Experiencing the Light Through our Skin - an EEG Study of Colored Light on Blindfolded Subjects

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***Abstract*—Light is omnipresent, surrounding us at every given moment, promoting different sensations and emotions. However, as we sense the light we do not only perceive it through our eyes, but our skin as well, as the epidermal contains photosensitive receptors similar to the retina, the opsins. In this study the sensations from the skin were measured through electroencephalography (EEG) to understand its contribution to our experience of light. For this experiment the subjects were blindfolded and placed in a daylight isolated room with artificial light. Here they were exposed to red, green and blue light as well as darkness. Through a temporal spectrum evolution (TSE) and a machine learning algorithm for visualizing highly dimensional data (t-SNE) the color based perception signatures were found to be distinguishable. T-SNE clustered the TSE maps into four separable segments, one for each scenario. Inside each of these clusters unique delta, theta, alpha and beta event related desynchronization and synchronization (ERD/ERS) biomarkers could be found. These biomarkers could cultivate the idea that when red and blue are sensed through the skin they elicit cortical arousal and awareness, while green promotes calmness and relaxation.**

***Index Terms*—Light, EEG, electroencephalography, opsins, colored light, perception, somato-sensory cortex**

I. Introduction

Light is all around us and influences all contexts we encounter. Being architectural spaces, nature or virtual spaces such as games, the light affects us to different extend. It can make us comfortable [7], [8], aroused [8], cautious [9], driven [9] and even happy [7]. The light setting makes areas approachable and avoidable, closed as well as open [7]. Beyond the subjective opinions towards light the physiological responses to different types of light are being investigated [11]–[13]. With this knowledge the very foundation of how we feel and think about any sort of context is evident. The body is constantly reacting and adjusting to the surrounding elements, where one of the most omnipresent elements is light. It is well known that daylight and the wavelengths it consist of adjust our circadian rhythm, our awareness and thus how our body works [14]. At the same time the digital apparatuses we use in our modern society emits both similar light waves as well as drastically different ones, which are altering our body and mind [10]. Studying the brain signals from viewing different colors of light provides an interesting picture of why we react to light as we do [8], [12]–[18].

While these studies discuss how we react when we see different colors of light, findings about photosensitive opsin proteins in the cells in our epidermal questions whether light is only perceived by our eyes, but with our skin as well [1]–[3]. Not only does these opsins react to light exposure, the melatonin level and the circadian rhythm are affected as well [4], [5]. This evidently shows us that the retina is not the only organ to receive light, but also the skin. interestingly the active opsins in the skin are of similar types as those in the retina, however, less reactive [1], This may indicate that the opsins in the epidermis should inherently have the same properties as the ones in the retina. When the retina receives the light photons they are converted to electrochemical signals, which are transported to the occipital lobe, in which they are interpret and constructs our visual world. Interestingly the electochemical signals traveling from the skin to the brain are processed in the somatosensory cortex. So any sensation of light on the skin will likely be interpreted as some sort of touch or temperature sensation on the skin rather than a visual sensation, as the visual cortex is located in the occipital lobe. Through EEG studies event related responses are found in the occipital and parietal lobe as a reaction upon visual stimuli perceived by the eye. Additionally, alpha desynchronization and lower alpha levels are found when we see compared to non visual stimuli, thus closed eyes. Moreover, since we are talking about the same types of opsins in the skin as well as in the retina, will the same alpha desynchronisation be observed in the somatosensory cortex as a direct response to light being sensed by the skin? And will different wavelengths of

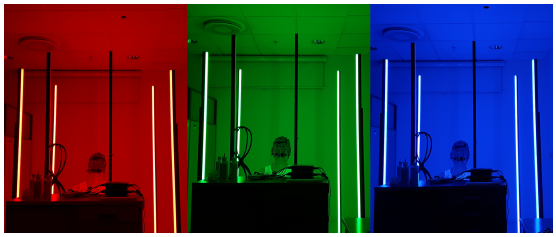

Fig. 1. showcases the three different lighting scenarios and the blindfolded subject in the middle

light be interpreted differently like the visual system? In S.L. Nielsen, C. Friberg, and E. K. Hansen [7] recent study they studied blindfolded subjects' qualitatively reported bodily and psychological sensations towards red, blue or amber colored light while the subjects laid down. Red was reported as being warm, enclosed, claustrophobic and heavy. Blue was described by the subjects as cold, floating, open and distant. While amber was proclaimed as calm, happy, loving and natural. This supports the idea that distinct EEG observations will be seen around the somatosensory cortex, as both the sensation of temperature and proprioception (the body in relation to the surrounding space) is mentioned in the study. While EEG may capture that sensation, the expressed feelings and associations may be tougher to observe through the given methodology, as amygdala and the hippocampus are sub cerebral brain regions. In our study we want to understand the EEG signals as a response to the sensations caught by the opsins in the skin. To achieve this the human subjects are blindfolded and exposed to different colors of light (red, green and blue) as well as darkness. The design of this study and its approach is based on the ongoing PhD research by S.L. Nielsen. The findings will support the importance of the messages the opsins in the skin emits to the brain and at the same time reveal how we passively perceive light even though we do not attend to it with our eyes.

II. Related Works

While the literature concerning EEG and light is solely emergent from the visual perception point of view, their findings will serve as inspiration for our study. The most researched EEG phenomenon regarding light is the alpha waves. These are found to decrease significantly in power when the subject is exposed to any source of light. Where exposure to red light provokes the strongest decrease followed by blue and then green [8], [12], [16], [18], [19], [22]. This decrease has been translated to cortical arousal, which, if we look at the subjective notions of e.g. red coincides, as this color has been associated with energy, activation and aggressivity [9]. Furthermore, as red has the strongest alpha power decrease it has the longest cortical recovery delay compared to blue light [13]. Albeit the significant alpha power decrease have been found in those studies a few others have not been able to reproduce the same results, either due to not enough perceptual difference in the conditions [17] or the subject being occupied by other tasks at the same time such as estimating the time that has past during the light exposure [15]. Yoto et al. have contrarily found opposing results with red provoking the highest alpha, then green and lastly blue [20], However, their study was with colored paper and not light, so the change of medium might have influenced the results.

We have previously developed a small BCI prototype to which we needed EEG markers related to colors. To support the development we flashed red, green and blue colors at the subjects, providing us with a qualitative look into how we react to those. Interestingly, these observations also provoked dissimilar results to rest of the literature, red provoking the highest alpha peaks, blue the highest beta peaks and green the highest delta [21].

Despite the disagreement found in the alpha, other frequencies have been observed as well as being related to the colors. Beta (12-30Hz) increase have been measured when the subject were exposed to red or blue relative to dim-light [14]. Additionally Zhang et al. found the relationship between beta and the colors to show red having the highest beta, then blue and lastly green [19]. Lastly delta have been found to be higher in a blue colored room compared to a red colored room [16]. Regarding the spatial distribution of the measurements the alpha decrease regarding red have been found in the parieto - occipital area [18] and for both red and blue centro - parietal area have been used as the measuring site [8].

Discussed in the introduction the important area for this study will be around the somatosensory cortex and the parietal areas, as these locations are related to each other, and EEG has an inherently bad spatial resolution. Seen in the visited literature the EEG measurements, which are likely to be localized only in the occipital lobe are bleeding into the neighbouring regions, as the processing of the stimuli requires higher cognitive and affective abilities. additionally EEG easily picks up signals not originating from the area just below the electrode.

Regarding the frequency bands it appears that the majority of the literature agrees that that red will have a significant lower alpha, than blue, green and darkness. Albeit if the results from this study differs we should not be surprised, as it is another sensory organ to receive the light. Thus, we can hypothesize that the red will have a significant lower alpha than blue, green and darkness. Additionally, green should have the highest alpha of the three colors. Since the literature also concerns with beta and delta we will investigate those to see if this study follows the literature, thus exposing the subjects to colored light will elicit higher beta than darkness and delta will be higher in blue light than red light.

III. Methods

A. Experimental setup

The subjects were situated in a 2.40 meter by 2.80 meter squared room encircled by six LED light fixtures. The fixtures were placed 70 centimeters from the subjects to ensure equal

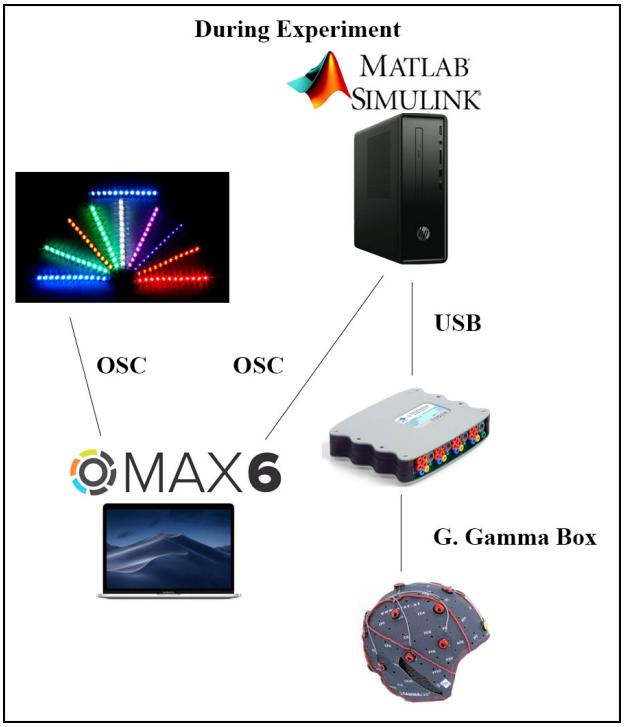

Fig. 2. a diagram showcasing the flow of data during the experiment

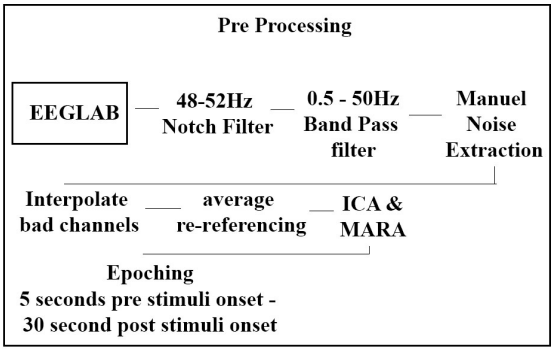

Fig. 3. an overview of the pre-processing process. Starting with the raw data in EEGLAB ending with the epochs ready to be analyzed

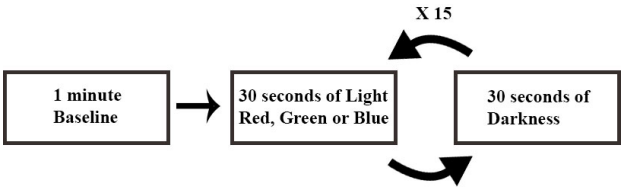

Fig. 4. an overview of the experimental procedure

exposure from each of the fixtures (Fig. 1). The LEDs were of the type SK6812 RGBW and for each fixture 288 LEDs were mounted. The lights were controlled wirelessly through a Mac pro computer running Max MSP. This script determined fixed temporal triggering of events using the Open Sound Control (OSC) protocol and furthermore had a randomization algorithm for the selection of events. The same protocol was used to communicate the temporal onset of the light to a Windows computer running a Matlab Simulink environment, which served as the EEG recording software. At a sample rate of 256Hz the EEG was acquired through a g.Tec Gammabox and a g.Tec g.USBAmp, which were connected through USB to the computer running the Matlab environment (a simple overview can be found in figure 2). The EEG was recorded from 16 electrodes covering most of the scalp within the 10-20 system: F3, Fz, F4, T7, C3, Cz, C4, T8, P7, P3, Pz, P4, P8, O1, Oz, and O2.

B. Experimental procedure

22 subjects were recruited using non-probabilistic convenient sampling using the internal communication systems at Aalborg University. These 22 were healthy students between 22 and 35 years old, equally divided by gender. After providing their consent, the subjects were placed in the middle of the light fixtures. They were equipped with a white tank top instead of their own upper body cloth and the EEG cap to which conductive gel was applied. The signal was checked to ensure proper conductivity, impedance and quality. The subjects were blindfolded using modified swimming goggles and asked to sit as comfortable and still as possible. Then the Simulink environment and the Max MSP program were engaged. The experiment started with 1-minute baseline recording which consisted of total darkness. It was continued by, 30 seconds of a random light (red - peak intensity at 625nm, green - peak intensity at 520nm or blue - peak intensity at 462nm) then 30 seconds of darkness again. Each of the colored light scenarios had the same (maximum) intensity settings in the Max MSP program. This alteration between light and dark was repeated 15 times, thus having 5 recordings of each light stimuli and 15 recordings of darkness per subject (see figure 4 for a quick overview of the experimental procedure).

C. EEG preprocessing

Using EEGLAB the EEG data was first submitted to a notch filter (48-52Hz) rendering out the power plug interference. Next a band pass filter (0,5-50Hz) was applied to cancel out signal drift, high frequency muscle artifact and current resonating from the light. The signal was manually checked for prevailing noise and noisy channels. All prevailing noise were excluded from the dataset and eventual bad channels were interpolated using spherical interpolation method. To make the data cross-study comparable average re-referencing was applied, thus the reference is not depending on a single electrode. Afterwards, ICA with the help of the MARA algorithm [6] was applied to clean the data completely and maximize the likelihood of having high quality data. Lastly, the data was epoched to contain data from 5 seconds before the onset of a stimuli to 30 seconds after the onset of a stimuli (see figure 3 for pre-processing overview).

D. EEG statistical analysis

Like Rasheed et al. [22] we are not only interested in the amplitudinal differences between the different types of light,

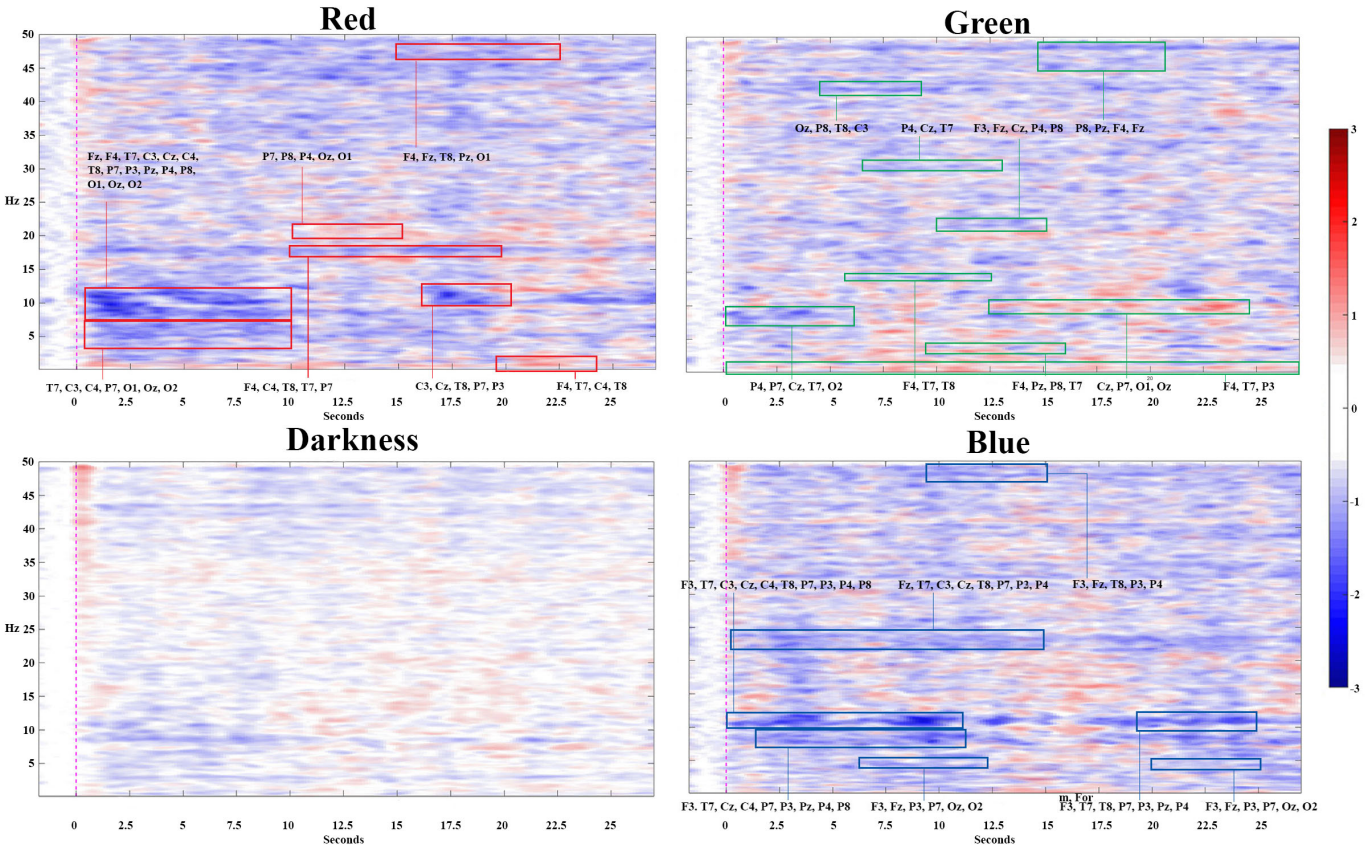

Fig. 5. in this figure it is seen how on the grand average scale the TSE maps for the different colors behaves. Each of the frames consist of all the electrodes superimposed to visualize the strongest tendencies across electrodes towards that specific stimuli. In the top left corner the TSE maps for the red light is superimposed. In the top right the green Light's TSE maps are found. In the lower left corner TSE maps from Darkness are found and lastly TSE maps for blue is found in the lower right corner

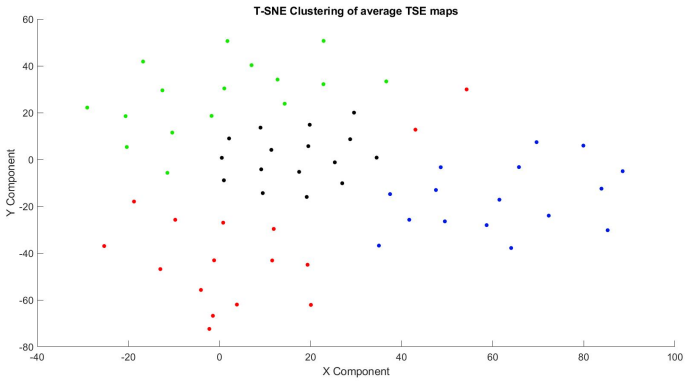

Fig. 6. this shows the t-SNE results from running t-SNE on the aggregated average TSE maps. The result is projected onto two arbitrary components, which can explain the spread in the dataset. The red dots represents TSE maps from the red light, the blue dots represents TSE maps from the blue light, the green dot represents the TSE maps from the green light and lastly the black dot represents TSE maps for darkness

but also when they happen. To get an insight into how the frequencies develops over time, temporal spectral evolution (TSE) analysis was applied using 3 cycles of Morlet Wavelet transform which progressively changes to 0.5 cycles when working from lower frequencies to higher frequencies. This was applied on every single subject for each of the conditions (red, green, blue, and darkness). Each of the TSE maps were collected. For each of the conditions the average TSE maps where computed together with a Standard Deviation representation to tell how representable each of the average maps were. The uniqueness of the average TSE maps will further be investigated through the t-SNE [26] a machine learning algorithm for visualization of highly dimensional data, which independently of labels can tell us how similar the average TSE maps were. t-SNE is a non-linear projection algorithm that preserves the neighborhood structures of a set of multi-dimensional data points [24]. In order for this data to be eligible to be analyzed through t-SNE the image dimensions were reduced from 963x1920x3 to 60x120x3, then reshaped to 1x21600. After which the dimensionality is further reduced to 50 through PCA. Lastly, the data was reduced to only two dimensions using t-SNE Barnes-Hut algorithm [27].

Additionally, Wilcoxon ranked sum test were used to test each frequency and time point within the TSE maps to see where the different conditions were significant different from each other.

IV. Results

Figure 5 portrays all the conditions TSE maps superimposed unto each other, from which we can see some intriguing patterns. In darkness there are no saturated colors, thus telling us that there are no areas where several electrodes have recorded ERD or ERS. Additionally, looking at figure 5 this observation is confirmed, as there are only weak (+1/-1 mV) fluctuations to be found.

Exposing the subjects to red colored light yielded strong ERD patterns in theta, alpha, beta and gamma, While ERS patterns were present in delta and beta. Especially the alpha and theta ERD patterns are interesting as they are present in many electrodes and it encompasses a broad range of frequencies. In the middle of the stimuli from 10-15 seconds a beta ERD / ERS pattern is present. However, looking at the responsible electrodes only P7 have observed both, while the ERS is seen in the parietal and the occipital lobe, the ERD is found primarily in the right hemisphere and temporal lobe, only to be present in P7 as well. The next clear pattern is the Gamma ERD, but it does not have a clear location anchoring, as the electrodes measuring the pattern are scattered all broadly over the scalp. The alpha ERD from 16-20 seconds however is primarily localized in the left hemisphere over the parietal and somatosensory region. Lastly, the late delta ERS is measured in the temporal and right frontal lobe.

As with red, exposing the subjects to blue color light provided a strong measurable ERD in the alpha range across many electrodes. In blue this is primarily measured at the parietal lobe, temporal lobe and at the somatosensory cortex. Interestingly in the same regions a beta ERD is measured during the same time, although lasting longer. 20 seconds into the stimuli there is a reprise of the alpha ERD. However, this time it is only in the temporal and parietal lobe the alpha ERD can be measured. During this late alpha ERD a theta ERD in the left frontal, left parietal and right Occipital lobe is present, which as well as the alpha is a reprise as it has happened before in the time range between 6-12 seconds. The last element which is noticeable is a Gamma ERD occurring from 10-15 seconds into the stimuli. It is originating from different parts of the brain, thus a few regions cannot be singled out as the area of interest.

Exposing the subject to green colored light shows different patterns than that of the two others. The start alpha ERD is narrower and the electrodes measuring this change are not connected by region neither hemispheres (P4, P7, Cz, T7, O2). Additionally delta (F4, T7, P3), theta (F4, Pz, P8, T7) and alpha (Cz, P7, O1, Oz) ERS are observed. However, as the alpha ERD, the electrodes recording these behaviors does not have much in common. Two beta and two Gamma ERD is also seen in different electrode constellations, with only right parietal lobe as a common denominator between all four high frequency ERDs.

While there seems to be many unique observations dependent on the color of light the parietal lobe shows different degrees of alpha ERD in the beginning of the stimuli independent of the light color. Additionally during both blue and red the Temporal Lobe and Parietal Lobe exhibits alpha ERD both early and late during the stimuli. Apart from the similarities there are many areas, which the colors and darkness significantly deviate from each other, as there are nearly no ERD/ERS to be observed in Darkness. The diversity is further confirmed by looking at figure 6. Here we see nearly perfect clustering of the average TSE maps in relation to the colors they are representing

A. significant differences

TABLE I
SIGNIFICANTLY DIFFERENT TO RED

Scenarios	where and when p <0.05					
	theta ERD 1-10 sec	***alpha ERD 1-10 sec***	***alpha ERD 16-20 sec***	***beta ERD 16-18Hz 10-20 sec***	***beta ERS 19-21Hz 10-15 sec***	***Gamma ERD 46-49Hz 15-22.5 sec***
Blue	None	C3	C3	T7	P4	Fz
Green	C4, O1, O2	C3, Cz, C4, Pz, O1, Oz, O2	C3, Cz, P7	C4	P4, P8	None
Darkness	None	F4, C4, T8, P7, P3, Pz, O1, Oz,	C3, Cz, T8, P7, P3	T7, P7	None	Fz

a) Red: The marked areas in figure 5 showcases where and how the brain responded towards the light, however, only some of it is unique. In Table I it can be seen where and when red is significantly different to the rest of the scenarios. When ERD is denoted it means that red is significantly smaller than the compared scenario, while when ERS is denoted, then red is significantly bigger than the compared scenario. Of the marked areas it appears that red and blue are quite similar only to be significantly different at a selected few electrodes. While when we compare red and green central and occipital electrodes are significantly different in the theta and alpha ranges. In beta the higher ERS is significantly different in the right parietal lobe. Comparing red with darkness reveals the strong alpha ERD in the beginning is significantly to darkness at many electrodes covering most of the scalp. This coverage is reduced at the later alpha ERD. Here the differences show up in the parietal lobe and the somatosensory cortex. For the beta ERD from 10-20 second the left parietal and temporal lobe shows significantly different signals. Lastly both blue and darkness show to have significantly higher gamma in the middle frontal electrode compared to red.

TABLE II
SIGNIFICANTLY DIFFERENT TO BLUE

Scenarios	where and when p <0.05					
	theta ERD 6-12.5 sec	***theta ERD 20-25 sec***	***alpha 8-10Hz ERD 2-12 sec***	***alpha 10-12Hz 1-12 Sec***	***alpha ERD 19-25 sec***	***beta ERD 22-25 Hz 1-15 sec***
Red	None	None	None	None	P3	P7
Green	Fz, P7, P3	Fz	T7, Cz, P4	T7, Cz, P4	T8, P7, Pz	None
Darkness	P3	None	F3, Cz, P7, P3, Pz, P4	F3, C3, Cz, T8, P7, P3, P4	P7	T7 P7

b) Blue: Examining the results in Table II reveals that the area of interest are all close to similar between blue and red with a few exceptions in the late alpha ERD and early beta ERD. Between blue and green, then the observed theta ERD is significantly smaller in the parietal and middle frontal lobes. The locations for the alpha differences are scattered on different placements on the scalp blurring the localization image, as both frontal, parietal and temporal lobe are producing significantly different results where blue <green. The significantly differences between darkness and blue is a different story. The observed alpha ERD is significantly smaller in blue than darkness at primarily the parietal lobe and at the somatosensory cortex. Additionally the early theta ERD, late alpha ERD and early beta ERD all show to be significantly difference at the left parietal lobe (blue <darkness)

c) Green: Opposed to the other scenarios green and darkness have a lot in common (see Table III), where only a few beta ERD differences can be found. Between green and blue the area of interest in green only show a few significant relationships, delta and theta ERS being significantly higher in the parietal lobe. The alpha ERS is significantly higher in the occipital lobe and somatosensory cortex. The significantly lower beta ERD is found in the frontal cortex, and the gamma difference is found at the somatosensory cortex. Between green and red the area of interest regarding green only seems to be significantly different at the alpha ERS and beta ERDs. The significantly different in alpha is observed from the occipital lobe to the somatosensory cortex. The difference found in the beta range is dependent on the frequency, low beta being significantly different at the frontal lobe, while for high beta the difference is observed at the parietal lobe and somatosensory cortex.

TABLE III
SIGNIFICANTLY DIFFERENT TO GREEN

Scenarios	where and when p <0.05					
	delta ERS 0-30 sec	***theta ERS 9-16 sec***	***alpha ERS 12.5-25 sec***	***beta 20-24Hz ERD 10-15 sec***	***beta 29-32Hz ERD 6-12.5 sec***	***Gamma 40-44Hz ERD 6-12.5 sec***
Red	None	None	Cz, P7, O1, Oz	F3, Fz	Cz, P4	None
Blue	P3	P8	Cz, Oz	F3	None	C3
Darkness	None	None	None	Fz, F3	P4	None

V. DISCUSSION

In this study we have measured the EEG of blindfolded subjects while they were exposed to four different light scenarios, red, green, blue and darkness. In an attempt to illuminate the brains electro-neuronal reactions to light when not sensed by the retina. We hypothesized, that since the eyes were not the active sensing organs, but rather the skin, then the biggest amount of differences in the EEG readings would be observed at the parietal lobe and the somatosensory cortex. Counting the amount of significant differences observed in the area of interest marked in figure 5 we observe that 34 observations in the parietal lobe, 20 observations at the somatosensory cortex, 13 observations at the frontal lobe, 11 at the occipital lobe and 9 observations at the temporal lobes. This indeed witness that the main of interest is the parietal lobe and the somatosensory cortex. Hemispherically the division of left, center and right is 42, 24, 22. This asymmetry is rather interesting as it can tell us that the processing of the light stimuli is skewed to the left side. For comparison let us look at P7 vs P8, as in P7 12 significant differences have been recorded, while in P8 2 have been recorded. This observation can point in two distinctive direction, either this can open up for some new types of interfaces, as we can discern colors of light through the skin in the left hemisphere or it could be an experimental bias where the subjects could have been closer to the right light fixtures, than to the left ones. This skewness of significant differences need to be studied further, as reproduction and clearance of eventual bias could lead to innovative brain computer interaction (BCI) systems.

We hypothesized that the alpha brainwaves will follow that of previous studies, where red had the strongest decrease of alpha, then blue and lastly the green [8], [12], [16], [18], [19], [22]. In this study we looked at the relative alpha power over time and found equivalent results to the literature despite working with a different sensory organ. Red did indeed produce the strongest alpha ERD, and with the broadest coverage over the scalp. Blue was however only significantly higher at Cz showing us that the recordings at the other electrodes produced an equally as strong alpha ERD as red. Green and darkness on the other hand produced less

strong ERD or nearly neutral relative alpha voltage. These are according to the previous literature higher alpha than red and blue. Interestingly green produced alpha ERS from 12.5 - 25 Seconds into the stimuli exposure, which is unique to it compared to the other. However, this was not a strong enough alpha ERS to make it different from darkness. These results points towards the same story as the previous literature, having higher cognitive arousal for red than green and darkness. But, only in specific cases up against blue due to the rather statistical similar alpha ERD. Another observation we can look at is the cortical recovery delay. In Ali M. R.'s study [13] he discusses that red has a longer recovery than blue. Even though we do not observe neutral relative alpha waves from the two colors during exposure we however see green having a quick recovering as it shifts from ERD to ERS and weak ERD after 5 seconds, while the two other colors still contain noticeable ERDs during all 30 seconds. Conclusively, we are able to discern that the opsins in the skin is faster to recover and ignore green light compared to red and blue.

Alpha was not the only frequency band of interest, beta also had significant qualities in the literature. However, we did not find the distinctive relationship portrayed in the literature. In the parietal region red had the highest beta power and the only color showing beta ERS. But it was only observed in a narrow time window from 10-15 seconds and only concerning 19-21 Hz. A broader finding was seen at green with beta ERD being lower power than the rest of the scenarios, however, only in the frontal lobe, between 10-15 seconds and in the frequency range 20-24Hz. So the broad range from 12-30 Hz at the middle line electrodes covering the whole stimuli, was not found as in [14]. Moreover, more specialized areas both in terms of time, frequency and location was discovered and could lead to some interesting further research, as to why the frontal beta and parietal beta acts differently depending on the color of light. If we look closer at figure 5 we will discover that the beta ERD in green also covers the parietal electrodes, thereby stigmatizing further that it is lower than red at that area. Thus for that very narrow area of beta this experiment elicited the same beta relationships as found in [14] red $>$blue $>$green darkness $>$green.

Delta was earlier found to be higher for blue than red. While we indeed did not find the same relationships in our study green shown to have a higher delta than blue at electrode P3, while no differences were found between green and red nor blue and red. Thus indicating that green is indeed more relaxing color for the opsins to observe, which is supported by the alpha ERS found during the stimuli exposure.

The last interesting finding is the occurrence of theta ERD and ERS. It appears to have the same relationship as alpha albeit not as strong (red and blue $<$green). The literature portrays theta as a marker for memory retrieval and working memory [25]. Albeit the experiment did not ask the subjects to remember anything, another relation that has been found is activation of the default mode network [23], which is usually activated in wakeful-rest, daydreaming and or mind-wandering. Adding that together with the found delta and alpha ERS in green they support each other, as they may indicate that exposing the subject to green is the most cortical relaxing and overall calming experience. While exposing the subject to red or blue light does not have the same calming properties, on the contrary we see more awareness and cortical arousal during these colors, where the beta ERS found in several electrodes in red witnesses that it is the color which promotes the highest amount of awareness.

VI. Conclusion

In this study we have measured the EEG from blindfolded subjects who were exposed to different colors of light (red, green, blue, darkness) to understand the interaction between the photosensitive opsins in the epidermal and the brain. Through a TSE analysis of the EEG different patterns unique to the different colors of light emerges. Red showcased the broadest coverage and the lowest alpha power from 1-10 seconds, which were accompanied by a theta ERD. These behaviors was followed by a beta ERS showcasing the highest beta among the colors in the parietal region from 10 - 15 seconds. The last unique element for red was a alpha ERD from 16-20 second, which originated from the parietal and central electrodes. This alpha deactivation and beta activation tells us that the subjects were aware and cortically aroused by the stimuli, as the signals was captured by the opsins in the skin and send to the brain.

When the subjects were exposed to blue light a similar story could be told. A broad alpha ERD during the first 12 seconds, which were on level with red apart from the alpha from Cz which were significantly higher than red. The beta ERS is not as present as in red rather there is a beta ERD during the first 15 seconds. Theta is neither as strongly decreased. These results paints a picture showing that blue raises cognitive arousal, but not the same amount of awareness as red, when the light is sensed through the skin.

Green light exposure showed however a completely different story than the two other colors of light. With delta (1-27 seconds), theta (10-16 seconds) and late alpha (12.5-25 seconds) ERS together with beta (10-15 sec) ERD showcases that green does not promote cortical arousal, rather the opposite as delta and theta ERS have been related to relaxation and activation of the default mode network. Green also has a small alpha (0-6 seconds) ERD in the beginning, however it is neutralized rather quickly, thus showing a short cortical recovery delay. The delta and theta is significantly different only to blue, and is located in the parietal lobe, while the alpha ERS is significantly bigger than both red and blue in the occipital lobe and around the somatosensory cortex. The unique beta ERD shows in the frontal lobe. This tells us that the skin quickly observes the green color, but contrary to the red and blue does not allocates much cortical resources to engage with it.

This shows us that there are in fact some differences when we are blindly exposed to different colors of light, which can promote different interactions with the environment as colors have different cortical signatures. Most of these difference were observed in the left parietal lobe and left somatosensory

cortex, which needs to be researched further to properly understand this skewness. Additionally, figure 6 showcases how t-SNE successfully managed to cluster the TSE maps from the colors into each of their own segments. This indeed supports that the light exposure can be separated dependent on the EEG based TSE maps. However, more research have to be done in order to properly understand the differences.

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