

Effects of blue light and caffeine on mood

Johan G. Ekström · C. Martyn Beaven

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Abstract

Rationale Both short wavelength (blue) light and caffeine have been studied for their mood enhancing effects on humans. The ability of blue light to increase alertness, mood and cognitive function via non-image forming neuropathways has been suggested as a non-pharmacological countermeasure for depression across a range of occupational settings.

Objectives This experimental study compared blue light and caffeine and aimed to test the effects of blue light/placebo (BLU), white light/240-mg caffeine (CAF), blue light/240-mg caffeine (BCAF) and white light/placebo (PLA), on mood.

Methods A randomised, controlled, crossover design study was used, in a convenience population of 20 healthy volunteers. The participants rated their mood on the Swedish Core Affect Scales (SCAS) prior to and after each experimental condition to assess the dimensions of valence and activation.

Results There was a significant main effect of light ($p=0.009$), and the combination of blue light and caffeine had clear positive effects on core effects (ES, ranging from 0.41 to 1.20) and global mood (ES, 0.61 ± 0.53).

Conclusions The benefits of the combination of blue light and caffeine should be further investigated across a range of applications due to the observed effects on the dimensions of arousal, valence and pleasant activation.

Keywords Arousal · Valence · Phototherapy · Drug potentiation

Introduction

Decades of research have been spent on investigating how to enhance mood. It is a highly relevant aspect when considering healthy human functioning in many different settings and has the potential to benefit a wide range of applications such as educational, occupational and human health environs and even sporting performance. During the last two decades, a renewed interest in the effects of light on cognitive performance and mood has emerged. There is now compelling evidence of a non-image forming visual system (NIF) which is dependent on light for regulation of neuroendocrine and neurobehavioural functions in humans (Perrin et al. 2004; Vandewalle et al. 2006). Specific melanopsin-sensitive photoreceptors have been identified that are capable of maintaining NIF functions, such as pupillary light reflex and photoentrainment of the circadian rhythms, even when classical photoreceptors are lost (Hattar et al. 2002; Berson 2003).

It is now well known that the NIF visual system is most sensitive to wavelengths at approximately 460 nm, which is perceived as blue light (Brainard et al. 2001; Berson et al. 2002; Hatori and Panda 2010). This can be contrasted with the visual forming system in which the cones are most sensitive to wavelengths of 555 nm, corresponding to the human perception of the colour green (Lockley et al. 2003). The practical relevance of the NIF visual system is highlighted in studies on blind humans, lacking functional outer retinae and light perception, that demonstrate that exposure to specific wavelength light increases brain activity in prefrontal areas and induces melatonin suppression (Czeisler et al. 1995; Zaidi et al. 2007). Blue light serves as a modulator of many human functions, such as alertness (Cajochen et al. 2000; Revell et al. 2006), arousal (Vandewalle et al. 2007), reaction time in cognitive tasks (Chellappa et al. 2011), work performance (Mills et al.

J. G. Ekström (✉)
Nationellt Vintersportcentrum, Department of Psychology, Mid
Sweden University, 83125 Östersund, Sweden
e-mail: johan.ekstrom@jll.se

C. M. Beaven
Swedish Winter Sports Research Centre, Department of Health
Sciences, Mid Sweden University, Östersund, Sweden

2007) and mood (Lee et al. 1997; Glickman et al. 2006; Viola et al. 2008; Iskra-Golec et al. 2012). It is also noteworthy that the positive effects of light on mood have shown to be applicable in clinical psychology and psychiatry, such as in treatment of non-seasonal depression (Golden et al. 2005; Lieverse et al. 2011) and seasonal affective disorder (Glickman et al. 2006; Meesters et al. 2011).

The effects of caffeine on different aspects of human well-being are well explored (Fredholm et al. 1999), and habitual coffee drinkers have been reported to have a decreased risk for depression (Lara 2010; Ruusunen et al. 2010; Lucas et al. 2011). In addition to the consistently reported effects on alertness, cognitive function and reaction times (Lieberman et al. 1987; Warburton et al. 2001; Childs and Wit 2006), caffeine has also been demonstrated to enhance mood (Smit and Rogers 2000; Haskell et al. 2005; Smith 2009). On the other hand, higher doses of caffeine have been associated with negative symptoms such as tension, nervousness and anxiety (Kaplan et al. 1997; Rogers 2007), as well as increased sleep latency and decreased sleep quality (Sicard et al. 1996). Caffeine consumption has also been associated with the induction of psychiatric symptoms (Broderick and Benjamin 2004).

Although caffeine and blue light share a range of similar effects and have been clinically implemented, their combined effects are not fully understood. One recent study assessed the effects of blue light and caffeine on cognitive function, demonstrating differential effects on executive function, while a cumulative effect was observed on performance in a visual psychomotor test (Beaven and Ekström 2013). The current study aimed to investigate the acute effects of blue light and caffeine on mood and alertness and further compared the effects of a combination of blue light and caffeine to blue light on the core affect dimensions of valence and activation. The following hypotheses were formulated:

1. Exposure to blue light and a placebo pill would have a positive effect on mood compared to subjects exposed to the polychromatic white light and placebo pill condition.
2. Caffeine ingestion (240 mg) and exposure to polychromatic white light would have a positive effect on mood compared to the white light and placebo pill condition.
3. Caffeine ingestion (240 mg) and polychromatic white light exposure would have different effects on mood compared to the blue light and placebo pill condition.
4. The combination of exposure to blue light and caffeine ingestion (240 mg) would demonstrate larger effects on mood than the blue light and placebo pill, polychromatic white light and placebo, and polychromatic white light and caffeine ingestion (240 mg) conditions.

Method

Participants

The study recruited 24 subjects (13 males, 11 females) from the Mid-Sweden region ($m=26$, $SD=4$ years). The participants were recruited by e-mailing all students on the Mid-Sweden University, campus Östersund. All participants were non-smokers, low to moderate caffeine and alcohol consumers and were not on any contraindicatory medication. Participants were excluded from participating if they had worked night shifts during the last year, had travelled through more than 1 time zone during the last 2 months or reported a medical condition likely to compromise the study results. Before participation, each participant signed an informed consent for full understanding of the experiments, with pre-approval obtained from the Regional Ethical Review Board (Application #2012-318-31 M). No financial compensation was provided.

Design

A randomised, controlled, crossover design study was used. The study consisted of 2 independent variables (light and caffeine). These had each 2 conditions (blue or white; caffeine or non-caffeine). Pre- and post-intervention data were collected. Thus, the experimental design was a 2 (blue or white light) $\times 2$ (caffeine or placebo) $\times 2$ (pre and post). Accordingly, there were four trial conditions: white light/placebo (PLA), white light/240-mg caffeine (CAF), blue light/placebo (BLU) and blue light/240-mg caffeine (BCAF). Counterbalancing was used to control for order effects. The caffeine/placebo distribution was double-blinded.

Procedure

The current study was performed during winter season in Östersund, Sweden (63.1° N), starting in the end of February until the beginning of April. The laboratory experiments were conducted in the early evening (5:00 to 7:00 p.m.) and lasted for 1 h. Each participant was scheduled to perform experimental trials on four occasions, within a 1-month time period. Note that the menstrual phase of the female participants was not controlled for. Subjects were asked to refrain from caffeine, strenuous exercise and alcohol on the experimental days.

The participants were instructed to rate their mood on the Swedish Core Affect Scales (SCAS). The participants then ingested a gelatine capsule containing either caffeine (240 mg) or a visually indistinguishable sugar placebo (300 mg), before entering the experimental room. The experimental room was a specially designed room, decorated to suit the purposes of the experiment. It contained four comfortable chairs, the walls hung with draperies and wall-to-wall carpet. The temperature

Table 1 The 12 bipolar adjectives used in SCAS

Valence	Arousal	Pleasant activation	Unpleasant activation
displeased–pleased	sleepy–awake	bored–interested	tense–serene
sad–glad	dull–peppy	indifferent–engaged	anxious–calm
depressed–happy	passive–active	pessimistic–optimistic	nervous–relaxed

in the room was controlled at a constant 20 ± 0.5 °C. No pharmacological intervention was used to influence pupil dilation or responsiveness. Until entering the experimental room, the participants were unaware of the light stimulus they would be exposed to: either a ~ 40 lx of blue light from a commercially available LED light source (Techlight® RGB, 3 W, $\lambda_{\text{max}}=470$ nm) or the white light alternative (~ 100 lx) for 1 h.

The participants were instructed to stay awake and to keep their eyes open while remaining comfortably seated. Every 15 min, a researcher entered the room to ensure subject compliance. At the end of the 1 h, the participants again completed the SCAS. A 1-h intervention time was chosen in order to match the light exposure time to the absorption time of caffeine as the peak concentration of plasma caffeine after a normal intake is between 15 and 120 min after oral ingestion (Fredholm et al. 1999) and the greatest effect of caffeine is approximately 1 h after intake in a previous study by Lieberman et al. (2002). In previous studies of blue light, duration of exposure varies from less than 1 min up to 8 h. It has been demonstrated that just 50 s of short-wave light exposure can cause detectable effects in the hippocampus and amygdala (Vandewalle et al. 2007), while Viola et al. (2008) reported positive effects in an occupational setting with full-length working days of blue-enriched white light exposure. Note that the selected light intensity (~ 40 lx) in the current study has been shown previously to induce an alerting effect after a 1-h exposure (Figueiro and Rea 2010).

Mood

Research indicates that mood can be measured by using emotion adjectives on self-reported questionnaires on two

dimensions in a circumplex (Reisenzein 1994; Lang 1995; Cacioppo et al. 1999). The Swedish Core Affect Scales (SCAS; Västfjäll and Gärling 2007) was used to measure core affects, which are defined as “cognitively accessible elements of a current mood, an emotional reaction, or an anticipated emotional reaction” (Västfjäll et al. 2002). The questionnaire consisted of 12 bipolar adjectives (Table 1) shown on a visual analogue scale (VAS). The SCAS uses two dimensions, valence and activation, when measuring mood. The intermediate dimension of the positive affect of valence and activation is named pleasant activation, whereas the negative counterpart is labelled unpleasant deactivation. The intermediate dimension of positive valence but negative activation is labelled pleasant deactivation, whereas the negative valence and positive activation is labelled unpleasant activation (Västfjäll et al. 2002). Thus, adjective pairs are presented that relate to one of the four sub-scales: valence, arousal, pleasant activation and unpleasant deactivation. The greater the score on the each scale, the more positive was the assessed mood of the subject. Herein, we explicitly define the summed score of the four sub-scales on the SCAS as ‘Global Mood’. The SCAS has reported Cronbach α ’s ranging from 0.62 to 0.93 (Västfjäll et al. 2002).

Statistical analyses

IBM® SPSS® Statistics Version 20.0 was used for the statistical calculations. Repeated measures analysis of variance (rANOVA) was used to compare the pre- and post-data from the four experimental conditions. Bonferroni corrections were applied to post hoc tests for the pairwise comparisons. The assumption of sphericity was not violated in any of the

Table 2 Means for BLU, CAF, BCAF and PLA on SCAS sub-scales registered after each experimental condition

Variable	Experimental condition			
	PLA	BLU	CAF	BCAF
Global mood	77.5 (9.9)**	80.9 (11.7)	77.7 (13.2)*	85.5 (9.0)
Valence	20.9 (2.5)	21.2 (2.5)	20.3 (3.2)*	22.2 (2.1)
Arousal	15.1 (4.3)**	17.9 (3.9)	16.9 (5.4)	19.1 (3.6)
Pleasant activation	19.9 (3.4)	20.0 (3.6)	19.7 (4.0)	21.8 (2.9)
Unpleasant deactivation	21.7 (3.0)	21.9 (3.8)	20.8 (4.2)	22.5 (2.7)

PLA white light/placebo, CAF white light/240-mg caffeine, BLU blue light/placebo, BCAF blue light/240-mg caffeine. Parentheses represent standard deviations. * $p < 0.05$ vs. BCAF condition; ** $p < 0.01$ vs. BCAF condition

Table 3 Pairwise comparisons are displayed for testing hypotheses 1 to 3

Variable	BLU vs. PLA		CAF vs. PLA		BLU vs. CAF	
	<i>F</i>	<i>p</i> value	<i>F</i>	<i>p</i> value	<i>F</i>	<i>p</i> value
Global mood	1.51	0.234	0.00	0.948	1.64	0.216
Valence	0.31	0.584	0.68	0.420	2.04	0.169
Arousal	4.19	0.055	3.11	0.094	0.44	0.517
Pleasant activation	0.01	0.907	0.05	0.821	0.11	0.748
Unpleasant deactivation	0.10	0.759	0.88	0.360	1.73	0.204

PLA white light/placebo, CAF white light/240-mg caffeine, BLU blue light/placebo

performed rANOVAS, tested with Mauchly's sphericity test. There were no missing values for any of the dependent variables; thus, no statistical attrition analysis was made. Magnitudes of the standardised effects (Cohen effect size [ES]) were interpreted using thresholds of 0.2, 0.6, 1.2 and 2.0 for small, moderate, large and very large, respectively (Hopkins et al. 2009). An effect was deemed unclear if the confidence interval overlapped the thresholds for both small positive and small negative effects. The significance level was set at $p \leq 0.05$.

Results

Two participants failed to complete all four experimental trials, and two subjects were excluded because of night shift work or travel at some occasion during the study. There was a significant main effect of light, $F(1, 19)=8.35$, $p=0.009$, but not for caffeine, $F(1, 19)=0.40$, $p=0.537$, or time, $F(1, 19)=0.07$, $p=0.797$ on mood. The means and standard deviations for the dependent post-measures are displayed in Table 2.

There were no reliable interaction effects in the main analysis between light $\times$ caffeine $F(1, 19)=2.42$, $p=0.136$, light $\times$ time, $F(1, 19)=0.87$, $p=0.362$, caffeine $\times$ time, $F(1, 19)=1.52$, $p=0.233$, or light $\times$ caffeine $\times$ time, $F(1, 19)=0.15$, $p=0.703$. Pairwise comparisons for global mood and the four dimensional sub-scales resultant from the three conditions BLU, CAF and PLA are displayed in Table 3.

Further pairwise comparisons revealed that the participants reported a more positive global mood when there had a combination of blue light and caffeine (BCAF), compared to blue light and placebo (BLU), $F(1, 19)=4.73$, $p=0.043$, $\eta_p^2=0.20$, caffeine and white light (CAF), $F(1, 19)=13.52$, $p=0.002$, $\eta_p^2=0.42$, and white light and placebo (PLA), $F(1, 19)=11.78$, $p=0.003$, $\eta_p^2=0.38$. Figure 1 illustrates the condition-induced differences on the SCAS assessments with pre-intervention subtracted from post-intervention. Only the BCAF condition elicited a moderate improvement in mood (ES, 0.61 ± 0.53).

Discussion

Here, our randomised, controlled, crossover study revealed a potentiated effect of blue light and caffeine on global mood as well as the specific dimensions of arousal, valence and pleasant activation. An enhancement in global mood could be observed after 1-h exposure to blue light when combined with 240 mg of caffeine. Similarly, although not significant at the 0.05 level, there were clear trends towards elevating arousal effects of both the BLU and CAF conditions compared to PLA. These results are in line with previous research that investigated the effects of blue light (Viola et al. 2008) and caffeine (Haskell et al. 2005) on mood individually.

It was hypothesised that blue light and caffeine would demonstrate different effects on aspects of mood on the core affect scale. While previous studies have tested the effects of caffeine and blue light on mood separately (Haskell et al. 2005; Childs and Wit 2006; Viola et al. 2008; Iskra-Golec et al. 2012), no data is available on any combined effects. The combination of bright white light and caffeine, however, has been previously demonstrated to suppress melatonin and

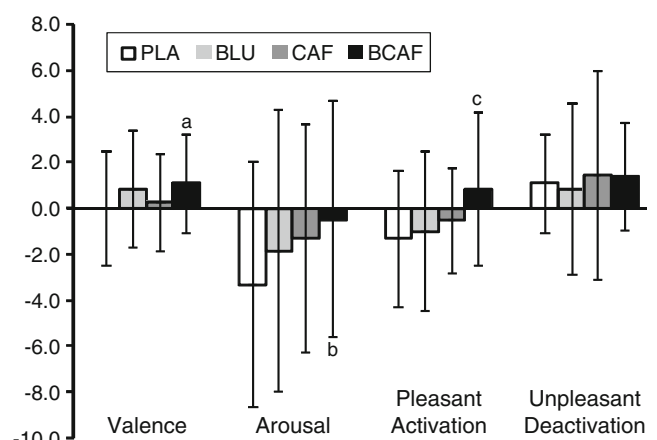


Fig. 1 Differences between mood resultant from the experimental conditions PLA white light/placebo, CAF white light/240-mg caffeine, BLU blue light/placebo, BCAF blue light/240-mg caffeine. *a* substantially different to PLA (ES, 0.41), *b* substantially different to PLA (ES, 1.20), *c* substantially different to PLA (ES, 0.82). Error bars represent SD

enhance cognitive performance to a greater extent than either intervention alone (Wright Jr et al. 1997, 2000). Previous work has demonstrated distinct effects of blue light exposure and caffeine dose on cognitive tasks that assessed different components of psychomotor function suggestive of differing mechanisms of action (Beaven and Ekström 2013). The absence of a ceiling effect in the current study corroborates these findings. The current study did detect post-intervention differences between the CAF and BCAF conditions in the valence dimension that were not apparent when comparing BCAF and BLU. In the context of our results, this observation may reflect anxious arousal (Nitschke et al. 2001) which were less evident in the blue light conditions.

The mechanisms by which the effects of caffeine on mood are realised have been investigated, with blockade of adenosine A1 and A2 receptors in the brain being particularly relevant given the known functional connectivity between adenosine receptors and the dopaminergic system (Fredholm et al. 1999; Boutrel and Koob 2004; Winston et al. 2005). Although this study did not specifically investigate underlying mechanisms, the blue light results may be considered in relation to what Rautkylä, Puolakka and Halonen (2012) propose as a hypothetical model of two NIF pathways whereby direct visual input from the retina is projected in to the amygdala. The importance of a dual pathway for the effects of light on human function is highlighted by the known role of the amygdala in emotion processing (Phelps 2006).

Despite the double-blinded study design, we cannot discount the possibility that some participants were conscious of the physiological stimulatory actions of caffeine and adjusted their subsequent self-assessment accordingly. Further, we acknowledge that the absolute, rather than relative doses of caffeine may have contributed to differences in peak caffeine levels in the individuals and that habitual caffeine consumption was not strictly assessed. However, recent research suggests that there is no association between habitual caffeine intake and peak or total serum caffeine concentrations (Skinner et al. 2013). Indeed, it has been suggested that individual differences in caffeine sensitivity are more likely a result of intrinsic differences in responsiveness to caffeine at sites of action in the brain, rather than from differences in absorption, distribution or metabolism of the substance (Goldstein et al. 1965). It should be noted that, in contrast to many studies investigating the effects of caffeine or light on mood (Lieberman et al. 2002; Phipps-Nelson et al. 2003; Rüger et al. 2006), the present study did not sleep deprive participants, thus improving the ecological validity of the study results. It has been suggested that many of the effects of caffeine constitute a return to normal function, or an amelioration of the effects of caffeine withdrawal (Rogers 2007). However, a number of researchers have demonstrated that caffeine has psychoactive effects even in the absence of withdrawal (Warburton et al. 2001; Smith et al. 2005; Childs and

Wit 2006), and work by Smit and Rogers (2000) argues against this ‘withdrawal reversal’ hypothesis.

The environment in which we evolved and developed our innate physiology, is vastly different to the biotope in which the vast majority of civilised humans now inhabit. Various effects of artificial exposure to blue light on our physiology have been recently documented (Cajochen et al. 2011; Wood et al. 2013). Further, appropriate lighting is associated with improved human health in hospital environments (Walch et al. 2005; Joarder and Price 2013), behavioural therapy (Golden et al. 2005; Morin et al. 2006), academic performance (Heschong et al. 2002; Mott et al. 2012) and workplace well-being (Viola et al. 2008; Iskra-Golec et al. 2012). The potentiating effects of blue light exposure when used in conjunction with caffeine on mood noted herein further demonstrate the importance of these convenient and accessible biomodulators in human functioning and performance.

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