British Journal of Applied Science & Technology
9(1): 1-11, 2015, Article no.BJAST.2015.241
ISSN: 2231-0843

SCIENCEDOMAIN *international*
www.sciencedomain.org

SCIENCEDOMAIN

A Blue Mind: A Brain Computer Interface Study on the Cognitive Effects of Text Colors

Raffaella Folgieri[1*], Claudio Lucchiari[2] and Beatrice Cameli[2]

[1]Department of Economics (DEMM), Università degli Studi di Milano, Italy.
[2]Health Sciences Department, Università degli Studi di Milano, Italy.

Authors' contributions

This work was carried out in collaboration between all authors. Authors RF and CL designed the study, wrote the protocol and managed literature searches. Author RF performed the statistical and the EEG analysis, and wrote the first draft of the manuscript. Author CL performed the behavioural analysis and discussed the related results. Author BC managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2015/17821
Editor(s):
(1) Arcady A. Putilov, Research Institute for Molecular Biology and Biophysics, Russian Academy of Sciences, Novosibirsk, Russia.
Reviewers:
(1) A. Papazafiropoulou, Department of Internal Medicine and Diabetes Center, Tzaneio General Hospital of Piraeus, Athens, Greece.
(2) Friday Okwaraji, Psychological Medicine, University of Nigeria, Nigeria.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=1136&id=5&aid=9156

Original Research Article

Received 27th March 2015
Accepted 15th April 2015
Published 8th May 2015

ABSTRACT

Aims: The paper reports results obtained from a set of experiments aiming to demonstrate the potentiality of the use of EEG signal detection through BCI devices in improving the analysis and the interpretation of colors-driven cognitive processes. The approach combines Information Technology methods and signal analysis with cognitive science investigation methods, considering the rising interest in these two disciplines in learning sciences.

Study Design: The presented experiment has been designed with the aim to compare the results of the traditional (qualitative and quantitative) cognitive analysis approach with the EEG signal analysis of the evoked potentials collected from participants.

Methodology: A sample of 38 students has been 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 colours represent the sensorial stimulus, while the cognitive task consists in remembering the words appearing on the screen, with different combination of foreground (words) and background colors.

**Corresponding author: E-mail: raffaella.folgieri@unimi.it;*

Results and Conclusions: The obtained results show interesting learning effects of primary (RGB) or complementary (CMY) colours as well as EEG correlates.

Keywords: Learning; memory; EEG; brain computer interface; BCI; colour processing; cognitive science.

1. INTRODUCTION

The reliability of commercial non-invasive BCI (Brain Computer Interface) devices and the low cost of these EEG-based systems, compared to other brain image techniques, such as fMRI or high-density EEG, determined the increasing interest in their application in different Research fields, also thanks to the portability of the equipment.

This last feature makes BCI devices particularly suited for experiments involving virtual and real (Friedman et al. [1]) situations and a larger number of subjects, especially when evaluating emotional or cognitive response of individuals. In fact, during EEG measures, anxiety induced by invasive devices could influence the emotive response of individuals. At the opposite, BCI devices, being projected also for entertainment applications, are paritcolarly confortable and allow the collection of data in a more ecological fashion.

Commercial BCI (Allison et al. [2]) devices consists in a simplification of the medical EEG equipment, communicating EEG response to stimuli by wi-fi connection, allowing to people to feel relaxed, to reduce anxiety and to move freely in the experiment environment, acting as in absence of the BCI devices.

Among the different BCIs proposed by commercial Companies, two small-sized, inexpensive devices are currently largely in use in the scientific and in the entertainment communities: the Emotiv Epoc and the Neurosky MindWave. Despite of the lower number of signals detected by the Neurosky BCI (it does not register facial expressions as Emotiv does), it appears particularly suitable for ecological experiments, both for the lower-cost and for the easiness-to-wear.

Most of BCI-based interfaces adopt a two-class approach as a modality for movement control, realizing a so-called limited explicit interaction. Other applications use signals registered by BCIs to modify the environment, realizing, in this case, the implicit approach. This latter is an interaction process not based on direct, explicit and voluntary user's action but on the users' state in a particular context. In games, some examples are given by the games “Bacteria Hunt” (Mühl et al. [3]), in which alpha brain rhythms levels are related to the controllability of the player's avatar, or “Alpha WoW” (Plass-Oude Bos et al. [4]), based on the game “World of War craft”, in which the user's avatar can transform into an animal following the alpha brain rhythm activity.

Commercial BCI (Allison et al. [2]) devices consists in a simplification of the medical EEG equipment, communicating an EEG response to stimuli by WI-fi connection, allowing people to feel relaxed, to reduce anxiety and to move freely in the experimental environment or in the game, acting as in the absence of the BCI devices.

The Neurosky Mindwave particularly represents a challenge, due to the apparently lower potentiality compared to the Emotiv Epoc. In fact, while the Emotiv BCI device reads brainwaves data from fourteen sensors, the Mindwave provides just one sensor, positioned on the frontal area of the scalp. However, the Mindwave BCI is inexpensive and results more comfortable for users, both for the easiness of positioning the device on the scalp, and because it uses a dry sensor, while Emotiv implements wet ones.

Conducting data recording by the use of this simple device will permit the direct transfer of results into future BCI-based easy-to use applications, e.g. in education contexts (Folgieri and Zichella [5]).

In the present study, we aimed to study, by behavioral and BCI-based data, the effects of text colors on memory.

Generally speaking, the colour of light plays an important role in mental functioning. Colours are often associated with one or more emotions; they may also convey specific meanings or information. From childhood we all have repeated experiences of colors in different situations and this gives rise to strong colour-related affective, cognitive and behavioral effects (Baldwin and Meunier [6]). These effects are unconscious and have an automatic consequence on our brain functioning (Bramao et al. [7]) although meanings may be activated by multiple and may depend on different contexts (e.g. at school red often signals an error, and then evokes an uneasy feeling that we want to avoid; at the opposite, in a romantic context red may symbolizes passion and hence it might act as a positive cue), Nakamura et al. [8] also highlighted that the meaning of a colour also depends on a given culture, that is to a sort culture-dependent emotion/colour dictionary established by combining the colors to objects and physical spaces (Naz and Epps [9]).

These properties seem to act even in children. For instance the study by Hamid and Newport [10] disclosed the power of colors to enhance the creative skills in 6 children (4/5 years) placed in rooms on several different colour conditions: pink in the room aroused physical strength and good mood, while the opposite was found in a room colored blue. These data therefore seem to support the different activating function of colour.

In particular, recent research a number of studies have stressed the role of the blue spectrum, i.e. light wavelengths around 450 nm, in modulating cognitive processes.

For instance, Knez [11] analyzed the influence of the light colour on self-reported mood, cognitive performance and the appreciation of lighting. To achieve this aim, the author compared warm (yellow spectrum) and cold (bluish spectrum) white lights. Warm white light were found to facilitated problem solving, while the cold lighting condition (bluish spectra) was found to enhance attention and short-term memory.

More recent evidence substantially confirmed these data, in particular with respect to the role of blue light in facilitating attention-related tasks. For instance, Cajochen et al. [12], studying the effect of the blue spectrum light produced by a LED monitor, found that subjects exposed to this direct light were significantly influenced both at the physiological and cognitive level. In particular, the circadian cycle was altered since an evening exposition to the LED light was able to stop melatonin production, thus shifting the day/night cycle, and increasing the attention level as well as memory performances.

Similarly Chellappa et al. [13] specifically analyzed the role of light temperature on attention. The temperature is a parameter of the white light indicating the blend of wavelengths present in the visible light. In particular, a warm light (under 3000 K) is rich in green and yellow components, while a cold light (higher than 6000 K) is rich of blue components. The cold light is a white intense light similar to the one of the dawn, and may be easily reproduced by a fluorescent lamp, while a warm light is characteristic of late afternoon and is generally produced by an incandescent lamp. Chellappa et al. [13] found that cold light is able to decrease the salivary level of melatonin, increasing instead the arousal level as well as the sustained attention as measured by a go-no-go task.

Finally, Vanderwalle et al. [14], in a review of recent studies about the relationship between the light quality and brain functioning, reported the impact of blue light components in different cerebral areas deputed to regulate attention, memory and the whole cognitive system. In particular, thalamus, limbic structures and the neo-cortex are all affected by the quality and the quantity of environmental light, showing that light has the power to influence attention, emotion, cognition and behavior due to a complex of interrelated functional circuits.

In a previous study (Lucchiari et al. [15]) we have tested the possibility to enhance the cognitive fitness modulating the quality of light (colour and temperature of white light). In fact, even a brief exposure to a blue light may increase arousal that in turn may promote the cognitive performance in certain tasks. However, further than cognitive performances it is possible to assume that exposure to a light source with a strong blue component allows a subject to find cognitive comfort, that is, to create the preconditions of a mental setting suitable for a task that requires attention and concentration. Hence, we propose that a blue stimulation pre-activates central nervous system in such a way to limit the cognitive stress by the pre-allocation of the required resources for a future task, thus promoting a cognitive fitness.

In the study that we present in this paper, we wanted to investigate whether the colour blue can have a direct effect on cognitive performance during a learning task. However, in this case we didn't modulate the environmental illumination, but we directly manipulated the colors used in the task (stimuli and background) since, we suppose that the computer display represents a light source sufficiently strong to influence the cognitive functioning, promoting attention and memory or, at the opposite, decreasing cognitive activities.

2. MATERIALS AND METHODS

2.1 Method

The primary aim of the study consists in investigating the impact of blue with respect to other colours on a cognitive performance. In order to pursue this aim, we analysed the cortical correlates of the colour modulation by the use of a Brain Computer Interface (BCI) device. Indeed, this instrument allows to record the EEG signal in the comfortable wireless way so as to improve the interpretation of cognitive processes through the combined approach of cognitive science and Information Technology (and specifically Artificial Intelligence) methods.

2.2 Subjects

Thirty-eight volunteers (19 males and 19 females) attending undergraduate courses at the University of Milan, participated in the study. Participants ages were between 21 and 36. All had normal or corrected-to-normal vision. All volunteers agreed to participate, but in some cases (N=3, 2 females and 1 male) the data was discarded since the BCI did not produce readings for these participants. Cases with missing data were not considered in the analysis, so the total record number corresponds to 35 participants.

2.3 Instruments

A Neurosky Mindwave BCI device was used to collect the EEG signals.

BCI devices 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), frontal in adults, posterior in children with high amplitude waves, detected during some continuous attention tasks (Aston Jones and Cohen [16]); 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 (Basar [17]; Basar et al. [18]). The BCI device communicates the EEG response to stimuli by WI-fi or Bluetooth connection, allowing people to move freely in the experimental environment, thus reducing anxiety. The limitation of a single electrode provided by the NeuroskyMindwave 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 method, hence, reduces the accuracy of the neurophysiological interpretation of results, but it was suitable for our research purposes. Indeed, we could measure the average of the activity of the whole brain, with a stronger contribution of the frontal lobes. In our case this fact does not represent a disadvantage, since we are interested in analysing higher cognitive brain activity, mainly recordable in frontal regions, rather than elementary stimulus related activity. The use of the Mindwave presents also another advantage: the wireless communication between the BCI device and the computer during the data recording is particularly appreciable since it provides to individuals a comfortable experience, thus enhancing the ecological validity of the experiment.

The oscillatory induces cortical activity were studied in relation to each experimental condition.

2.4 Procedure

To test the impact of blue on cognitive performance, we set up four experimental conditions, in order to represent different combinations of colours, thus contrasting the effect of blue with other possible contrasts. We have combined primary (red, green, blue - RGB) and complementary (cyan, magenta, yellow - CMY) colours. In the first condition, we delivered to participants a sequence of black words on primary colour (RGB) backgrounds and black words on complementary colour (CYM) backgrounds. Participants in the second condition have been asked to look at a sequence of primary colour words and complementary colour words on a white background. In the third experimental session we put primary colour words on primary colour backgrounds and complementary colour words on complementary colour backgrounds. In a last condition, we submitted participants a sequence of primary colour words on complementary colour backgrounds and complementary colour words on primary colour backgrounds. We delivered all the possible RGB-CMY combinations. Each stimulus was repeated 5 times. At the end of the experimental session, subjects were involved in a simple distracting task (fulfilling a questionnaire with personal data, habits, preferences and the like) requiring about two minutes to be completed. Anyway, a standard time was set up for each participant, so that the subsequent memory test started exactly 5 minutes after the end of the stimulation phase.

Participants' memory has been tested through a recall test during which subjects were asked to write the words they remembered (in descending order). To be sure that participants' attention and cognitive tasks could be colour-related, words have been chosen among Italian unusual obsolete words.

Before performing the experiment, participants were trained and familiarized with the cognitive task. At the end of the experiment, individuals were asked to answer a post-test consisting of a cognitive questionnaire to assess their attention levels and the impact of colours.

Participants were seated in a comfortable position, at a distance of fifty centimetres from a computer screen, wearing the Mindwave device. They were asked to avoid talking or moving during the observation of the test words, in order to avoid the influence of Electromyography (EMG) signals in the collected data. The only task assigned to users consisted in stay concentrated reading the words.

To manage the connection with the device, and to synchronize the recording of EEG data with the computer task, we used the OpenVibe software, an open source platform for designing and performing BCI and neuroscience experiments.

For the data analysis, we used different software tools, based on EEGLAB and ad hoc implemented MATLAB^{TM} code.

3. RESULTS AND DISCUSSION

3.1 Statistical analysis

Though the main objective of the study consists in investigating the impact of blue text on cognitive performances, we also aimed to verify 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. The analysis of the collected data was divided into three stages: (1) the behavioural data analysis, based on the findings deriving from the questionnaire submitted to participants; (2) the EEG signal analysis of the evoked potentials, performed on the data collected from individuals participating in the experiments; (3) the comparison of the results from the two approaches to match (or not) the respective findings.

We want to recall that Evoked Potentials (EP) or Evoked Fields (EF) indicate the variations in EEG or MEG signals associated with a sensorial stimulus. More generally, Event-Related Potential (ERP) or Event Related Field (ERF) stand for 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. For this reason, in the EEG signal analysis, we also calculated a synchronization index (Varela et al. [19]). 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, and 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 of the EEG signal collected by the single electrode. In this work we are interested in calculating the synchronization index between each band couple.

Given phase's ϕ^1(t) and ϕ^2(t) of two signal's frequency bands, we get the phase difference ϕ^2(t)- ϕ^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 sine values. The index g_{12} range is [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 (Varela et al. [19]). 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.

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

3.2 Results

On the collected data, we performed both the analysis of the EEG signals and a cognitive-based analysis. The cognitive-based analysis consisted in a frequency analysis of the results obtained from the memory test used at the end of each session to verify subjects' learning. In this way we aimed to detect the effect of blue colour on cognitive tasks.

3.3 Behavioural Data Analysis

In the first condition, participants observed a sequence of six obsolete or nonexistent words written in black on primary and complementary colour backgrounds. The statistical analysis performed on the results of the memory test showed that participants remembered more the word put on a yellow background (26 individual on a total of 35), followed by that written on a cyan background (10 of 35; see Fig. 1). Words written on a green background have been the most difficult to remember (only 3 participants in 35).

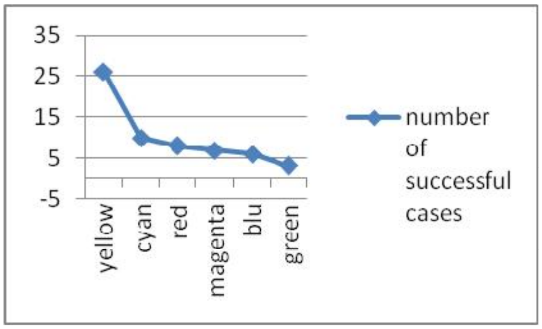

Fig. 1. Number of words successfully remembered with respect to background colour

In the second experimental session, the sequence of obsolete or meaningless words submitted to participants has been written in primary and complementary colours on white backgrounds. As shown in Fig. 2, the word most remembered has been the one written in blue (26 participants in 35), followed by the green one (24 of 35). The worst result has been registered for the word written in red (7 of 35).

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

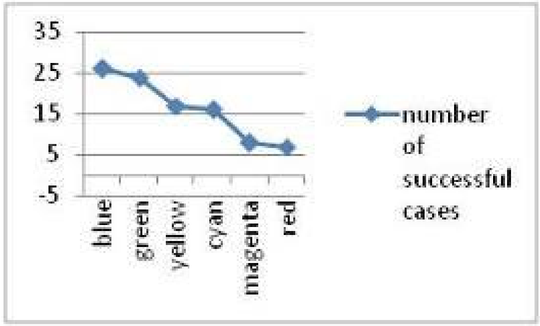

Fig. 2. Number of words successfully remembered with the respect to corresponding text colour on white background

In the fourth and last session, participants observed words written in complementary colours on complementary colour backgrounds.
In this case, the most remembered word corresponds to the combination cyan/magenta (12 participants in 35). The most confusing combination resulted the yellow/magenta (0 individuals in 35), jointly with the combination yellow/cyan (1 of 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 out of 35, while magenta/yellow registered 8 successes of 35).

3.4 The EEG Analysis

The BCI device transmits an EEG signal already filtered to remove the 50 Hz frequency band related to electric power equipment. Moreover, it detects also eye blinks, thus avoiding a specific filtering work. Other motion related activities should be detected with ad hoc signal analysis, not been considered here because the visual inspection the signal in general did not show these typical features.

Collected data have been divided into stimulus-image related epochs. The epoched data were preliminary filtered in the interval 1-80 Hz. Subsequently, we performed the band decomposition and we visually inspected all the rhythms (delta, theta, alpha, beta and gamma).

We computed the Pearson correlation index and the band synchronization index 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 (ranging from 0.47 to 0.89) has been registered for bands couples theta/alpha, theta / beta and alpha/beta. Concerning the results related to the alpha/beta couple, the Pearson correlation can easily be explained considering the interdependent complementary of the alpha and the beta rhythms. Interesting enough, 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);
- 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).

Also the minimum value of the Pearson correlation index corresponds, in most cases, 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.

The synchronization index gives indication on neuron co-operation for perceptual or cognitive tasks. This is the reason why the correspondence among the different analysis performed and the indices calculated is particularly significant. 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.

As told, we computed the synchronization index for the band couples theta-beta and theta-alpha, for all the individuals, for each experimental session and for each stimulus, following the indication of the Pearson correlation analysis. The band couple theta-beta showed the highest values in synchronization index, thus revealing the performance of cognitive process (see Table 2).

Table 1. Intra-band Pearson correlation index corresponding to each stimulus

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
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

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	0.84
cyan	0.908
green	0.785
magenta	0.74

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. In this case, the found synchronization index corresponds with behavioural findings, as shown, as an example, in next diagrams related to one randomly chosen participant and to theta-beta rhythms couple (see Fig. 3).

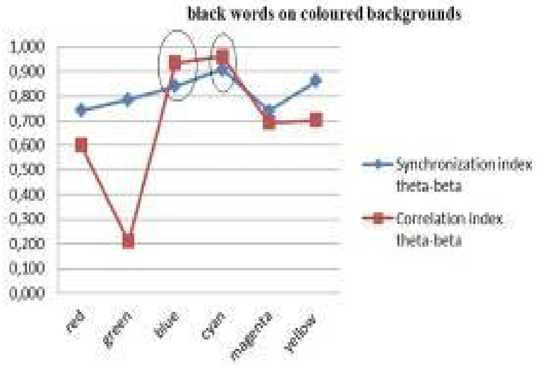

Fig. 3. Comparison among the Pearson correlation and the synchronization index for each colour stimulus related to a randomly chosen participant.

3.5 Discussion

The comparison of the results obtained by the two cognitive / behavioural analysis and EEG signal analysis approaches indicated some relevant results concerning the power of blue spectrum components. Indeed, results obtained by the behavioural analysis matched the results of the EEG analysis, revealing a high activation of cognitive processes corresponding to theta, alpha and beta cerebral rhythms.

First of all, we noted that to a high synchronization index the most remembered word corresponds. Confirming our hypothesis on yellow and cyan colours, for almost all participants in the first condition the value of the synchronization index of the cyan colour is higher than the yellow one.

We found that the colours having a greater impact on remembering words were cyan, blue and the combinations red/blue, blue/red and cyan/magenta, respectively:

- The cyan background in the first experimental session (words in black on coloured background).
- the blue colour in the second experiment (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 experiment (complementary colour words on complementary colour backgrounds).

Interestingly, the effect of the blue spectra colours is particularly consistent among the different conditions, while other colours effects seem to be modulated by a variety of factors. The EEG data tend to confirm this consistency, clearly suggesting that the effect of blue stimuli is grounded in the biology of the human nervous system.

From a cognitive point of view, our results suggest that a blue stimulus may play an important role in positively modulate the cognitive comfort of a subject, increasing alertness, memory performance and the psychological experience. It is well known that short wavelength light, in particular the blue spectrum, represents a modulator signal for the functioning of the central nervous system (Goldstein [20]). About a decade ago a new kind of receptor, described as a light/dark signaller, was discovered in the retina (Brainard et al. [21]). Interestingly, the receptor is tuned to be sensitive only to the blue light and its reactivity seems to be enhanced when a red signal precedes a blue stimulation (Hill and Barton [22]). The light/dark receptors are aimed to tell the brain whether it's light or dark outside, and they work sending inputs to the biological clock (i.e. the suprachiasmatic nucleus), rather than the vision cortex (Soldat et al. [23]). We wish to recall that the circuit formed by the suprachiasmatic nucleus, the dorsomedial hypothalamic nucleus and the nucleus coeruleus (NC), seems to play an important regulatory role in the functioning of the brain and cognitive performance, changing the level of alertness. In particular, the NC is modulated by the suprachiasmatic nucleus which in turn is modulated by the light perceived by the eye. In particular, the wavelength peak corresponding to the blue colour (between 450 and 480 nm) captured by the light/dark retina receptors are able to modify the firing level of the NC. The NC is part of a circuit output used by the central nervous system to adjust the periodicity of a series of processes, through the release of a neurotransmitter called norepinephrine. Norepinephrine regulates the excitability of neurons in the thalamus and the cerebral cortex. The NC is also activated by stimuli of particular importance during wakefulness, thus playing a role as a modulator of the alert and arousal and, more generally, of the cognitive performance. In particular, the activity of the NC during wakefulness is related to the level of attention. When the neurons of the CN show phasic activity (i.e. is responsive to specific stimuli) the maintenance of focused attention with respect to specific stimuli and/or tasks (Aston-Jones and Cohen [16]) is facilitated. Hence, a blue stimulation could act on the central nervous system as a kind of signal reset, so resetting the cycle in progress and restoring the attention system at a high level, i.e. waiting for input data to be processed. Our results support the hypothesis that a blue or cyan text on particular backgrounds (i.e. those with high contrast) may provide a better cognitive performance due to the high level of expectation triggered by the exposure to a blue radiation.

We have also found interesting results regarding the correlation among cognitive performances, the colour features and the EEG modulation. In fact, the synchronization of theta waves during learning tasks seems to be meaningful. Previous research showed the event-related theta band power responds specifically to prolonged visual emotional stimulation (Krause et al. [24]) and a synchronization was revealed in case of coordinated responses indicating alertness, arousal and readiness to process information (Basar [17]). In other studies, theta activity has been reported in neocortical areas as well, as in Kahana and colleagues (Kahana et al. [25]; Caplan et al. [26]) who used intracranial EEG measurements. The spectral analyses of scalp-recorded EEG are dominated by cortical activity and shows clear patterns of theta activity in memory paradigms. Our results confirm the correlation between theta synchronization and attention-related tasks. Furthermore, it seems plausible that the level of alertness is modulated by the colour of text and that the synchronization of frontal theta.

4. CONCLUSION

Through the preliminary studies presented in this paper, we wanted first of all to test the reliability and the effectiveness of the use of a BCI device as a tool to find out cortical correlates of cognitive tasks, so to easily bridge basic and applied cognitive research.

We were seeking for a portable device, allowing individuals to feel comfortable during and experiment while we were registering EEG signals, interesting for its high time resolution. In fact, from a cognitive point of view, we needed to evaluate conscious and unconscious response from users, focusing both on the intensity of the brain mechanisms activation and on the time passing from the stimulus onset and the individuals' reaction thus orienting to the EEG Brain Imaging technique. The use of a confortable, easy-to-use, single electrode BCI device demonstrated to a valid option for research aimed to link behaviour and brain functioning from an olistic point of view. In fact, even if such a study cannot clarify the brain mechanisms underlying specific behaviours, it is possibile to find out interesting correlations between cortical signals and overt performance. This indication might be very useful in understanding global cognitive processes, such as attention and memory, and to give rise to brain-based tools potentially useful in a number of fields (Folgieri and Zichella [5]), e.g. education and cognitive empowerment.

In conclusion, the present study clearly suggests that the exposition to a blue stimulus and the use of a combination of item/background dominated by the blue hues constitute conditions able to improve the cognitive comfort of subjects. A blue stimulation seems to act preparing both the body and the brain of a subject to be ready to face demanding environments. Indeed, a blue light increases alertness, help to focus attention, but also act on the emotional sphere by increasing the self-confidence and the feeling to be able to cope with the situation. Similarly, a blue stimulus seems to be able to directly affect the cognitive systems, improving memory and learning. To reach this aim it's clear that the non-visual and the visual optical systems need to collaborate in order to optimize the performance and to get an adequate cognitive fitness suitable to recruit the resources needed to cope with a give task. In particular, the enhancing effect of red features when coupled with blue stimuli seems to prove this important functional collaboration (Chellappa et al. [13]).

It is also notable that we found some important clues about antagonistic effect among colours. In particular, coupling stimulation within the blue spectrum with green and yellow features clearly resulted in a decrease of the cognitive fitness. Also in this case, the effect should be read as the result of the antagonist effects of two different optical systems not adequately stimulated. Hence, it is clear that a text written in antagonist colours will result in worse cognitive performance, and thus should be avoided.

Taken on a whole, our results suggest that a cognitive-driven design of the artificial illumination and overall of working and didactic materials should strongly improve learning performances. This might be particularly true in case of learning disorders, both in adults and children. Our data not only suggest that text should be written following a cognitive guide, but also the analysis of physiological and cortical correlates of empowered performances should be used to plan neurodidactic tools and protocols directly aimed to help teachers and educators to obtain better results from their pupils or to contribute in rehabilitation programs within clinical settings.

Obviously, cautions should be used in generalizing the presented data. Indeed, some methodological limits are clearly present. In particular, our stimuli were presented in ways different from usual reading conditions, and so we cannot completely evaluate the effect of different combination of colours on the memory of usual text formats. Furthermore, we tested only memory of items in just one occasion and a few minutes after the trial. It would be interesting to evaluate long term effect, so to be able to extend our results to more general learning process. It is also clear that our interpretation of data is limited by the experimental setting and the BCI device used. The experimental setting could improved through a better control and measure of the light/colour stimulation actually perceived by subjects. Finally, the use a mono-electrode device naturally constrains our ability to analyse cortical correlates. However, one of our hypothesis was that also a simple BCI device should provide data usable to interpret behavioural and cognitive results, even though these data might have a different meaning with respect to normal EEG data. Future research should address these aspects, since we believe that the wearable and comfortable technology, e.g. a wireless light BCI, will play a fundamental role in cognitive science in order to collect data in a more ecological fashion.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Friedman D, et al. Navigating Virtual Reality by Thought: What Is It like? Presence. 2007;16(1):100-110.
2. Allison BZ, Wolpaw EW, Wolpaw JR. Brain-computer interface systems: progress and prospects. Expert Review of Medical Devices. 2007;4(4):463-74.
3. Mühl C, Gürkök H, Plass-Oude Bos D, Thurlings ME, Scherffig L, Duvinage M, Elbakyan AA, Kang S, Poel M, Heylen DKJ. Bacteria Hunt: A multimodal, multiparadigm BCI game, in Proc. of the International Summer Workshop on Multimodal Interfaces, Genua; 2010.
4. Plass-Oude Bos D, Reuderink B, Laar B, Gürkök H, Mühl C, Poel M, Nijholt A, Heylen D. Brain-Computer Interfacing and Games, in Brain-Computer Interfaces, ser. Human-Computer Interaction Series, D. S. Tan and A. Nijholt, Eds; 2010.
5. Folgieri R, Zichella M. A BCI-based application in music. Theoretical and Practical Computer Applications in Entertainment. 2012;10:3.
6. Baldwin MW, Meunier J. The cued activation of attachment relational schemas. Social Cognition. 1999;17:209-227.
7. Bramão I, Faísca L, Forkstam C, Reis A, Petersson KM. Cortical brain regions associated with colour processing: An FMRi Study. The Open Neuroimaging Journal. 2010;4:164-173.
8. Nakamura T, Sakolnakorn OPN, Hansuebsai A, Pungrassamee P, Sato T. Emotion induced from colour and its language expression. Proceedings of

Interim Meeting of the International Colour Association. 2004;29–36.

9. Naz KA YA, Epps H. Relationship between colour and emotion: a study of college students. College Students Journal. 2004;38(3):396-405.
10. Hamid PN, Newport AG. Effect of colour on physical strength and mood in childrem, Perceptual and Motor Skills. 1989;69(1): 179-185
11. Knez I. Effects of colour of light on nonvisual psychological processes. Journal of Environmental Psychology. 2001;21(2):201-208.
12. Cajochen C, Frey S, Anders D, Späti J, Bues M, Pross A, Stefani O. Evening exposure to a light-emitting diodes (LED)-backlit computer screen affects circadian physiology and cognitive performance. Journal of Applied Physiology. 2011; 110(5):1432-1438.
13. Chellappa SL, Steiner R, Blattner P, Oelhafen P, Götz T, Cajochen C. Non-visual effects of light on melatonin, alertness and cognitive performance: can blue-enriched light keep us alert? PloS one. 2011;6(1):e16429.
14. Vandewalle G, Maquet P, Dijk DJ. Light as a modulator of cognitive brain function. Trends in cognitive sciences. 2009;13(10): 429-438.
15. Lucchari C, Pravettoni G. Moodlight 2: misurazioni psicofisiologiche ed esperienziali (Moodlight 2: psycho-physiological and experiential measures). Internal IRIDe research center report; 2009.
16. Aston-Jones G, Cohen JD. Adaptive gain and the role of the locus coeruleus-norepinephrine system in optimal performance. Journal of Computer and Neurology. 2005;493(1):99-110.
17. Başar E. A review of alpha activity in integrative brain function: Fundamental physiology, sensory coding, cognition and pathology. International Journal of Psychophysiology. 2012;86(1):1-24.
18. Basar E, Basar-Eroglu C, Karakas S, Schurmann M. are cognitive processes manifested in event-related Gamma, Alpha, Theta and Delta Oscillations in the Eeg?. Neuroscience Letters. 1999;259(3): 165-8.
19. Varela F, Lachaux J, Rodriguez E, Martinerie J. The brain web: phase synchronization and large scale integration. Nature Review Neuroscience. 2011;2:229-239.
20. Goldstein K. Some experimental observations concerning the influence of colors on the function of the organism. Occupational Therapy and Rehabilitation. 1942;21:147–151.
21. Brainard GC, Hanifin JP, Greeson JM, Byrne B, Glickman G, Gerner E, Rollag MD. Action spectrum for melatonin regulation in humans: evidence for a novel circadian photoreceptor. Journal of Neuroscience. 2001;21(16):6405-12.
22. Hill RA, Barton RA. Red enhances human performance in contests. Nature. 2005; 435:293.
23. Soldat AS, Sinclair CR, Mark MM. Colour as an Environmental Processing Cue: External Affective Cues Can Directly Affect Processing Strategy Without Affecting Mood. Social Cognition. 1997;55-71.
24. Krause CM, Sillanmaki L, Koivisto M, Saarela C, Haggqvist A, Laine M, Hamalainen H. The Effects of Memory Load on Event-Related Eeg Desynchronization and Synchronization. Clinical Neurophysiology. 2007;111(11): 2071-8.
25. Kahana MJ, Sekuler R, Caplan JB, Kirschen M, Madsen JR. Human Theta Oscillations exhibit task dependence during virtual maze navigation. Nature. 1999;399(6738):781-4.
26. Caplan JB, Madsen JR, Raghavachari S, Kahana MJ. Distinct Patterns of Brain Oscillations underlie two basic parameters of human maze learning. Journal of Neurophysiology. 2001;86(1):368-80.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=1136&id=5&aid=9156