

1 Original Research Article

2 **A blue Mind: A Brain Computer Interface study**

3 **on the cognitive effects of text colors**

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7 **ABSTRACT**

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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.

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

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10 *Keywords: learning, memory, EEG, Brain Computer Interface, BCI, colour processing,*

11 *cognitive science*

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14 **1. INTRODUCTION**

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16 The reliability of commercial non-invasive BCI (Brain Computer Interface) devices and the

17 low cost of these EEG-based systems, compared to other brain image techniques, such as

18 fMRI or high-density EEG, determined the increasing interest in their application in different

19 Research fields, also thanks to the portability of the equipment.

20 This last feature makes BCI devices particularly suited for experiments involving virtual and

21 real [19] situations and a larger number of subjects, especially when evaluating emotional or

22 cognitive response of individuals. In fact, during EEG measures, anxiety induced by invasive

23 devices could influence the emotive response of individuals. At the opposite, BCI devices,

24 being projected also for entertainment applications, are particularly comfortable and allow the

25 collection of data in a more ecological fashion.

26 Commercial BCI [1] devices consists in a simplification of the medical EEG equipment,

27 communicating EEG response to stimuli by wi-fi connection, allowing to people to feel

28 relaxed, to reduce anxiety and to move freely in the experiment environment, acting as in

29 absence of the BCI devices.

30 Among the different BCIs proposed by commercial Companies, two small-sized, inexpensive

31 devices are currently largely in use in the scientific and in the entertainment communities:

32 the Emotiv Epoc and the Neurosky MindWave. Despite of the lower number of signals
33 detected by the Neurosky BCI (it does not register facial expressions as Emotiv does), it
34 appears particularly suitable for ecological experiments, both for the lower-cost and for the
35 easiness-to-wear.

36 Most of BCI-based interfaces adopt a two-class approach as a modality for movement
37 control, realizing a so-called limited explicit interaction. Other applications use signals
38 registered by BCIs to modify the environment, realizing, in this case, the implicit approach.
39 This latter is an interaction process not based on direct, explicit and voluntary user's action
40 but on the users' state in a particular context. In games, some examples are given by the
41 games "Bacteria Hunt" [18], in which alpha brain rhythms levels are related to the
42 controllability of the player's avatar, or "AlphaWoW" [23], based on the game "World of
43 Warcraft", in which the user's avatar can transform into an animal following the alpha brain
44 rhythm activity.

45 Commercial BCI [1] devices consists in a simplification of the medical EEG equipment,
46 communicating an EEG response to stimuli by WI-fi connection, allowing people to feel
47 relaxed, to reduce anxiety and to move freely in the experimental environment or in the
48 game, acting as in the absence of the BCI devices.

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

55 Conducting data recording by the use of this simple device will permit the direct transfer of
56 results into future BCI-based easy-to use applications, e.g. in education contexts.

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

59 Generally speaking, the colour of light plays an important role in mental functioning. Colours
60 are often associated with one or more emotions; they may also convey specific meanings or
61 information. From childhood we all have repeated experiences of colors in different
62 situations and this gives rise to strong colour-related affective, cognitive and behavioral
63 effects [3]. These effects are unconscious and have an automatic consequence on our brain
64 functioning [8] although meanings may be activated by multiple and may depend on different
65 contexts (e.g. at school red often signals an error, and then evokes an uneasy feeling that
66 we want to avoid; at the opposite, in a romantic context red may symbolizes passion and
67 hence it might act as a positive cue). [21] also highlighted that the meaning of a colour also
68 depends on a given culture, that is to a sort culture-dependent emotion/colour dictionary
69 established by combining the colors to objects and physical spaces [22].

70 These properties seem to act even in children. For instance the study by [15] disclosed the
71 power of colors to enhance the creative skills in 6 children (4/5 years) placed in rooms on
72 several different colour conditions: pink in the room aroused physical strength and good
73 mood, while the opposite was found in a room colored blue. These data therefore seem to
74 support the different activating function of colour.

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

77 For instance, [18] analyzed the influence of the light colour on self-reported mood, cognitive
78 performance and the appreciation of lighting. To achieve this aim, the author compared
79 warm (yellow spectrum) and cold (bluish spectrum) white lights. Warm white light were
80 found to facilitated problem solving, while the cold lighting condition (bluish spectra) was
81 found to enhance attention and short-term memory.

82 More recent evidence substantially confirmed these data, in particular with respect to the
83 role of blue light in facilitating attention-related tasks. For instance, [9], studying the effect of
84 the blue spectrum light produced by a LED monitor, found that subjects exposed to this
85 direct light were significantly influenced both at the physiological and cognitive level. In
86 particular, the circadian cycle was altered since an evening exposition to the LED light was
87 able to stop melatonin production, thus shifting the day/night cycle, and increasing the
88 attention level as well as memory performances.

89 Similarly [11] specifically analyzed the role of light temperature on attention. The
90 temperature is a parameter of the white light indicating the blend of wavelengths present in
91 the visible light. In particular, a warm light (under 3000 K) is rich in green and yellow
92 components, while a cold light (higher than 6000 K) is rich of blue components. The cold
93 light is a white intense light similar to the one of the dawn, and may be easily reproduced by
94 a fluorescent lamp, while a warm light is characteristic of late afternoon and is generally
95 produced by an incandescent lamp. [11] found that cold light is able to decrease the salivary
96 level of melatonin, increasing instead the arousal level as well as the sustained attention as
97 measured by a go-no-go task.

98 Finally, [24], in a review of recent studies about the relationship between the light quality and
99 brain functioning, reported the impact of blue light components in different cerebral areas
100 deputed to regulate attention, memory and the whole cognitive system. In particular,
101 thalamus, limbic structures and the neo-cortex are all affected by the quality and the quantity
102 of environmental light, showing that light has the power to influence attention, emotion,
103 cognition and behavior due to a complex of interrelated functional circuits.

104 In a previous study [20] we have tested the possibility to enhance the cognitive fitness
105 modulating the quality of light (colour and temperature of white light). In fact, even a brief
106 exposure to a blue light may increase arousal that in turn may promote the cognitive
107 performance in certain tasks. However, further than cognitive performances it is possible to
108 assume that exposure to a light source with a strong blue component allows a subject to find
109 cognitive comfort, that is, to create the preconditions of a mental setting suitable for a task
110 that requires attention and concentration. Hence, we propose that a blue stimulation pre-
111 activates central nervous system in such a way to limit the cognitive stress by the pre-
112 allocation of the required resources for a future task, thus promoting a cognitive fitness.

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

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121 **2. MATERIAL AND METHODS / EXPERIMENTAL DETAILS / METHODOLOGY**

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123 **Method**

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

131 **Subjects**

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

138 **Instruments**

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

140 BCI devices collect several cerebral frequency rhythms: the Alpha band (7 Hz – 14 Hz),
141 related to relaxed awareness, meditation, contemplation; the Beta band (14 Hz – 30 Hz),
142 associated with active thinking, active attention, solving practical problems; the Delta band (3
143 Hz – 7 Hz), frontal in adults, posterior in children with high amplitude waves, detected during
144 some continuous attention tasks [2]; the Theta band (4 Hz – 7 Hz), usually related to
145 emotional stress, such as frustration and disappointment; the Gamma band (30 Hz – 80 Hz),
146 generally related to cognitive processing of multi-sensorial stimuli [4][5]. The BCI device
147 communicates the EEG response to stimuli by WI-fi or Bluetooth connection, allowing people
148 to move freely in the experimental environment, thus reducing anxiety.

149 The limitation of a single electrode provided by the NeuroskyMindwave implies that the
150 possible analysis of the brain activity relates to very general phenomena, and cannot be
151 used easily to identify ERPs or to associate a specific brain activity with a specific brain area.
152 This method, hence, reduces the accuracy of the neurophysiological interpretation of results,
153 but it was suitable for our research purposes. Indeed, we could measure the average of the
154 activity of the whole brain, with a stronger contribution of the frontal lobes. In our case this
155 fact does not represent a disadvantage, since we are interested in analysing higher cognitive
156 brain activity, mainly recordable in frontal regions, rather than elementary stimulus related
157 activity. The use of the Mindwave presents also another advantage: the wireless
158 communication between the BCI device and the computer during the data recording is
159 particularly appreciable since it provides to individuals a comfortable experience, thus
160 enhancing the ecological validity of the experiment.

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

163 **Procedure**

164 To test the impact of blue on cognitive performance, we set up four experimental conditions,
165 in order to represent different combinations of colours, thus contrasting the effect of blue with
166 other possible contrasts. We have combined primary (red, green, blue - RGB) and
167 complementary (cyan, magenta, yellow - CMY) colours. In the first condition, we delivered to

168 participants a sequence of black words on primary colour (RGB) backgrounds and black
169 words on complementary colour (CYM) backgrounds. Participants in the second condition
170 have been asked to look at a sequence of primary colour words and complementary colour
171 words on a white background. In the third experimental session we put primary colour words
172 on primary colour backgrounds and complementary colour words on complementary colour
173 backgrounds. In a last condition, we submitted participants a sequence of primary colour
174 words on complementary colour backgrounds and complementary colour words on primary
175 colour backgrounds. We delivered all the possible RGB-CMY combinations. Each stimulus
176 was repeated 5 times. At the end of the experimental session, subjects were involved in a
177 simple distracting task (fulfilling a questionnaire with personal data, habits, preferences and
178 the like) requiring about two minutes to be completed. Anyway, a standard time was set up
179 for each participants, so that the subsequent memory test started extaly 5 minutes after the
180 end of the stimulation phase.

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

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

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

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

197 For the data analysis, we used different software tools, based on EEGLAB and ad hoc
198 implemented MATLABTM code.

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200 **3. RESULTS AND DISCUSSION**

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202 **Statistical analysis**

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204 Though the main objective of the study consists in investigating the impact of blue text on
205 cognitive performances, we also aimed to verify how EEG detection through BCI device can
206 improve the analysis and the interpretation of cognitive processes through the combined
207 approach of cognitive science and information technology methods. The analysis of the
208 collected data was divided into three stages: (1) the behavioural data analysis, based on the
209 findings deriving from the questionnaire submitted to participants; (2) the EEG signal
210 analysis of the evoked potentials, performed on the data collected from individuals
211 participating in the experiments; (3) the comparison of the results from the two approaches
212 to match (or not) the respective findings.

213 We want to recall that Evoked Potentials (EP) or Evoked Fields (EF) indicate the variations
214 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 and of an increment of the power of the signal. For this reason, in the EEG signal analysis, 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, 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 $\phi^1(t)$ 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:

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

where brackets $\langle \rangle$ 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 [24]. 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.

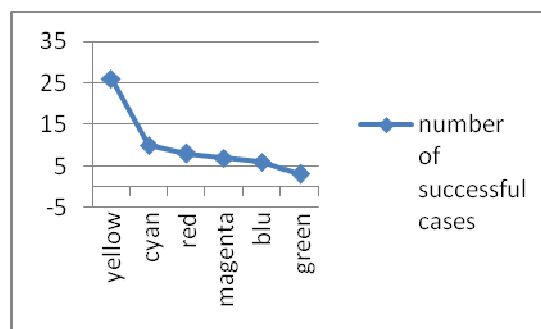
The observed data and the following analysis indicated some variation depending on the choice of the colours (primary or complementary).

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.

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 figure 1). Words written on a green background have been the most difficult to remember (only 3 participants in 35).



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Figure 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 figure 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).

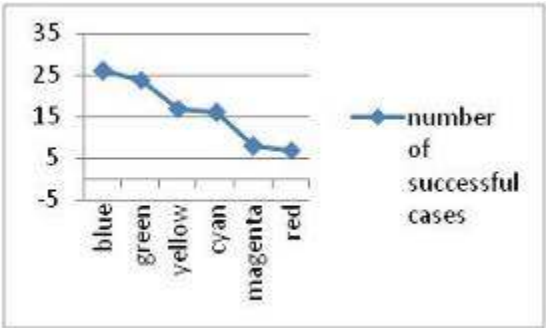


Figure 2. Number of words successfully remembered with the respect to corresponding text colour on white background

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. 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).

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.

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

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 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 figure 3).

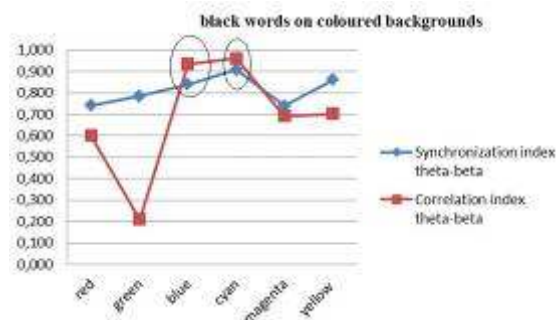


Figure 3. Comparison among the Pearson correlation and the synchronization index for each colour stimulus related to a randomly chosen participant.

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

386 results of the EEG analysis, revealing a high activation of cognitive processes corresponding
387 to theta, alpha and beta cerebral rhythms.

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

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

394 - The cyan background in the first experimental session (words in black on coloured
395 background).

396 - the blue colour in the second experiment (coloured words on white background)

397 - the red/blue and blue/red combinations in the third experimental session (primary
398 colour words on primary colour backgrounds)

399 - The cyan/magenta combination in the fourth experiment (complementary colour
400 words on complementary colour backgrounds).

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

405 From a cognitive point of view, our results suggest that a blue stimulus may play an
406 important role in positively modulate the cognitive comfort of a subject, increasing alertness,
407 memory performance and the psychological experience. It is well known that short
408 wavelength light, in particular the blue spectrum, represents a modulator signal for the
409 functioning of the central nervous system. About a decade ago a new kind of receptor,
410 described as a light/dark signaller, was discovered in the retina [7]). Interestingly, the
411 receptor is tuned to be sensitive only to the blue light and its reactivity seems to be
412 enhanced when a red signal precedes a blue stimulation. The light/dark receptors are aimed
413 to tell the brain whether it's light or dark outside, and they work sending inputs to the
414 biological clock (i.e. the suprachiasmatic nucleus), rather than the vision cortex. We wish to
415 recall that the circuit formed by the suprachiasmatic nucleus, the dorsomedial hypothalamic
416 nucleus and the nucleus coeruleus (NC), seems to play an important regulatory role in the
417 functioning of the brain and cognitive performance, changing the level of alertness. In
418 particular, the NC is modulated by the suprachiasmatic nucleus which in turn is modulated
419 by the light perceived by the eye. In particular, the wavelength peak corresponding to the
420 blue colour (between 450 and 480 nm) captured by the light/dark retina receptors are able to
421 modify the firing level of the NC. The NC is part of a circuit output used by the central
422 nervous system to adjust the periodicity of a series of processes, through the release of a
423 neurotransmitter called norepinephrine. Norepinephrine regulates the excitability of neurons
424 in the thalamus and the cerebral cortex. The NC is also activated by stimuli of particular
425 importance during wakefulness, thus playing a role as a modulator of the alert and arousal
426 and, more generally, of the cognitive performance. In particular, the activity of the NC during
427 wakefulness is related to the level of attention. When the neurons of the CN show phasic
428 activity (i.e. is responsive to specific stimuli) the maintenance of focused attention with
429 respect to specific stimuli and/or tasks [2] is facilitated. Hence, a blue stimulation could act
430 on the central nervous system as a kind of signal reset, so resetting the cycle in progress
431 and restoring the attention system at a high level, i.e. waiting for input data to be processed.

432 Our results support the hypothesis that a blue or cyan text on particular backgrounds (i.e.
433 those with high contrast) may provide a better cognitive performance due to the high level of
434 expectation triggered by the exposure to a blue radiation.

435 We have also found interesting results regarding the correlation among cognitive
436 performances, the colour features and the EEG modulation. In fact, the synchronization of
437 theta waves during learning tasks seems to be meaningful. Previous research showed the
438 event-related theta band power responds specifically to prolonged visual emotional
439 stimulation [19] and a synchronization was revealed in case of coordinated responses
440 indicating alertness, arousal and readiness to process information [5]. In other studies, theta
441 activity has been reported in neocortical areas as well, as in Kahana and colleagues who
442 used intracranial EEG measurements [17,10]. The spectral analyses of scalp-recorded EEG
443 are dominated by cortical activity and shows clear patterns of theta activity in memory
444 paradigms. Our results confirm the correlation between theta synchronization and attention-
445 related tasks. Furthermore, it seems plausible that the level of alertness is modulated by the
446 colour of text and that the synchronization of frontal theta.

447

448 **4. CONCLUSION**

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

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

466 In conclusion, the present study clearly suggests that the exposition to a blue stimulus and
467 the use of a combination of item/background dominated by the blue hues constitute
468 conditions able to improve the cognitive comfort of subjects. A blue stimulation seems to act
469 preparing both the body and the brain of a subject to be ready to face demanding
470 environments. Indeed, a blue light increases alertness, help to focus attention, but also act
471 on the emotional sphere by increasing the self-confidence and the feeling to be able to cope
472 with the situation. Similarly, a blue stimulus seems to be able to directly affect the cognitive
473 systems, improving memory and learning. To reach this aim it's clear that the non-visual and
474 the visual optical systems need to collaborate in order to optimize the performance and to
475 get an adequate cognitive fitness suitable to recruit the resources needed to cope with a give
476 task. In particular, the enhancing effect of red features when coupled with blue stimuli seems
477 to prove this important functional collaboration [11]

478 It is also notable that we found some important clues about antagonistic effect among
479 colours. In particular, coupling stimulation within the blue spectrum with green and yellow
480 features clearly resulted in a decrease of the cognitive fitness. Also in this case, the effect

481 should be read as the result of the antagonist effects of two different optical systems not
482 adequately stimulated. Hence, it is clear that a text written in antagonist colours will result in
483 worse cognitive performance, and thus should be avoided.

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

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

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