Journal of Environmental Psychology 39 (2014) 77–91

Contents lists available at ScienceDirect

Journal of Environmental Psychology

journal homepage: www.elsevier.com/locate/jep

Bright light and mental fatigue: Effects on alertness, vitality, performance and physiological arousal

Karin C.H.J. Smolders [a,b,*], Yvonne A.W. de Kort [a,b]

[a] Human–Technology Interaction, School of Innovation Sciences, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
[b] Intelligent Lighting Institute, Eindhoven University of Technology, P.O. Box 513, MetaForum 3.077, 5600 MB Eindhoven, The Netherlands

A R T I C L E I N F O

Article history:
Available online 4 January 2014

Keywords:
Lighting
Mental fatigue
Alertness
Performance
Physiological arousal
Daytime

A B S T R A C T

Alertness-enhancing effects of bright light are particularly strong at night or after sleep deprivation. Alerting effects during daytime also exist, yet these appear to be more modest. In this study, we investigate whether a higher illuminance level particularly benefits individuals who suffer from mental fatigue – not from sleep pressure, but from mental exertion. A 2 × 2 within-subjects design ($N = 28$; 106 sessions) was applied to investigate effects of 1000 vs. 200 lx at the eye on self-report measures, task performance and physiological arousal after a mental antecedent condition (fatigue vs. control). Results showed that participants felt less sleepy, more vital and happier when exposed to bright light. Effects on subjective sleepiness and self-control capacity were stronger under mental fatigue. Vigilance benefited from bright light exposure – although this effect emerged with a delay irrespective of the antecedent condition. Other tasks showed more mixed and sometimes even adverse effects of bright light.

1. Introduction

As humans evolved as a diurnal species, their psychological functioning is primarily less optimal in the late evening or at night compared to daytime hours (e.g., Cajochen, Kräuchi, & Wirz-Justice, 2003; Dijk, Duffy, & Czeisler, 1992; Hull, Wright, & Czeisler, 2003; Van Dongen & Dinges, 2005). However, persons may also experience fatigue and resource depletion during daytime, even in the absence of sleep deprivation. During the day, we use and deplete mental resources (Hartig & Staats, 2003; Kaplan & Kaplan, 1989). Engagement in many work-related and demanding tasks requires focused attention, motivation and allocation of mental resources (Baumeister, Vohs, & Tice, 2007; Inzlicht & Schmeichel, 2012; Kaplan & Berman, 2010; Meijman & Mulder, 1998). Accumulation of effort spent throughout the workday might result in increased feelings of sleepiness, lack of energy, loss of self-control, psychological stress and decrements in motivation and task performance (e.g., Baumeister et al., 2007; Hagger, Wood, Stiff, & Chatzisarantis, 2010; Inzlicht & Schmeichel, 2012; Kaplan & Berman, 2010; Meijman & Mulder, 1998).

Research has shown that the physical environment may affect the level of mental fatigue people encounter. Several studies have, for example, demonstrated that context and ambient conditions, such as office layout, indoor plants or views to the outside, can revitalize office workers and help them recuperate from stress or mental fatigue (e.g., De Kort, Meijnders, Sponselee, & IJsselsteijn, 2006; Dijkstra, Pieterse, & Pruyn, 2006; Hartig, Böök, Garvill, Olsson & Garling, 1996; Ulrich et al., 1991; Veitch, 2011). This suggests that environmental features of an office environment have the potential to influence individuals' experienced level of mental fatigue, vitality level and performance. Several field studies have shown that lighting too is a potential environmental feature impacting office workers' mental wellbeing, behavior and performance. More specifically, these studies indicated that the color of white lighting and the type of light source can affect employees' feelings of alertness, self-reported performance and their need for recovery during regular working hours (Mills, Tomkins, & Schlangen, 2007; Smolders, De Kort, Tenner, & Kaiser, 2012; Viola, James, Schlangen, & Dijk, 2008).

In addition, a large body of research has demonstrated acute activating effects of bright light exposure on subjective and objective indicators of alertness and arousal. Most of these studies investigated effects of light intensity under conditions of relatively high fatigue and sleep pressure. Several laboratory studies have, for example, demonstrated that exposure to higher illuminance levels at night resulted in lower levels of melatonin secretion, increased physiological arousal, higher subjective alertness, and improved

* Corresponding author. Human–Technology Interaction Group, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands. Tel.: +31 (0) 402475205; fax: +31 (0) 402431930.
E-mail addresses: k.c.h.j.smolders@tue.nl, karinsmolders_@hotmail.com (K.C.H. J. Smolders).

0272-4944/$ – see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jenvp.2013.12.010

sustained attention and cognitive task performance (e.g., Badia, Myers, Boecker, & Culpepper, 1991; Boyce, Beckstead, Eklund, Strobel, & Rea, 1997; Cajochen, Zeitzer, Czeisler, & Dijk, 2000; Campbell & Dawson, 1990; McIntyre, Norman, Burrows, & Armstrong, 1989; Myers & Badia, 1993; Rüger, Gordijn, Beersma, de Vries, & Daan, 2006; Rüger, Gordijn, de Vries, & Beersma, 2005). Similar beneficial effects of bright light exposure during daytime have been demonstrated for individuals who had first experienced substantial light and/or sleep deprivation (Phipps-Nelson, Redman, Dijk, & Rajaratman, 2003; Rüger et al., 2006; Vandewalle et al., 2006). Together, these studies indicate that light can benefit persons under conditions of high circadian and/or homeostatic need for sleep and when they are particularly sensitive to light due to prior exposure to very low light levels.

A few recent studies also showed alerting effects of bright light on healthy day-active persons during regular working hours. A field study by Smolders, De Kort, and Van den Berg (2013) provided support for a direct link between exposure to more intense light and feelings of vitality during daytime and in everyday situations. Their results showed that hourly light exposure was a significant predictor for feelings of vitality, indicating that persons who were exposed to more light experienced higher feelings of vitality, over and above the variance explained by person characteristics, time of day and activity patterns. In addition, a recent laboratory study showed that even in the absence of sleep and light-deprivation, exposure to a higher illuminance at eye level can induce subjective alertness and vitality, increase physiological arousal and improve performance on a sustained attention task (Smolders, De Kort, & Cluitmans, 2012). Together, these studies suggest that – although the effects were more modest than at night – exposure to a higher illuminance level may also (temporarily) help overcome tiredness and decreased vitality during regular daytime hours. In fact, the field study by Smolders et al., 2013 showed that the relationship between light exposure and vitality was most pronounced when participants experienced relatively low vitality during the previous hour.

In the study by Smolders, De Kort, and Cluitmans (2012), effects on self-report measures of sleepiness and vitality and on heart rate were immediate and consistent during the hour of bright light exposure. In contrast, the effects of a higher illuminance level on task performance and heart rate variability were dependent on duration of exposure: These effects were most pronounced towards the end of the 1-h long phase of testing and light exposure. A potential explanation for the delayed effect of bright light on performance found in the laboratory is that more intense light improves performance mainly when persons suffer from sleepiness and resource depletion. This is consistent with research showing that light exposure at night or among sleep-deprived participants can improve reaction times immediately (Lockley et al., 2006; Phipps-Nelson et al., 2003). Indirect indications for this also come from a study performed by Vandewalle et al. (2006), who investigated daytime effects of bright light on task performance and brain activity using fMRI. These authors excluded participants who did not show a response in alertness to exposure to a higher illuminance. In the supplemental analyses they reported that these participants already had faster response times at baseline than participants who did respond to light, suggesting that they already were very alert. An alternative explanation for the delayed emergence of bright light effects on performance and heart rate variability could be that effects on these variables need extended exposure to bright light, due to required exposure thresholds or (relatively) slow activation mechanisms (e.g. Vandewalle, Maquet, & Dijk, 2009).

In the current laboratory study, we test whether bright light particularly benefits individuals' level of alertness and vitality during daytime when they suffer from fatigue due to mental exertion. We thus compared effects of an illuminance manipulation (200 lx vs. 1000 lx at the eye) during daytime between situations in which persons' resources had been mentally depleted and in which their resources were not depleted prior to the light exposure. As earlier studies have suggested that effects of bright light may differ depending on the type of measure (e.g., Rüger et al., 2006; Smolders, De Kort, & Cluitmans, 2012), we investigated effects of daytime light exposure on subjective sleepiness and vitality as well as objective indicators of task performance and autonomic nervous activity. If the effects of bright light on feelings, performance and physiology are dependent on a person's prior mental state, we should see both stronger and more immediate effects of the illuminance manipulation when participants experience fatigue. In contrast, we should see less pronounced effects for rested participants, i.e., more subtle or delayed effects. Based on earlier findings of light exposure patterns and vitality in real-life situations (Smolders et al., 2013), we expected this interaction for the self-report measures. In addition, based on findings on daytime exposure to a higher illuminance level in the laboratory (Smolders, De Kort, & Cluitmans, 2012), we hypothesized that if mental fatigue indeed was responsible for the delay in bright light effects there, we should also find a significant interaction between illuminance level and individuals' prior mental state on task performance and heart rate variability in the current study. In addition to the potential state-dependent effects of bright light on alertness and arousal, we investigated whether individuals' mood as well as their appraisals of the lighting, experience of the space and beliefs concerning the effect of the lighting on performance and mood differed as a function of the lighting condition and their mental state. The current study will thus provide insights in whether persons' sensitivity to bright light effects on experiences, performance and physiology during daytime depends on their psychological state.

2. Method

2.1. Design

A 2 × 2 within-subjects design was applied to test effects of two illuminance levels (200 vs. 1000 lx at eye level, 4000 K) under two antecedent conditions (Fatigued vs. Control). Participants came to the lab on four visits on separate days during the same timeslot in the morning (9:00am, 10:20am or 11:45am) or in the afternoon (1:15pm, 2:45pm or 4.15pm). Every session started with a 7-min baseline phase and a 29-min mental fatigue vs. control manipulation under the same lighting condition (200 lx and 4000 K at work plane), followed by exposure to one of the experimental lighting conditions for 30 min. The order of conditions was counterbalanced across participants. There was no daylight contribution in the room during this experiment.

2.2. Participants

Twenty-eight students participated in this laboratory study, of which 12 were male and 16 female (mean age 23, $SD = 4.1$, range 19–39). Four participants were not able to participate in the fourth session and in two sessions the lighting did not work properly, resulting in 106 75-min sessions. None of the participants were extreme chronotypes according to the Munich Chronotype questionnaire (MCTQ; Roenneberg, Wirz-Justice, & Merrow, 2003), nor did they have eye complaints or complaints about their general health.

2.3. Procedure

Before the start of the first session, participants signed a consent form. At the start of each session, participants applied electrodes for heart rate and skin conductance measures according to the