INTEGRATION OF EYE-TRACKING METHODS IN VISUAL COMFORT ASSESSMENTS

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ABSTRACT

Discomfort glare, among different aspects of visual discomfort is a phenomenon which is little understood and hard to quantify. As this phenomenon is dependent on the building occupant's view direction and on the relative position of the glare source, a deeper knowledge of one's visual behavior within a space could provide pertinent insights into better understanding glare. To address this need, we set up an experiment to investigate dependencies of view direction distribution to a selected range of brightness and contrast distributions in a standard office scenario. The participants were asked to perform a series of tasks including reading, thinking, filling in a questionnaire and waiting. The direction of their view was monitored by recording participants' eye movements using eye-tracking methods. Preliminary results show that different facade configurations have different effects on the eye movement patterns, with a strong dependency on the performed task. This pilot study will serve as a first step to integrate eye-tracking methods into visual comfort assessments and lead to a better understanding of the impact of discomfort glare on visual behavior.

INTRODUCTION

Daylight, while undeniably a desirable component in any working and living space [1, 2], can create uncomfortable situations that may reduce visibility and create dissatisfaction and visual discomfort. Among the different types of visual discomfort that can be caused by daylight in an indoor environment, a phenomenon known as discomfort glare is recognized as the most common problem; yet, despite years of study, it still has not been fully quantified and understood. The studies on discomfort glare are mainly subjective and based on light measurements combined with conventional psychophysical procedures [1]. They have resulted in a series of glare indices that predict the expected degree of discomfort an occupant will experience as caused by different light settings. These indices are in general drawn upon four physical quantities: the luminance, the size and the position index of the glare source, and the general field of luminance that the eye adapts to (cf. Fig. 1). The position index is a complex equation, which expresses the change in discomfort based on the angular displacement of the glare source from the line of sight [3, 4]. The main assumption in the definition of this index is that the line of sight is fixed and focused on a given point.

In a natural experience of a space, the view direction is not fixed but varies through time and space. To change their line of sight, humans move body, head and eyes. The hypothesis is that there might be clear relations between these movements and discomfort glare perception.

Eye-movement analysis is used in fields such as car safety, surgery, software usability, product design, and also in assessing glare from monitor screen. Very few studies so far have

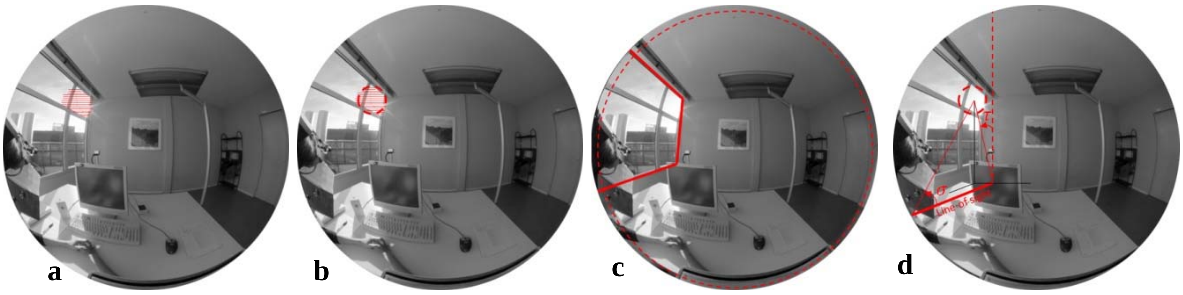

Figure 1: Discomfort glare depends on four general variables a) Luminance of glare source, b) Solid angle of source, c) Background luminance, and d) Position index

investigated the relationship between eye movements and building-induced visual context, such as a window [5, 6]. None went as far as connecting findings on eye-movements patterns to glare perception. The use of this new method can lead on one hand to novel and quantitative insights in the cognitive factors driving eye movements in natural settings, and on the other hand to objective measures of comfort and more reliable predictions of occupant response, that together contribute to support improved workplace design.

To investigate this, a pilot study was designed in a realistic scene using eye tracking methods. The experiment included five participants and was carried out in an office-like room where photometric quantities relevant to visual comfort were gathered. A sequence of four daylight conditions was created by changing the facade configuration, and a fifth light configuration was considered using artificial lighting. Eye movements were recorded for each light-condition sequence and task event by means of an eye-tracker.

This paper describes the overall methodology adopted to approach this problem and illustrates the potential for new insights offered by integrating eye-tracking methods in discomfort glare assessments. It also presents preliminary results of the pilot study conducted in the daylight test room at Fraunhofer-ISE, Freiburg, Germany.

METHODS

The method adopted for this study included measuring eye movements of human participants in an office-like environment. In natural visual behavior, we avoid the discomfort glare sensation changing our view direction and putting the source of glare out of our visual field. Looking into this behavior by means of objective measurements such as eye movements, can lead to a better understanding of this phenomenon in indoor spaces.

Eye-tracking

Using eye tracking has the potential to provide objective measures of comfort and more reliable predictions of a building occupant's response, which contributes to improved workplace design. Eye movements in general are divided into volitional and reflexive movements and in natural stimuli are driven by local features of visual stimuli [7], visual context [8] and task [9, 10, 11]. In addition to eye movements, humans may change their line of sight by head and body movements, which frequently interact with eye movements. For applicability to realistic scenarios, the eye-tracking method should not constrain the participant's movements. To monitor gaze and head movements simultaneously, we therefore employed the EyeSeeCam (Fig. 2), a mobile, state-of-the-art eye tracker [12] that performs binocular video oculography and records real-time head-centered and gaze-centered movies.

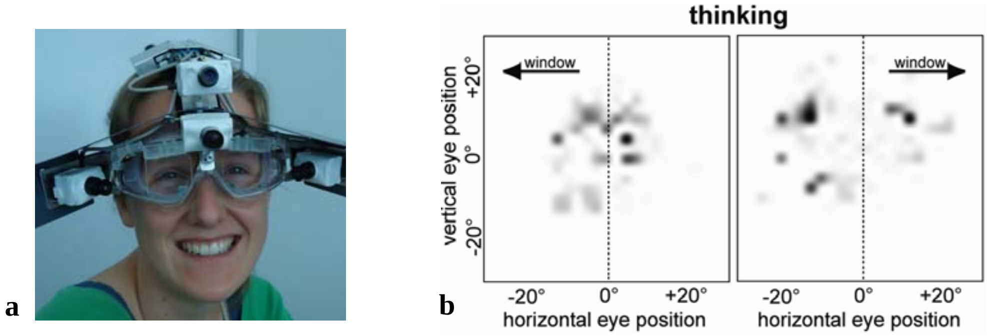

Figure 2: EyeSeeCam a) EyeSeeCam worn by a participant b) Eye-tracking analysis: Heat maps of eye positions recorded with the EyeSeeCam.

Because eye-tracking is an objective, quantifiable method, it provides a new perspective in visual discomfort glare assessment. It adds an objective measurement of occupant response through eye-movement recordings and moves beyond the conventional subjective assessment based on questionnaires.

Experimental setup

As a first step, a pilot study was conducted, whose objective was to investigate the possible relations between eye-movement patterns and light distribution in the room. The experiments were performed in an office-like side-lit module located on top of a four story building in the south-western part of Germany in Freiburg. The module is 360º rotatable so as to allow reasonably repeatable experiments for varying sun positions. The glazing type is a double glass with a light transmission of 54%, a U-value of 1.1 W/m^2K, and a total solar energy transmission of 29%. The room is equipped with control systems such as interior venetian blinds, roller blinds, and covering sheets for reducing the glazing surface.

The sequence of light conditions ranging from dark and low contrast to bright and extreme contrast was determined through initial testing with different facade configurations compared in simulation using Radiance [13] and in the real space with the help of High Dynamic Range imaging techniques [14]. The main concern was to have different significant contrast conditions and glare situations in the room while maintaining the view contact to the outside and ensuring an easy flow of the measurement procedure. Based on this comparison, four daylight conditions were considered for the experiment (cf. Fig. 3). In addition, an artificial situation was also considered as the fifth light system.

Each task event started with the participant coming in from the outside, first to the neighbor module and then to the test scene so as to have a similar eye adaptation processes to indoor light. Light variations outdoors were monitored with a meteorological station that records the global, total and diffuse illuminance (lux), as well as the global horizontal irradiance (W/m^2) [15]. Indoor light distribution was monitored by lux meters and calibrated HDR cameras equipped with a fish-eye lens used as a multiple point luminance-meter. Eye-movements were recorded by means of the EyeSeeCam eye-tracker system. Photometric quantities relevant to visual comfort as well as subjective glare rating were gathered.

Test procedure

The test procedure consisted of five parts with five different light settings and included five task events: 1) reading from the monitor screen, 2) thinking/waiting, 3) answering one multiple choice question on the reading, 4) filling in the questionnaire, 5) pause.

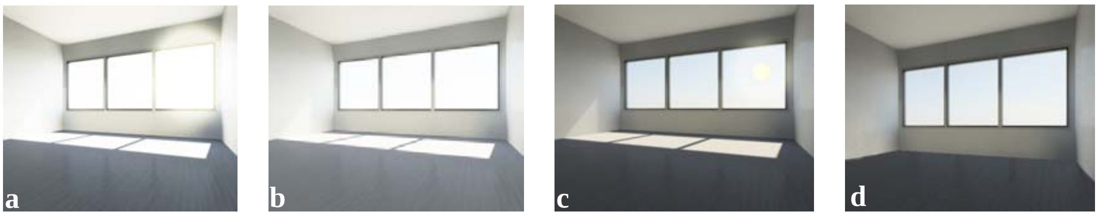

Figure 3: The visualization of the four daylight conditions a) dark and low contrast, b) dark and high contrast c) bright and high contrast d) bright and extreme contrast (direct sun).

In order to ensure the homogeneity of the reading task for all participants, its appearance on the monitor screen was standardized based on ergonomics of human-system interaction (ISO 9241-303). To avoid uncontrolled skimming or skipping that occurs naturally when reading a continuous paragraph [16] the text was carefully adjusted and set to the center of the monitor. The texts were chosen with a text difficulty that could be read in 1 minute.

Five volunteers were recruited in the age group of 20 to 30 of native German speakers amongst the Fraunhofer-ISE staff. Participants wore the EyeSeeCam to measure eye movements, and performed one trial per facade condition. Each trial consisted of five one-minute tasks as described above. The reading text was chosen randomly among six different paragraphs and displayed on the monitor at the beginning of each trail. The order chosen for the lighting condition sequence was randomized across participants to avoid any order effects. For each task (except for the 3rd event), eye-tracking parameters and subjective comfort ratings were assessed as dependent variables, the overall luminance distribution (resulting from each facade configuration) being considered the independent variable. Photometric quantities relevant to visual comfort were recorded continuously during each task. These measured quantities included: work plane illuminance (lux), illuminance (lux) on the monitor plane, vertical illuminance (lux) at the participant's eye, and luminance distribution (cd/m^2).

RESULTS

The effect of light condition sequence and task was addressed in a preliminary analysis of the eye movement data. This analysis will be restricted to the two extreme facade configurations for glare, namely the dark and high contrast and the bright and extreme contrast, further discussed below. Variance over the horizontal eye-in-head position signal ('horizontal variance') is likely to measure behavior with some more sensitivity than radial variance or vertical variance as window is always to left.

The illuminance measure at the eye level of participants for each facade configuration, have created a good diversity of perceived light and have kept a reasonable consistency through each trail (cf. Fig. 4) .

Horizontal variance increased in the tasks that invite participants to explore the surroundings ('think' and 'pause') as compared to the two tasks where gaze is restricted to the monitor ('read' and 'question') (cf. Fig. 5a). During the 'think' phase of the trials this increase is lower for the bright and extreme contrast facade. This suggests that horizontal variance of eye-in-head orientation is sensitive to the effects of light conditions on comfort.

To quantify this, a three-way ANOVA was performed on horizontal variance. The factors used were facade ('2: dark and high contrast', '4: bright and extreme contrast'), task ('read', 'wait', 'question' or 'pause') and eye ('left' or 'right').

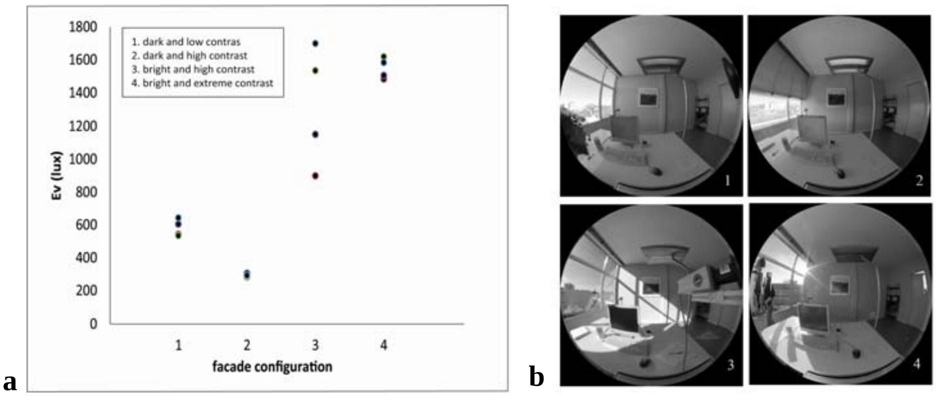

Figure 4: Measurement results a) Comparison between illuminance (lux) at the eye level of participants in all four facade configurations b) Representation of the four façade configurations

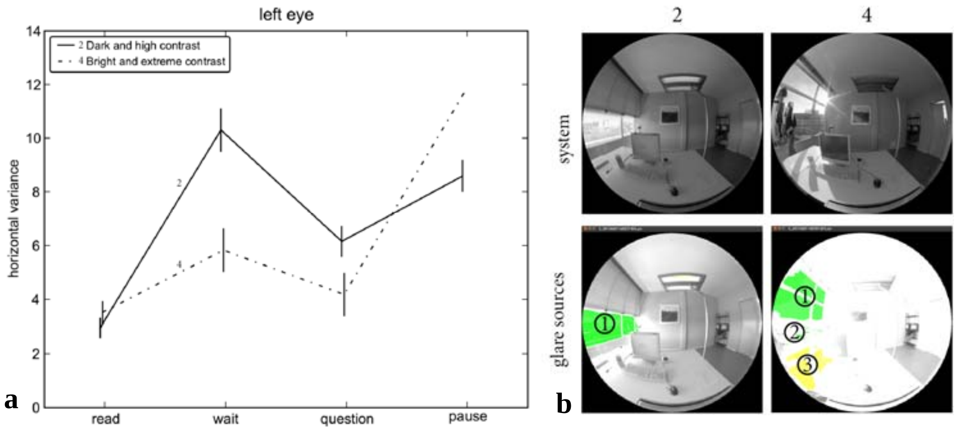

Figure 5: Analysis results a) Horizontal variance between two facade configurations: '2: dark and high contrast' '4: bright and extreme contrast' b) The two facade configurations and the glare sources within the field of view

There are main effects of facade ($F(1, 40) = 34.49$, $p<.001$) and task ($F(3, 40) = 70.94$, $p < .001$). There is no main effect of eye ($F(1, 40) = 3.04$, $p = .088$). There is a two-way three-way interactions (all $p > .643$). Interaction between facade and task ($F(12) = 17.99$, $p < .001$). There were no other two- or three-way interactions (all $p > .643$).

The effect of the facade means that eye-orientation varies depending on which system is used. A glare evaluation made by Evalglare, a Radiance-based tool [15], illustrates the distribution of glare sources in the field of view (cf. Fig. 5b) which shows that more glare sources in the field caused has created a different effect. The results also indicate that facade effect is different for different tasks. For example, when participants are reading, the variation of eye-orientation is mainly determined by the task, but when they are thinking or making a pause variation of eye-orientation is mainly determined by the facade.

DISCUSSION

This paper presents the preliminary results of a pilot study conducted to evaluate the potential of integrating eye-tracking methods as an objective insight to visual comfort assessment. An experiment was designed as a first step towards this end that demonstrated there are significant changes of eye movement behavior in different light settings. This method can reveal new perspectives in understanding discomfort glare.

The goal of this research is, ultimately, to refine our understanding of dependencies of view direction as a function of light distribution. To reach this goal, further detailed analysis needs to be done on the light distributions based on head-in-room orientation to allow for more precise assessment of comfort dependent gaze. Moreover, subjective glare ratings are also to be considered in order to have a better understanding of subjective assessments. The inclusion of measurable gaze in visual comfort studies creates a basis for identifying objective relationships between eye-movement patterns and perceived comfort, and between occupant response patterns and lighting conditions.

Findings will advance the state of the art in visual comfort assessment in interior spaces by providing new insights into the position index as a parameter that is - possibly - dependent on light distribution and forming a basis on which lighting conditions, glare perception and gaze patterns can be brought together.

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