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UNCOVERING RELATIONSHIPS BETWEEN VIEW DIRECTION PATTERNS AND GLARE PERCEPTION IN A DAYLIT WORKSPACE

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ABSTRACT

This paper presents the results of an experimental study that aims to provide objective insights as to how luminance distribution in an office setting modulates our view direction (VD) in a daylit workspace while performing office tasks. Using the office-like test facility at Fraunhofer ISE (Freiburg, Germany) to create a range of controlled daylighting conditions, and a wearable mobile eye-tracker to measure eye and head orientation, we assessed VD distributions for subjects performing a standardized sequence of typical office tasks relative to two different daylight conditions: low contrast condition with no direct sunlight as compared to high contrast condition with direct sunlight coming into the room. Our results show that while the participants look more outside the window during a non-cognitive and non-visual office task, this effect is lower under the high contrast lighting conditions. Moreover, the focus of the VDs is on the task area when the participants are performing a task involving visual and cognitive activities.

Keywords: Discomfort glare, Eye-tracking methods, Office space lighting

1. INTRODUCTION

Daylight plays a determining role of how a workspace will ultimately correspond to its occupants' needs, expectations, visual comfort and appraisal of the space (VEITCH 2001, NEWSHAM, et al. 2005, OSTERHAUS 2005, WEBB 2006). Considering the substantial proportion of daily office tasks involving mainly visual activities, there is a strong need for optimized daylighting strategies that support visually comfortable workspace design (CORREIA DA SILVA, et al. 2012). One of the main challenges in this regard is maximizing daylight access while maintaining a glare-free indoor environment.

The risk of discomfort glare can be quantified using one of at least seven recognized indices conceived for that very purpose. One index of note is the Daylight Glare Probability (WIENOLD, CRISTOFFERSEN 2006), which is derived from day-lit conditions. While there are many situations where these indices disagree with each other, most are drawn upon the same four physical quantities: the glare source luminance, size and position in the field of view (FOV), and the adaptation luminance.

A major limitation, shared by all known glare indices, is that they ignore the glare perception dependencies on VD, which ultimately causes ambiguities in glare indices applications (CLEAR 2012). VD is where we direct our gaze by combined shift of eye, head and body movements. The perception of discomfort glare differs greatly depending on the locations of the glare source in the FOV with respect to the VD line (LUKIESH, GUTH 1949, IWATA, et al. 1991, KIM, et al. 2009). Existing glare evaluation models – whether derived from field study methods or from High Dynamic Range image analysis – assume that the occupants' VD is fixed and is directed towards the office task area. The extension of VD to a pre-defined, static range has been proposed lately (JAKUBIEC 2012) to account for probable head and eye movements ('adaptive zone' concept) though without considering the actual VDs of the occupants. Natural visual behavior associated with glare indicates that by blinking and changing our VD we are able to avoid glare (BOYCE 2004). As we have none or slight conscious knowledge of where our eyes are fixating at any instant, observing this natural visual behavior in relation with glare in realistic scenarios can provide us an objective insight in understanding this phenomenon. This type of observation is now more applicable due to recent advances in eye-tracking methods (HUBALEK, SCHIERZ 2005). However, so far the relation between the VD distributions and the perception of discomfort glare has not been investigated. Based on observation on actual VD distributions, the correct angular displacement of the glare source and the actual adaptation luminance present in the FOV can be integrated into the discomfort glare assessments.

In this article, we present the results of a recent set of experiments with focus on VD distributions in relation to low and high contrast lighting conditions. Our earlier investigations showed that the change of position of VDs is towards the “view outside the window” while the participants are not performing a visually focused office task under low contrast daylit condition (SAREY KHANIE, et al. 2013). Here, the VD distributions under two daylit conditions were measured and compared.

2. METHODOLOGY

Based on our pilot study, where we saw a clear effect of four daylight conditions on VD distributions (SAREY KHANIE, et al. 2011), we set up a new series of experiments to further investigate this effect. Using the office-like rotatable test facilities, the objective in that initial study was to test a range of conditions for view outside the window and daylight conditions. Towards this end, we first investigated the VD distributions in relation to two views outside the window. The two views fell into the category that is most appreciated by the office workers (HELLINGA, 2010, TAUYCHAROEN, 2007). The results showed that the participants’ VDs did not change in function to which of the two views was displayed (SAREY KHANIE, et al. 2013).

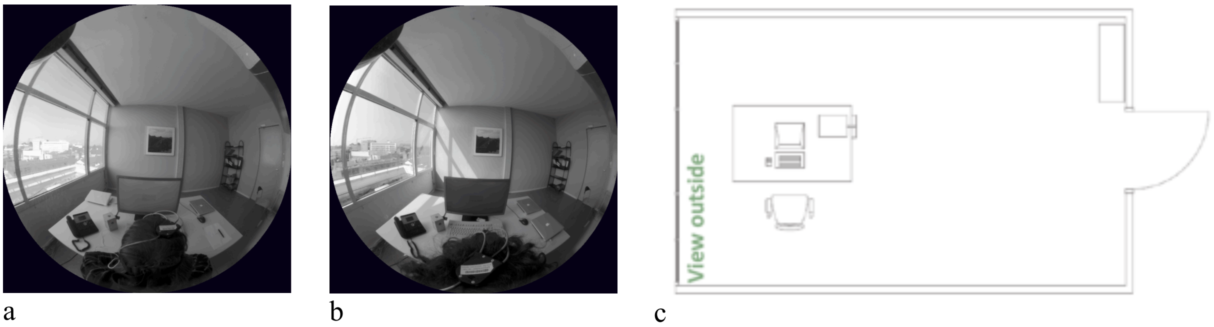

Figure 1 –a) Low contrast with no direct sunlight b) High contrast with direct sunlight inside, c) The room layout

Second, we compared the view-direction distributions under two lighting conditions: low contrast with no direct sun in the room and high contrast with direct sun in the room (Fig. 1a,b) that are discussed in further detail in the next sections.

2.1. Experimental setting

The experiments were done in an office-like side-lit module, located on top of a four-story building at Fraunhofer ISE (Freiburg, Germany). The module is 360º rotatable so as to allow repeatable experiments for varying sun positions. The office layout is a single workstation pertinent to standard space requirements (NEUFERT, 2012) (Fig. 1c). The glazing type is a double glass with a light transmission of 54 %, a U-value of 1.1 W/m²K, and a total solar energy transmission of 29 %. Indoor luminance variations were recorded every 30 second using luminance mapping with HDR imaging techniques with two calibrated luminance cameras equipped with fish-eye lenses. The cameras were situated above the participants’ head and were adjusted according to each participant’s height when seated. The eye movements were measured by means of a mobile eye-tracker, EyeSeeCam (SCHNEIDER, et al. 2009), that records both eye and head movements for accurate VD positions in the 3D space.

2.2. Test Procedure

Each test was divided into three task blocks where three different task supports (monitor screen, paper, phone) were used to aid the office task (Fig. 2a, b and c). In each task block the participant performed a standardized (ISO/FDIS 9241-303 2008, LEGGE 2006, SIVAK 1989, ÖSTBERG, et al. 1975) office task consisting of four main phases: “Input”, “Thinking”, “Response” and “Interaction”. The office task sequence was designed to allow for a combination of visually highly demanding (Input) and of non-visual office task activity (Thinking), while maintaining a realistic flow. In office worker’s age group, 33 participants, among them 5 females and 28 males, were recruited under consent from the Fraunhofer-ISE staff to participate in the experiment. At the beginning of each trial, to allow for a similar visual adaptation interval to the indoor light, the participant entered from the outside first through the adjacent room, and then to the test scene. Thereafter, the eye-tracker was calibrated for each participant and demographic data was gathered. Each participant’s head position in the room was measured in order to obtain an accurate VD measure in the 3D space.


a b c

Figure 2 – Task supports: a) monitor screen, b) paper and, c) phone

2.3. Daylight conditions

The experiments were performed under two different daylight conditions (Fig. 1 a, b). The low contrast condition is defined as a situation where there was no direct sunlight coming into the room and the sky condition was either overcast or clear. The high contrast condition is defined as a situation where there was direct sunlight coming into the room and the sky condition was clear. Each measurement set was categorized based on observations made at the time of the experiment. Thereafter, based on the photometric measurement evaluations using Evalglare (WIENOLD, CHRISTOFFERSEN 2006) we refined the groupings of the participants (Fig. 3a,b, and c).

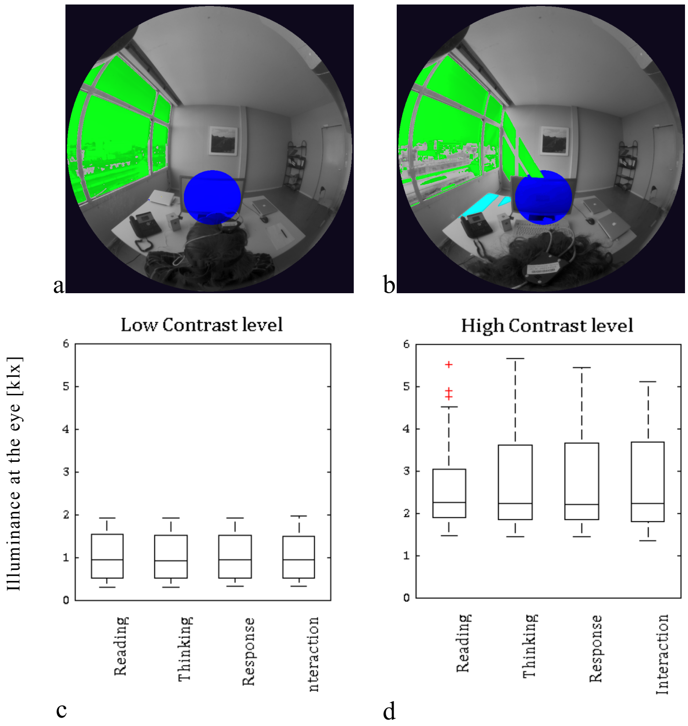

Figure 3 –Daylight conditions: Glare evaluations were used for refining the groupings: a) Low contrast, b)High contrast; c, d) The boxplot shows illuminance variations reaching the eye at a vertical level.

3. RESUTLTS

3.1. Eye-tracking results

We studied the effect of the two daylight conditions in the analysis of the VD data. The radial standard deviation of the VD distributions, which is an appropriate measure to demonstrate the general spatial tendencies, was used in the analysis.

To quantify the effects of the independent factors we made an Analysis of variance (ANOVA) on the radial standard deviation of the VDs under each task phase. The factors were the lighting conditions (low contrast, high contrast) and the task supports (monitor screen, paper, phone). During the "Input" phase the effect of lighting condition is small ($F=0.76$, $p<0.05$), though the task-support's effect is apparent ($F=17.16$, $p=0$). There was an effect of lighting condition under the "Thinking" phase ($F= 4.58$, $p<0.05$). There was neither any effect of lighting conditions nor of the task support during the response phase. The last phase was the interaction phase where we found an effect of task-support ($F=8.66$, $p<0.001$).

3.2. Dominant view direction (VD) distributions

The dominant VDs represent the direction that the participant has looked at the most during the task phase. This was determined by organizing the VD data in matrix of bins of 5° spread and selecting the maximum values. Here we compare the two distinct phases of "Input" and "Thinking" being respectively the most and the least visually demanding phases. As shown in the ANOVA results, the VDs were mainly determined by the task-support during the "Input" phase under both light conditions (Fig. 4a). The VDs during the thinking phase are more dispersed (Fig. 4b). Our results also show that the focus on the task area is less apparent for the telephone call. Even though the phone is situated on the left hand side of the participant, there is a clear tendency towards the inside of the room (right) under the high contrast lighting conditions (Fig. 5a). During the monitor and phone task blocks, the tendency of the VDs under the low contrast levels is mainly towards the view from the window but on the other hand under the high contrast level lighting conditions, this tendency is lower (Fig. 5b). This result does not apply to the paper task block due to the presence and availability of the task support at all times.

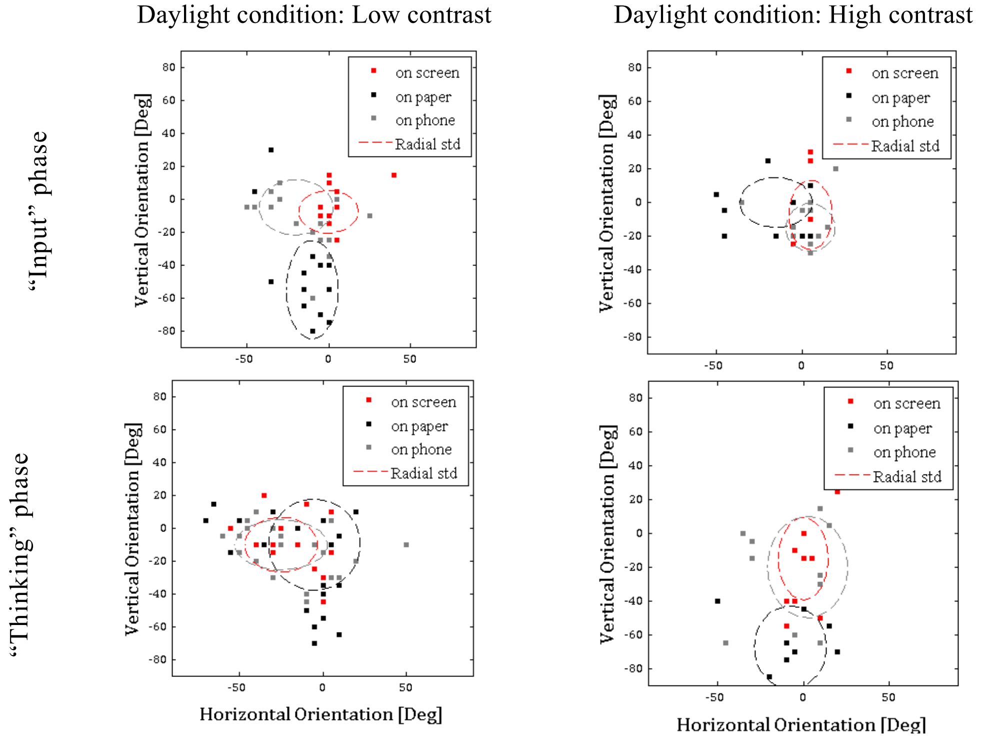

Figure 4 – During the "Input" phase the VD is more focused on the task area under both light conditions, where as during the "Thinking" phase the VD is more dispersed over the space.

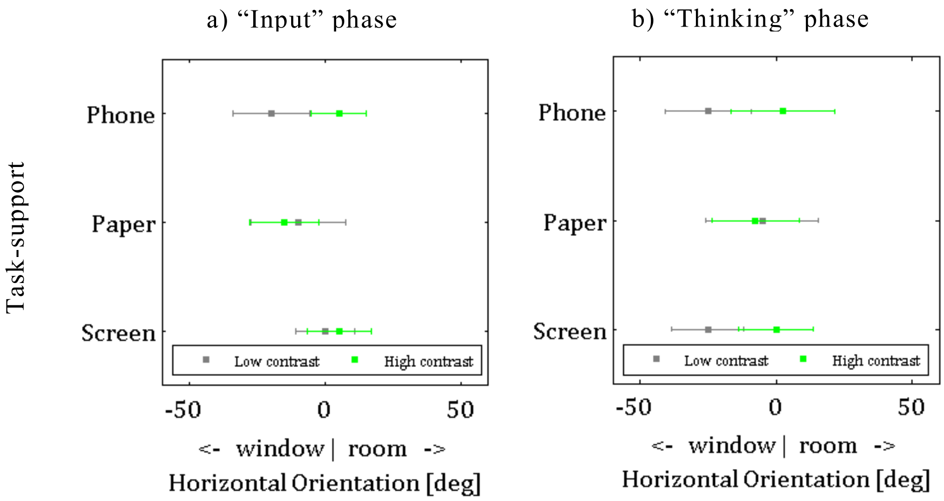

Figure 5 – The mean and radial standard deviations are compared here during: a) the "Input", b) the "Thinking" phase.

4. DISCUSSION AND CONCLUSION

The proposed work seeks to start guiding the design of workspaces in a new direction with regard to visual comfort by integrating eye-tracking methods to – ultimately – construct a dynamic model of glare through an uncovering of inter-dependencies between perceived comfort, VD and lighting conditions. The hypothesis is that a certain range of luminance affects the VD, thus creating predictable patterns over a luminous space.

In this study, we investigated VD distributions under two different lighting conditions while the participants were performing standardized office tasks. The comparisons show that when the participants are not engaged in any visually focused task and the presence of the task support is minimal, the VDs are inclined towards the view outside the window under the low contrast lighting conditions, but this tendency is less apparent and sways more towards the inside of the room under high contrast lighting conditions. Based on our current findings, we will run a second series of experiments including a larger number of participants for statistical validity in which we will include participants' subjective assessments of the lighting conditions. Finally, analysis needs to be done to integrate dynamic VDs with participants' subjective assessments in the discomfort glare assessments.

5. ACKNOWLEGEMENT

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