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Shining light on memory:

The effects of daytime bright light exposure on memory task performance varying in difficulty level.

L. M. Huiberts¹, K. C. H. J. Smolders^{1,2}, W. A., IJsselsteijn¹, & Y. A. W. de Kort¹

¹ *Human-Technology Interaction, School of Innovation Sciences, & Intelligent Lighting Institute, Eindhoven University of Technology, Eindhoven, the Netherlands*

² *University of Groningen, Groningen, the Netherlands*

Introduction

For humans, lighting is the most important environmental factor for visual perception. However, light can also exert non-visual circadian and acutely physiological, psychological and cognitive effects, although the latter class of effects has received less attention than the first (e.g., Cajochen, 2007). In general, this line of research suggests that bright light exposure, as compared to dim light exposure, leads to acute alerting effects and improvements on (cognitive) task performance.

Recently, two studies focusing on the non-visual effects of diurnal light exposure, investigated the effects of bright (1000 lux) versus dim light (200 lux) on cognitive task performance (Smolders, & de Kort, 2014; Smolders, de Kort, & Cluitmans, 2012). These studies revealed that bright light exposure, although beneficial for vigilance tasks (i.e., the Psychomotor Vigilance Task; PVT) proved to be detrimental for more complex tasks measuring inhibitory capacity (GoNoGo task) and working memory abilities (2-back task). Similarly, studies employing nocturnal light exposure also revealed differential performance effects for different types of tasks, some showing improvement under bright light, while others appeared unaffected (e.g. Badia et al., 1991; Boyce et al., 1997). More research is needed to develop a deeper understanding of these differential non-visual effects of light on cognitive performance.

One possible mediating variable for these differential effects may be participants' state arousal level. The impact of arousal on task performance has been originally described by the Arousal Theory developed by Yerkes and

Dodson (1908). The Yerkes-Dodson Law (YDL) states that the relationship between arousal and task performance follows the pattern of an inverted U-shape, with lower performance levels if arousal is too low or too high, and maximum performance levels under intermediate arousal levels. Furthermore, YDL states that performance levels on relatively difficult tasks (i.e., tasks relying on higher executive functions) indeed show an inverted U-shape relationship with arousal levels, while easier tasks (i.e., tasks needing only focused attention on a restricted range of stimuli) benefit from increased arousal levels in a dose-dependent manner following a logistic function. Since previous studies found that bright light exposure can enhance bodily arousal levels (Smolders et al., 2012; Rüger et al., 2006; Saito et al., 1996), it could be hypothesized that the non-visual effects of light on cognitive performance depends on task complexity.

A second mediating mechanism is implied by a handful of studies focusing on light-induced brain modulation (see Vandewalle, Maquet, & Dijk, 2009 for a review). These studies indicate that light exposure during the execution of a cognitive task can modulate specific brain areas that are involved during the performance of this specific task. Based on these studies, it could be hypothesized that light-induced modulation of these brain networks may temporarily enhance cognitive capacities, which may subsequently result in improved task performance.

In sum, there is considerable evidence that environmental light exposure can exert non-visual effects on cognitive performance. However, the mechanisms through which these effects are manifested are still not fully understood. Task difficulty could be a

possible factor explaining the inconsistent findings of bright light exposure on cognitive task performance.

Especially in our current society, where partial sleep deprivation resulting in sleepiness during the day is not uncommon (Groeger, Zijlstra, & Dijk, 2004) and where busy daily schedules often lead to mental fatigue (Åkerstedt et al., 2004), it would be highly beneficial to investigate possibilities to improve alertness and cognitive performance during the day. We therefore argue that it is important to develop a deeper understanding of the effects of illuminance level on tasks with various complexity levels. Therefore, the current study investigated the effects of bright versus dim light on cognitive performance, employing two tasks in which the difficulty level was manipulated. We controlled for potential time-dependent variations in cognitive performance caused by homeostatic and circadian regulation.

Method

Design

We employed a mixed design to investigate the effect of light intensity (200 vs 100 lux at eye level) on cognitive performance as a function of task difficulty. Illuminance level and digit-span difficulty were manipulated within subjects. *N*-back task difficulty and time of day were manipulated between subjects.

Participants

Sixty-four participants (mean age: 21.4; *SD* = 2.1) completed both lighting manipulation condition. The order of experimental conditions was counterbalanced across participants.

Participants were recruited at the University of Technology in Eindhoven via advertisements, social networks as well as via the University's participant database. Extreme chronotypes, as measured by the Munich Chronotype Questionnaire (MCTQ; Roenneberg, Wirz-Justice, & Merrow, 2003), were excluded from participation. Participants were informed to register for the same timeslot on both experimental sessions (9:00 AM, 10:45 AM, 12:15 PM, 13:45 PM

or 15:45 PM), which were separated by at least two full days.

Setting

The laboratory room was a simulated office environment at the Eindhoven University of Technology in The Netherlands with a size of 3.9 m by 7.4 m. Four work stations were created of approximately 1.95 m by 3.7 m, separated by a curtain and a 1.8m high panel in between desks. Each work station was fitted with a desk and chair, and a 15.6-inch laptop with a keyboard, headphones and mouse.

The laboratory room was equipped with recessed Philips Savio luminaires in the ceiling. Each ceiling luminaire (Philips Savio TBS770 3x54W/827/865 HDF AC-MLO CVC) contained three fluorescent tubes of 54 W, of which two tubes of 6500 K and one tube of 2700 K. All luminaires have an acrylate micro-lens optic cover, which blends the two lamp types to create a virtually homogeneous luminous surface.

Light manipulation

During the baseline phase, participants were exposed to 100 lux at eye-level in both lighting conditions (275 lux at the work plane). Subsequently, illuminance levels were set to either 200 lux, 4000K at eye-level (580 lux at the work plane) or 1000 lux, 4000k at eye-level (2900 lux at the work plane).

Measures

Task performance: In each measurement block, participants first engaged in a 3.5-minute *n*-back task (Mackworth, 1959), where they heard a sequence of one-syllable consonants (at 1-second intervals) and were asked to press a button every time a consonant was identical to the consonant *n* positions back. This task assesses working memory and in particular mental updating abilities. For this task, correct target responses and reaction times (RTs) to targets were used as outcome variables. Subsequently they completed an auditory FDST, of six digit-span lengths (4, 5, 6, 7, 8 and 9 digits long, two trials per length) and an auditory BDST (3, 4, 5, 6, 7, and 8 digits long, two trials per length). These tasks

respectively assess short-term memory retrieval and working memory abilities. For both tasks, the total number of correct responses per measurement block were used as an outcome variable.

Subjective task performance: After each task, participants rated their performance on the previous task. Visual Analogue Scales (VAS), ranging from 0 (not at all) to 100 (very much) assessed how well participants thought they had performed on the task, how motivated they were to perform the task to their best ability, how much effort they put into performing the task, how well they could concentrate on the task, and how much mental effort they had to put into the task.

Subjective sleepiness, vitality, mood and tension: Subjective sleepiness was examined after each task using the Karolinska Sleepiness Scale (KSS; Åkerstedt & Gillberg, 1990), ranging from 1 (extremely alert) to 9 (extremely sleepy - fighting sleep). Positive and negative affect, subjective vitality and tension (Thayer, 1967) were assessed after each measurement block using six-item scales ranging from 1 (definitely not) to 5 (definitely).

Procedure

Each experimental session started with instructions and a practice phase in which all tasks were practiced. Subsequently, participants completed a 15-minute baseline phase (100 lux at eye level). After the baseline phase, illuminance levels were set according to the experimental condition, and participants completed four additional 15-minute blocks. A 15-minute block consisted

of all three tasks (*n*-back, then FDST, then BDST), short questionnaires on sleepiness and subjective performance after each task, and vitality mood and tension ratings at the end of each block. A full overview of the experimental procedure is shown in Table 1. After completing both sessions participants received a 30-euro compensation. The study took place from March to May 2014.

Statistical analyses and results

The complete results of this study (including figures and statistical data) will be covered during the conference.

Linear mixed model (LMM) analysis using Lighting condition and Measurement block as fixed factors were used to examine the effects of illuminance level on repeated measures data of task performance and subjective indicators. To compare difficulty levels for each of the tasks, Task type (for BDST vs FDST) and N-back version were also used as fixed factors. In addition, Time of Day was added as a fixed factor to investigate differential effects of illuminance level for morning versus afternoon sessions.

Regarding the FDST and the BDST, no Lighting condition * DST version * Time of day interaction was found, indicating no effect of task difficulty on performance. Investigating the tasks separately, results showed a trend towards better performance under bright light on both tasks during the morning sessions, while there was no effect of illuminance level during the afternoon sessions on the FDST and worse performance on the BDST.

Tab. 1: overview of a full experimental session

100 lux at eye-level		200 or 1000 lux at eye-level				
Practice phase	Baseline	Light exposure phase; measurement blocks similar to baseline				
Instructions and task practice	Baseline task performance, and subjective ratings	Block 1	Block 2	Block 3	Block 4	Questionnaires: light ratings, prior wakefulness etc.
10 minutes	15 minutes	15 minutes	15 minutes	15 minutes	15 minutes	5 minutes

When comparing the 2- and 3-back task on accuracy (the 1-back task was not included because of a ceiling effect), a trend towards a significant Lighting condition * N-back version * Time of day interaction was found. Post-hoc comparisons showed that illuminance level did not affect performance on the 3-back task, neither in the morning nor in the afternoon. However, performance on the 2-back task yielded a trend towards better performance during the morning sessions under bright light exposure, but significantly worse performance under bright light exposure during the afternoon sessions.

No effects of light intensity were found on RTs on any of the *n*-back tasks. This is partly in line with the study of Smolders et al. (2014) showing no effects of similar light exposure on 2-back RTs.

In sum, we did indeed see non-significant trends towards differential effects of bright light for less vs. more complex tasks (FDST vs BDST and 2-back vs. 3-back). However, Time of day appeared to be a more pronounced moderator of bright light effects than task difficulty: participants seemed to benefit slightly from bright light exposure (in terms of accuracy) during the morning hours on most of the tasks (FDST, BDST and 2-back task) while they did not benefit or even performed worse under bright light during the afternoon hours on these tasks.

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