The Effect of Colored Light on Arousal and Valence in Participants Primed with Colored Emotional Pictures

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Introduction

In earlier days, Gerard (1958) and Wilson (1966) investigated the relation between colored light and several arousal-related physiological measures. Gerard reported a polarity between red and blue colored light illumination, with red being on the warm or high arousal pole and blue being on the cool or low arousal pole. In addition, Wilson found that red induced higher arousal levels than green. Both researchers claimed that different colored illuminations induce a differential physiological activation.

After the discovery of the intrinsically activating properties of blue light mediated via the retinal melanopsin (Yoto et al., 2007; Lockley et al., 2006), the arousing effect of red light should be questioned. Mikellides (1990) suggested that not hue but rather variations in saturation caused the arousing effect of red light reported by Wilson and Gerard. Support for this reasoning comes from Robinson (2004), who noticed that the green and red stimuli in Wilson's study indeed were not equated with regard to lightness and saturation.

Furthermore, not only an improper design, but also cognitive processes might explain the different hue effects on arousal in the different studies. Gerard reported that red light evoked a variety of unpleasant associations related to blood, injuries, fire and danger, while blue light was associated with positive thoughts such as friendliness, romantic love and blue skies. Similarly, Mehta and Zhu (2009) reported that red was associated with danger and mistakes, whereas blue was associated with peace and openness. These observations indicate that increased arousal not necessarily means that one feels positively energized, but can also reflect anger, fear or other unpleasant feelings. Therefore, to get an answer on the question whether short exposures to colored light affect arousal, a properly controlled study, measuring not only arousal, but also valence, i.e. the intrinsic attractiveness (positive valence) or aversiveness (negative valence), should be performed.

Based on these considerations, Rajae-Joordens (2011) designed an experiment in which the effect of hue (red, green and blue), lightness and saturation of 60-sec colored light exposure on arousal and valence was investigated. Red light was found to be less pleasant and more arousing than green and blue light as measured by subjective evaluations, and saturated light was assessed to be more arousing than desaturated light. Conversely, no clear physiological effects were found, and moreover, participants indicated to have no associations.

Because Gerard's participants reported unpleasant arousing associations in red light and positive calm thoughts in blue light, the question arose whether Rajae-Joordens would have found an effect on physiology if the light stimuli had triggered positive-calming or negative-arousing associations in her participants as was the case in the study of Gerard. To address this question, we repeated the Rajae-Joordens experiment investigating the effect of hue (red, green, and blue), lightness, and saturation of twelve 60-sec colored light stimuli on arousal and valence. To enable color-induced associations, participants were primed with predominantly red, green, and blue colored pictures with a positive-calming or negative-arousing emotional content before being exposed to twelve colored light stimuli. Valence and arousal were examined by means of subjective evaluations and a variety of objective physiological measures.

Material and Method

Stimulus selection

Twelve emotional pictures (6 positively calming and 6 negatively arousing) with one predominant color (4 red, 4 green, and 4 blue) were selected (see Fig.1). To create a balanced design in which each participant was primed with four negative pictures of two colors and four positive pictures of two other colors, we also selected two positively calming and two negatively arousing white pictures. Consequently, each picture was presented to half of the participants.

Using CIELAB color space (4300K as reference white), we defined twelve light settings of three different hues, two different saturation levels, and two different light levels (see Table 1) for the five RGB LED wall washers (16 LEDs per color). Saturation was defined as $((a^2+b^2)0.5/L^*)$. Due to technical limitations, the lightness of the saturated and desaturated blue light stimuli was lower than those of red and green. As a consequence, three analyses were needed. In a first analysis of hue, saturation and lightness effects, only red and green light data were taken into account. In a second analysis testing the hue and saturation effect of red, green and blue light, only 63%-lightness data were used. Finally, a third analysis was performed on blue light data only to test the lightness and saturation effect of blue light.

The CIELAB reference white for the light stimulus selection, obtained by the fluorescent light units in the ceiling (4300K, 500 cd/m^2) while the wall washers were off, was also chosen as the neutral setting in-between two light stimulus presentations.

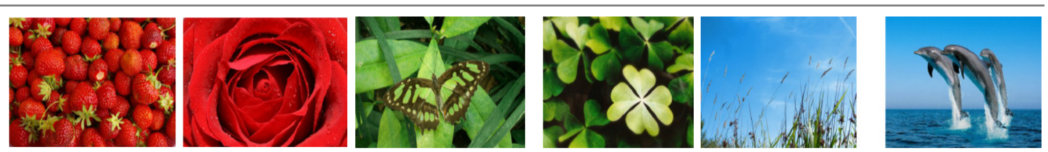
Experimental Procedure

Forty participants (18 females and 22 males, age 21-51 years) without any form of color blindness took part in this study. Electrodes were placed in order to capture skin conductance, respiration, blood volume pulse, and skin temperature by means of a NEXUS-10 (Mind Media BV, the Netherlands). Thereafter, a sub-selection of eight priming pictures was presented two times 10 sec on a LCD-TV located in the corner of the neutrally lighted test room.

Subsequently, the participant took place on a chair facing a white wall with the wall washers located on the floor in such a way that their light output fully covered this wall. After a 3-minute baseline measurement under neutral light, the fluorescent lights turned off and the wall washers turned on for 60 sec showing one of the twelve predefined settings. Next, the room lighting turned back to its neutral light setting. This procedure was repeated until all twelve light stimuli were presented according to a fully balanced design to control for order effects. At the end of the experiment, the physiological measurements were stopped and each light stimulus was presented shortly once again to allow the participants to evaluate the stimulus with regard to arousal and valence on two pictorial 5-point scales and to report on possible associations that they had in an open question.

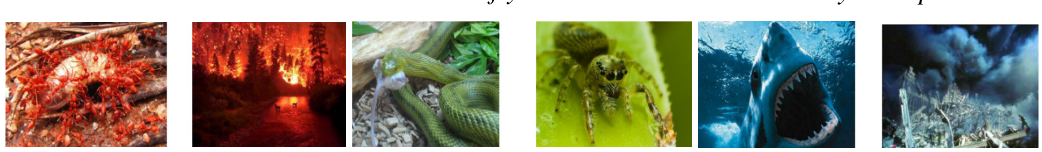
Content | **Red priming pictures** | **Green priming pictures** | **Blue priming pictures**

Positive-calming



Strawberries – Roses | *Butterfly – Clover* | *Blue sky – Dolphins*

Negative-arousing



Red ants – Bushfire | *Snake – Spider* | *Shark – Disaster*

Fig. 1: Pairs of (predominantly) red, green and blue positive and negative priming pictures.

Table 1: Hue (H in degrees), Saturation (S) and Lightness (L in %) values of the 12 light stimuli.*

Light stimuli (n=12)	Red		Green		Blue	
	Saturated	Desaturated	Saturated	Desaturated	Saturated	Desaturated
*L**=81%	H=21° S=2.3	H=21° S=0.8	H=162° S=2.3	H=162° S=0.8	- -	- -
*L**=63%	H=21° S=2.3	H=21° S= 0.8	H=162° S=2.3	H=162° S=0.8	H=262° S=2.3	H=262° S=0.8
*L**=54%	- -	- -	- -	- -	H=262° S=2.3	H=262° S=0.8

Results

Subjective Evaluation

For each color (red, green, and blue), we performed a repeated measures on the arousal and valence scores with Saturation and Lightness as within-subject factors and Priming Picture (positive or negative) as between-subject factor. Five of these six analyses revealed no significant effect of Priming Picture, suggesting that priming with predominantly red, green, and blue colored pictures with a positive or negative emotional content does not affect the subjective evaluations to colored light stimuli. Therefore, the factor priming picture was left out further analyses.

Mean arousal and valence scores of the 12 light stimuli are depicted in Fig.2. Due to the incomplete design, three analyses were performed. Strong and recurrent effects were found for Saturation and Hue. First, the repeated measures on arousal and valence of the green and red stimuli with Saturation,

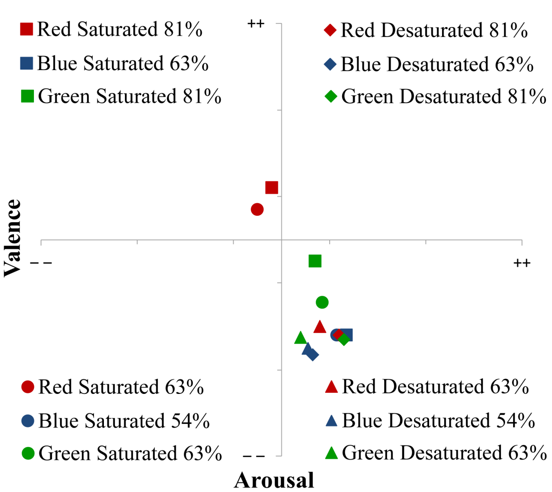


Fig. 2: Mean valence/arousal of the 12 light stimuli.

Hue, and Lightness as within-subject factors demonstrated that the saturated stimuli were judged significantly more arousing ($F(1,39)=66.619$; $p<0.001$) and less pleasant ($F(1,39)=6.364$; $p<0.05$) than the desaturated stimuli. Secondly, the repeated measures on arousal and valence of the 63%-lightness stimuli with Saturation and Hue as within-subject factors revealed a significant main effect of Hue on arousal ($F(2,38)=37.364$; $p<0.001$) and on valence ($F(2,38)=3.683$; $p<0.05$). Post-hoc tests showed that the red stimuli were scored significantly less pleasant and more arousing than the blue stimuli. Finally, the repeated measures on arousal and valence of the blue stimuli only with Saturation and Lightness as within-subject factors showed that saturated blue light stimuli were rated to be more pleasant than the desaturated stimuli ($F(1,39)=7.746$; $p<0.01$).

Objective measures

From the recorded physiological data, nine measures (skin conductance level, skin conductance response, skin temperature, skin temperature slope, respiration rate, respiration depth, heart rate, heart rate variability, and respiration – heart rate coherence) were derived. None of the measures showed a significant effect in the repeated measures per color (red, green, and blue) with Saturation and Lightness as within-subject factors and Priming Picture (positive or negative) as between-subject except for a significant red priming picture effect on the coherence between respiration and heart rate. Because no effects were seen for the blue and green priming pictures, the priming effect on coherence was considered to be rather weak and was therefore ignored in further analyses.

Additional analyses provided only two significant effects. First, the repeated measures on skin conductance response (SCR) of the 63%-lightness stimuli with Saturation and Hue as within-subject factors revealed a significant main effect for Hue on SCR, indicating that red light stimuli triggered more SCR's per minute than blue light stimuli ($F(2,36)=3.740$; $p<0.05$). Secondly, the repeated measures on SCR of the blue stimuli with Saturation and Lightness as within-subject factors showed that SCR was higher for saturated light stimuli than for desaturated light stimuli ($F(1,37)=9.873$; $p<0.005$).

Conclusion

This study replicated the results of Rajae-Joordens (2011). More arousing and less pleasant evaluation scores were found for saturated than desaturated stimuli (except for saturated blue stimuli being more pleasant than desaturated blue stimuli), and for red compared to blue stimuli. In contrast with Rajae-Joordens, we observed significant physiological effects on the number of skin conductance responses (SCR), probably due to the substantially larger sample size of 40 instead of 20 participants. The SCR was higher for red compared to blue stimuli, and for saturated compared to desaturated stimuli. Thus, the SCR nicely corresponds with the scores on the subjective arousal scale.

Priming with predominantly green, red and blue colored pictures with a positive-calming or negative-arousing emotional content did not affect the subjective evaluations and physiological responses to colored light stimuli. Possibly, the priming pictures were not strong enough to evoke associative responses as described by Gerard (1958).

Participants mentioned that the red stimuli appeared unpleasantly saturated compared to the green and blue ones. This perceived saturation difference is likely due to the fact that the white point properties of the relative warm neutral setting of 4300K in-between the colored light stimuli was also used as reference white point to equate the colored light stimuli in the CIELAB color space. Consequently, the saturation levels of all light stimuli were set relative to this somewhat orange-reddish white point, making the red stimuli appear more saturated compared to the blue and green ones. This unforeseen difference in perceived saturation underlines the difficulty of equating saturation levels of colored light stimuli in a further completely dark room without any reference light.

In summary, whereas the priming pictures showed no effects in this study, consistent arousing effects of saturation on both subjective and objective measures were found. The observation of red light stimuli being more arousing than blue light stimuli is likely due to perceived saturation differences.

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