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Discomfort glare perception in daylighting: influencing factors

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Abstract

The mechanism behind the discomfort glare phenomenon, the kind of glare provoking an irritating or distracting effect, is not well understood. Since some of the factors influencing this phenomenon are still unknown, no current indices can properly explain the high variability existing between individuals' discomfort glare perception. A list of potential factors influencing the degree of perceived discomfort glare in daylighting has been established from existing literature. In addition to the physical quantities commonly used in glare indices, other variables, whether psychological, physiological, related to light or to the context, could influence the degree of perceived discomfort glare.

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1. Introduction

Energy efficiency and well-being are both major challenges in construction nowadays. Due to the growing interest given to these matters, discomfort glare indices are becoming more significant and increasingly used. On the one hand, automatic management systems are implemented in buildings to optimise interactions of special techniques including heating, lighting, ventilation, and air conditioning. With regard to visual comfort management, control models implemented in this kind of system aim to use indices such as the Daylight Glare Probability (DGP)

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or the Discomfort Glare Index (DGI). Thresholds of visual discomfort are predetermined in the models so that when in-situ measured values exceed these thresholds, actions are taken by the system [1, 2].

On the other hand, office buildings windows are optimised to maximise the amount of daylight. Since a large amount of glazing implies an increased risk of discomfort glare, recommendations to limit discomfort glare from daylight are now being written and will be part of the new European daylight standard (prEN17037). These recommendations use the Daylight Glare Probability (DGP) as a reference index. Concerning discomfort glare from artificial lighting, CIE recommendations are based on another index, the Unified Glare Rating (UGR).

However, these discomfort glare indices cannot properly explain the high variability existing between individuals' discomfort glare perceptions. Since the mechanisms governing discomfort glare are still unknown, unidentified variables, such as physiological or even psychological factors, could influence the degree of perceived discomfort glare and explain this high variability between individuals' discomfort glare perception.

This paper aims to review factors potentially influencing the degree of perceived discomfort glare from windows. Every factor having at least been the object of an experiment as a potential element influencing discomfort glare perception is listed. The conclusion suggests a prioritisation list for future research.

2. Assessment of daylight discomfort glare factors

Discomfort glare is defined by the CIE [3] as “glare which causes discomfort glare without necessarily impairing the vision of objects”. Indices developed to predict the degree of perceived discomfort glare, such as the Daylight Glare Index (DGI) or the Daylight Glare Probability (DGP), are generally based on four physical quantities:

- the luminance of the glare source, which is the intensity of the luminous flux emitted per unit area of the source;
- the adaptation level, which is the luminous flux reaching the eyes and setting the adaptation of the eyes;
- the solid angle of the glare source, which expresses the size of the glare source as seen by the observer;
- the position index, which is a correction factor considering the different perceptions of glare sources for the horizontal and vertical displacements from the line of vision of the observer.

The influence of these variables has been proven through statistical inferences. Several laboratory experiments have been conducted in which subjects were asked to rate their perceived discomfort glare while measures of the luminous environment were taken. These four variables have been adopted in discomfort glare indices, as up until now, they have ensured the best correlation between the perceived and measured assessments of discomfort glare. But this correlation is far from perfect. Therefore, similar experiments have been conducted to evaluate the influence of other factors on discomfort glare perception. Each factor having been the object of at least one experiment as a potential variable of discomfort glare perception is discussed in this paper. Factors are described and classified according to whether they are related to the lighting, to the context, or to the observer. References to the most significant studies having investigated each factor are also mentioned. Finally, an indicator is suggested, which expresses the probability of influence of the factor on discomfort glare perception. This probability is evaluated as either certain, likely, unlikely, uncertain or null. This evaluation is made by considering the number of studies supporting or rejecting the influence of the factor as well as the methodological and statistical relevance of these studies. When there are contradicting results, that is to say a similar number of studies supporting and rejecting the influence of the factor, the influence probability is assessed as uncertain.

3. Daylight discomfort glare factors

Table 1 lists all factors studied in the literature for their potential influence on discomfort glare perception. The most significant studies having examined these factors are specified, as well as the influence probability indicator.

Table 1. Factors potentially influencing discomfort glare perception, with major references and influence probability

Factors	Major references	Influence probability
Luminance of the glare source	Petherbridge and Hopkinson 1950 [4]	CERTAIN
Adaptation level	Petherbridge and Hopkinson 1950 [4]	CERTAIN
Contrast effect	Chauvel, Collins et al. 1982 [5]	CERTAIN
Saturation effect	Bourassa and Wirtschafter 1966 [6]	CERTAIN
Size of the glare source as seen by the observer	Hopkinson 1972 [7]	CERTAIN
Position of the glare source as seen by the observer	Luckiesh and Guth 1949 [8]	CERTAIN
Spectrum of light	Berman, Bullimore et al. 1995 [9]	LIKELY
View direction	Khanie, Stoll et al. 2016 [10]	LIKELY
Attractiveness of the view through the window	Tuaycharoen and Tregenza 2007 [11]	CERTAIN
Room temperature	Yamin Garretón, Rodriguez et al. 2015 [12]	UNCERTAIN
Time of the day	Kent, Altomonte et al. 2015 [13]	LIKELY
Season	Van Den Wymelenberg 2013 [14]	LIKELY
Task difficulty	Sivak, Flannagan et al. 1989 [15]	LIKELY
Questionnaire and rating scale	Fotios 2015 [16]	UNCERTAIN
Gender	Iwata, Shukuya et al. 1992 [17]	NULL
Age	Bennett 1977 [18]	UNCERTAIN
Culture	Pulpitlova and Detkova 1993 [19]	LIKELY
Chronotype	Kent, Altomonte et al. 2015 [20]	UNCERTAIN
Self-assessed glare sensitivity	Saur 1969 [21]	LIKELY
Vision correction	Hirning, Isoardi et al. 2013 [22]	NULL
Iris pigmentation	Osterhaus 2001 [23]	UNCERTAIN
Macular pigment optical density	Stringham, Garcia et al. 2011 [24]	UNCERTAIN
Cortical hyperexcitability	Bargary, Furlan et al. 2015 [25]	LIKELY
Contrast sensitivity	Hansen, Khanie et al. 2016 [26]	UNCERTAIN
Previous luminous environment	Altomonte, Kent et al. 2016 [27]	LIKELY
Physical state	Osterhaus 2001 [23]	UNCERTAIN
Emotional state	Altomonte, Kent et al. 2016 [27]	UNCERTAIN
Caffeine ingestion	Kent, Altomonte et al. 2015 [20]	UNCERTAIN
Food ingestion	Kent, Altomonte et al. 2015 [20]	UNLIKELY
Fatigue	Altomonte, Kent et al. 2016 [28]	UNCERTAIN

The potentially influencing factors have been categorised in three groups, namely the factors related to the lighting, the factors related to the context, and the factors related to the subject.

3.1. Factors related to the lighting

The luminance of the glare source(s), the adaptation level, the contrast effect, and the saturation effect have been included in discomfort glare indices early on [4, 7]. The exact definitions of these factors are, however, still not established. One reason for that is the ambiguity of the glare source definition itself. In the case of daylighting, the glare source could be interpreted as the window [29], the sky seen through the window [5], some brighter spots in the window plane, or even the light reflecting from any bright surface in the field of view [30]. Another reason could be

that unlike glare from artificial lighting, the contrast and saturation effects do not operate distinctly in the case of glare from daylighting [4]. When glare comes from small sources such as artificial lights, the adaptation level is mainly influenced by background luminance. But if a large glare source such as a window covers a wide area in the field of view, the interaction between the glare source and the surroundings plays a role in the eyes adaptation process.

Discomfort glare perception also depends on the spatial situation of the observer in relation to the glare source. This situation is evaluated through the solid angle of the glare source and the position index. The further away an observer is from a window, the smaller the solid angle and the lesser the perceived discomfort glare [31]. Furthermore, the more peripheral the position of the glare source, the lesser the perceived discomfort glare [32].

3.2. Factors related to the context

Nowadays, discomfort glare is mostly assessed by asking the observer to fill out a questionnaire on a VDT screen [12, 33-35]. This subjective evaluation is then compared to a luminance map of the observer's field of view, which is directed towards the screen and motionless, unlike the eyes. This technique thus fails to take into account the influence of the view direction on discomfort glare perception. Yet, by changing our view direction, the luminance distribution across the field of view is altered. Recent studies have shown a significant difference between gaze-driven and fixed-gaze glare evaluation method [10]. The difficulty of the task that the observer has to accomplish while assessing glare is also believed to influence discomfort glare perception, in such a way that perceived discomfort glare tends to be lower when no task is required [36]. Furthermore, the questionnaires and rating scales currently used to collect observers' evaluation of discomfort glare might as well have an influence [16]. The design of experiments should be made very consciously when studying discomfort glare. Several distortions in the results could occur due to the method chosen and have an influence, not on the discomfort glare perception, but on the translation of this perception into an evaluation.

Factors related to the environmental context should also be considered during discomfort glare evaluation, and especially in the case of daylight. Since the main source of glare is the window, the glazing or the orientation could interfere in discomfort glare perception. For instance, since the spectral distribution can vary with the type of glazing, a glazing that filters some parts of the light spectrum might have an influence on discomfort glare perception. Several studies [9, 37] have investigated this effect but no significant tendency could be shown. On the contrary, the attractiveness of the view through the window, which encompasses the interest and the amount of view, has been acknowledged several times [11, 22, 35] as having a direct influence on the acceptance of discomfort glare, especially when the observer has a strong opinion about the view.

In addition to the influence of the window characteristics, factors such as the room temperature might also have an influence on discomfort glare perception. It has indeed been suggested in one study [12] that observers had a different tolerance towards discomfort glare when they were outside their thermal comfort zone. Another study [20] indicated that as the day progresses, tolerance towards discomfort glare increases. Seasons might also have an effect on discomfort glare perception, as it has been noticed in one study [38] that observers are more sensitive to glare during fall than during summer.

3.3. Factors related to the observer

Factors directly related to the observer might have an influence on discomfort glare. Demographic variables, such as gender [15, 17, 20, 21] and age [33, 39], have repeatedly been studied for their influence on discomfort glare perception. Gender is believed to have no influence but, as visual functions are changing with age, age might have a small effect on discomfort glare perception. The culture of the observer, defined in this case as the climatic and indoor conditions to which the subject has been accustomed during the major part of his life, his behaviour towards this indoor environment, and his expectations about it, has a tendency to influence discomfort glare perception as well [19, 29]. Although the effect is not well understood, it seems that Asian observers have a greater tolerance towards discomfort glare than European and American observers.

Several physiological factors have also been studied for their influence on discomfort glare. For instance, the chronotype, namely the behavioural manifestations of the observer's circadian rhythm, might influence discomfort glare in such a way that earlier chronotype observers tolerate higher levels of discomfort glare [20]. The self-assessed glare sensitivity, a characteristic that subjects can generally quite easily determine for themselves, is believed to be closely linked to the cortical hyperexcitability. This cortical hyperexcitability is the degree of activity of the neurons in the visual cortex, namely the neural tissues composing the outer layer of the part of the brain responsible for the vision. The effect of neuronal activity on discomfort glare perception could explain the difference existing between a glare-sensitive and a glare-insensitive person [21, 23, 25].

Factors directly related to the vision and the eye should be taken into account as well. Studies [17, 21, 39] investigating the influence of wearing glasses or lenses suggest that discomfort glare perception does not depend on that factor. The ambiguity is more noticeable when investigating iris pigmentation. Despite a very small tendency to indicate that light-eyed people could be more sensitive to discomfort glare [18, 23], there is so far no strong evidence of the influence of this factor. Likewise, studies [24, 37, 40] do not agree on the effect of macular pigment optical density (MPOD), which is the density level of protective pigment in the macula, on discomfort glare perception. Recently, the contrast sensitivity, a visual function that allows us to perceive luminance ratios in the field of view, has been raised [26] as another potential factor, since observers often have a loss in contrast sensitivity when there is light scattering in the eyes.

Temporal factors [20] such as the previous luminous environment, namely lighting conditions that an observer experienced during the hours/days preceding a glare assessment, could influence the perceived degree of discomfort glare. Furthermore, it is believed that there is a tendency for observers not having ingested caffeine to be more tolerant towards glare source luminance. Food ingestion should have no influence on discomfort glare perception.

The last factors to encompass in the study of discomfort glare perception are those relative to the feeling of well-being of the observer, namely the psychological factors. For instance, the current emotional state of a subject could affect his or her perception of comfort [23, 27]. Therefore, positive emotions could lead the subject to be less critical of the luminous conditions, and inversely for negative emotions. The same principle applies to the physical state of the observer; as different physical conditions (disease, head pain, back pain, etc.) can reduce the perceived comfort, this factor could influence his or her discomfort glare perception in a negative way. The extreme fatigue of the observer could also generate a lower tolerance towards discomfort glare. But so far, no strong evidence has permitted to establish the effect of a psychological factor on discomfort glare perception [20, 23].

4. Conclusion

As the list of potential factors influencing discomfort glare perception is long, more studies are needed to explain the high variability between individuals' discomfort glare perception. This literature review helps define which factors need to be deeper investigated and which are less likely to bring improvement if implemented in indices. Regarding the order in which these factors should be further examined, the authors believe that in the first place, efforts should be targeted towards variables having an influence probability indicator labelled as "certain" or "null". These factors are the most likely to help explaining subjects' discomfort glare perception or to be set aside. Factors with a probability indicator labelled as "uncertain" should be examined last, as they are controversial and their influence might be very small.

Besides, focus should be laid on factors being easily determined, unlike MPOD or cortical hyperexcitability. Factors such as iris pigmentation could be further studied with little effort, since a sample of subjects having different eye colours is easily found. At last, the influence of the four main factors should not be questioned, but the exact definition of these factors needs to be deepened.

As a result, discomfort glare models might be adapted according to the determined influencing factors. For instance, the introduction of a variable related to the attractiveness of the view could be a great improvement. Nonetheless, the fact that psychological factors influence discomfort glare perception, brings a different perspective on discomfort glare indices. Discomfort glare in the field of view produces a sensation to the observer, who perceives it as more or less discomforting according to several psychological factors. Since subjective perception matters in the case of discomfort glare, indices should not be made exclusively of physical quantities.

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