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Research report

Dawn simulation light impacts on different cognitive domains under sleep restriction

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HIGHLIGHTS

- We investigated morning light effects on cognition after a night of sleep restriction.
- Morning light effects depend on cognitive domain.
- Morning light effects depend on individual performance levels.

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ABSTRACT

Chronic sleep restriction (SR) has deleterious effects on cognitive performance that can be counteracted by light exposure. However, it is still unknown if naturalistic light settings (dawn simulating light) can enhance daytime cognitive performance in a sustainable matter.

Seventeen participants were enrolled in a 24-h balanced cross-over study, subsequent to SR (6-h of sleep). Two different light settings were administered each morning: a) dawn simulating light (DsL; polychromatic light gradually increasing from 0 to 250 lx during 30 min before wake-up time, with light around 250 lx for 20 min after wake-up time) and b) control dim light (DL; <8 lx). Cognitive tests were performed every 2 h during scheduled wakefulness and questionnaires were completed hourly to assess subjective mood.

The analyses yielded a main effect of "light condition" for the motor tracking task, sustained attention to response task and a working memory task (visual 1 and 3-back task), as well as for the Simple Reaction Time Task, such that participants showed better task performance throughout the day after morning DsL exposure compared to DL. Furthermore, low performers benefited more from the light effects compared to high performers. Conversely, no significant influences from the DsL were found for the Psychomotor Vigilance Task and a contrary effect was observed for the digit symbol substitution test. No light effects were observed for subjective perception of sleepiness, mental effort, concentration and motivation.

Our data indicate that short exposure to artificial morning light may significantly enhance cognitive performance in a domain-specific manner under conditions of mild SR.

1. Introduction

Numerous factors can influence cognitive performance, chief among them are the impact of time of day [1,2] and homeostatic sleep pressure [3]. Chronic sleep restriction (SR) has deleterious effects not only on daytime alertness but also on cognitive performance [4,5].

Indeed, sleep disruption results in specific cognitive impairments including deficits in attention, executive function, non-declarative and declarative memory, as well as emotional reactivity and sensory perception [6–8]. Some studies show that

Abbreviations: NIF, Non-Image Forming; fMRI, functional Magnetic Resonance Imaging; SR, sleep restriction; DsL, Dawn simulation light; DL, dim light; MTT, Motor Tracking Task; DSST, Digit Symbol Substitution Test; PVSAT, Paced Visual Serial Addition Task; simRT, Simple Reaction Time Task; SART, Sustained Attention to Response Task; PVT, Psychomotor Vigilance Task; V1-V2-V3, 1,2,3-back: Visual N-back Task; SC, superior colliculus.

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light exposure can act as countermeasure for these cognitive impairments in humans [9,10].

These acute impacts of light are usually referred to as non-visual (or Non-Image Forming – NIF) effects, since they drift apart from classical involvement of rod and cone photopigments in visual responses to light. NIF light effects at shorter wavelength via novel photoreceptors containing the photopigment melanopsin appear to strongly impact the human circadian timing system [11,12]. Behavioural responses triggered by light encompass improved alertness and performance, as indexed by specific cortical responses to cognitive tasks in Photon Emission Tomography and functional Magnetic Resonance Imaging (fMRI) techniques [13]. However, dosage (intensity and duration), timing and wavelength of light for domestic use and in the workplace environments are difficult to define and may critically depend on environmental and the individual factors.

In a previous study, we have shown that exposure to gradually increasing light prior to awakening can counteract sleep restriction effects on well-being and cognitive performance across the day, leading to an optimized level of alertness, which impinges on enhanced performance on specific cognitive tasks tightly related to sustained levels of attention [14].

Most of the effects were visible on the first day after the sleep restriction night but not on the second day after two nights of sleep restriction, most likely due to the increase in sleep pressure.

The overall aim of the present study was to investigate whether dawn simulation light following sleep restriction, enhances performance according to cognitive domain and whether these effects are sustained during the entire day.

2. Material and methods

2.1. Study participants

Study volunteers were recruited through advertisements at different local universities and websites in Switzerland, Germany and France. Screening procedure began with a telephone interview, involving a detailed study explanation. All participants gave written informed consent before the start of the laboratory part. Study protocol, screening questionnaires and consent forms were approved by the local ethics committee (EKBB/Ethikkommission beider Basel, Switzerland) and conformed to the Declaration of Helsinki.

All applicants completed questionnaires about their sleep quality, life habits and health state. These questionnaires comprised a consent form, a general medical questionnaire, Beck Depression Inventory II [15], Epworth Sleepiness Scale [16], Horne Ostberg Morningness Eveningness Questionnaire [17], Munich Chronotype Questionnaire [18] and Pittsburgh Sleep Quality Index. Potential candidates with a Pittsburgh Sleep Quality Index score >5 were excluded from participation [19]. Further exclusion criteria were smoking, medication or drug consumption, body mass index <19 and >28, shift work and transmeridian flights within the last three months, as well as medical and sleep disorders. Since our study protocol included two nights of partial sleep restriction (restriction to 6-h), we also excluded participants with habitual sleep durations <7-h and >9-h [20], to minimize a possible confounding effects of sleep duration.

Eighteen young men (20–33 years old; mean + Standard Error of Mean: 23.1+.8) fulfilling all the criteria were enrolled in the study. A comprehensive toxicological analysis of urine for drug abuse was carried out before the study, along with an ophthalmologic examination to exclude volunteers with visual impairments.

One week before the study, participants were not allowed to drink excessive alcohol, and to consume caffeine or cacao containing drinks or meals (at most 5 alcoholic beverages per week, and 1 cup of coffee or 1 caffeine-containing beverage per day). They were also instructed to keep a regular sleep-wake schedule (bed and wake times within ±30 min of self-selected target time). Compliance to this outpatient segment of the study was verified by wrist actigraphy (actiwatch L, Cambridge Neurotechnologies, Cambridge, UK) and self-reported sleep logs.

The study was carried out during the winter season (January to March) in Basel, Switzerland, and comprised two segments, distributed in a balanced cross-over design, separated by at least 1-week intervening period. The volunteers reported to the Centre for Chronobiology at the Psychiatric Hospital of the University of Basel on two occasions (control condition and one experimental conditions), where they stayed in individual windowless bedrooms with no information about time of day. Since we did not find significant effects on cognitive performance neither after the blue light exposure nor after the DsL exposure after the second night of sleep restriction, we decided to focus here on the first 24-h of the control condition and the DsL condition. The most likely explanation was that sleep pressure was too high after the second night of sleep restriction, and thus the morning light could not counteract its

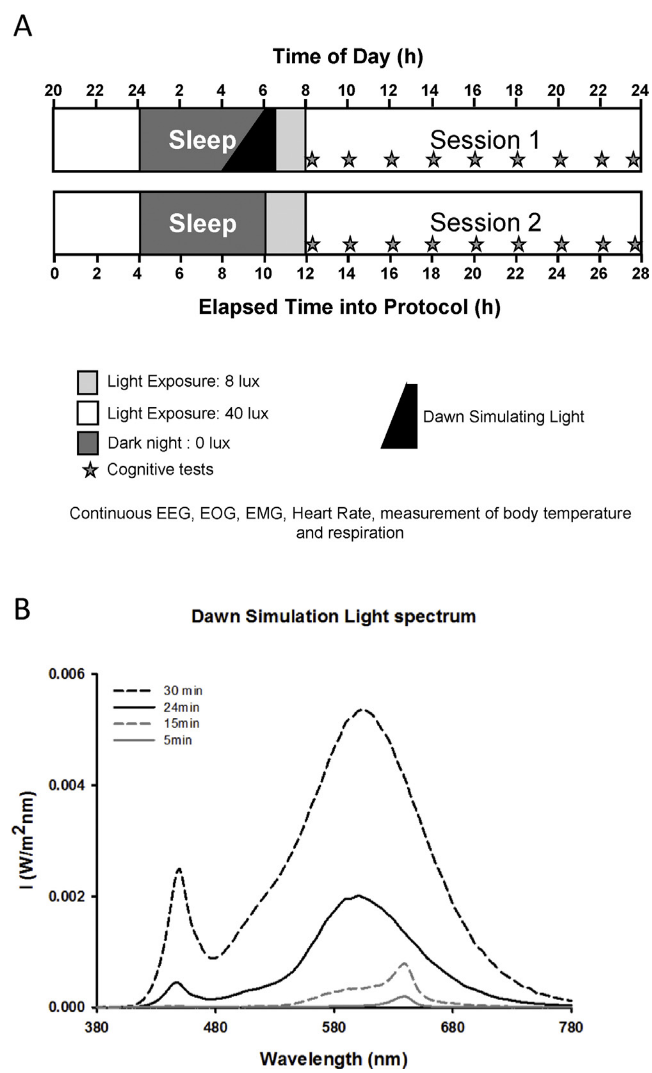

Fig. 1. (A) **Protocol design**. Two arms of a 6-h sleep restricted protocol with different morning light exposures. Elapsed time indication is relative to an arrival in the lab at 8 p.m. Time-of-day indication varied across all subjects but was given in the figure as an example (taken from the mean of the sleep/wake time from all participants). (B) **Morning light device.** Spectral composition (light wavelength by irradiance (W/m2nm)) of the Dawn Simulation Light at 5 min (grey solid), 15 min (grey dash), 24 min (black solid) and 30 min (black dash).