Bright Light Effects on Mental Fatigue

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Introduction

During workdays, we use and deplete mental resources. Accumulation of effort spent throughout the workday might result in increased feelings of sleepiness, lack of energy, psychological stress and decrements in performance. Bright light, on the other hand, has been shown to positively impact alertness, vitality and performance and may thus counteract fatigue by helping recover decreased mental resources. In the present study, we investigate whether lighting (i.e., illuminance) particularly benefits office employees who suffer from resource depletion.

Research has shown that light is important for our wellbeing, health and performance. Light can, for instance, have both direct and phase shifting effects on people's circadian rhythm (see e.g. Dijk & Archer, 2009). In addition, studies have shown that exposure to higher illuminance levels can result in increased feelings of alertness and better performance at night (Cajochen, Zeitzer, Czeisler & Dijk, 2000; Campbell & Dawson, 1990). Moreover, light shows similar beneficial effects during daytime if individuals have first experienced substantial light or sleep deprivation (Phipps-Nelson, Redman, Dijk & Rajaratman, 2003; Rüger, Gordijn, de Vries & Beersma, 2006). A recent study by Smolders, de Kort and Cluitmans (2012a, 2012b) revealed beneficial effects of bright light exposure also during daytime under regular circumstances. This study showed that even in the absence of sleep or light-deprivation, higher illuminance at eye level can improve employees' alertness, vitality and objective cognitive task performance, and influence physiological arousal measured with heart rate, heart rate variability (HRV) and EEG. In the latter study, effects on subjective alertness and vitality, and physiological arousal were immediate and consistent during the hour of bright light exposure. In contrast, the effects on performance and HRV were dependent on duration of exposure: These effects were most pronounced towards the end of the light exposure. A potential explanation for the delayed effect of bright light on cognitive performance is that more intense light improves cognitive performance mainly when participants suffer from mental fatigue. This is consistent with research showing that light exposure at night or among sleep-deprived participants can improve reaction times immediately (Phipps-Nelson et al., 2003; Lockley, et al., 2006). Furthermore, a lab study showed that participants who did not respond to exposure to a higher illuminance already had faster response times than participants who did, suggesting that they did not benefit from bright light because they already were very alert (Vandewalle et al., 2006). In the current study, we investigate whether daytime exposure to a higher illuminance level has an alerting and vitalizing effect mainly when a person is suffering from mental fatigue and resource depletion.

Method

Design

In the current study, a 2x2 within-subjects design (N = 28; 106 sessions[1]) was applied to explore effects of two illuminance levels (200 vs. 1000 lx at eye level, 4000 K) after mental fatigue induction (fatigue vs. control). Participants came to the lab on four separate visits during the same timeslot in the morning (9:00am, 10:20am or 11:45am) or in the afternoon (1:15pm, 2:45 or 4.15pm). The conditions were counterbalanced across participants.

[1] Four participants were not able to participate in the fourth session and in two sessions the lighting did not work properly.

<table>
<tr><td rowspan="3">Baseline Measures</td><td colspan="3">Fatigue induction vs. control</td><td rowspan="3">Q</td><td colspan="2">Lighting condition</td></tr>
<tr><td>MATB</td><td colspan="2">Modified Stroop task</td><td rowspan="2">Measurement block 1</td><td rowspan="2">Measurement block 2</td></tr>
<tr><td>Movie</td><td>Reading magazines</td><td>Stroop</td></tr>
<tr><td>7 min</td><td>9 min</td><td>17 min</td><td>3 min</td><td>1</td><td>13 min</td><td>17 min</td></tr>
<tr><td colspan="5">200 lx at desk (4000 K)</td><td colspan="2">200 lx vs. 1000 lx at eye level (4000 K)</td></tr>
</table>

Fig. 1: Schematic overview procedure.

Procedure

Before the start of each session, participants applied electrodes for heart rate, skin conductance and temperature measures according to the instructions given by the experimenter. Every session started with a 7-minute baseline phase consisting of a 1-minute rest period, performance tasks and a short questionnaire. Baseline performance was measured using three different tasks: A 3-minute auditory Psychomotor Vigilance task (PVT), a 1-minute auditory Go-NoGo task and a 1-minute 2-back task. After the baseline measurements, the mental fatigue vs. control manipulation started, which took about 29 minutes. After this, participants completed a short questionnaire. During the baseline measurements and fatigue induction, participants experienced 200 lx and 4000K at the work plane.

After the fatigue vs. control manipulation, participants were exposed to 200 lx or 1000 lx (at the eye) for 30 minutes. During this light exposure, subjective and objective measures were administered in two repeated measurement blocks. Each block started with a 1-minute rest period. Subsequently, performance was measured with a 5-minute auditory PVT, a 3-minute auditory Go-NoGo task and a 3-minute 2-back task. At the end of each block, participants completed a short questionnaire (see Figure 1).

At the end of each session, participants completed questions concerning subjective self-control, their evaluation of the lighting and the environment, time of going to sleep the night before, time of awakening and time spent outside. In addition, at the end of the last sessions, questions concerning person characteristics, such as light sensitivity, chronotype and trait vitality, were administered. Every session lasted 75 minutes and the participants received a compensation of 12,50 Euros per session.

Mental fatigue induction

Mental fatigue was induced with two demanding tasks: a 9-minute Multi-Attribute task battery (MATB) and a 20-minute modified Stroop task. The MATB is a multi-task using a flight simulation in which the participant keeps track of multiple parallel processes (maintaining the volume in two fuel tanks, repairing the fuel system when broken, monitoring the aircraft, tracking the aircraft with a joystick, and adjusting the communication channel when needed). Participants were instructed to keep track of all parts and perform the tasks as well as possible.

After the MATB, participants engaged in a modified Stroop colour-naming task. Each word was presented for 1 second with a 2.2-second interval between the words. For each word, participants had to indicate the colour of the ink by pressing the corresponding key on the keyboard, except when the word was presented in red in one version or in yellow in another version. In these cases, participants had to name the text instead of the ink.

In the control condition, participants watched a 9-minute nature movie and then read magazines for 17 minutes. At the end of the control condition, participants engaged in a 3-minute Stroop task with congruent trials.

Measures

Subjective sleepiness was measured with the Karolinska Sleepiness scale (KSS; Åkerstedt & Gillberg, 1990). Vitality and tension were assessed with six items selected from the Activation-Deactivation checklist (Thayer, 1989). In addition, two items assessing positive and negative affect (happy and sad) were administered in this questionnaire. Subjective state self-control was assessed at the end of each session using six items selected from the State Self-Control Capacity Scale (Ciarocco, Twenge, Muraven & Tice, under review).

Three tasks were employed to assess cognitive performance. An auditory PVT assessed sustained attention. An auditory Go-NoGo task measured executive functioning and inhibition. In addition, a 2-back task was administered as a measure for working memory and executive functioning. During this task, characters were presented on the screen after each other and participants had to press the spacebar as fast as possible if the character presented was the same as two characters before. Each character was presented for 200 ms with an interval of 800 ms between two characters.

Physiological arousal was investigated using heart rate, skin conductance and temperature measures. These variables were measured continuously during the experiment using TMSi software.

Statistical analysis

Linear Mixed Model (LMM) analyses were performed with Lighting condition, Fatigue induction (fatigue vs. control) and Measurement block as predictors (separate analyses for each dependent variable). In these analyses, Participant was added as random variable to group the data per participant, i.e. to indicate that each participant was measured multiple times. To control for differences at baseline, the baseline measurement was added as covariate in the analyses. In addition, person characteristics were added as covariates to control for these variables.

Results

In this section, we will report the first results of the effects of Lighting condition and Fatigue induction on subjective measures of sleepiness, vitality, mood and self-control, and PVT performance.

Effects of lighting and fatigue induction on subjective measures

A manipulation check of the fatigue induction revealed that participants felt sleepier and less energetic immediately after the fatigue induction compared to the control condition (all $p < .01$).

Results during the light exposure revealed a main effect of Fatigue induction on subjective sleepiness and vitality suggesting that the effect of the manipulation on these variables lasted also during the light exposure (both $p < .01$).

Lighting condition had a main effect on subjective feelings of sleepiness ($p = .02$) and vitality ($p < .01$): Participants reported lower feelings of sleepiness and more vitality in the 1000 lx compared to the 200 lx condition. These results replicate the earlier findings by Smolders et al. (2012). For the current research question, we were mainly interested in the interaction between Lighting condition and Fatigue induction. This interaction approached significance for the KSS ($p = .06$) showing an effect of Lighting condition only after the fatigue induction ($p < .01$), but not after the control condition ($p = .78$). The interaction effect between Lighting condition and Fatigue induction on vitality was not significant ($p = .59$) suggesting that the effect on feelings of energy was not moderated by mental fatigue. Measurement block had no effects on the subjective measures (all $p > .10$) suggesting that the effects were immediate and consistent throughout the session.

Effects of lighting and fatigue induction on performance

Results of the PVT revealed that participants had slower reaction times after the fatigue induction compared to the control condition ($p < .01$). Lighting condition had no significant main effect on the mean reaction times of the PVT ($p = .61$). Measurement block had a significant main effect on the mean reaction times with slower responses in Block Two than Block One ($p < .01$). There was also a marginally significant interaction between Lighting condition and Measurement block ($p = .06$) suggesting a trend for slower reaction times in the 200 lx than in the 1000 lx condition only in Block Two ($p = .06$) and not in Block 1 ($p = .33$). The interaction between Lighting condition and Fatigue induction was, however, not significant ($p = .84$).

At the conference, the results of the Go-NoGo task and 2-back tasks will also be presented.

Discussion

The results of the current study suggest that exposure to bright light has an immediate and positive effect on subjective feelings of alertness and vitality. The effect on sleepiness was moderated by the fatigue induction, suggesting that 1000 lx (at eye level) had an effect on sleepiness only when the participants suffered from mental fatigue.

Although we expected a comparable direct effect of bright light on performance on the PVT when participants felt mentally fatigued, the effect of bright light on sustained attention seemed to only depend on duration of exposure. In line with results by Smolders et al. (2012), participants performed better on the PVT towards the end of the bright light exposure. Current study suggests a delayed effect of bright light on mental performance regardless of the mental fatigue status (fatigued vs. relaxed) prior to the light exposure.

Results of the other performance tasks and physiological measures will provide additional insights in the effect of bright light after mental fatigue during daytime and normal office hours.

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