Looking through blue glasses: bioelectrical measures to assess the awakening after a calm situation*

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Abstract— **Colors can elicit cognitive and emotional states. In particular, blue colour is associated to "refresh" and "restart" effects and is suggested to enhance a wake-up after a calm situation. In this exploratory study, these claims are investigated using Electroencephalographic (EEG), Skin Conductance (SC) and pupil diameter data. The results confirmed the "wake-up effect" for subjects wearing the lenses, as measured by Global Field Power (GFP) in Theta Band, Skin Conductance Response (SCR) and pupil diameter data.**

I. INTRODUCTION

It is well known that colors can elicit different cognitive and emotional states, modulating psychological functioning in humans [1]: this have been effectively used e.g. in the fields of marketing [2], food and beverage [3] and medicine (the so called "chromotherapy") [4].

In particular, blue colour have been linked to a "restart" and "refresh" effect [5]; furthermore its ability to improve a wake-up from a calm situation have been suggested [6]. Applicative implications of such claims include the use of blue light to boost (i.e. make faster or more efficient) the initial phases of mental daily activities.

Traditionally, cognitive/emotional responses to colours have been assessed using Electroencephalographic (EEG) and Skin Conductance (SC) measurements [7]: in this exploratory study, an objective measure of the hypothesized "wake-up effect" by means of EEG, SC and pupil diameter data has been proposed. In particular, we used Global Field Power (GFP) in Delta Band because it has been previously related to sedative effects [8], while GPF in Theta Band [9], as well as Total Power (TP) in both Theta [10] and Delta bands [9], have been previously related to meditation states. As for autonomous and biometrical data, we focused on the amplitude of Skin Conductance Response (SCR), previously related to an increase of attention level [11], and pupil diameter as an index of improved performance in cognitive tasks [12].

Blue lenses (2 mm thick, 50% of Visible Light Transmission, VLT), mounted on a glass frame, are used in order to filter the ambient light and to produce a "blue light" perception. The use of lenses instead of direct light have been previously adopted to assess the influence of colours on physiological and emotional responses [13].

II. METHODS

A. Instrumentation

EEG data were recorded using a B-Alert x10 (ABM Inc.), a wireless (Bluetooth connection) device equipped with 9 EEG channels (in a monopolar montage) and 1 auxiliary and electrical-separated differential channel. Ag/AgCl electrodes, embedded in a flexible plastic strips, were arranged according to locations F3, Fz, F4, C3, Cz, C4, P3, POz, P4 of 10-20 System. The device records at a sample frequency of 256 Hz and a resolution of 12 bits [14]. Reference and ground electrodes were placed on the mastoids (M1, M2) and the auxiliary electrodes were placed approximately 1 cm above and below the left eye, in order to record the Vertical Electrooculographic (vEOG) signal. B-Alert data were collected using iMotions (iMotions A/S) software, an integrated research platform that allows study design, stimuli presentation and real-time synchronization of various devices (e.g. EEG, ECG, EyeTrackers).

SC signal was recorded using a SA9309M (Thought Technology Inc.) sensor. According to recommendations in the literature [15], SC was recorded using a constant-voltage mode (0.5 V) by means of 2 Ag/AgCl electrodes placed on the index and ring finger from the non-dominant hand. The sensor was connected to the FlexComp System (Thought Technology Inc.), a 10 channels general-purpose bio-signal acquisition device. The sample frequency was set at 256 Hz and the resolution at 14 bits. FlexComp data were collected using BioGraph Infiniti (Thought Technology Inc.) software.

In order to ensure a synchronization between iMotions and BioGraph Infinity data, a T7670 (Thought Technology Inc.) sensor was connected to the FlexComp device. T760 is a photosensor equipped with an optical-fibre attached to the stimuli monitor able to discriminate between high and low luminance level. A synchronization sequence was presented as stimulus for each subject, consisting of alternated black (B) and white (W) patterns (500 ms each, in the order W-B-W-B-W-B).

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Finally, gaze and pupil diameter data were recorded with a ProSpectrum x60, a 150 Hz EyeTracker bar (max gaze angle 30°, with 0.3° of accuracy and 0.06° RMS of precision for gaze position) by Tobii LLC. The data were synchronized using iMotions.

B. Study Population and Experimental Protocol

Sixteen healthy subjects were enrolled in the experiment (8 men, mean age 39.75±5.79, range 32-49 years). In order to test the effect of blue lens on the wake-up after rest, the subjects were assigned to 2 groups: 8 wearing the lenses (WL group) and 8 not wearing the lenses (nWL group). The nWL group served as a control group. The study protocol was approved by the ethical committee of IULM University and informed written consent was obtained from each participant before starting the experiment.

Each subject sat on a chair placed in front of a 23.8 inches monitor (EIZO FlexScan EV2451) – the experimental station. The operator positioned the SC and EEG sensors and checked the quality of the signals before starting the recording. In particular, before the application of EEG electrodes the skin was properly prepared (scrub with isopropyl alcohol, followed by the application of conductive cream). After the application the impedance was measured and ensured to be less than 10 kΩ, according to the guidelines [16].

After the synchronization sequence, the subject performed the B-Alert Benchmark in order to extract cognitive metrics of High Engagement, Low Engagement, Workload and Drowsiness (for details, see [17] and [18]) and an eye-tracking calibration task in order to map the gaze on the monitor surface.

The subject was thus asked to move to a relaxing station, a reclinable chair placed approximately 1.5 m away to the experimental station. A classical music piece was played for 10 minutes, while the subject listened keeping the eyes closed. Mozart's music (serenade in G, K.525) was chosen because of its documented relaxing effects, i.e. in decreasing cortisol levels [19] and lowering both blood pressure and heart rate values [20]. After 10 minutes, a "wake-up phase" started: the subject was asked to open the eyes, still listening to the same music for 3 minutes. At the beginning of this phase, the WL group put on the lenses.

The subject moved back to the experimental station and sat in front of the monitor. A 60 s long eye-closed baseline (EYC) was executed, followed by a 60 s long neutral baseline (BSL) where the subject was asked to simply fixate a white dot on a black background. A re-activation task was administrated: the subject was presented a sequence of 4 different shapes (persistent for 5 s each) and had to recall and digit on a modified PC keyboard the previously seen sequence.

Finally, a web-based version of the Psychomotor Vigilance Task (PVT) was administrated in order to measure subject's reaction times [21]. PVT consists on a series of visual stimuli presented randomly on the screen: the subject has to click on them when they appear, as quick as possible. As the subject click on the stimulus, it disappears and a new one is presented (after a random waiting interval).

Additionally, at the end of the experiment psychometric data were collected using a questionnaire – not considered in the present study.

C. EEG Processing

EEG data were processed in Matlab (The Mathworks Inc.) v.R2018b using EEG Lab toolbox [22], according to the following pipeline:

- Suppression of power line noise with a notch filter on both 50 Hz (primary power-line frequency) and 100 Hz (2nd harmonic);
- Removal of ocular artifacts using a Stable Conventional Recursive Least Square (SCRLS) regression algorithm from the vEOG signal;
- Filtering with a Zero-phase FIR Band-Pass filter between 2 and 48 Hz (with 0.1 Hz of transition band width);
- Independent Component Analysis (ICA) decomposition using the Second-Order Blind Identification (SOBI) algorithm since, according to a previous study, it exhibits good performance with respect to the majority of artifacts types [23];
- Automatic identification of artifactual components using the MARA algorithm [24] that identifies artifactual (i.e. Blinking, EMG noise) Independent Components (ICs) from a set of spatial, temporal and statistical features;
- Rejection of artifact-marked ICs and back-projection of the remaining ICs to the original signal space;
- Re-referencing to the Small Laplacian (or Current Source Density, CSD).

The Individual Alpha Frequency (IAF) was estimated by the peak frequency of the Power Spectral Density (PSD) in the extended alpha band (7~12 Hz) during the EYC condition, as suggested in [25]. The PSD was estimated using a Welch's periodogram with a 1 s long Hamming window with 50% overlapping.

Individual Theta Band (ITB) e Individual Delta Band (IDB) were thus computed respectively as [IAF-6; IAF-4] and [IAF-8; IAF-6], as suggested in [26].

EEG data were band-pass filtered in the ITB and ITD and then the Global Field Power (GFP) functions were computed in order to get a spatial measure of the EEG activity. GFP is defined as:

$$GFP(t) = \sqrt{\sum_{k=1}^{N} \left(x_k^B(t) - \mu_k^B(t)\right)^2}, \qquad (1)$$

where $x_k^B(t)$ is the k-th EEG channel (over a total number of N) filtered in the band B, $\mu^B(t)$ is the mean across all filtered channels at time instant t. High GFP is associated to scalp potentials with a steep gradient, while low GFP is associated to uniform scalp potential distributions [27].

Additionally, the total Theta and Delta Power (TTP and TDP, respectively) functions were computed, in order to get a "global measure" of the EEG activity. Total power in the generic band X is defined as:

$$TXP(t) = \sum_{k=1}^{N} x_k^X(t)^2, \tag{2}$$

where $x_k^X(t)$ is the k-th EEG channels (over a total number of N) filtered in the band X.

GFP, TTP and TDP signals are epoched according to the experimental conditions and z-score transformed using the mean value and the standard deviation calculated inside the BSL epoch. Z-score transformation removes the subjective variability performing a scaling and an offset correction using a neutral baseline. Z-scored GFP functions are finally averaged inside each epoch to get a task-related average GFP value.

D. SC Processing

SC data were first band-pass filtered using a zero-phase 4th order FIR filter (0.001~0.35 Hz). Then, a threshold for SC extreme values (0.05~60 μS) and extreme rate of changes (±8 μS/s) was used in order to detect artifacts [28]. Once identified, artifactual points were replaced by a linear interpolation. From artifact-corrected SC was extracted its phasc Skin Conductance Response (SCR) by means of the cvxEDA algorithm [29].

SCR was epoched, z-score transformed and averaged inside each epoch.

E. Pupil data processing

The pupil diameter data were evaluated during the execution of the PVT and, in particular, during the epoch before the stimulus appears. The collected values were averaged both across each epoch and across all the epochs in order to have a mean pupil diameter associated to the phases of the PVT that require the highest attention (i.e. the waiting intervals).

F. Statistical analysis

Statistical analyses were performed using Matlab. For both WL and nWL group, outliers were identified by means of the Interquartile range (IQR) criterion (i.e. values with distance from the median value greater than 1.5 times the IQR) and discarded from further analysis. Subjects with more than 6 outlier values were excluded.

Mean values of metrics related to the PVT epoch (EEG, SC, and pupil diameter) and PVT scores were computed for each group. For each metric, the Jarque-Bera test for normality (unknown mean and variance) was applied: based on its results, the Wilcoxon signed-rank test (not normal data) or the two-samples t-test (normal data) was used (both 2 tailed).

Additionally, correlation analysis was performed using as variables both subject's condition (WL or nWL) and metrics/scores. When one of the 2 variables was the condition (coded as WL=1, nWL=0), the point biserial correlation coefficient r_b was computed. Otherwise, the proper correlation coefficient was computed based on the normality of the variables' distributions: if normal, Pearson's coefficient r_p was used; otherwise Kendall's r_k.

Even if a large number of tests was performed, it was decided not to apply any multiple test adjustment (e.g. Bonferroni correction), following the general recommendations in exploratory studies [30].

III. RESULTS

In the Table 1 are summarized the descriptive statistics (mean values and standard deviations in parenthesis) of the metrics that showed a significant difference ($p<0.05$, marked with an asterisk) or near-to significant difference ($p<0.10$, not marked) between groups.

Previous studies have related different bioelectrical measures to both relaxing and awakening states. In [8], an increase in Delta GFP was associated with sedative effects. In [11], SCR amplitude was related to an increase of attention level and in [12] higher pupil dilation was linked to improved performances in cognitive tasks. In [5], a positive correlation between TDP and reaction times during a blue-light exposure was found. In [18], higher levels of low engagement have been measured during monotonous tasks.

In the present study, significant differences for Delta GFP ($t=2.353$, $p=0.034$) was found, as well as a negative significant correlation between condition and Delta GFP ($r_b=-0.515$, $p=0.034$). Delta GFP was lower for WL subjects and the correlation between Delta GFP and condition (that is, the direction of GFP's change with respect to the condition) was negative and significant. This confirms that blue lenses favour an arousal effect.

As evidence that blue lenses increase the attention level, SCR was significant higher in WL subjects ($t=2.353$, $p=0.044$), and the correlation between SCR and pupil diameter was positive and significant ($r_p=-0.619$, $p=0.032$), even if the difference of pupil diameter in the 2 conditions was not significant.

Near-to significant differences were found for TDP ($t=-2.048$, $p=0.061$) and Low Engagement ($t=-1.995$, $p=0.067$), suggesting an improvement of reactivity and an increase of attention level, respectively.

No significant effects with GFP Theta and TTP have been found, probably due to the inability of theta activity to trace a wake-up effect as opposite to a relaxing state (even if additional studies are required).

IV. CONCLUSIONS

This study objectively tested the wake-up effect by means of EEG (TP and GFP in Delta and Theta bands), SC and biometric (pupil diameter) data.

TABLE 1. SIGNIFICANT DIFFERENCES BETWEEN METRICS

Metric	*WL*	*nWL*	*p-value*
GFP Delta*	0.085 (0.346)	0.707 (0.663)	0.034
TDP	0.479 (0.733)	3.554 (3.895)	0.061
SCR*	2.656 (2.327)	0.575 (0.870)	0.044
Low Engagement	0.364 (0.081)	0.448 (0.037)	0.067

TABLE 2. SIGNIFICANT CORRELATIONS BETWEEN METRICS

Metric #1	*Metric #2*	*Correlation*	*p-value*
Delta GFP	Condition	-0.515	0.034
SCR	Pupil diameter	-0.619	0.032

An arousal effect was confirmed by Delta GPF data (both in group differences and correlation with the condition). Moreover, an increase of attention level was confirmed by SCR data (both in group differences and correlation with pupil diameter). Finally, an increase in reactivity and attention level was suggested by TPD and Low Engagement data.

As a future perspective, the analysis of collected psychometric data will serve to investigate the relationship between measured physiological activity and subjective ratings, in terms of group differences and variables relations through multigroup analysis (e.g. Structural Equations Models, SEM).

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