The effects of ambient blue light on anger levels: Applications in the design of unmanned aircraft GCS

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ABSTRACT

Light exercises broad psychophysiological effects besides vision including hormone secretion, body temperature, sleep, alertness, cognition, and emotion regulation. This study proposes that applying an integrative interaction design to the ground control station (GCS) that uses colour-coded lights to deliver peripheral information to GCS operators using blue light as a chromatic cue could promote relaxation and reduce physiological reactions associated with negative emotions with implications for emotional health and cognitive performance. Therefore, the aim of this study was to test the effects of blue light in reducing negative emotions in an enclosed environment that resembles a GCS cabin for operating unmanned aircraft. Thirty healthy participants were invited to carry out a 12-min anger-inducing task in a car driving simulator. Three equal experimental groups were formed: the first group was primed to the relaxation effects of blue light (BL1), the second group was exposed to blue light without priming (BL2) and the third group was not exposed to any ambient blue light (control group). Light was presented at three stages: prior to the task for 5 mins and during anger induction due to 2 simulated traffic jams (TJ1, TJ2). Psychological state of anger was measured using questionnaires and psychophysiological measures including: Blood Pressure (BP), Cardiac Output (CO), Heart Rate (HR), and facial Electromiography (fEMG). There was a decrease in subjective feelings of anger in the BL1 condition relative to the control condition. Systolic BP was also significantly reduced in the BL1 condition compared to the control condition. In addition, corrugator muscle activity and stroke volume (a component in CO measurement) were lower in the BL2 group compared to the control condition. The findings have implications for the design of the photometry of GCS lighting and in particular the use of blue light in confined darkened GCSs.

Keywords: Anger, blue light, cardiovascular measures, chromatic cues, emotional health, psychophysiology.

Introduction

Blue Light Enhances Responses to Emotional Stimuli

Operating unmanned aircraft could involve monotonous surveillance tasks, interspersed with spells of intense multi-tasking high-mental-workload air crew activity when landing the aircraft, in a situation of 'lost-link' loss of communication between the unmanned vehicle and the ground control station (GCS), or during supervision of multiple UAVs by a single air crew. [1] When tasks are too monotonous or the cognitive demand is overstretched by multitasking, disengagement from the task is likely to occur [2] which would increase human error in operations. Also, piloting an unmanned aircraft in a dark environment being deprived of natural light for long periods of time

there is a risk of mood disorders resulted from a deficit in melanopsin receptors sensitive to the blue waves in the natural light [3]; Fig. 1. Ambient light is an ever present feature of the environment with effect on physiological reactions [4], including hormone secretion, body temperature, sleep, alertness, cognition, and emotion regulation [5-9]. A major milestone in our understanding of the non-visual influence of light came with the discovery of melanopsin retinal ganglion cells [10] a type of photoreceptor in the eye that is uniquely sensitive to blue light [11]. Vandewalle et al. [4] have explained that these non–image-forming responses to light are mediated through a non-classical photoreception system that is maximally sensitive to blue light (≈ 480 nm) but not to the classical photopic luminance visual pathways, which are maximally sensitive to green light (≈ 550 nm). Melanopsin is highly sensitive to blue wavelengths and the finding that patients with seasonal affective disorders have deficient melanopsin genes has encouraged the use of blue light as a therapeutic intervention for that condition. However, the mechanisms by which these cells communicate with the brain are complex [12], the melanopsin cells provide signals to the suprachiasmatic nucleus (SCN), the brain's body clock [13] and other regions of the brain.

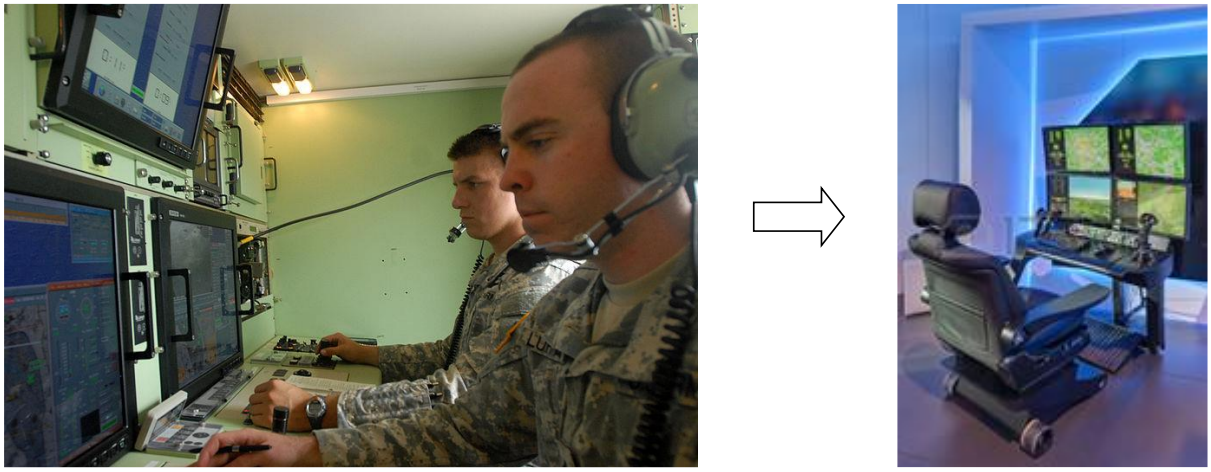

Fig. 1.Standard GCS (left) and an example of GCS with blue ambient light (right).
Images: Left - Staff Sgt. Scott Tynes - Camp Shelby Joint Forces Training Center;
Right - Igor Dolgov, Dreamstime ID 63895429.

The study of Vandewalle et al. [4] assessed brain activity of healthy participants as they listened to "angry voices" and "neutral voices" in the presence of blue or green light. Blue light enhanced emotional stimuli in the Broca Area and in the hippocampus. Blue light also promoted interaction between suprachiasmatic nucleus of the hypothalamus, amygdala and the Broca Area. These findings inform our understanding of the mechanisms by which changes in lighting environment could improve mood. However, the changes occur at a subconscious level at the hypothalamus site, and hedonic emotion regulations were not accounted for. Vandewalle et al. [4] demonstrated that blue light proved superior to other wavelengths with respect to increased activity in the left frontal and parietal cortices during a working memory task. As activation of the left frontal site has also been implicated in electrocortical responses to positive valenced emotional stimuli [14], it is suggested that exposure to blue light may influence the processing of emotional stimuli. Nonetheless, the endocrine pathways from the hypothalamus have been found to communicate circadian and photic information to the adrenal glands. [15] In this case, the light exposure could exert an effect on the

adrenal glands, on cortisol levels. However, the results of the search for an existence of a mechanism by which photic information can acutely influence the human adrenal glands were not congruous. Light exposure has been reported to decrease [15], increase [16] or have little effect [17] on cortisol levels. The inconsistent findings could be explained by differences among studies including the intensity of light (~500 to 5500 lux), duration of the light exposure (15 min to 4 h), and circadian phase of light exposure; all of which affect cortisol levels.

One light colour more often associated with variations in cortisol levels is blue. [18] Some studies found arousing properties of blue light [19-21] whereas other studies (e.g., [22]) did not find that blue light increases arousal. Nonetheless, in Varkevisser et al.'s [22] study, arousal was assessed subjectively by means of self-report manikins [23], and correlated with cardiac reactivity. What they found was a cardiac effect (heart rate increase) for a light condition where blue light was combined with red light; but not when the blue light was combined with green light. The findings indicated that subjective appraisal of colour properties was in contradiction to cardiac effects. However, the cardiac effects were not always conclusive and overt interpretation of colour could have been the factor influencing the strength of the cardiovascular responses. Also, the low illuminance levels (45-195 lux) used in their study probably had limited effect on cardiovascular responses. [24] The absence of heart rate variability in conditions of different illuminance levels was also reported in other studies. [16,17] Perhaps, the subjective appraisal of colour was more important than the illuminance, or the experimental set up evoked a specific vagal withdrawal possibly related to the mental stressors and not to the different lighting conditions.

Such contrasting findings regarding the arousing properties of blue light could be attributed to different contextual experimental set-ups. For example, different video contexts exercised various reactions. The work of Kim et al. [25] could be mentioned here. They proposed an emotionally interactive lighting system that enhances affective experiences while watching video content. The emotional lighting system was activated according to the individual's emotional state; a blue light indicated relaxation, whereas a red light indicated high arousal. Their emotion recognition system used three different physiological signals (photoplethysmography, skin temperature, and galvanic skin response), an emotion lighting control system, and an emotion ambient lighting system. The findings indicated that a blue light stimulus increased photoplethysmography signals (a photoplethysmogram was obtained by using a pulse oximeter which illuminated the skin and measured changes in light absorption) when watching a relaxing video. In contrast, the frequencies of the photoplethysmography signals decreased significantly following a red light stimulus when arousing video content was played. The results indicated that red and blue light could be classified as effective manipulators of emotional arousal and relaxation experiences during displays of arousing and relaxing video content, respectively. However, the conclusions are based on a reduced number of participants and the measures were obtained post-task which reduced the physiological responses. It could be highlighted that it is crucial to objectively measure the users' emotional changes in real time. In addition, a certain amount of compensation for the individuality of emotional regulation should be applied.

Blue Light as an Environmental Cue for Emotion Regulation

Adaptive functioning necessitates effective emotion regulation. [26] Attenuation of anger, in particular, has direct benefits for health by reducing the likelihood of coronary

heart diseases. [27] The regulation of emotion may be attained using top-down processes, including reappraisal in which the person might re-evaluate the perceived relevance of a stimulus. [28] Contextual information (i.e., light) can facilitate emotion regulation, such as when a task seems less threatening in the presence of blue light, whereby such light colour is associated by the individual with a relaxation state. Such contextual light-related cues are capable of conveying a sense of security despite the presence of other apparent threats, and have been labelled “safety signals” (e.g., [29]). When used successfully, safety signals can effectively regulate negative emotional reactions and support constructive behavioural responses to aversive situations.

Recent research suggests that distinct colours may implicitly signal the presence or absence of danger and therefore influence emotional regulation and motivational disposition. Elliot et al. [30] proposed that the colour red signals danger in achievement contexts and implicitly evokes a motivation to avoid threats. As a consequence, red light narrows selective attention to the specific threats. Elliot and Maier's [30,31] research has primarily focused on the effects of red light as a danger cue, nonetheless their conceptual framework served as the basis for a new theory [29] that when colours signal safety (e.g., blue) they tend to expand rather than constrict the scope of attention. Therefore, blue colour as a safety-conveying colour promotes task performance in a manner opposite that of red. Mehta and Zhu [32] indeed observed that the colour blue is typically associated with relaxation and should therefore function as a cue for a benign situation. Nonetheless, the cue used in their analysis was rather implicit and acted in the absence of conscious emotional experience. It was suggested that implicit “benign situation” cues tend to broaden the attention, and implicit “threatening situation” cues to narrow the attention. A substantial number of research findings involving a diverse set of such implicit affective cues (e.g., enactment of approach and avoidance behaviours [32]; incidental exposure to colours signaling safety vs. danger [30]) supports this proposition. Based on this interpretation, ambient light could act as a contextual cue [33], and enable the individual to self-regulate in accord with the demands of the task. For example, blue has been considered a signal for safety. [29] Consequently, blue light stimuli could be appraised as favourable and moderate the motivation in the absence of conscious emotional effort. While the consensus of the literature supports the construct that safety signals (e.g., blue light) broaden while threat cues (e.g., red light) constrict involvement in the task [33], little is known about the psychophysiological underpinnings of this process.

The proposition that blue / red colours convey different signals about the nature of the current situation has received substantial empirical support. As an example, Elliot et al. [34] found that participants equipped with body motion sensors demonstrated tendency to lean away from a test cover to a greater degree when it was coloured red compared with green or gray. This tendency toward physical avoidance is consistent with the premise that red implicitly signals danger. Similarly, Mehta and Zhu [32] observed that participants exposed to blue were less concerned with avoiding mistakes, therefore blue implicitly tends to promote a construal of the task as benign. In contrast, when participants were exposed to red colour they expressed greater concern with avoiding mistakes than when exposed to an achromatic environment, therefore reinforcing that red elicits a construal of the experimental task as somewhat threatening (cf. [30]). Cumulatively, these results support the argument that blue elicits attentional broadening and is an indicator of safety compared to red that elicits attentional narrowing and the signalling of danger. However, labelling of colour as

safety versus danger could be culturally dependent, a consequence of a learnt effect. [35] Studies found that blue is perceived as cold and evil in East Asia [36], but stands for warmth in The Netherlands, coldness in Sweden, death in Iran and purity in India. [37] It denotes masculinity in western cultures – e.g., France, Sweden, UK, and the USA. [38] Blue means high quality, trustworthy and dependable in the USA, Japan, Korea and China. [39] In sum, learnt meanings of blue colour could influence the way ambient blue colour is used as an environmental cue. Hence, future studies should aim to investigate whether blue light could be a manipulator of psychophysiological reactivity to negative emotions such as anger when individuals are primed to the psychological meaning of the colour and whether self-regulation plays a part in this process.

Research on affective computing systems - a discipline that concerns itself with the development of computer interfaces for measuring and responding to users' emotions [40] - has often focused on detection of negative emotion in order to improve self-regulation [41,42] and has been applied to psychophysiology measures to delimit emotional states. [43] The discipline of affective computing aims to give machines the ability to recognise and generate affective states. In part, affective computing addresses the shortcomings of traditional Human Computer Interaction (HCI) systems, which tend to neglect changes in affective states in users. Such neglect may explain why many users view interactions with computers as "cold, incompetent and socially inept." ([44], p. 1). A solution is to warrant that user interfaces of the future are able to "detect subtleties of and changes in the user's behaviour, especially his/her affective behaviour, and to initiate interactions based on this information rather than simply responding to the user's commands" ([44], p. 1). These subtleties may be related to motivational states underlying the experience of interacting with technology. [45,46] Consideration to motivational states (being in control vs not being in control) promotes the concept of adaptive computer interfaces, where software responds to the state of the user in order to challenge or help the individual according to the user's response. [47-49] Researchers look mainly at adapting the difficulty of the task to keep the users active [50] but there was no consideration of emotional impact while performing the task.

The present study was designed as a pseudo-biofeedback manipulation that consisted of exploring the effectiveness of ambient light interventions in the context of anger induction via uncontrollable, impossible tasks. If ambient blue light will reduce physiological reactions to anger especially when paired with individual's knowledge of its relaxation properties then the input of blue light in environments with a high risk of anger generated by uncontrollable, unresponsive, malfunctioning systems (e.g., pilots of ground control station; GCS) would be recommended. It was hypothesised that subjective and psychophysiological manifestation of anger (fEMG, BP, HR, CO) will be lower in participants presented with blue light and informed about its relaxation qualities compared to the participants not informed and participants not being presented with light (control). During the light induction phase, the contrast between control group and the light groups will investigate the effects of overt priming and sensory stimulation vs. sensory stimulation alone.

Method

Participants

Participants were recruited from a nonclinical population with no history of mental or cardiovascular problems. Using participant self-reports, the inclusion criteria were:

right handed, mentally and physically healthy, not being under a course of medication, absence of vision deficiencies (e.g., colour blindness), and not having high levels of anger (scored below the 80th population percentile on the Trait Anger Expression Inventory of the STAXI 2 [51]) to reduce the likelihood of the researcher being exposed to aggressive behaviour during the anger induction protocols used in the study. Blood pressure and resting heart rate were measured prior to the experiment to ascertain that the participants were not hypertensive or experienced elevated heart rate. All procedures for participant recruitment and data collection were approved by Liverpool John Moores University Ethical Committee prior to commencement of the study.

Thirty healthy volunteers of 18-41 years of age were deemed suitable to take part in the experiment. Ten participants (5 female) were assigned to three experimental groups (Table 1). The mean age of the participants was 23.4 years (SD = 3.6 years).

Table 1: Age of participants on each light condition.

	Age (yrs)	
Light Colour	**Mean**	**SD**
BL1	24.3	6.0
BL2	22.9	2.1
C	23.0	2.4

BL1: Blue Light 1, BL2: Blue Light 2, C: No light.

Experimental design

A mixed design was employed. Exposure to light was a between-participants manipulation and exposure to experimental phases (Baseline, Light induction, Traffic Jam1-TJ1 and Traffic Jam2- TJ2) was a within-participants variable. Subjective measures and cardiovascular reactivity to both traffic jams were compared to a baseline condition and a light induction phase, whereby data were collected in the presence of the different light induction procedures:

- Blue Light 1 group (BL1): exposure to blue light plus overtly primed to associate blue light with relaxation;
- Blue Light 2 group (BL2): exposure to blue light without priming of the effects of blue light;
- No light group (C): without exposure to blue light.

The BL1 condition involved overt priming; hence participants were instructed explicitly to relax during the light induction phase in the presence of blue light. In the BL2 condition, participants were not informed about any possible benefits of blue light or the significance of the blue light when it was presented. This was meant to be a condition where participants were not overtly primed but experienced the same sensory stimulation with respect to blue light. In the control condition, participants were not told about the effects of blue light and were not exposed to ambient light during the car drive.

Simulator trial procedure

The procedural sequences of events and collection of self-reported questionnaire data consisted of the following: *practice trial* (5 mins); *attachment of psychophysiological apparatus* (10 mins), *baseline period* while watching a neutral video (6 min [52]); *ambient light induction* (6 mins); and *simulated drive* task (12 mins). The driving simulator has similar primary functionality as tasks carried out by an operator in GCS. Driving a machine remotely, often in a dark environment was considered to resemble a mobile GCS design. [53] Participants were asked to complete the STAXI after baseline, after the light induction, and after the drive. On completion of the drive, participants were given a debriefing form and a money voucher. The procedures for anger induction through a simulated driving task involved completing the task on a scheduled time with financial penalties for failing to reach the destination in the designated time (8 min) and for breaking traffic rules during the task (£1/error). There were 2 simulated traffic jams to manipulate the challenge/threat motivational dichotomy; the first traffic jam (TJ1) allowed participants to complete the task on time without incurring financial penalties (challenge) while the second traffic jam (TJ2) annulated any chances for the participants to finish the task on time (threat). Deception was required to maintain the motivation for task involvement; however, participants were fully debriefed and reimbursed for their participation in the study.

The simulated car task was prepared using STI SIM Driving Simulator software (STI Inc.). This PC-based software allowed interaction via a steering wheel/pedals console and the driving scene was projected onto a large screen (approximately 3.66 m × 4.57 m), yielding a visual angle of approximately 80°. The infrastructure of the simulated route included a number of bends, crossroad intersections with stop lines, and several sets of traffic lights. The simulated drive started with a 3-min low traffic density, after which, participants encounter a first traffic jam (TJ1) which lasted for 3 mins followed by a low density traffic again for approximately 3 mins and ending with another traffic jam (TJ2) for 4 mins. The combined delay introduced by both traffic jams made it impossible for the participants to reach the destination within the required 8 min (Fig. 2). All the times given are estimates as each driver reached the traffic events at different times depending on their speed. Nonetheless, the set drive adjusted for each driver and the time differences were in the range of 1 to 2 mins, and the end of the drive was still no possible if the driver respected all the traffic rules.

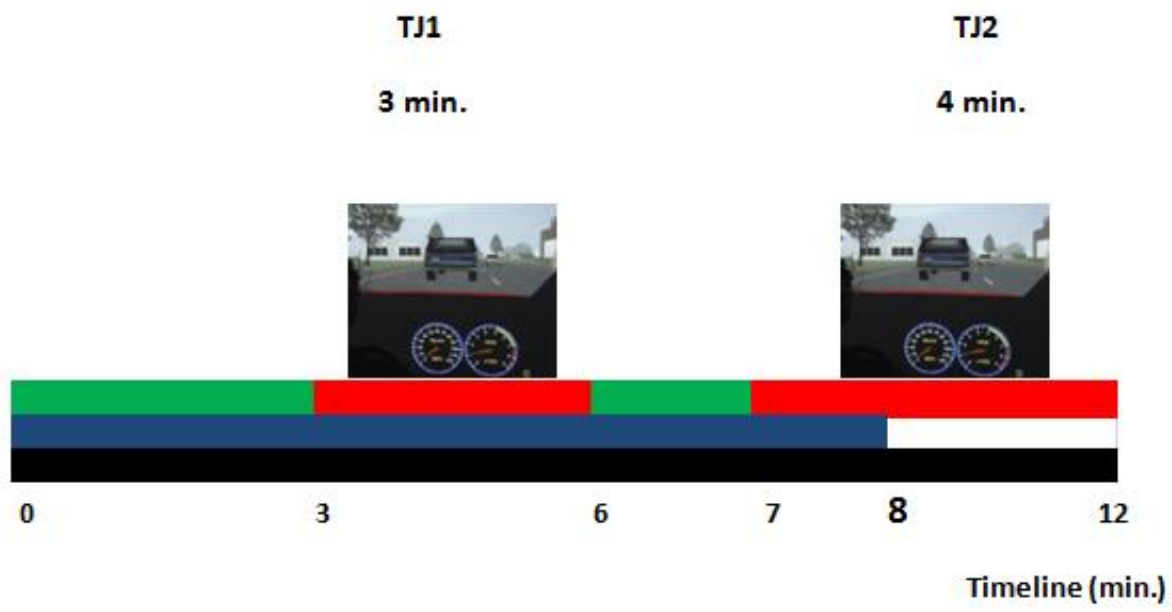

Fig. 2: Timeline: Simulated car journey 2 in the STI SIM Driving Simulator.
Note: TJ1 = traffic jam1; TJ2 = traffic jam 2; green = traffic-jam-free journey, red = traffic jam, blue = target journey time, black = actual journey time.

Photic stimulation

The light stimuli were presented using a 43.2 cm (17 in) flat-panel LCD monitor to avoid interference with the light generated by the projector. The lighting system consisted of two fluorescent tubes with led lights (Philips Master TL-D 18W/ 452 ActiViva) placed behind the LCD monitor in the upper part to provide a diffuse ambient light. Light levels were measured using a Lux meter (Model CEM DT-1301 Light Meter). The average horizontal luminance measured at eye level while sitting was 500 Lux in the 2 coloured light conditions (BL1 and BL2; the LED tubes were blue. The rationale for choosing 500 Lux was based on the findings that stronger effects are expected for brighter lighting (500 Lux) compared to standard lighting (300 Lux). [24] Windows in the room were covered with opaque blinds during the study to block outdoor light interference. Following previous experimental protocols on light exposure investigations [54,55] a control group was formed and included in the study. Participants in the control group did not receive photic stimulation.

Self-report measures

The State Anger Expression Inventory 2 [51] was used to measure the differences in anger levels between light conditions at baseline, post-light induction, and post-driving. The State-Trait Anger Expression Inventory (STAXI-2) is a 57-item questionnaire developed to measure *Trait Anger, State Anger*, and Expression and Control of Anger. [51] The State Anger Scale assesses the intensity of anger as an emotional state at a particular time. Fifteen items measured on a scale from 1 to 4 (1 = not at all, 4= very much so) form three 5-item State Anger subscales. The three sub-scales are: a) feelings of anger (*S-Ang/F*), (b) feel like expressing anger verbally (*S-Ang/V*), and (c) feeling like expressing anger physically (*S-Ang/P*). The Trait Anger Scale was used to measure how often angry feelings are experienced over time. The Trait Anger measure was based on 10 Trait Anger items validated by Spielberger [51] with 2 subscales: 4-item anger temperament scale and 4-item angry reaction scale. The

internal consistency for all scales and subscales was satisfactory with Cronbach alpha values ranging from .76 for the 4-item T-Anger/R subscale to greater than .84. [51,56] On the subject of construct/factor analytic validity, several exploratory and confirmatory factor analytic studies have reported empirical support for the STAXI-2 structure. [57-60] Evidence of predictive validity of the STAXI-2 in the measurement of anger has been provided in several research. [61-63]

Physiological measures

Cardiac activity

Cardiac activity was recorded using NICO100C Noninvasive Cardiac Output Module (BIOPAC Systems Inc.) at an operational frequency of 50 kHz and a magnitude range of 5 Ohms/volt in conjunction with the MP150 data recording system (BIOPAC Systems Inc.); Cardiac activity was recorded using a 4 - band electrode configuration placed on the back of the neck and the thorax [64]; Fig. 3.

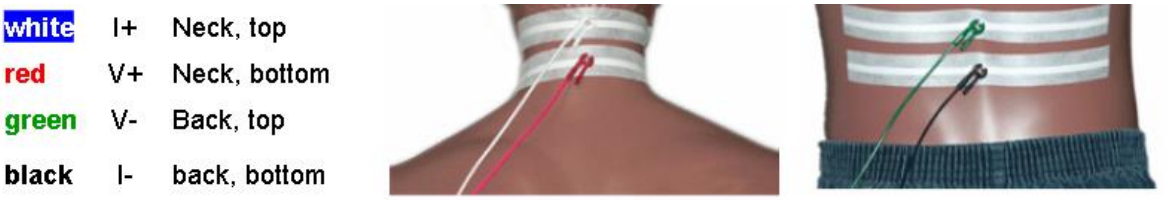

Fig. 3: ICG 4-band electrode configuration (BIOPAC Systems, Inc.)

The signal from the electrodes was filtered through the BIOPAC module that delivered impedance magnitude (Zo) and derivatives (dZ/dt) at 1000 Hz. The impedance signals were analysed using BIOPAC software in the first study and an algorithm developed in our own laboratory in order to detect the following measures for each cardiac cycle: Cardiac Output (CO), Stroke Volume (SV), Left Ventricular Ejection Time (LVET), Pre-Ejection Period (PEP), and Total Peripheral Resistance (TPR). The algorithm provided a calculation for *electrical bioimpedance* measures using the Kubicek formula. [65] The C point was defined as the maximum point in the dz/dt signal in a time window 60–200 ms from the R peak [66], the X point was defined as the minimum point over the course of the cycle after the C point whereas B was set as the maximum derivative of the dz/dt signal in a time window 150–100 ms before the C point. The algorithm was validated based on visual inspection and manual scoring from a trained observer. Baseline data (10 mins) from the study from 20 participants were scored manually by the trained experimenter and compared to the results from the algorithm. With respect to LVET times, the mean deviation between the manual and computerised scores was 82 ms (SD = 30 ms; range = 23–110 ms). For PEP, the mean deviation was 25 ms (SD = 23 ms; range = 5–79 ms). A correlation was conducted across the whole data set to assess PEP between manual scoring from a trained observer vs. computerised analysis, it was found that scores were highly correlated (r = 0.89) indicated a high reliability of the algorithm.

Heart rate measures

The Inter-Beat Interval (IBI) from the heart was calculated from an electrocardiographic (ECG) signal filtered between 0.5 and 0.35 Hz and sampled at 1000 Hz. This signal was collected via a two-lead electrode sensor placed on the

participants' left and right rib cage connected to the TEL100C data capture signal (BIOPAC Systems Inc.) that was attached to the MP150 system (i.e., the ground electrode for the ECG was not required as there was a ground electrode already incorporated in the NICO100C apparatus). This stable configuration provides better noise performance and stability. The TEL100C system includes a portable amplifier/transmitter, which converts up to four channels of data into a modulated data stream. This data stream travels over a single lightweight coaxial cable to the receiver module. The receiver module demodulates the data and sends it to the MP for recording and analysis.

Blood pressure was measured using a CARESCAPE Vital Signs Monitor (V100) (DINAMAP Inc.) which involved placement of an inflatable cuff on the upper left arm. Readings of systolic blood pressure, diastolic blood pressure, heart rate and mean arterial pressure (MAP) were all obtained using the oscillometric method (note: for the purpose of analysis, heart rate was measured from the ECG trace obtained via the MP150, not the CARESCAPE monitor).

Other cardiovascular measures included: Ventricular Contractility and pre-ejection period (with smaller values of pre-ejection period indicating greater VC) derived from the ECG and the ICG waves. Pre-ejection period was identified as the time elapsed between the Q point on the ECG wave (the left ventricle contracting) and the B inflection on the ICG wave (the opening of the aortic valve). [67] Total Peripheral Resistance (TPR) was calculated by combining information from the CARESCAPE and the NICO100C; i.e., TPR = MAP x 80 / CO).

Facial Electromyogram (fEMG)

fEMG were obtained from the Zygomaticus major and the Corrugator supercilii muscles as indicators of positive and negative emotion, respectively. fEMG data were sampled at 1000 Hz and filtered between 30 and 500 Hz. The EMG100C Electromyogram Amplifier was added to the MP150 system for recording of the zygomaticus facial muscle electrical activity. The Zygomaticus activity was recorded through two electrodes connected to the EMG100C module attached to the BIOPAC MP150 system. Corrugator muscle activity was indexed through two external electrodes from the BIOSEMI apparatus. During post-processing, the sample rate was reduced to 512 Hz and artifacts due to eye blinks were removed (vertical EOG was recorded separately and this signal was subtracted from the corrugator trace). The resulting fEMG data was normalised using a root-mean-square (RMS) transformation. The signal was then rectified, time integrated, and divided by the duration of the segment to obtain the mean rectified voltage. [68]

Results

Subjective measures

The protocol consisted of reducing anger levels in the participants who were exposed to blue light and had knowledge that the blue light was a trigger for relaxation. State anger was captured using the STAXI in three sub-scales: (a) feelings of anger, (b) feel like expressing anger verbally, and (c) feel like expressing anger physically. Change scores were calculated by subtracting post-baseline STAXI scores from post-induction scores to capture the effect of light induction procedure only; i.e., a positive number is associated with increased anger during light induction procedure. All the three subscales were subjected to 3 x 3 MANOVA (Group x State anger). The analysis

showed a significant effect for Group with respect to the feelings of anger sub-scale $F(2,27) = 4.82$, $p < .05$, $\eta^2 = .26$). Post-hoc tests indicated stronger feelings of anger in the control group compared to the BL1 group only $p < .05$ (Fig. 4). The sub-scales of the STAXI relating to verbal and physical expression of anger did not significantly differentiate between the three experimental groups.

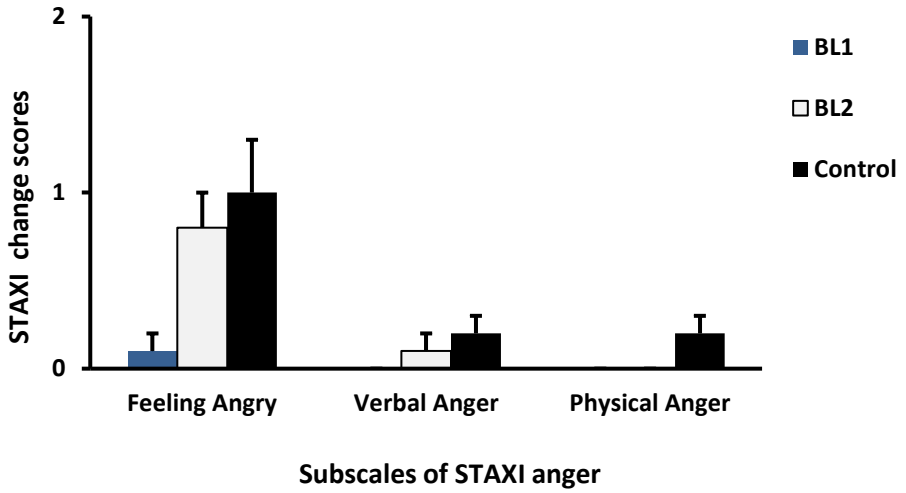

Fig. 4: Means and SE for three sub-scales of the STAXI based on difference scores (post-light induction minus baseline) between conditions (BL1; BL2; Control). N = 30.

Facial Electromyography (fEMG)

Muscle activity from the corrugator supercilii was captured and normalised (via RMS transformation) prior to analysis and the baseline subtracted for the three stages of the experiment (light induction, TJ1 and TJ2). The data was baselined due to significant variations between groups at the baseline phase. [69] A 3 x 3 ANOVA (Group x Experimental Stage) was performed. The analysis of corrugator supercilii revealed significant interaction Group between Stage ($F(3.33, 4.30) = 2.69$, $p = .05$). Post-hoc analyses indicated that participants in both *blue light* conditions exhibit reduced levels of corrugator activity compared to the control group [$p < .05$]. It was observed that participants in the light conditions had an opposing reactions at TJ1 with participants in the BL1 showing less Corrugator muscle reactivity than participants in BL2 condition. This effect could be seen in Fig. 5.

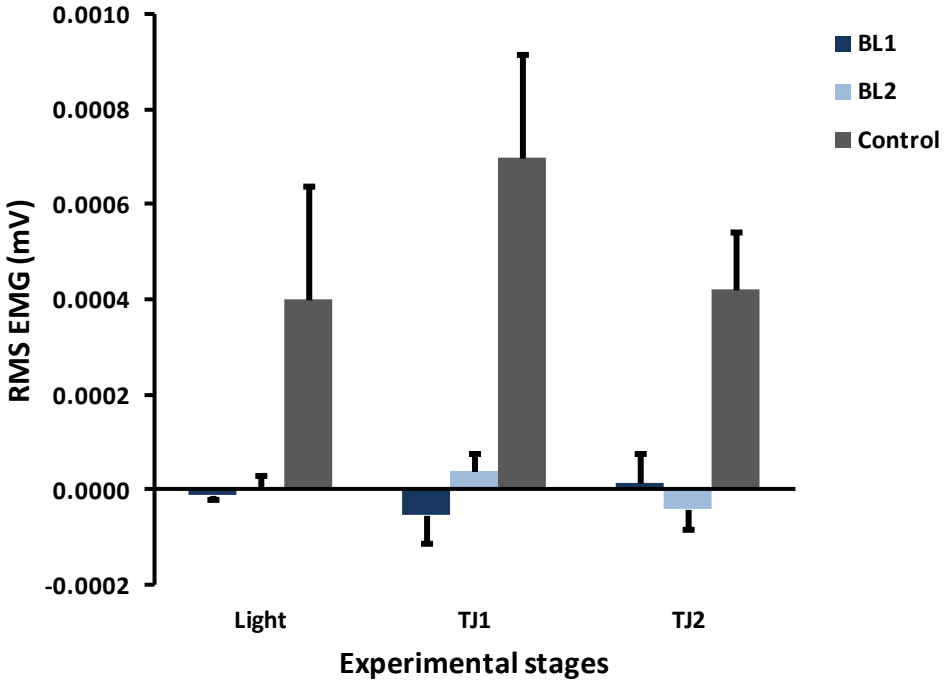

Fig. 5: Group mean and SE for baselined Corrugator muscle activity within experimental stages (Light, TJ1, Tj2). N = 30.

Cardiovascular measures

Cardiovascular responses were tested at baseline between the three experimental groups using a MANOVA analysis. There was a significant difference between light conditions in relation to PEP [$F(3, 36) = 2.93$, $p < .05$, $\eta^2 = .43$]. Hence, it was necessary to baseline the data for systolic BP. [69] For reasons of consistency all other cardiovascular variables were also baselined (i.e., Systolic BP, Diastolic BP, CO, MAP & HR). In the statistical analysis, a 3 (light groups) x 3 (light induction, TJ1, TJ2) ANOVA model was applied to all cardiovascular data.

The analysis of SBP revealed a significant main effect for group ($F(2,23) = 5.04$, $p < .05$, $\eta^2 = .31$). Post-hoc tests revealed a significant increase of SBP for the Control group compared to both blue light groups (BL1, BL2).

Diastolic BP was significantly different between groups [$F(2, 52 = 9.63$, $p < .05$, $\eta^2 = .27$] with highest values at the TJ1 in BL1 and control group and the lowest in BL2 group. There was a main effect for stages [$F(4, 52) = 5.98$, $p < .001$, $\eta^2 = .32$]; DBP significantly increased from light induction (M = .27, SE = .59) in the TJ1 (M= 2.5, SE = .85). There was no significant Group effect for the analysis of MAP, however there was a significant effect for experimental stages [$(F(2,52) = 6.53$, $p < .05$, $\eta^2 = .20$].

The ANOVA on HR revealed a significant main effect between the three experimental phase [$F(2,52) = 10.07$, $p < .001$, $\eta^2 = .30$] with highest HR in TJ1 (M = 4.04, SE = 1.03) when compared to induction period (M = .78, SE = .55) and TJ2 (M = 2.22, SE = .96) [$p < .05$].

There was a PEP effect $F(2,48) = 4.08$, $p < .05$, $\eta^2 = .14$) however the differences

within participants across experimental stages and the differences between conditions (Table 2) were not significant.

In terms of the stroke volume, there was a significant interaction between experimental stages and conditions ($F(4, 52) = 4.53$, $p < .05$, $\eta^2 = .26$ with participants in the control condition (no light) having significant higher SV responses ($M = 11.32$, $SE = 6.85$) compared to BL2 condition ($M = -16.22$, $SE = 6.49$) ($p < .05$).

Regarding the CO responses, the interaction Phase x Group was significant ($F(4, 52) = 3.20$ $p < .05$, $\eta^2 = .20$). Participants in the BL2 condition experienced high blood circulating volume during blue light induction and then a decrease through the stages of the experiment (TJ1 and TJ2). Nonetheless, the multiple comparisons adjusted for error via Bonferroni did not identify significant post-hoc differences between groups ($p > .05$)

Table 2: Mean and standard error for baselined cardiovascular measures and impedance results during light induction and both traffic jams. Number of participants in round brackets.

		Light Induction	TJ1	TJ2
SBP (mmHg)	BL1 (10)	-1.50 [1.34]	.400 [2.5]	-2.6 [1.9]
	BL2 (7)	1.57 [1.6]	4.43 [2.45]	5.00 [2.27]
	Control (9)	3.00 [1.41]	7.33 [2.12]	5.56 [2.01]
DBP (mmHg)	BL1 (10)	.22 [1.07]	1.56 [1.52]	-.33 [1.37]
	BL2 (9)	1.20 [1.01]	1.1 [1.45]	-3.1 [1.3]
	Control (10)	-0.6 [1.01]	5.00 [1.45]	2.6 [1.3]
HR (bpm)	BL1 (9)	.001 [.95]	1.00[1.79]	.22 [1.66]
	BL2 (9)	1.33 [.95]	4.56 [1.79]	2.89 [1.66]
	Control (9)	1.00 [.95]	6.56 [1.8]	3.56 [1.66]
MAP (mmHg)	BL1 (10)	-1.5 [1.14]	1.2 [1.8]	-.90 [1.17]
	BL2 (9)	.78 [1.21]	.89 [1.90]	-1.11 [1.86]
	Control (10)	.2 [1.14]	5.00 [1.8]	2.8 [1.76]
PEP (ms)	BL1 (9)	.001 [.007]	-.006 [.009]	.001 [.008]
	BL2 (9)	.001 [.007]	-.023 [.009]	-.009 [.008]
	Control (9)	-.006 [.007]	-.014 [.009]	-.011 [.008]
LVET (ms)	BL1 (10)	-.004 [.006]	.001 [.011]	-.004 [.008]
	BL2 (8)	.001 [.007]	-.003 [.013]	-.016 [.009]
	Control (9)	-.008 [.007]	.014 [.012]	.005 [.009]
SV (ml)	BL1 (10)	-8.61 [7.56]	12.05 [9.61]	3.07 [7.15]
	BL2 (10)	-.35 [7.56]	-21.06 [9.61]	-27.24 [7.15]
	Control (9)	2.4 [7.97]	16.14 [10.13]	15.43 [7.54]
CO (L/min)	BL1 (9)	-.5 [.73]	.69 [1.05]	.46 [.96]
	BL2 (10)	1.03 [.73]	-.52 [1.05]	-.99 [.98]
	Control (10)	-.25 [.77]	.84 [1.1]	.85 [1.03]

In sum, BL1 was successful in attenuating subjective feelings of anger compared to the control group; fEMG and SBP marked expressive anger in the control group more than in the light groups.

Discussion

The experimental protocol aimed to reduce anger levels in participants who were exposed to ambient blue blight and utilised blue blight as an external explicit cue for relaxation (BL1), compared to participants exposed to blue light only (BL2) and to a control group. In sum, BL1 was successful in attenuating subjective feelings of anger compared to the control group in the light induction stage; but, both light conditions were equally effective compared to the control condition in reducing fEMG, BP and self-appraisal responses to anger inducting driving scenario. Although, the heart rate did not differentiate between groups, the effects observed at TJ1 and TJ2 were in congruence with the threat /challenge model proposed by Blascovich and Tomaka [70] in that there was a reduced increase in HR in the TJ2 (anger/threat) condition compared to TJ1 (anger/challenge) relative to the baselined induction phase. It could be considered that the induction phase acted as baseline for the actual test. The differences found, hence, are relative to an experimental stage and by no means, are indication of absolute threat and challenge entities.

Since feelings of anger were significantly lower in the BL1 group relative to the control group, it could be claimed that BL1 participants were actively processing the presence of light stimuli and memorising its effects which comes in line with Vandewalle et al.'s [4] findings that blue light could enhance responses in the left frontal brain activity, part of the brain also involved in processing positive valenced emotional stimuli during a working memory task. [14] In this context, relaxation was the positive valence emotion and the working memory was necessary to associate blue light with positive emotion. However, because the study measured the impact of light on anger, the relaxation was considered the opposite of anger state measures (the less angry, the more relaxed). Therefore, the assumption that relaxation opposed anger should be the subject of future work. In sum, blue light with overt priming made BL1 participants more relaxed when there was nothing else to distract them.

The fact that fEMG and BP marked expressive anger in the control group more than in both light groups indicated either a reduce effect of the manipulation of primings or a sole effect of the blue light. The first explanation that could be brought forwards could be that overt priming had no effect because the appearance of blue light in BL2 was sufficient to prompt relaxation due to the biological effects of blue light wave on melanopsin receptors. [13] However, the mechanisms by which these cells communicate with the brain are complex [12], Since melanopsin cells sends messages to the SCN of the hypothalamus [4], which in turn communicates with endocrine pathways to reduce cortisol [15], perhaps the biological regulation occurs due to the blue light wave properties on their own. Other explanation could be a cultural association between blue light and states of low psychological arousal. [37] Even participants not primed to the effects of blue light expressed similar reduced corrugators' activity. It could also be that the overt priming used in BL1 had no effect on actual relaxation during TJ1/TJ2; i.e., overt priming was superfluous due to biological effects or cultural associations.

A further explanation points to a flaw with the methodology. Sitting in the dark during light induction for the control participants caused fear and apprehension, which increased subjective, fEMG and SBP markers during that phase and distorted the results. Moreover, the effects of ambient light was strongest in the light induction phase when it was the sole source of light compared to the simulator phases where it was a secondary light source. Although the present study showed various increasing trends between BL1 and BL2 during the drive compared to the light induction, the statistical power of such findings was limited given the reduced scale of the comparison groups. At this stage, an extra control condition could be suggested where participants are not introduced to any ambient light prior to the task and exposure to ambient light throughout the task could have been appropriate. It maybe suggested that future studies use a GCS and unmanned aircraft pilots to enhance the ecological validity of blue light interventions.

CONCLUSION

What we learnt from the present study was that negative emotion such as anger exacerbated by uncontrollable situations (i.e., traffic jams or unresponsive systems) could detrimental for health in the long-term [71], but the experience of negative emotion could be modulated by environmental factors such as blue light. Moreover, the influence of light on physiological responses could be enhanced by idiosyncratic appraisal of the situation which is on line with previous research in the area (e.g., [72]). The next step would be to investigate whether it would be possible to create technological systems designed to function as countermeasures for negative emotion experienced by professionals predisposed to anger in uncontrollable scenarios. Users of GCSs are such individuals that could benefit from a biofeedback platform based on emotion reading computer interface. Psychophysiology has the potential to quantify different psychological states (e.g., anger in the present study), to monitor changes in state along a psychological continuum (e.g., low vs. high anger) and to function as a proxy for input control (e.g., a brain-computer interface - BCI). Psychophysiological data may also be used to identify stable personality traits, including motivational tendencies [73] and predispositions related to health, such as stress levels. [74] Although the GCS architecture is highly processor-oriented, the GCS requires pilots to maneuver the UAVs and a payload operator to monitor the computer systems, gather intelligence, and forward intelligence from the UAV to other end users. [53] By ensuring emotional self-control of GCS operators, we would be developing a two way interactive platform where the user controls the UAV while another computer controls the user's psychophysiological state to ensure optimum physical, mental and emotional functioning.

NOTATION

Physiological measures

CO	Cardiac Output
CV	Cardiovascular
DBP	Diastolic Blood Pressure
DC	Direct Current
ECG	Electrocardiography
fEMG	Facial electromyography
HR	Heart rate
ICG	Impedance cardiography
LVET	Left ventricular ejection time

MAP	Mean Arterial Pressure
PEP	Pre-ejection period
SAM	Sympathetic-adrenomedullary response
SBP	Systolic blood pressure
SV	Stroke volume
TPR	Total peripheral resistance

Self-report measures

STAXI 2	State-Trait Anger Expression Inventory 2

Conditions

BL1	Blue light condition 1 with priming
BL2	Blue light condition 2 without priming
TJ1	Traffic jam 1
TJ2	Traffic jam 2

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