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Bright light exposure does not prevent the deterioration of alertness induced by sustained high cognitive load demands

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A B S T R A C T

The present work investigated the effects of bright light exposure to prevent increased sleepiness and decreased alertness induced by a dual working memory task in which high cognitive demands (HCL) are adapted to the individual's maximal capacity. In a randomized cross-over study, twenty participants were exposed to two sessions that included 20 min of light exposure (dim light or bright light). Subjective sleepiness (Karolinska Sleepiness Scale) and objective alertness (Psychomotor Vigilance Task) were assessed before and after light exposure and before and after performing with the high cognitive demands task. Bright light exposure did not prevent decreased alertness and increased sleepiness prompted by the task. These results suggest that bright light administered prior to a cognitively demanding task is not beneficial to prevent impairments ensuing from high cognitive demands.

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1. Introduction

Levels of alertness of living organisms from cyanobacteria to other animals, including humans, are modulated by circadian rhythms (Edgar et al., 2012). These endogenous cycles are synchronised to the external environment via the 24-h light/dark cycle through visual effects exerted by light (Duffy & Czeisler, 2009). Light is effective to restructure circadian rhythmicity (Appleman, Figueiro, & Rea, 2013), and other beneficial effects include the improvement of mood (Pail et al., 2011) or sleep disturbances (Kamei, 2009). Moreover, in humans, exposure to bright light is known to influence cognitive brain function through the non-visual effects of light (Perrin et al., 2004; Vandewalle, Maquet, & Dijk, 2009; Vandewalle et al., 2011, 2006) and to exert an impact on the autonomous nervous system (Rüger, Gordijn, Beersma, De Vries, & Daan, 2005; Smolders, de Kort, & Cluitmans, 2012; Scheer, van Doornen, & Buijs, 1999; but see; Rüger, Gordijn, Beersma, de Vries, & Daan, 2006; Smolders & de Kort, 2014) and endocrine functions (Lowden, Akerstedt, & Wibom, 2004). Bright light administration is able to improve vigilance or alertness (Phipps-Nelson, Redman, Dijk, & Rajaratnam, 2003) and transiently prevents subjective sleepiness (Vandewalle et al., 2006). Alertness is central in regulating attention, consciousness and information processing and maximal efficiency in performance is reported for intermediate levels of arousal (see Yerkes–Dodson law; Yerkes & Dodson, 1908). The beneficial effects of light exposure depend on several factors, especially the range and intensity of light exposure. Blue-enriched light in the 420–520 nm range seems to be the most beneficial type of light to enhance alertness and cognitive functions (Chellappa et al., 2011; Lehrl et al., 2007; Lockley, Evans, Scheer, Brainard, Czeisler, & Aeschbach, 2006; Rahman et al., 2014). Time of day is an additional factor that influences the effects of light. Whereas light exposure at night affects physiological factors, e.g. increased heart rate and core body temperature (Rüger et al., 2006), its effects to modulate brain function have been reported both during day (Vandewalle et al., 2011) and night (Perrin et al., 2004) times. Improved alertness and increased physiological arousal have been reported when light exposure occurs at night (Figueiro, Bullough, Bierman, Fay, & Rea, 2007; Perrin et al., 2004), in the afternoon (Chellappa et al., 2011; Sahin & Figueiro, 2013) and during the early morning (Brainard et al., 2001). The type of cognitive demand may also play a role in the impact of light exposure. Chellappa et al. (2011) showed beneficial effects of blue-enriched light on performance in pure attentional tasks but not in more complex cognitive tasks. Moreover, exposure to bright light resulted in adverse effects in a working memory 2-Back and an inhibition Go-NoGo paradigm (Smolders & de Kort, 2014). Finally, inter-individual differences in the cognitive status prior to light

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exposure may also represents an important factor, still barely investigated. For instance, Smolders & de Kort, (2014) showed that participants benefited more from bright light exposure after fatigue induction, and subsequently presented higher levels of mental exhaustion.

Light exposure has been shown as a promising tool to improve levels of alertness and vigilance in situations in which circadian rhythms are altered such as jet-lag, shift work or space missions (Whitmire et al., 2009), sleep deprivation (Leproult et al., 2003; Wright, Badia, Myers, & Plenzler, 1997), or in the context of natural daily oscillations such as the post-lunch dip (Slama, Deliens, Schmitz, Peigneux, & Leproult, 2015). Although several studies suggested the effectiveness of light exposure to counteract the deterioration of vigilance and sleepiness under these conditions, the potential benefits of light exposure prior to the administration of a cognitively highly demanding task remain to be investigated. In this framework, the present study tested whether exposure to white bright light (enriched with blue light in the range of 460 nm) could delay or prevent high cognitive load (HCL) task-related increases in the feeling of sleepiness which accompany decreased alertness (Bakotic & Radosevic-Vidacek, 2013; Cluydts, De Valck, Verstraeten, & Theys, 2002), as well as decreasing behavioural performance during sustained task practice. Hence, we hypothesized that exposure to bright light for 20 min prior to the administration of the HCL task would prevent task-related changes in vigilance and subjective sleepiness.

In addition, we also expected preserved alertness following bright light exposure to prevent the typically observed decrease in performance during sustained attentional demands (Borragán, Slama, Destrebecqz, & Peigneux, 2016). Indeed, it was proposed that decreased performance with time on task results from a task disengagement process (Matthews et al., 2010). Cognitive models suggest that the individual's baseline state of alertness influences his/her willingness to engage in a task. Furthermore, that task disengagement entails a situation of reduced alertness is endorsed by the main models accounting for decreasing performance decrease over time, i.e., the Malleable Attentional Resources Theory [MART] model (Young & Stanton, 2002) and the dynamic model of stress and sustained performance (Hockey, 1997; Hancock & Warm, 1989). Therefore, the individual may be encouraged to spend more time on the task if his/her alertness levels are adequate, with the consequence that performance is maintained at the same level (Gonzalez, Best, Healy, Kole, & Bourne, 2011).

2. Methods

2.1. Participants

Twenty young right-handed healthy volunteers (mean age ± SD = 23.7 ± 3.6 years; 12 men) participated in this study conducted in agreement with the Declaration of Helsinki and approved by the Faculty ethics committee of the Université Libre de Bruxelles. Three participants were excluded (2 men). One did not complete the entire experimental procedure, the other two had outlier performance (>2SD from the group average in the TloadDback). None of the participants included in the experiment presented an extreme chronotype. Group average score in the Morningness–Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) was 53.29 ± 8.65. Participants were asked to sleep at least 7 h per night, go to sleep before midnight and get up before 9.00.

2.2. Protocol

The entire experiment lasted for 3 consecutive days (see Fig. 1 for an overview of the experimental design). On Day 1, the participant's maximal cognitive load on the TloadDback task was determined during a pre-test session (see below; Material). The TloadDback task was then administered on Day 2 and Day 3 at the individual's maximal capacity to induce comparable levels of high cognitive load in all participants (Borragán et al., 2016). The protocol consisted of two randomized cross over interventions counterbalanced between Day 2 and Day 3: (a) bright light condition (2000 lux) and (b) dim light condition (<200 lux). After completing the St-Mary Hospital Questionnaire (Ellis et al., 1981) for sleep quality and sleep duration on the previous night, the session started with 20 min exposure to dim or bright light. The duration was based on current safety recommendations for bright light therapy exposure (Terman, 2007). During light exposure, participants were comfortably seated in a quiet room while watching an animal documentary. Right after, they were administered with the TloadDback task (Borragán et al., 2016) for 16 min. All stimuli (Arial font size 120) were presented in black on a white background on a 16-inch computer screen (refresh rate 60 Hz). Psychomotor Vigilance Task (PVT; Dinges & Powell, 1985), cognitive fatigue (CF; Lee, Hicks, & Nino-Murcia, 1991), sleepiness (Karolinska Sleepiness Scale, KSS; Akerstedt & Gillberg, 1990), mood (Monk, 1989) and positive/negative affects (Watson, Clark, & Tellegen, 1988) were assessed at three time points during the experimental session: before (p1) and after (p2) the light intervention, and immediately after the TloadDback task (p3). All participants were tested at the same time of day for all sessions, between 15 h and 17 h, i.e. approximately 9 h after wake up time. Participants wore a wrist actigraphy monitor (ActiGraph, wGT3X-BT Monitor, EEUU) for 4 days (i.e. the day before the beginning of the experiment and the three experimental days) to control the regularity of sleep/wake schedules during the experiment. Due to a technical issue, actigraphy data were available in 13 out of the 17 participants.

2.3. Material

2.3.1. Light exposure

For the bright light condition, we used white light enriched with blue light in the range of 460 nm, a wavelength known to be the most effective to activate eye photoreceptors (Lockley et al., 2006; Wright, Lack, & Kennaway, 2004). For the dim light condition, we used white dim light enriched with orange light in the range of 600 nm. Both light conditions were administered using a wearable glasses-like device (Lucimed SA, Belgium; Spectral power distribution for bright and dim lights is showed in Fig. 2) equipped with light reflectors to project the light on the retina, especially targeting non-image forming photosensitive retinal ganglion cells. The device for light exposure was designed to be used in ecological contexts (e.g. reading), is worn like normal glasses, and generates an even distribution of light on the eyes, without risk of glare (Langevin, Laurent, & Sauvé, 2014). Background ambient light was constantly maintained to70 lux on average in both conditions. Light intensities, both ambient and during the intervention, were measured via a luxmeter at the eye level. Indeed, illuminance is a poor descriptor of the stimulus to the ipRGC but our study was not designed to explore the mechanisms of the non-visual effects of light.

2.3.2. TloadDback task

Decreased alertness on the PVT and increased self-reported sleepiness were triggered using the TloadDback task (Borragán et al., 2016). This task combines two different memory demands with a classical 1-back working memory-updating task (Kirchner, 1958) and a parity digit decision task for a duration of 16 min. The task aims at ensuring a large recruitment of working memory resources, eventually leading to decreased performance and

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