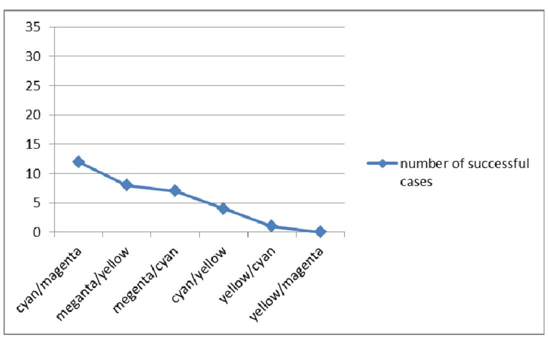

Figure 5. Number of successful cases in remembering words, related to corresponding combination text/background complementary colours.

We computed the intra-band Pearson correlation index for the rhythm couples theta-alpha, theta-gamma, alpha-gamma and beta-gamma, for all the participants to the experiments, for each experiment and for each stimulus, discovering that the correlation index values are greater for the combination of rhythms theta-beta in the 98% of the participants. Moreover, the maximum value of the theta-beta intra-band correlation index has been always detected corresponding to the most remembered word in all the experiment. Due to the large amount of data, we just show, in next table, a randomly chosen example of the Pearson correlation index analysis for one subject.

Table 1. intra-band Pearson correlation index corresponding to each stimulus for each experiment, for a random selected participant.

experiment 1: black words on coloured backgrounds					
background colour	theta-alpha	**theta-beta**	theta-gamma	alpha-gamma	beta-gamma
red	0,116	0,601	0,025	0,521	0,684

green	0,866	0,210	0,091	0,344	0,244
blue	0,948	0,935	0,612	0,378	0,541
cyan	0,923	0,961	0,935	0,909	0,940
magenta	0,411	0,692	0,415	0,678	0,255
yellow	0,282	0,703	0,345	0,434	0,303
experiment 2: coloured words on white backgrounds					
words colour	theta-alpha	**theta-beta**	theta-gamma	alpha-gamma	beta-gamma
green	0,798	0,946	-0,680	0,630	0,584
blue	0,859	0,966	0,435	0,367	0,445
red	0,789	-0,190	-0,044	-0,509	0,853
magenta	0,463	0,676	0,128	0,538	0,246
yellow	0,231	0,864	0,892	0,456	0,900
cyan	0,879	0,854	0,306	0,641	0,888
experiment 3: primary coloured words on primary coloured backgrounds					
colours combination	theta-alpha	**theta-beta**	theta-gamma	alpha-gamma	beta-gamma
red/blue	0,002	0,985	0,424	0,274	0,779
red/green	0,930	0,765	0,859	0,557	0,973
blue/red	0,930	0,786	0,859	0,985	0,973
bleu/green	-0,211	0,239	0,741	0,381	0,682
green/blue	0,239	0,467	0,497	0,538	0,906
green/red	0,610	0,455	0,716	0,387	0,262
experiment 4: complementary coloured words on complementary coloured backgrounds					
colours combination	theta-alpha	**theta-beta**	theta-gamma	alpha-gamma	beta-gamma
cyan/magenta	0,959	0,972	0,415	0,619	0,911
yellow/cyan	0,640	0,531	-0,214	-0,128	0,505
magenta/cyan	0,781	0,596	0,488	-0,071	0,750
magenta/yellow	0,609	0,919	0,127	0,822	0,789
yellow/magenta	0,532	0,496	0,830	0,349	0,594
cyan/yellow	0,574	0,702	0,022	0,635	0,786

4.2 The EEG analysis

Data have been divided into stimulus-image related epochs. Epoched data were preliminary filtered in the interval 1-80 Hz. Subsequently, we performed the band decomposition and we visually inspected delta, theta, alpha, beta and gamma rhythms., We then computed the Perason correlation index and compared the results with the intra-band synchronization index (see below) calculated for each epoch (around the stimulus onset) to evaluate the synchronization among priming and colours.

The Pearson correlation index and the intra band synchronization index has been computed for all band couples and for each participant. To obtain a uniform result among all individuals, we performed the same steps on each single epoch for each participant. The comparison of the obtained indexes among all participants for each epoch confirmed the results obtained in single participants analysis. Due to this reason, we will summarize the results referring to epochs and to comparison among all the participants, reporting in the following figures some relevant example of the obtained results.

For all the participants, and for all the combinations of colours, the maximum value of the Pearson correlation index (going from 0.47 to 0.89) has been registered for bands couples theta/alpha, theta/beta and alpha/beta. Concerning this last result, the Pearson correlation can easily be explained considering the interdependent complementary of the alpha and the beta rhythms. Interesting, the correlation between theta and, respectively alpha and beta rhythms, has been found also considering the epochs corresponding to words correctly remembered, indicating a high attentional level of participants who saw:

- the cyan background in the first session (words in black on coloured background). We recall that we considered the cyan instead of the yellow colour because the yellow has been the last seen by participants.
- the blue colour in the second session (coloured words on white background)
- the red/blue and blue/red combinations in the third session (primary colour words on primary colour backgrounds)
- the cyan/magenta combination in the fourth session (complementary colour words on complementary colour backgrounds)

In most cases also the minimum value of the Pearson correlation index corresponds to the less remembered words, except for the combination given by primary colour words on primary colour backgrounds. Indeed, in this case the minimum correlation index has been registered for the combination green/blue, instead of blue/green.

We also calculated a synchronization index. Considering a single electrode side, the phase coherence time can be easily revealed by inspecting the analytic phase. In fact irregularity in analytic phase plots reveal the so-called *phase slips*, occurring when the phase is "reset". Phase coherence time lapse can last 100ms ~ up to a few seconds, then new phase locked oscillations arise. Around a stimulus onset, the phase coherence interval is shorter. This phenomenon can be observed by computing the analytic phase of single filtered bands. To perform the phase analysis we applied the Hilbert transform to the EEG signal collected by the single electrode. In this work we are interested in calculating the synchronization index between each band couple. Given phases $\phi^1(t)$ and $\phi^2(t)$ of two signal's frequency bands, we get the phase difference $\phi^2(t)-\phi^1(t) = \phi^{1,2}(t)$ and a synchronization index, as in the following formula:

$$g_{12}^2 = \left\langle \cos(\phi^{1,2}(t)) \right\rangle^2 + \left\langle \sin(\phi^{1,2}(t)) \right\rangle^2 \qquad (1)$$

where brackets < > denote the average of the computed cos and sin values. The index g_{12} ranges in [0,1], where 1 represents the perfect phase synchronization and 0 stays for the absence of phase synchronization. The presence of phase synchronization in cortical activity reveals neurons firing in-phase, corresponding to the neurons co-operation for perceptual or cognitive tasks[18]. In our experimental setup we collected one signal from a specific topographic position so we could explore phase synchronization index between different wave bands, revealing the kind of functional activity of the brain. As already said, the phase synchronization index give us indication on neurons co-operation for perceptual or cognitive tasks, so we chose to compute this index to verify its value in correspondence of the coulours stimuli. In table 1, as an example, we show the values of the synchronization index obtained from one of the participants in the first session, around each stimulus onset, for the band couple theta-beta.

Table 2. Stimulus-related synchronization index during the first experimental session (black words on primary and complementary colour backgrounds), for the band couple theta-beta.

Stimulus	Synchronization index theta-beta
yellow	0.861
red	0.714
blue	0.840
cyan	0.908
green	0.785
magenta	0.740

We noted that to a high synchronization index the most remembered word corresponds. Note that, as for almost all participants, in the first experiment the value of the synchronization index for the cyan colour is higher than the yellow one. This confirm our chose to consider the cyan result instead of the yellow for the most remembered word, so excluding the possibility that the yellow-written words has been rimembered because it was the last shown. For all subjects, for each experimental session and for each stimulus, we computed the synchronization index for the band couples theta-beta and theta-alpha, following the indication of the Pearson correlation analysis.

The highest values in synchronization index were obtained in the band couple theta-beta, revealing the performance of cognitive process. Particularly, confirming the results obtained by the Pearson correlation analysis, the highest synchronization values were obtained in correspondence of the colour stimuli allowing a greater remembering of the presented words. The synchronization index found in this case corresponds with behavioural findings, as shown, as an example, in next diagrams related to one randomly chosen participant and to theta-beta rhythms couple.

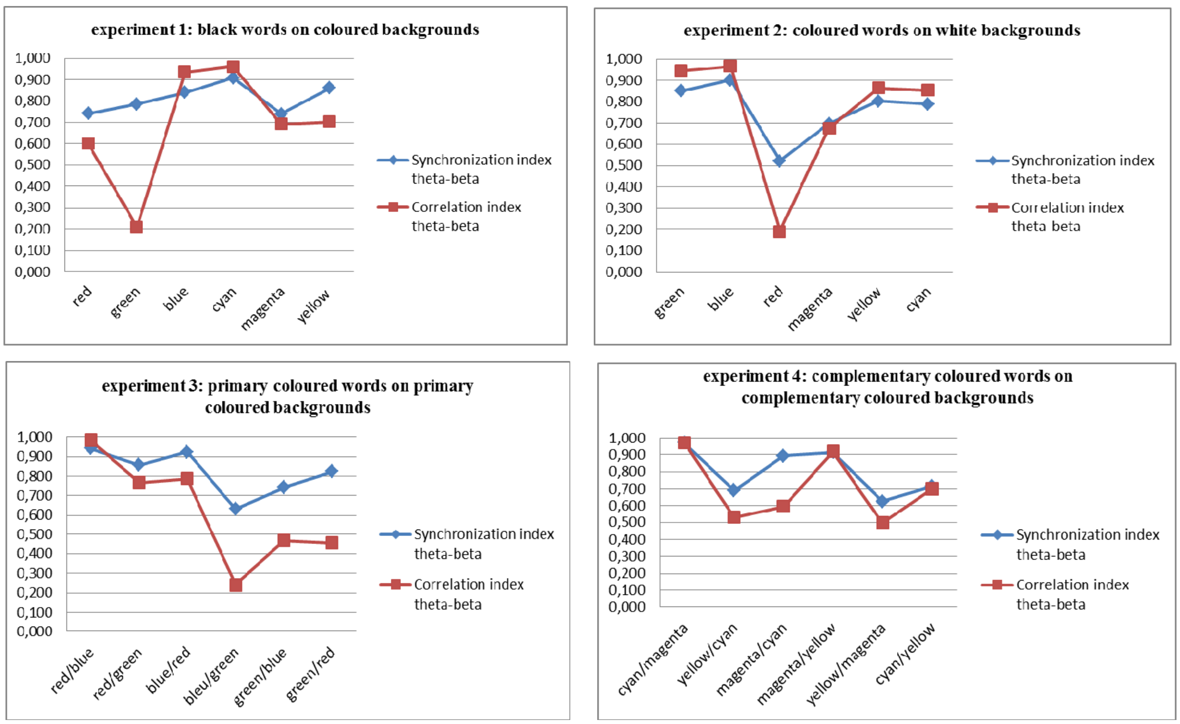

Figure 6. Comparison among the Pearson correlation and the synchronization index for each colour stimuli and for each experiment, related to a randomly chosen participant.

5. CONCLUSIONS AND FURTHER WORKS

In this work we analysed data collected from a sample of students involved in a learning process during which they received visual stimuli based on colour variation. The manipulation of stimuli regarded both the background of the text to remember and the colour of the characters. The present experiment indicated some relevant results concerning the use of primary red, green, blue (RGB) and complementary cyan, magenta, yellow (CMY) colours. Particularly, results obtained by the behavioural analysis have been confirmed by the EEG analysis, revealing a high activation of cognitive processes corresponding to theta, alpha and beta cerebral rhythms. The colours having a greater impact on remembering words were:

- the cyan background in the first experimental session (words in black on coloured background). We recall that we chose to consider the cyan instead of the yellow colour because the yellow has been the last seen by participants and we wanto to be sure about the rpiming power of the colour avoiding false results due to the order of the presented stimuli. the blue colour in the second experimental session (coloured words on white background)
- the red/blue and blue/red combinations in the third experimental session (primary colour words on primary colour backgrounds)

- the cyan/magenta combination in the fourth experimental session (complementary colour words on complementary colour backgrounds)

The obtained results encouraged us to continue experiments in a future phase extending the research to other, more complex, experimental setups.

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REFERENCES

[1] Allison B. Z., Wolpaw E. W., Wolpaw J. R., “Brain-computer interface systems: progress and prospects,” Expert Rev Med Devices, 4(4):463-74 (2007).

[2] Banzi A., Folgieri R. (2012), “Preliminary Results on Priming Based Tools to Enhance Learning in Museums of Fine Arts,” Proceedings of EVA 2012 Florence. Firenze, 9 – 11 May 2012, p. 142-147, Firenze University Press, ISBN: 978-88-6655-127-0 (2012).

[3] Banzi A., Folgieri R., “EEG-Based BCI Data Analysis On Visual-Priming In The Context of a Museum Of Fine Arts,” Proceedings of DMS 2012, 18th International Conference on Distributed Multimedia Systems, , Miami Beach, USA (2012).

[4] Calore, E., Folgieri, R.,Gadia, D.,Marini, D., “Analysis of brain activity and response during monoscopic and stereoscopic visualization,” Proceedings of IS&T/SPIE’s 24th Symposium on Electronic Imaging: Science and Technology , San Francisco, California, (2012).

[5] Egeth, H. E., Virzi, R. A., & Garbart, H, “Searching for conjunctively defined targets,” Journal of Experimental Psychology: Human Perception and Performance, 10, 32–39 (1984).

[6] Folgieri R., “VR for cultural heritage valorization: a communication problem,” Proceedings of Electronic Imaging & The Visual Arts. Firenze, Italy, p. 146-151, Cappellini, ISBN: 88-371-1837-6 (2011).

[7] Wright, A., “The beginner’s guide to color psychology,” Singapore: Kyle Cathie (1998).

[8] Folgieri R., Zampolini R., 2012, “BCI promises in emotional involvement in music and games,” Computers in Entertainment, ed. ACM, in press (2012).

[9] Folgieri R., Zichella M., “Conscious and unconscious music from the brain: design and development of a tool translating brainwaves into music using a BCI device,” in proceedings of AHFE, San Francisco, California, USA (2012).

[10] Kirmizialsan, E.; Bayraktaroglu, Z.; Gurvit, H.; Keskin, Y.; Emre, M.; Demiralp, T.. "Comparative analysis of event-related potentials during Go/NoGo and CPT: Decomposition of electrophysiological markers of response inhibition and sustained attention," Brain Research, 1104 (1): 114–128. doi:10.1016/j.brainres.2006.03.010 (2006).

[11] Laurier, C., Sordo, M., Serra, J. and Herrera, P. “Music mood representations from social tags,” in Proc. of Int. Soc. For Music Information Retrieval Conf. (ISMIR) , Kobe, Japan (2009).

[12] Lu, D., Liu, L. and Zhang, H. “Automatic mood detection and tracking of music audio signals,” in IEEE Transactions on Audio, Speech and Language Processing, vol. 14, no. 1, pp. 5-18, (2006).

[13] Marini D., Folgieri R., Gadia D., Rizzi A. ,”Virtual reality as a communication process,” Virtual Reality, Ed. Springer London, vol.16:3, p. 233-241, ISSN 1359-4338, DOI 10.1007/s10055-011-0200-3, url http://dx.doi.org/10.1007/s10055-011-0200-3 (2012).

[14] Morris, J.D., “SAM: The Self-Assessment Manikin, An Efficient Cross-Cultural Measurement of Emotional Response,” Journal of Advertising Research, (1995).

[15] Nuel, L., “Art & visual literacy, in Journal of visual verbal languaging,” fall, 77-79 (1984).

[16] Russell, J. A. “A Circumplex Model of Affect,” J. Personality and Social Psychology, vol. 39, no. 6, pp. 1161-1178 (1980).

[17] Schmidt, L.A., Trainor, L.J., “Frontal brain electrical activity (EEG) distinguishes valence and intensity of musical emotions,” Cognition and Emotion 15, 487–500 (2001).

[18] Varela, F. et al, “The brainweb: phase synchronization and largescale integration,” Net. Rev. Neurosci. 2, 229-239 (2001).

[19] Vuontela, V., Reamae, A., Aronen, H., & Carlson, S., “Selective dissociation between memory for location and color,” Neuroreport: An International Journal for the Rapid Communication of Research in Neuroscience. August, 10, 2235-2240 (1999).
[20] Zhang, W. W., & Luck, S. J., “Feature-based attention modulates feedforward visual processing,” Nature Neuroscience, 12, 24–25 (2009).
[21] Wiggs, C. L., Martin, A., “Properties and Mechanisms of Perceptual Priming. Current Opinion in Neurobiology,” 8(2): 227-233 (1998).
[22] Wolfe, J. M., & Horowitz, T. S. “What attributes guide the deployment of visual attention and how do they do it?,” Nature Reviews. Neuroscience, 5, 495–501 (2004).
[23] Byrne, A. & Hilbert, B. R., “Color realism and color science, Behavioral and Brain Sciences,” Cambridge Univ. Press, (2003).
[24] Guilford, T., & Rowe, C., “Unpalatable evolutionary principles,” Nature, 382, 667–668 (1996).
[25] Goldstein, K., “Some experimental observations concerning the influence of colors on the function of the organism,” OccupationalTherapy and Rehabilitation, 21, 147–151 (1942).
[26] Fehrman, K. R., & Fehrman, C., “Color: The secret influence,” (2nd ed.), Upper Saddle River, NJ: Prentice Hall (2004).
[27] Elliot, A.J., Maier, M.A., Moller, A.C., Friedman, R., & Meinhardt, J., “Color and psychological functioning: The effect of red on performance attainment,” Journal of Experimental Psychology: General, 136, 154–168 (2007).
[28] Hill, R. A., & Barton, R. A., “Red enhances human performance in contests,” Nature, 435, 293 (2005).
[29] Vandewalle G, et al., “Spectral quality of light modulates emotional brain responses in humans,” Proc Natl Acad Sci USA, 107:19549–19554, (2010).