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Intense illumination in the morning hours improved mood and alertness but not mental performance

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Cognitive performance and alertness are two determinants for work efficiency, varying throughout the day and depending on bright light. We conducted a prospective crossover study evaluating the impacts of exposure to an intense, early morning illumination on sustained attention, alertness, mood, and serum melatonin levels in 33 healthy individuals. Compared with a dim illumination, the intense illumination negatively impacted performance requiring sustained attention; however, it positively impacted subjective alertness and mood and had no impact on serum melatonin levels. These results suggest that brief exposure to bright light in the morning hours can improve subjective measures of mood and alertness, but can also have detrimental effects on mental performance as a result of visual distraction. Therefore, it is important that adequate lighting should correspond to both non-visual and visual demands.

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1. Introduction

With its increasing economic and social demands, the Western world has developed more and more into a meritocracy, desiring the optimum in almost every aspect of life, no matter the time of day or night, demanding top performance and productivity, particularly in the working sector. Many factors, such as fatigue and the duration and quality of sleep, account for the quality of work performance. Excessive sleepiness is one major cause of sleep-related errors in tasks requiring cognitive performance (Haavisto et al., 2010) and accounts for many accidents in driving professions (Braeckman et al., 2011). Selective attention contributes to mental performance and is therefore decisive for work efficiency (Spaeth et al., 2012) and safety (Rajaratnam and Arendt, 2001). In order to adapt to exogenous factors, most endogenous processes vary in a distinct circadian pattern, determining the quality of psychological and physical performance, including performance that requires alertness (Monk et al., 1997; Carrier and Monk, 2000; Wright et al., 2002).

Blue light with 420–480 nm wavelengths has a strong biological impact (Revell et al., 2006) and influences cognitive as well as physical performance (Dollins et al., 1993; Fraschini et al., 1999; Atkinson et al., 2003). Daytime absence of short wavelength light was proven to phase delay sleep onset (Figueiro and Rea, 2010). However, light of long wavelength seems to have stronger effects on brain activity associated with alertness as compared to short wavelength in the afternoon hours (Sahin and Figueiro, 2013). Light acts in the intrinsic photosensitive ganglion cells of the retina through melatonin and its metabolites (Zeitzer et al., 2000), which are strongly involved in the circadian variations of rhythmic physiological systems (Cajochen et al., 2003), as well as performance (Chellappa et al., 2011). Exposure to bright light (BL) causes cognitive and behavioural changes not only during the biological night (Lockley et al., 2006), but also during the day (Sahin and Figueiro, 2013). Brief exposure to light enhances thalamic and frontal and parietal activities that affect fatigue (Lockley et al., 2006; Vandewalle et al., 2006, 2007a,b). The extent of the physiological changes depends on whether the light exposure occurs before or after the midday hours (Lockley et al., 2006). Dynamical lighting systems with variations in illumination and colour temperature are proposed to benefit productivity and health (van

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Bommel, 2006; Hoffmann et al., 2008). BL interventions can be effective for treating depressive disorders, especially seasonal ones (Terman and Terman, 2005); they can also positively affect cognitive (Lockley et al., 2006; Vandewalle et al., 2006, 2007a,b) as well as physical (Kantermann et al., 2012) functions in healthy individuals.

Besides those inputs from the circadian system (light and melatonin level), homeostatic factors, and most importantly, the elapsed time since awakening, must be taken into consideration for day-dependent variations; because circadian factors and homeostatic factors interact strongly with one another (Carrier and Monk, 2000). The time of the start of work and/or the time of awakening determine the amount of perceived sleepiness (Kecklund and Akerstedt, 1995; Braeckman et al., 2011).

Recently it was shown that 1 h of exposure to bright, white light in the morning not only advances sleep and wake-up parameters, but also affects cognitive performance and alertness (Corbett et al., 2012), amending previous research and suggesting that an adequately applied light intervention could positively affect alertness, and thus performance, at work. We hypothesised that a brief, early morning BL intervention would effectively enhance attention, alertness, and mood parameters and, additionally, would cause a decrease in serum melatonin levels.

2. Material and methods

2.1. Participants

Via the internet 35 study participants between 18 and 45 years of age with occupations requiring high levels of selective attention from the Tiroler Landeskrankenanstalten (Tilak), the Health and Life Sciences University UMIT, and the Tyrolean Confederation of Marksmen were recruited. None of the participants took medications, had ever worked in shifts, had taken a transmeridian flight in the previous 2 months, or suffered from chronic diseases such as chronic headache, migraine, metabolic disease (diabetes mellitus, etc.), cardiovascular disease (hypertension), renal or liver disease, neurologic disease such as epilepsy, mental or psychiatric disease (depression), sleep disturbances, retinal disease, glaucoma, or cataract.

2.2. Study design and procedures

A prospective, explorative crossover design with a wash-out phase of 7 days was chosen. To control for natural daylight, all our investigations were performed in the winter months (15 November 2009–25 February 2010). All participants were sleeping at their homes, waking up at 6:00 a.m. and arriving at the study location at 7:00 a.m. (Table 1). During the study period, the sun rose at 07:18 h on 15 November, 07:40 h on 1 December, 08:01 h on 1 January, 07:41 h on 1 February, and 07:07 h on 25 February, thus guaranteeing that the sun had not yet risen at the start of the protocol at 07:05 h. Twice, with an interval of 7 days, each study participant was exposed to light for 30 min starting at 07:40 h. One of the exposures was to BL, and the other exposure was to Dim Light (DL). 17 of the participants were randomly assigned to receive the BL exposure first, followed by the DL exposure 7 days later, and the other 16 participants were assigned to receive the DL exposure first, followed by the BL exposure 7 days later. Identical experimental procedures on both days of exposure were applied (Table 1).

2.2.1. Light exposures

Exposure to bright light (BL) was performed in a light cabin having the following light specifications at eye level: the cabin was equipped with fluorescent lamps with a maximum horizontal and vertical light intensity of 5000 lx, a colour temperature of 6500 K and a maximum environmental luminance of 1500 cd/m^2. A detailed description of the light device and BL protocol can be seen in Leichtfried et al. (2010). BL exposure was chosen according to pertinent recommendations of BL therapy for seasonal affective disorders (Terman and Terman, 2005). As a result of the innovative light setup used in the study at hand duration and intensity of BL exposure could be diminished (Leichtfried et al., 2010).

Specification of the dim light setup (DL) was chosen according to a conventional office illumination. Study procedures of the DL setup were performed in an office equipped with fluorescent lamps from ceiling luminaire with a light intensity of 400 lx, a correlated colour temperature of approximately 4000 K at eye level, and a luminance of 850 cd/m^2.

Table 1
Experimental procedure on both days of the study.

Time of the day		Light
06:00 h	Wake up	Dim light
07:00 h	Arrival at the setup	Dim light
07:05 h	Blood sampling I (t0)	Dim light
07:15 h	VAS pre (mood & subjective fatigue)	Dim light
07:20 h	Motor performance tests I (data not shown)	Dim light
07:40–08:10 h	Light exposure	5000 lx or 400 lx, respectively
08:12 h	VAS post (mood & subjective fatigue)	Dim light
08:15–09:00 h	Sustained attention test (Vienna Test System)	Dim light
09:05 h	Blood sampling II (t1)	Dim light
09:15 h	Motor performance tests II (data not shown)	Dim light
11:05 h	Blood sampling III (t2)	Dim light

VAS, visual analogue scale.

2.2.2. Performance test

Sustained attention was the main outcome parameter which was assessed directly after the light exposures using a part of the Vienna Test System® (sustained attention test, version S3, Dr. G. Schuhfried Ltd., Moedling, Austria) given on a computer workstation. Identical workstations were used for all computer based tests (Toshiba laptop, TECRA S10-143). After receiving instructions on the display, the study participants spent a total of 35 min performing a number of time-critical trials: one row of seven white triangles (with 150 cd/m^2 luminance) appeared on the dark display (with 10 cd/m^2 luminance), the tips of the triangles pointing either upwards or downwards; whenever a certain number of triangles pointed downwards, the participant pressed a green-coloured button on the keyboard. The accuracy (number of right/false reactions) and speed of the participants' reactions (reaction times during right/false reactions) were recorded. Cronbach's alphas for the test are $r = 0.98$ for the number of correct reactions and $r = 0.97$ for the number of false reactions. Norm samples of 302 persons and a sample of 369 neurologic patients are given.

2.2.3. Questionnaires

The chronotypes of the participants were evaluated at the beginning of the study using the Morningness–Eveningness Questionnaire (MEQ) (Horne and Ostberg, 1976), a self-assessment instrument consisting of 19 multiple-choice questions which are combined to form a composite score indicating the degree to which the respondent favours morning versus evening. The Cronbach's alpha for the MEQ is reported to be $r = 0.837$ (Rhee et al., 2012).

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