Changes in attention and mental rotation performance in relation to luminance variations in educational spaces

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***Abstract*— This paper attempts to investigate attention and mental rotation performance of students under two groups of luminance ratios in the visual field during VDT work. Each experiment was conducted under daylit conditions and consisted of two trials (with and without shading device) which were carried out in one experimental session. Twenty university students were recruited as participants to perform cognitive test as well as to administer subjective evaluations in a mock-up VDT station. Luminance ratios were grouped based on the ratios between bright light and direct surroundings. Results showed that the students gave faster responses for finding the correct target when the luminance distribution was not uniform whereas the number of correct answers given was higher when the luminance distribution was uniform. Subjective sensation of visual discomfort and lighting appraisal were in the same trend, indicating uniform luminance distribution was more appreciated by the participants. Based on these findings, the study provides additional insights in the effect of luminance patterns on individuals' performance, health and wellbeing in educational buildings.**

Keywords*— *daylight, shading devices, visual comfort, cognitive performance, luminance distribution

I. Introduction

Daylighting in particular in educational buildings has become an important topic of investigation in recent years. A well-designed daylighting is able to enhance performance, provide health and well-being as well as maintaining a pleasant environment for students [1-3]. The influence of daylight on learning processes in educational spaces has been examined in many studies, indicating its vital role on not only for visual but also for non-visual mechanisms [4-5]. In many studies, higher illuminance levels have been proven to influence subjective alertness by providing higher levels of vitality and hence better performance and improved wellbeing [6-9]. On the other hand, some studies showed that higher illuminance levels do not always bring positive impacts [10-11], for example, in some circumstances higher light intensities produce visual discomfort such as glare, that may inhibit students from performing a task. This type of poorly lit environments even lead to awkward sitting postures that eventually negatively affect the individuals' health. Hence, good distribution of light in educational buildings is crucial to assist students to enhance their health, well-being and ability to learn and focus.

In this context, the aim of this study was to compare the differences in students' cognitive performance, visual comfort, lighting appraisal and well-being as they were exposed to various luminance patterns. In particular, alertness, reaction speed and accuracy as well as lighting appraisal and subjective-visual comfort assessment were analyzed while cognitive and visual demanding computer-based tests were being performed, in order to find out optimum luminance distribution for students in terms of visual and non-visual processes.

II. Method

A. Participants

Twenty volunteers (15 men, 5 women, mean age=21.9 years, SD=0.4) were recruited from students in the Department of Energy Engineering, Systems, Territory and Constructions, University of Pisa. The sample was limited to those aged between 20 and 30 because light sensitivity is similar among individuals who are within this age range [12]. Other inclusion criteria were using a computer at least 8h on workdays for representing normal VDT user population, having normal or corrected-to-normal visual acuity and keeping their sleep–wake cycle two days before the experiment as similar as possible to their sleep routine on workdays (±30 min) according to the Munich Chronotype Questionnaire (MCTQ) [13]. Information on participants' visual acuity was collected through an online visual displaying test before participating in the study (Vision test; www.essilor.com) [14]. All of them were naïve as to the scope of the research and the expected outcomes of the experiment.

B. Experimental Setting

The experiments were performed in a full-scale mock-up office space of 2 x 2 x 2.4 m at the Lighting and Acoustics Laboratory of the University of Pisa. The mock-up was a southeast facing side-lit space equipped with a double-glazed clear glass window with a light transmission of 80%. The space was furnished with a desk (1.4 x 0.9 m), an Intel® CoreTM i5-7500 CPU @ 3.40GHz 3.41GHz desktop computer with Asus 2400 Brilliance 15.600 LCD monitor and an office chair. Display height, display tilt and working distance were adjusted in compliance with EN ISO 9241–5 (1998) ergonomics standards for VDT workstation design and were kept the same for all participants [15-16]. Participants were allowed to adjust their sitting height but their head position and viewing distance were stabilised with a chin and forehead rest which was set at 60 cm from the screen. The desk was also placed parallel to the windows and the participants were seated facing the glazing at a distance of 1 meter. This ensured that the impacts of the variations in

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daylight availability would be observed quite distinctly in the subjects' cognitive and affective processes although this sort of workplace setup is not highly recommended. Finally, non-reflective interior surfaces were chosen to minimize possible distractions such as excessive contrast, strong brightness and annoying reflections caused by the surrounding. The sides and the ceiling were covered with a non-reflective curtain fabric and had a reflectance of 6%, the floor was grey with a reflectance of 28% and the desk was black with a reflectance of 14%.

C. Study Design

The current study sought to explore the impact of various luminance distributions within the field of view on students' performance, behavior and physiological measures during computer use. Repeated within-subjects design was adopted to investigate the effects of luminance variations on students' cognitive performance by manipulating the solar control device (shading-on; shading-off). In other words, they performed the tests twice under two different light scenes, which were counterbalanced across the participants. All experiments were between 02:00 p.m. and 04:00 pm for a period of four weeks in 2019 (from 15 April to 13 May). Although the experiments were conducted entirely at the same time slot in spring, high variability in the external sky conditions across measurement days resulted in significant overlaps between shading-on and shading-off settings.

D. Procedure

Before the start of experimental sessions, short practice trials on each test were performed so that the participants would familiarize themselves with the procedure of the experiment while some adaptations to the experimental setting were being provided. During the experimental sessions, apart from the extended versions of the cognitive tests, participants were also asked to complete a series of questionnaires before and after the tests which were regarding self-reported performance, alertness, glare sensation and lighting appraisal. The sequence of the activities were kept the same during one experimental session but the visual stimuli in tests were constantly randomized. A full experimental procedure which consists of two sessions took approximately 30 minutes and was depicted in Fig. 1.

E. Stimuli

Luminance ratios between a bright light (e.g. glare source) and direct surroundings should not exceed 1:20 in order to prevent discomfort glare [17]. According to this approach, luminances on six points were measured by using the photo-radiometer Delta Ohm HD2102.1 before each session. These points comprised of certain directions of the participants' visual field of view (see Fig. 2).

Each time the experiments were conducted, the point P_1 always provided excessive brightness from sky and hence, based on Velds's approach, we averaged the luminances of points P_2-P_6 (surroundings) and divided by P_1 (bright light). Note that luminances on P3 were not taken into account because the values measured on screen remained approximately constant. The participants were grouped into high (ratio > 1:20) or low (ratio < 1:20) visual discomfort (see Fig. 3) and the groups were named as L_{low} and L_{high} to be hereafter referred in the next sections.

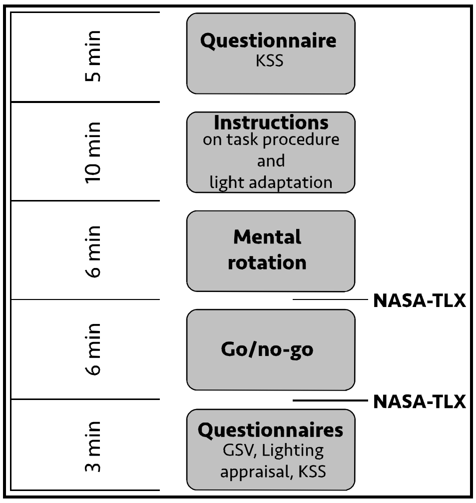

Fig. 1. Time schedule of the experimental flux.

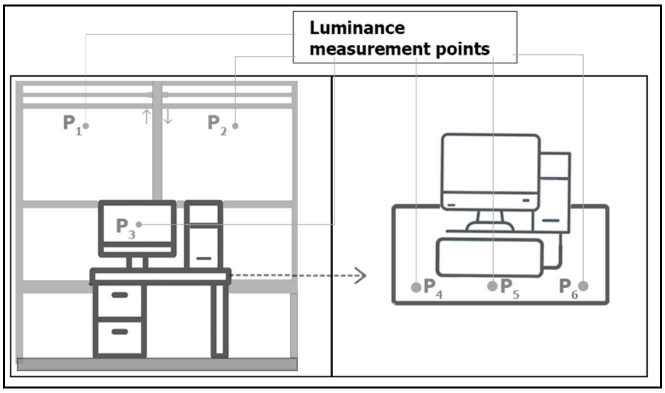

Fig. 2. Luminance measurement points within the field of view.

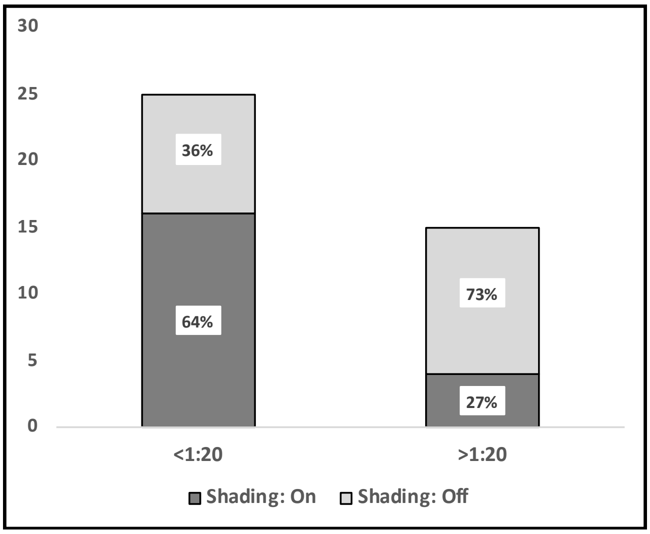

Fig. 3. Percentage of participants that belongs to L_{low} and L_{high} groups.

F. Measures

1) Sustained attention: GO/NOGO test was used to measure the participants' capacity reaction time of a participant's during a sustained attention task [18-19]. Participants were instructed to press the space bar as soon as possible when the word of "GO" appears on the screen, and not to press any buttons when they see "NO GO". The current study comprised 60 GO and 10 NO GO stimuli, which were randomized within each session. Mean response time and the accuracy of responses were used as outcome variables.

2) Mental rotation: In this type of test, participant is required to find out whether a stimulus corresponds another stimulus through mental rotation [20-21]. In the current study, average time spent to find out if a stimulus matches another stimulus and the percentage of correct trials were used as outcome variables.

3) Lighting appraisal: A lighting quality scale was used to assess the level of lighting appraisal in which higher scores suggest that the lighting is evaluated as better [22]. The original version was developed by Veitch et al. [23] and consists of eight items but in the present study we considered the average of the following six items measured on a four-point likert scale: unpleasant - pleasant, uncomfortable - comfortable, somber - cheerful, nonuniform - uniform, subdued - stimulating, favorable - unfavorable.

4) Alertness: The Karolinska Sleepiness Scale (KSS) is a self-assessed method of measuring sleepiness that consists of a 9-point Likert scale, where 1="very alert", 3="rather alert", 5="neither alert nor sleepy", 7="sleepy, but no difficulty remaining awake", and 9="very sleepy, fighting sleep, an effort to remain awake" [24]. In the present study, KSS was administrated at the beginning and end the end of each experimental session, and the average rate of both was used as the outcome variable.

5) NASA-Task Load Index (NASA-TLX): The NASA-TLX [25] is a widely used multidimensional rating scale that uses six dimensions to assess mental workload: mental demand, physical demand, temporal demand, performance, effort, and frustration. Each dimension has a 20-point scale with response options from 1 (low) to 20 (high). While the overall workload of a task can be defined by the overall TLX score, the scores for each dimension provides cues of particular concerns [26]. In the present study, we used the average rate of six measures (Raw TLX).

6) Glare sensation: A GSV (Glare sensation vote) scale was employed to measure the perceived level of glare at the end of each session [27]. This scale consists of a 4-point scale which ordinally ranges from 1 (imperceptible) to 4 (intolerable).

III. RESULTS

In this section, the results of the effects of luminance variations on subjective measures of glare, mental workload, alertness, lighting appraisal, and objective measures of performance will be presented. For the analysis, Wilcoxon signed-rank test was carried out to investigate within-subject differences on performance and subjective parameters in response to two groups of luminance ratios which represent the acceptable and disturbing ranges (L_{low}-L_{high}). Fig. 4 displays the luminance ratios obtained from the experiments of each participant. L_{high} (disturbing ranges) is represented by the upper part of the red dashed line, while L_{low} (acceptable ranges) belongs to the lower part of the same line which is below the threshold of 20 cd/m^2.

A. Effects of Luminance Variation on Performance Measures

Results of the GO/NOGO test revealed that participants had significantly higher performance in terms of response time (p = 0.03) under L_{high} luminance distribution compared to the L_{low} luminance distribution. Accuracy of correct trials, on the other hand, showed an opposite trend and were found to be increased under L_{low} although was not statistically (p = 0.08). In mental rotation test, there were no statistically significant differences between L_{low} and L_{high} groups in terms of both percentage of correct trials (p = 0.18) and the time spent for finding out the right stimulus (p = 0.08).

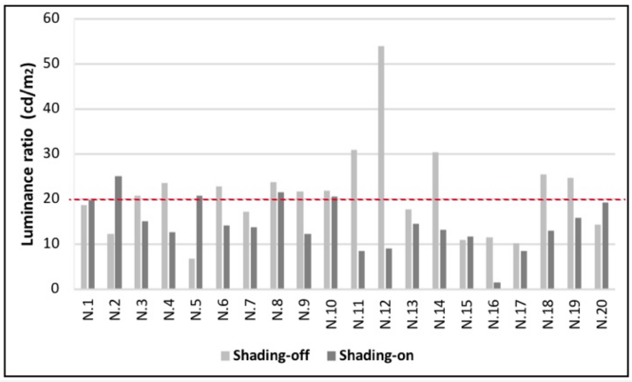

Fig. 4. Luminance ratios obtained from the experiments of each participant (a total of 20; N1-N20) under two scenarios; shading-off and shading-on. Red dashed line represents the 20 cd/m2 visual comfort threshold between the bright light and surroundings.

However, similarly with the results from GO/NOGO test, shorter reaction times were observed under L_{high} condition (approximately 23%) whereas the percentage of correct trials were higher under L_{low} condition, which is around 7% (see Table 1).

TABLE I. RESULTS FROM THE WILCOXON-SIGNED RANK TEST OF OBJECTIVE MEASURES

	L_{low}	L_{high}	
Task type	Mean (SD)	Mean (SD)	*p*
GO/NOGO *Response time (ms)*	624(78.95)	561.03(74.73)	0.03
Accuracy (%)	69.24(0.97)	68.33(1.23)	0.08
Mental rotation			
Correct trials (%)	86.08(8.54)	80.40(8.21)	0.18
Time spent (ms)	3604(1278)	2774(1053)	0.08

a. Differences are significant at p < 0.05 level.

B. Effects of Luminance Variation on Subjective Measures

Results from the GSV scores revealed a significant effect of luminance variations on the perceived level of glare (p = 0.004) indicating that the high ratios between the bright light and surroundings led to an increase in the level glare sensation. The results from GSV scores are in line with the previous findings of Leccese et al. [28], which were mainly interested in the interaction between illuminance at the eye and glare sensation. Similarly, lighting was appraised as better under L_{low} (p = 0.03).

Moreover, KSS scores showed a main effect of luminance variations on alertness levels (p = 0.04). Participants reported higher level of alertness under L_{low} scenario suggesting that they felt sleepier when the light is distributed more uniformly within the field of view. Finally, no significant differences in the NASA-TLX during two type of tests were found (both p > 0.05). Descriptive statistical values for the subjective measures and the p values of Wilcoxon-signed rank statistics are provided in Table 2.

TABLE II. RESULTS FROM THE WILCOXON-SIGNED RANK TEST OF SUBJECTIVE MEASURES

Subjective measures	L_{low}	L_{high}	
	Mean (SD)	Mean (SD)	*p*
GSV	1.52(0.55)	2.00(0.65)	0.03
Lighting appraisal	2.51(0.35)	2.23(0.48)	0.03
KSS	4.12(1.53)	3.73(1.47)	0.04
NASA-TLX- *GO/NOGO*	11.18(2.89)	10.75(3.14)	0.70
NASA-TLX-*Mental rotation*	9.54(2.03)	9.74(2.66)	0.77

[a] Differences are significant at p<0.05 level.

IV. CONCLUSION

The findings of the present study suggest that luminance ratios between the bright light and the direct surroundings that exceed 1:20 (L_{high}) led participants to give faster response times on both GO/NOGO and mental rotation tests suggesting that participants were sort of in alert situation, most probably as a result of bright light source within the field of view. On the other hand, participants gave more accurate responses under the conditions where the ratios were lower than 1:20 (L_{low}), which could be explained by the positive effect of less light disturbance that stimulated them to focus more on the task. The effect of extreme luminance ratios on GSV was expectedly high, indicating that participants perceived higher level of glare under L_{high} conditions. Results from the lighting appraisal scale were in a similar trend with GSV results, implicating that participants appraised the lighting as much better when they were feeling lower levels of visual discomfort. In regard to KSS votes, participants reported themselves as being less alert when the luminance distribution is more uniform (L_{low}). Although we expected a similar effect of luminance distribution on NASA-TLX, self-reported mental workload was not reported significantly higher by the participants when they were feeling less alert under L_{low} condition.

V. DISCUSSION

From the current results, the main conclusion to be drawn is that deciding on accurate ranges of luminances for different tasks that require various cognitive functions remains challenging when other factors such as visual comfort, human behavior and psychology are involved in. The findings of this study may provide some useful recommendations on improving cognitive performance of students by means of a simple solar control device in educational buildings, in order to provide optimal luminance patterns that promote performance of a student on tasks requiring different cognitive demands. In future studies, findings from the other cognitive performance tests and subjective measures are believed to provide additional insights in the effect of luminance patterns on individuals' performance, health and wellbeing in educational buildings.

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