Review of factors influencing discomfort glare perception from daylight

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Abstract - As well-being is becoming a major challenge in construction nowadays alongside energy efficiency, there is an increasing need to be able to quantify discomfort in buildings. In the case of discomfort glare, the kind of glare provoking an irritating or distracting effect, no current indices can properly explain the high variability existing between individuals' discomfort glare perceptions. This is due to the fact that some of the factors influencing discomfort glare perception are still unknown and the mechanism behind the discomfort glare process is not well understood. Therefore, this paper aims to review the factors potentially influencing discomfort glare perception from daylight. Every factor having been studied at least once for its potential influence on discomfort glare perception has been listed, described and analyzed. Furthermore, this study categorizes the influence of these factors on discomfort glare by introducing an influence indicator based on the number of studies having investigated the factor, the sample size of these studies, and the agreement between them. The suggested categories rate a factor influence as "almost certain", "more likely", "somewhat likely", "inconclusive", "somewhat unlikely", "less likely", or "almost certainly null". Tables summarize the main information about the studies and the influencing factors. As expected, factors almost certainly influencing discomfort glare perception are the luminance of the glare source, the adaptation level, the contrast effect, the size and position of the glare source. On the opposite, factors which almost certainly do not influence discomfort glare perception are the gender and the optical correction of the observer. All other factors from the list of thirty, such as the attractiveness of the view through the window or the culture of the observer, require additional studies to determine whether or not they are influencing discomfort glare perception.

Keywords - discomfort glare, daylighting, visual perception, glare metrics, influencing factors

1. Introduction

Nowadays, energy efficiency and well-being are both major challenges in construction. With the rapid development of new technologies, systems are implemented in buildings to control interactions and operations of special techniques such as heating, ventilation or air conditioning. This is also the case for lighting. In a growing number of office buildings, shading devices and artificial lighting are integrated in systems working on the basis of models and sensors. The control algorithms implemented in these systems aim to use indices such as the Daylight Glare Probability (DGP) or the Discomfort Glare Index (DGI) to evaluate visual discomfort. Thresholds of visual discomfort are therefore predetermined in the models and if the values evaluated by the indices are not consistent with these thresholds, actions are taken by the system (Chaiwiwatworakul et al. 2009, Chan and Tzempelikos 2013, Goovaerts et al. 2017, Shen et al. 2014). But the visual discomfort indices used in those systems have not been developed to provide such accurate threshold values. This is especially true for indices predicting discomfort glare, which is the kind of glare provoking an irritating or distracting effect but not impairing the view (CIE 1983). As the mechanisms governing discomfort glare are still unknown, current indices predict the degree of perceived discomfort glare by approximating a value, but certainly not by defining a precise threshold. Approximating the degree of perceived discomfort glare has been the best way so far to take this effect into consideration in the occupant's well-being evaluation.

There exists a high variability between individuals' discomfort glare perception, as it has already been pointed out several times (Boyce 2014, Eble-Hankins and Waters 2005, Galasiu and Veitch 2006, Rodriguez and Pattini 2014, Stone and Harker 1973, Van Den Wymelenberg et al. 2010, Wirtschafter and Bourassa 1966). This variability could probably be better understood by reconsidering discomfort glare indices. In addition to the physical quantities currently used, other variables such as physiological or psychological factors could influence the degree of perceived discomfort glare and explain this large variability between individuals. One of the current knowledge gaps in discomfort glare is the lack of information about the moderating effect of culture, age or outside view for instance (Van Den Wymelenberg 2014).

This paper aims to go back to the foundations of discomfort glare indices by making an exhaustive review of factors potentially influencing the degree of perceived discomfort glare from windows. First, a contextualization of what is currently acknowledged on discomfort glare from daylight is given. Common variables and indices related to discomfort glare from windows are summarized as well as the method used to define the factors influencing discomfort glare perception. Every factor having at least been the object of an experiment as a potential element influencing discomfort glare perception is listed, described and analyzed. At last, the conclusion sums up the factors and put forward some suggestions for future research on discomfort glare from daylighting.

2. Assessment of daylight discomfort glare factors

In order to describe the factors playing a role in a particular process, understanding the mechanism behind this process is highly recommended. This is not conceivable for discomfort glare since there is no solid scientific explanation behind this process. Discomfort glare is defined by the Commission Internationale de l'Eclairage (CIE 1983) as "*glare which causes discomfort without necessarily impairing the vision of objects*". The indices developed to predict the degree of perceived discomfort glare are made of variables which contributions have only been proved through statistical inferences.

Four physical quantities are commonly used as variables of discomfort glare equations. These variables, related to lighting or to space, are:

- the luminance of the glare source, which is the intensity of the luminous flux emitted par unit area of the source;
- the adaptation level, which is either defined as the luminance of the background or as the vertical illuminance at eye level, namely the luminous flux reaching the eye;
- the solid angle of the glare source, which expresses the seen size of the glare source;
- the position index, which is a correction factor considering the horizontal and vertical displacements of a glare source from the line of vision of the observer.

These four variables were already mentioned by the CIE as the four physical quantities influencing discomfort glare (CIE 1983). Nowadays, most indices assessing the degree of perceived discomfort glare use them as only variables. They will be described thoroughly in Section III.

More than sixty years of research have demonstrated that discomfort glare is a sort of visual discomfort due to two main causes (Iwata et al. 2011a). Glare is defined as a "*condition of vision in which there is discomfort* (discomfort glare) *or a reduction in the ability to see details or objects* (disability glare)*, caused by an unsuitable distribution or range of luminance, or to extreme contrasts*" (CEN 2011). The two causes of discomfort glare can therefore be described as:

- the total amount of light reaching the observer's eyes is too large. This means that even if the source was seen under a proper contrast with the background, the observer would feel discomfort as his or her eyes could not adapt to the light. This first cause of discomfort glare is called the saturation or absolute glare.
- the contrast between the viewing direction (e.g. visual task) and a bright spot in the field of view is too strong. Either the observer's eyes adapt to the relatively low luminance of the visual task causing the luminance of the glare source to be too high, or the observer's eyes are forced to

adapt to a bright environment and the visual task is perceived as too dim. This discomfort glare is called the contrast or relative glare.

These two causes, namely the saturation effect and the contrast effect, should be implemented in current discomfort glare indices. The distance and the position of the glare source in the field of view should also be taken into account as discomfort glare perception will vary whether the observer is far or close to the glare source and whether the glare source is in the central or lateral part of the field of view.

Hopkinson was the first to develop an index assessing the degree of perceived discomfort glare from windows with the Cornell equation (Hopkinson 1972). The index was then modified by Chauvel et al. (Chauvel et al. 1982) to become the Daylight Glare Index (DGI):

$$DGI = 10\log_{10}\left[0.478\sum_{i=1}^{n}\frac{L_{s,i}^{1.6}*\omega_i^{0.8}}{L_b+0.07\omega^{0.5}*L_{win}*P_i^{1.6}}\right] \tag{1}$$

where $L_{s,i}$ is the luminance of the glare source(s) [cd/m²]; ω_i the solid angle of the glare source(s); L_b the luminance of the background [cd/m²]; ω the solid angle of the window; L_{win} the luminance of the window [cd/m²]; P_i the position index relative to the glare source(s).

The DGI delivers a value between 16 and 28, being considered respectively as just perceptible discomfort glare and just intolerable discomfort glare. A contradiction appears already in the formula as the authors differentiate between the luminance of the source and the luminance of the window which is supposed be the glare source in the case of daylighting. This issue will be addressed in the following section.

Iwata et al. started developing another index to assess the degree of perceived discomfort glare from windows which was first called the Glare Sensation Vote (GSV) (Iwata et al. 1992a, Iwata et al. 1992b). The GSV index was revised some years later into the Predicted Glare Sensation Vote (PGSV) (Iwata and Osterhaus 2010, Tokura et al. 1996):

when $L_s/L_b > L_{ave}/L_{ad}$ (with $L_{ave} = E_v/\pi$),

$$PGSV_{contrast} = \log\frac{L_s^{3.2}\omega^{-0.64}}{L_b^{(0.61-0.79\log\omega)}} - 8.2 \tag{2}$$

when $L_s/L_b \leq L_{ave}/L_{ad}$ (with $L_{ave} = E_v/\pi$),

$$PGSV_{saturation} = \frac{-3.87}{1+(L_{ave}/1250)^{1.7}} + 3.3 \tag{3}$$

where L_b is the background luminance [cd/m²]; L_s the luminance of the source [cd/m²]; L_{ave} the mean luminance of the visual field [cd/m²]; L_{ad} the adaptation luminance [cd/m²]; E_V is the vertical eye illuminance [lux]; ω the solid angle of the window. The PGSV is the only index which accounts explicitly for the two causes of discomfort glare, namely the contrast and saturation glare.

The PGSV values are in the range from 0 to 3, meaning respectively just perceptible and just intolerable discomfort glare. The position index is not included in this formula because the glare source, thus the window, is expected to be always on the line of vision of the observer.

Wienold and Christoffersen (Wienold and Christoffersen 2006) also developed a discomfort glare index for daylighting, which is called the Daylight Glare Probability (DGP):

$$DGP = 5.87*10^{-5}E_V + 9.18*10^{-2}\log_{10}\left(1+\sum_{i=1}^{n}\frac{L_{s,i}^2*\omega_i}{E_V^{1.87}*P_i^2}\right) + 0.16 \tag{4}$$

where E_V is the vertical eye illuminance [lux]; $L_{s,i}$ the luminance of the glare source(s) [cd/m²]; ω_i the solid angle of the glare source(s); P_i the position index relative to the glare source(s).

The DGP, unlike other indices, expresses the probability that a person will be disturbed by glare. Its validated range goes from 0,2 to 0,8. A differentiating characteristic of DGP is that it uses the vertical illuminance at eye level as adaptation level. The formula is made of two main terms; the illuminance term standing for the saturation effect and the contrast term with the ratio between the glare sources and the adaptation level. The two terms will be analyzed in the following section.

These three indices are the most commonly used to predict discomfort glare from daylighting. They all have been developed through laboratory experiments. The experiment methodologies consist of asking the subjects to rate their perceived discomfort glare while measures of the luminous environment are taken. The parameters and the formula are defined to get the best correlation between the perceived and measured assessments of discomfort glare.

The same method, namely statistical inference, has been used so far to evaluate the influence of several factors on discomfort glare perception. To get rid of any interference between the studied factors, all the experimental conditions have to be controlled. This might be an important challenge when studying daylight glare from windows since daylight cannot be regulated. Similar lighting conditions can be achieved in laboratory experiments, by using a rotating cell (Rodriguez et al. 2016, Wienold and Christoffersen 2006), but hardly in field studies. Moreover, the notion of discomfort might be related to some psychological factors that, similarly, cannot be controlled. Another important issue of statistical analyses is the dependency of factors. Two factors are considered dependent on each other when the effect of one can be explained by the effect of the second. Therefore, only one of two dependent factors should be used as a variable influencing the perceived discomfort glare.

The factors later discussed in this paper are reported as having a potential influence on perceived discomfort glare. The criterion to discuss them is that at least one study investigated their effect, argumenting that the factor could have an influence on discomfort glare perception. But factors are not always studied under daylight conditions since some here-referenced experiments used artificial light or simulated windows as glare sources. The influence of a factor studied under artificial lighting conditions is assumed to be transferable to daylight conditions. Precautions should, however, be taken when interpreting the results as some studies (Borisuit et al. 2015, Laurentin et al. 2000) confirmed that people perceive discomfort glare differently whether it is from artificial lighting or daylighting.

All factors having been the object of at least one study as a potential variable of discomfort glare perception are reviewed and classified according to whether they are related to the lighting, to the context or to the observer. They are all listed in Tables 1 to 7, with the reference of the authors who investigated their effect on discomfort glare, listed in chronological order. To get a hint of the size of each study referenced, the *Subjects* column contains the number of subjects having taken part in the study. The *Evaluations* column gives the total number of glare evaluations if the study referenced is a field or laboratory experiment, namely a study involving subjective evaluations compared to physical measurements of glare. The total number of glare evaluations is the number of subjects times the number of condition(s) times the number of subjective glare evaluation(s) per condition. If the published study consists in a literature review or presents results from several past studies, an “R” letter is mentioned since the sample size and the number of glare evaluations cannot be displayed. If the study is based on a survey, which means that no measurements of glare are collected, an “S” letter is added next to the total number of participants in the survey. When the glare evaluation is made objectively, namely when glare perception is measured through a physiological response rather than evaluated by the subject (Iodice et al. 2017), an “O” letter is annotated. If the number of subjects, glare evaluations, or influence direction could not be determined from the publication, a “?” symbol is mentioned in place of the missing information. At last, a “P” letter means that the influence of the factor deduced from the publication does not refer to the study, but to the authors’ point of view.

Furthermore, the *Influence* column indicates whether an influence of the factor on discomfort glare perception is endorsed (V) or denied (X) by the study referenced. For all studies supporting the influence of a factor, an additional information is given in the *Influence direction* column. This column gives an overview of the agreement rate on the direction of the influence (increase or decrease of discomfort glare perception). For instance, two "A" letters for two studies having investigated the same factor mean that the two studies agree that discomfort glare perception is reduced or increased by the factor at stake.

In addition, an *Influence indicator* is proposed by the authors to express the likelihood –or unlikelihood– of the influence of the factor on discomfort glare perception. This indicator is based on the number of studies supporting or rejecting the influence of the factor as well as the sample size of the experiments. For more than two studies investigating an influencing factor, the influence indicator is defined as follows (definition of "studies" and "large experiments" see below the listing):

- almost certain if:
  ≥ 5 large experiments support the influence with a similar meaning
  & ≥ 10 studies support the influence with a similar meaning
  & 0 large experiment rejects the influence
  & ≤ 1 study rejects the influence
- more likely if:
  ≥ 2 large experiments support the influence with a similar meaning
  & ≥ 7 studies support the influence with a similar meaning
  & ≤ 1 study rejects the influence
- somewhat likely if:
  ≥ 2 studies support the influence with a similar meaning
  & ≤ 1 study rejects the influence
- inconclusive if:
  any other case
- somewhat unlikely if:
  ≥ 2 studies reject the influence
  & ≤ 1 study supports the influence
- less likely if:
  ≥ 2 large experiments reject the influence
  & ≥ 7 studies reject the influence
  & ≤ 1 study supports the influence
- almost certainly null if:
  ≥ 5 large experiments reject the influence
  & ≥ 10 studies reject the influence
  & 0 large experiment supports the influence
  & ≤ 1 study supports the influence

"Studies" include review studies, surveys, field and/or laboratory experiments.
"Large experiments" include field and/or laboratory experiments with sample size of 30 subjects or more.

For factors investigated by only one or two studies, the categories of the influence indicator have been defined as follows:

- somewhat likely if:
  ≥ 1 study support the influence with a similar meaning
  & 0 study rejects the influence
- inconclusive if:
  any other case
- somewhat unlikely if:
  ≥ 1 study reject the influence

& 0 study supports the influence.

This influence indicator is suggested in order to summarize the information and help define a prioritization list for future research. However, other characteristics than the sample size of the referenced studies should obviously be taken into consideration for the evaluation of the relevance of a study, such as the design of the experiment, the accuracy of the measurements, or the statistics. Since this information is either not available or not applicable for an objective comparison, the sample size was used as the only characteristic representative of the study relevance. This influence indicator should therefore be used with awareness of its restrictions and the classification into categories should not be interpreted as definitive or exclusive.

3. Description of daylight discomfort glare factors

3.1. Related to the lighting

3.1.1. Lighting environment

3.1.1.1. Luminance of the glare source

As stated previously, the luminance of a glare source is the source intensity in the observer viewing direction per unit area of the source. From the beginning, experiments conducted to better understand the basic factors of discomfort glare determined the glare source brightness to be one of the major variables (Luckiesh and Guth 1949, Petherbridge and Hopkinson 1950). In his work to summarize the established facts on discomfort glare, Einhorn acknowledged that discomfort glare increases if the source luminance increases (Einhorn 1969, 1979). A study of Ngai and Boyce (Ngai and Boyce 2000) confirmed the influence of the glare source luminance some years later. More recently, a study from Völker et al. in road lighting confirmed one more time the influence of the luminance of the glare source on discomfort glare perception (Völker et al. 2017).

The luminance of the glare source has already been considered as a discomfort glare index on its own. In this case, it was stated that the higher the luminance of the source, the more glare will be perceived (Carlucci et al. 2015). Other studies looked at the validity of the luminance of the window as a discomfort glare index in daylighting (Van Den Wymelenberg and Inanici 2016, Wienold and Christoffersen 2006). Moreover, glare source luminance thresholds have been suggested in different studies (Bülow-Hübe 2008, Dubois 2001, Lee et al. 2007, Shin et al. 2012), but until now, there has been no universal agreement on these threshold values. The use of unique luminance thresholds as discomfort glare indices should, however, be disregarded. Despite the correlation existing between the luminance of the glare source and discomfort glare perception, the luminance of the glare source alone cannot predict discomfort glare properly since other factors, such as the adaptation level (see § 1.1.2), the solid angle of the glare source (see § 1.2.1) or its position in the field of view (see § 1.2.2) have been acknowledged to significantly influence discomfort glare perception.

In most of today’s daylight glare indices, the luminance of the glare source is not the only variable needed to predict the visual discomfort due to glare but is certainly one of the most important. However, one essential aspect to pay attention to is the meaning of “the source” when we assess discomfort glare from daylight. The glare source is naturally thought to be the window when studying daylight glare. But some years ago, the most common interpretation of the daylight glare source was the luminance of the patch of sky seen through the window (Chauvel et al. 1982, Hopkinson 1972, Velds 2000). Another interpretation of the glare source luminance was the one of Tokura and Iwata who referred to the vertical luminance of the window measured at one point in the center of the window (Tokura et al. 1996). For the development of the China Glare Index (Huang and Wang 2016), Huang and Wang used the average luminance of the entire window. However, during the development of the DGP index, Wienold observed that the window luminance did not correlate with subjects’ discomfort glare perception (Wienold 2009a). Therefore, the bright spots in the field of view exceeding four times the task area average luminance were used as glare sources instead of the window. The task area does not contain areas of the window or any potential glare source in this case.

The non-uniformity of the window luminance should also be taken into account. The luminance distribution on a window plane will never be uniform in the real world as some parts will always be slightly brighter than others, due to the position of the sun or the clouds. Some obstacles in front of the window can even create shadows, making the range of luminance on the window plane larger. The orientation of the room can also play a role in the non-uniformity of the window. According to the orientation and latitude of a building, more direct sunlight will hit some of the building facades while other facades will never endure direct sun rays. In a Dutch office building, subjects reported more discomfort glare from windows facing South than East or West. The north orientation was the one causing the least problems with discomfort glare due to direct sunlight (Hellinga 2013). Moreover, several studies have pointed out that perceived discomfort glare from non-uniform sources is different than from uniform sources. Waters et al. observed that when a subject looks directly to a glare source, non-uniform sources are perceived as more glaring than uniform sources. On the contrary, when the glare source is in the observer's periphery, non-uniform sources are perceived as less glaring (Waters et al. 1995). Velds partly confirmed this observation as she noticed that when asking subjects to rank the perceived visual discomfort, discomfort glare from non-uniform sources was higher than from uniform sources with identical average luminance (Velds 2000). Moreover, in a study with real windows, N. Tuaycharoen pointed out that a view with a wide range of luminance would result in higher perceived discomfort glare than a more uniform view (Tuaycharoen and Tregenza 2007). On the opposite, E. Mochizuki observed in an experiment with a real window covered with a screen that large glare sources with a non-uniform luminance distribution induced less discomfort glare than uniform glare sources (Mochizuki and Iwata 2005). This finding was supported by Eble-Hankins and Waters, as in their experiment, non-uniform glare sources were rated as less discomforting than uniform glare sources (Eble-Hankins and Waters 2009). However, it was also concluded from that experiment that the contrast spatial frequency of the non-uniform glare sources had a significant effect on discomfort perception, and that this effect would vary according to the position of the glare source in the field of view. This last observation could be an explanation for the contradiction found between the different studies. More recently, several studies having observed an influence of the non-uniformity of artificial glare sources, such as LEDs, on discomfort glare perception, are working on modifications and alternatives of the Unified Glare Rating (UGR) index for non-uniform light sources (Cai and Chung 2012, Donners et al. 2016, Geerdinck et al. 2014, Scheir et al. 2015, Scheir et al. 2017, Tashiro et al. 2015, Yang et al. 2017). Hence, the non-uniformity of a window should be taken into account, excluding the average luminance of the window as the luminance of the glare source definition.

Currently, glare sources in a daylit scene are generally defined as the bright spots in the field of view. The challenge still lies in the definition of an objective and universal method to identify these spots (Clear 2013). A first method was implemented in findglare (Ward 1993). This method identifies as glare sources every spot in a High Dynamic Range (HDR) image being seven times higher than the average luminance of this image. More recently, another method was developed by Wienold and Christoffersen to identify glare sources (Wienold and Christoffersen 2006). The algorithm of the tool Evalglare recommended for typical office situations calculates the average luminance of a given zone, such as the task area, from an HDR image and points up the spots having luminance x-times higher than the average luminance of the reference zone (Wienold 2009b). The task zone should not contain areas of the window and, therefore implicitly, any other potential glare source. These spots can then be evaluated as glare sources.

The most advanced and reliable determination method of glare sources seems to be so far the task-threshold-method. This is partly due to the fact that this method takes into account the adaptation process of the eye, but also considering that in a daylit environment, not only the window can be a source of glare. Daylight reflections might also generate discomfort and should therefore be considered as glare sources as well. This method can, however, lose robustness when the glare source is within the defined task area, which was explicitly excluded in the original publication of Wienold and Christoffersen (Wienold and Christoffersen 2006). In this case, the glare identification threshold is dramatically increased and the method was demonstrated as being not sensitive enough for glare sources detection (Van Den Wymelenberg and Inanici 2014). This could be solved by applying other identification methods in this particular situation, such as a fixed glare identification threshold. Moreover, the task-threshold-method requires the arbitrary definition of a "threshold multiplier", namely a factor by which the average luminance of the task area has to be multiplied to set the glare detection threshold. Depending on the choice of this threshold, the results of some of the glare metrics were shown to vary significantly (Sarey Khanie et al. 2015).

In conclusion, the influence of the glare source luminance on perceived discomfort glare is not a matter of debate anymore. Recent studies confirm the high correlation existing between the luminance of a glare source and the perceived degree of discomfort glare (Chen et al. 2015, Huang et al. 2017, Lin et al. 2014, Rodriguez and Pattini 2014, Tyukhova 2015), although this correlation is not large enough to explain discomfort glare perception in entirety. The glare source luminance is the most decisive factor when assessing discomfort glare, but should not be used as a discomfort glare index on its own. This is due to the other factors playing a role in discomfort glare perception, such as the adaptation level. Moreover, the existing and commonly applied methods to detect glare sources nowadays lack robustness when applied to glare metrics only relying on glare sources. Further research is therefore needed to clarify the definition of discomfort glare sources. In the meanwhile, an efficient way of validating the glare sources detection made by an algorithm is by examining each image visually.

3.1.1.2. Adaptation level

The adaptation level can be defined as the light level in a room which sets the adaptation of the eyes to the luminous environment. According to the lighting conditions, the pupil either constricts or dilates, regulating the intensity of light coming on the retina.

Stringham et al. investigated the effect of subject's pupil diameter on discomfort glare perception of twenty-six subjects and found out a negative relationship between the two (Stringham et al. 2011). The statistical results indicated that the smaller the pupil diameter was, the higher the discomfort glare was perceived, despite a smaller amount of light reaching the retina. This last result might be paradoxical as it can be assumed that the wider the pupil diameter, the larger the amount of light entering the eyes and the higher the perceived discomfort glare. But the variation of the pupil size should not be looked at as a cause of discomfort glare but as a consequence. The pupil diameter responds to the surrounding luminous conditions. Therefore, when the light in the field of view is very bright, the pupil diameter tends to narrow and filter the amount of light in order to protect the retina.

To allow the eye to adjust to the lighting conditions, a certain time, called the adaptation time, is needed. Hopkinson was the first to study whether the duration of exposure to a glare source has an influence on discomfort glare perception (Hopkinson 1957). The results of his experiment showed that momentary exposure produced more discomfort from glare than continuous exposure. This is not surprising since the momentary exposure in this study was only a few seconds long, which is a very short adaptation time. The duration time of exposure to large glare sources was studied by Iwata et al. in an experiment with a simulated window (Iwata et al. 1990). They observed that a glare source was already perceived as less glaring thirty seconds after exposure than immediately after it. Sivak et al. also studied the influence of exposure duration on discomfort glare perception in road lighting (Sivak et al. 1997). They observed that the longer was the exposure duration –with the shortest exposure being 0.125 and the longest 2 seconds-, the higher was the glare rating. More recently, in a study of Geerdinck, it was observed that the first assessment of glare was generally a good predictor for the glare perception after one hour, suggesting that a very long exposure time would not influence discomfort glare perception (Geerdinck 2012). This is the reason why in all subjective glare assessment experiments, subjects should be given some time to adapt to ambient lighting conditions.

Two physical quantities have been used to evaluate the adaptation level in discomfort glare indices: the vertical illuminance at eye level and the background luminance.

- Vertical illuminance at eye level

The illuminance is the total amount of the luminous flux reaching a surface, related to the surface area. The vertical illuminance at eye level provides a measure of the amount of light reaching the eyes of the observer. When included in a metric to stand for the adaptation level, the vertical illuminance takes into account the glare sources.

The CIE Glare Index (CGI) was the first glare metric to include the term of vertical illuminance at eye level instead of background luminance as the adaptation level (Einhorn 1979). The illuminance of the scene was also used as an independent variable to evaluate discomfort glare in a study of Ngai and Boyce instead of the background luminance (Ngai and Boyce 2000). More recently, the vertical illuminance at eye level was referred to in the DGP formula (Wienold and Christoffersen 2006). The illuminance is included in the denominator of the contrast term to account for the adaptation level.

- Background luminance

The background luminance, although more often used in the beginning of discomfort glare research than the vertical illuminance, has been a controversial factor due to the uncertainty about its determination. The CIE definition of the background luminance is "*the uniform luminance of the whole surroundings which produces the same illuminance on a vertical plane at the observer's eye as the visual field under consideration excluding the glare sources*" (CIE 1995). But in the literature, the definition of the background luminance is not always explicit and might be interpreted differently.

Luckiesh and Guth first studied the effect of adaptation level by using an "*extended visual field of uniform brightness"* named the field brightness (Luckiesh and Guth 1949). In Petherbridge and Hopkinson's first laboratory experiment on discomfort glare (Petherbridge and Hopkinson 1950), the adaptation level is defined as the "*general background brightness of the surroundings*", which may suggest that the glare sources are included. Later, Hopkinson invoked the "*surround luminance*" as the adaptation level in an expression assessing discomfort glare (Hopkinson 1957). Although no clear explanation is given to determine this surround luminance, it can be deduced that it excludes the glare sources. In the Daylighting book, the background luminance is referred to in the glare index as the luminance of the adapting visual field, which is a "*function of the average luminance of the room interior*" (Hopkinson et al. 1966). In a later expression of the glare index, the background luminance is further defined by Hopkinson as "*the average luminance of the visual field in which the glare sources are seen*" (Hopkinson 1972). In the current version of DGI by Chauvel et al., the background luminance is referred as "*the average luminance of the interior surfaces of the room which contribute to the visual field of an occupant of the room*" (Chauvel et al. 1982). From the explanations provided in the appendices of this last reference to measure the background luminance, the glare sources are assumed as not being included in the background luminance evaluation. On the other hand, Hopkinson and Chauvel et al. also mentioned that besides the background luminance, the window luminance should be added in the denominator of the glare index expression, since "*the light from the large glaring light source is seen itself to affect the average luminance of the visual field*" and therefore increase the adaptation of the eye (Chauvel et al. 1982, Hopkinson 1972). In a study on discomfort glare from daylight, Tokura et al. resorted to the background luminance as the average luminance in the field of view deduced from the vertical illuminance at eye level, minus the luminance of the window (Tokura et al. 1996). On the other hand, when working on a new version of the DGI index, Nazzal recommended the use of the "*adaptation luminance*" instead of background luminance (Nazzal 2005). In this case, the adaptation luminance includes the luminance of the window and is evaluated from the vertical illuminance. Kim and Koga recommended the use of the immediate background luminance, defined as "*the luminance of the local background containing the source when the entire background consists of numerous local backgrounds*" instead of the background luminance (Kim and Koga 2004). In road lighting, the average luminance of the road seems to be used as the adaptation luminance, although this is refuted by Völker et al. (Völker et al. 2017).

Besides the fact that there is some confusion about what should be evaluated as the background luminance (Clear 2013), authors seem to disagree on the importance of its effect on discomfort glare perception. In a study with real windows, Iwata made the assumption that background luminance had a small influence on the degree of discomfort glare (Iwata et al. 1992b). Moreover, Saur could not observe any influence of an increased background luminance on discomfort glare perception (Saur 1969). On the other hand, Kim and Koga concluded from their laboratory experiment on discomfort glare that "*the background luminance is one of the main factors affecting the degree of discomfort glare*" (Kim and Koga 2004). They added that the threshold luminance bearable for the subjects was mainly determined by the immediate background luminance. Recent studies also confirmed that discomfort glare perception can be significantly decreased with the addition of a luminous surround (Lin et al. 2014, Sweater-Hickcox et al. 2012).

Although nowadays, the background luminance is generally interpreted as the average luminance of the visual field excluding the glare sources (Bellia et al. 2008, Cantin and Dubois 2011, Carlucci et al. 2015, Jakubiec and Reinhart 2011, Kent 2016, Tyukhova 2015), other interpretations of this background luminance still occur, such as the average luminance of the visual field including the glare sources (Huang and Wang 2016), or the average luminance of the visual task (Hirning et al. 2014). There is thus a need to clarify what exactly the background luminance is.

The CIE defines the background luminance as the indirect vertical illuminance at eye level divided by π (CIE 1995). Kim and Kim used a similar definition of the background luminance –replacing the indirect vertical illuminance by the total vertical illuminance- as an estimation of the average luminance of the field of view (Kim and Kim 2012). However, per definition, the vertical illuminance considers the cosine of the angle of incidence. Therefore, CIE definition is mathematically not equal to the background average luminance due to the ponderation with the cosine of the angle of incidence. For "almost homogeneous background" environments, the difference between the mathematical average and the CIE definition is small, and in practice, without impact. But it should be noted that software tools may calculate the background average luminance differently (e.g. by calculating the mathematical average luminance without ponderation with the cosine of the angle of incidence). From the CIE definition of the background luminance, it follows that the main difference between the vertical illuminance at eye level and the background luminance is the inclusion or exclusion of the glare sources in the evaluation of the term. Moreover, in most discomfort glare indices for large glare sources using the background luminance, the luminance of the glare source is added in the denominator with a certain weight to account for its effect on the observer's eyes adaptation. Therefore, in practice, both methods are similar, except for the weighting of the glare source luminance and the π constant. Fisekis et al. compared the DGI values for two interpretations of the background luminance, namely on one hand the average luminance excluding the glare sources, and, on the other hand, the average luminance of the whole surroundings given by the division of the vertical illuminance by π (Fisekis et al. 2003). Although the double contribution of the source in the adaptation term was considered as a theoretical issue when using the second interpretation, it was concluded that excluding the glare source from the background luminance offered a better prediction of subjects' discomfort glare assessments.

In conclusion, what should be taken into consideration is that large glare sources covering a wide area in the field of view will change the adaptation level. The adaptation level of the eyes in the case of small sources is mainly influenced by the background luminance. In the case of large sources, the interaction of the glare source and the surroundings plays a role in the eyes adaptation process, as explained by Petherbridge and Hopkinson in 1950 (Petherbridge and Hopkinson 1950). In the current version of PGSV index, both approaches are used (Iwata et al. 2011b); on one hand, the background luminance excluding the glare sources is used in the term representing the contrast glare, and on the other hand, the adaptation luminance, evaluated from the vertical illuminance including the glare sources, is used in the term for the saturation glare type.

3.1.1.3. Contrast effect

One of the two types of discomfort glare is due to the contrast between the glare source and the adaptation level. Hopkinson came to this conclusion years before, distinguishing the contrast effect leading to the relative discomfort glare from the saturation effect leading to the absolute discomfort glare (Hopkinson et al. 1966). In most of current discomfort glare indices, the contrast effect is expressed as a ratio. The ratio between the glare source luminance and the adaptation level appears for instance in DGI (Chauvel et al. 1982), PGSV (Iwata et al. 2011b) and DGP (Wienold and Christoffersen 2006), often associated with the solid angle of the glare source (§ 1.*ii*.a) and the position index (§ 1.*ii*.b).

Chauvel et al. acknowledged the interaction between the luminance of the sky and that of the surroundings as being one of the two most important parameters in the assessment of glare from windows (Chauvel et al. 1982). Recently, Hirning et al. recommended the use of the ratio between the background and the window (Hirning et al. 2017) as this ratio is said to be a more sensitive parameter of discomfort glare perception than the ratio between the window and the task. On the other hand, a study based on a re-evaluation of an existing dataset suggests that there are certain definitions of luminance ratio, for instance the luminance ratio between the task area and the immediate surround, which have better correlations with subjective glare assessments in offices with daylighting (Hansen et al. 2016). In Carlucci et al.'s review of glare indices, the luminance ratio between the central zone of the field of view and the surroundings represents a discomfort glare index in itself (Carlucci et al. 2015). In the case of core zones of open-plan offices where discomfort glare is mainly due to contrast, it was also demonstrated that the ratio between maximum window luminance and visual task luminance performed much better at predicting discomfort glare than any other glare metrics (Konis 2014). Moreover, several studies have been carried out to determine the maximum luminance ratio between the source and the background in order to prevent discomfort glare (Linney 2008, Osterhaus 2009, Veitch and Newsham 2000).

3.1.1.4. Saturation effect

The second type of discomfort glare, the absolute glare, is occurring when the amount of light of a glare source exceeds a certain threshold, inducing glare regardless of the contrast in the visual field. This saturation effect has often been evaluated by the vertical illuminance at eye level. Although this term was never included in the factors influencing the perceived discomfort glare by the CIE, it seems that some authors still relate eye illuminance to visual discomfort caused by glare.

In 1966, Bourassa and Wirtschafter concluded from an experiment that the discomfort glare threshold is directly linked to the total illuminance on the eyes (Bourassa and Wirtschafter 1966). Later on, Sivak et al. found out that illuminance at eye level strongly influences discomfort glare ratings (Sivak et al. 1989). Similarly, during an experiment on discomfort glare from a real window, Iwata et al. observed that the vertical illuminance at eye level, or the amount of light entering the eyes, had the largest effect on the glare sensation vote (Iwata et al. 1992b). Velds also found a good correlation between glare assessments and measured vertical illuminance orientated towards the window (Velds 2000). Kim and Kim used the illuminance at eye level to evaluate an average luminance in the visual field (Kim and Kim 2012). They observed that the logarithm value of the so-calculated average luminance was in proportional relationship with the perceived discomfort glare values from the entire window. Consequently, they proposed an equation to determine a glare threshold in which the only variable is the vertical illuminance at eye level. The DGP also includes a specific term representing the absolute glare with the vertical illuminance at eye level (Wienold and Christoffersen 2006). And the current PGSV index differentiates between contrast and saturation effects by offering two distinct expressions (Iwata et al. 2011b). In road lighting, the vertical illuminance has been several times acknowledged to be a significant variable influencing discomfort glare rating (Sivak et al. 1997, Völker et al. 2017).

To conclude this section, both glare types, the absolute and contrast glares, should be considered when evaluating glare from daylight. From the existing discomfort glare metrics, only PGSV and DGP are considering both types, either through two independent terms or with two different expressions. The DGI index, on the other hand, only considers the contrast effect. Therefore, it was demonstrated that when the glare source covers the entire field of view, DGI cannot properly predict discomfort glare (Inoue and Itoh 1989, Iwata and Tokura 1998). The issues of integration of both glare effects as well as source and background luminance distinction have already been discussed in the past (Clear 2013). Jakubiec and Reinhart also suggested that the prediction of visual discomfort should integrate several metrics since a single metric cannot cover all situations (Jakubiec and Reinhart 2016). Furthermore, in the case of discomfort glare from daylight, more rigor regarding the definition of the glare sources and the adaptation level is required, as well as a deeper understanding of these terms.

Table 1. Factors related to the lighting environment having a potential influence on discomfort glare perception from daylight. *Author(s)*/*Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Luminance of the glare source	Luckiesh & Guth	1949	50	50	V	A	**ALMOST CERTAIN**
	Petherbridge & Hopkinson	1950	6	?	V	A	
	Einhorn	1969/1979	R	R	V	A	
	Hopkinson	1972	R	R	V	A	
	Chauvel et al.	1982	R	R	V	A	
	Waters et al.	1995	12	288	V	?	
	Tokura et al.	1996	240	2400	V	A	
	Ngai & Boyce	2000	16	1280	V	A	
	Velds	2000	84	656	V	A	
	Dubois	2001	R	R	V	A	
	Mochizuki & Iwata	2005	19	114	V	?	
	Lee et al.	2007	42	630	V	A	
	Tuaycharoen & Tregenza	2007	168	600	V	?	
	Bülow-Hübe	2008	R	R	V	A	
	Eble-Hankins & Waters	2009	67	1608	V	?	
	Wienold	2009a	76	349	V	A	
	Cai & Chung	2012	?	536	V	?	
	Shin et al.	2012	48	2400	V	A	
	Clear	2013	R	R	V	A	
	Hellinga	2013	558	S	V	?	
	Geerdinck et al.	2014	42	668	V	?	
	Lin et al.	2014	12	864	V	A	
	Rodriguez & Pattini	2014	25	200	V	A	
	Carlucci et al.	2015	R	R	V	A	
	Chen et al.	2015	8	576	V	A	
	Scheir et al.	2015	R	R	V	?	
	Tashiro et al.	2015	8	?	V	?	
	Tyukhova	2015	47	1692	V	A	
	Donners et al.	2016	82	NA	V	?	
	Huang & Wang	2016	R	R	V	A	
	Van Den Wymel. & Inanici	2016	48	1379	V	A	
	Huang et al.	2017	18	324	V	A	
	Scheir et al.	2017	20	1440	V	?	
	Völker et al.	2017	R	R	V	A	
	Yang et al.	2017	20	3120	V	?	
Adaptation level	Luckiesh & Guth	1949	10	30	V	A	**ALMOST CERTAIN**
	Petherbridge & Hopkinson	1950	6	?	V	A	
	Hopkinson	1957a	3	?	V	?	
	Hopkinson	1957b	R	R	V	A	
	Hopkinson et al.	1966	R	R	V	A	
	Einhorn	1969/1979	R	R	V	A	
	Saur	1969	?	168	X		
	Hopkinson	1972	R	R	V	A	
	Chauvel et al.	1982	R	R	V	A	
	Iwata et al.	1990	80	800	V	?	
	Iwata et al.	1992b	46	552	V	A	
	Tokura et al.	1996	240	2400	V	A	
	Sivak et al.	1997	16	1600	V	?	
	Ngai & Boyce	2000	16	1280	V	A	
	Fisekis et al.	2003	10	133	V	A	
	Kim & Koga	2004	25	375	V	A	
	Nazzal	2005	R	R	V	A	
	Wienold & Christoffersen	2006	76	349	V	A	
	Stringham et al.	2011	26	468	V	A	
	Geerdinck	2012	42	840	V	?	
	Sweater-Hickcox et al.	2012	10	200	V	A	
	Kim & Kim	2012	108	4428	V	A	
	Clear	2013	R	R	V	A	
	Lin et al.	2014	12	864	V	A	
	Tyukhova	2015	47	1692	V	A	
	Völker et al.	2017	R	R	V	A	

Contrast effect	Hopkinson et al.	1966	R	R	V	A	**ALMOST CERTAIN**
	Chauvel et al.	1982	R	R	V	A	
	Veitch & Newsham	2000	94	94	V	A	
	Wienold & Christoffersen	2006	76	349	V	A	
	Linney	2008	48	144	V	A	
	Osterhaus	2009	R	R	V	A	
	Iwata et al.	2011b	12	108	V	A	
	Konis	2014	14	523	V	A	
	Carlucci et al.	2015	R	R	V	A	
	Hansen et al.	2016	76	428	V	A	
	Hirning et al.	2016a	341	341	V	A	
Saturation effect	Bourassa & Wirtschafter	1966	3	15	V	A	**MORE LIKELY**
	Sivak et al.	1989	12	1080	V	A	
	Iwata et al.	1992b	46	552	V	A	
	Sivak et al.	1997	16	1600	V	A	
	Velds	2000	84	656	V	A	
	Wienold & Christoffersen	2006	76	349	V	A	
	Iwata et al.	2011b	12	108	V	A	
	Kim & Kim	2012	108	4428	V	A	
	Völker et al.	2017	R	R	V	A	

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

3.1.2. Interaction between the observer and the glare source

3.1.2.1. Size of the glare source as seen by the observer

Although there is a clear definition of a glare source missing, the size of it is defined by the solid angle which expresses the width of the source as it appears to the observer eyes. Distance from the window is therefore impacting the way we perceive discomfort glare. The further away we are from the window, the smaller the solid angle subtended at the eye and the lesser is the perceived discomfort glare. Velds confirmed this effect in her PhD thesis as she observed that subjects at the back of the room felt in general less glare than the ones near the facade under similar lighting conditions (Velds 2000). Aries et al. also concluded from their survey on subject's well-being at work that the further the subject sat from the window, the more satisfied he/she was since he/she experienced less discomfort glare (Aries et al. 2010).

The solid angle has always been included in discomfort glare formulas to account for the apparent area of the glare source (Einhorn 1969, 1979, Luckiesh and Guth 1949, Petherbridge and Hopkinson 1950). Since a glare source is not clearly defined, this indistinctness impacts also the usage of the size of a glare source. Hopkinson mentioned the solid angle subtended by the patch of sky seen through the window to refer to the glare source size (Hopkinson 1972) and was followed by Chauvel et al. some years later (Chauvel et al. 1982). In the first version of the GSV index, the source size is evaluated as the solid angle subtended by the entire window to the point of observation (Tokura et al. 1996). In the DGP index, the solid angle of a glare source is the sum of the solid angle of the pixels in a HDR image belonging to this glare source (Wienold and Christoffersen 2006). As already mentioned, more research is required to build a robust method to define glare sources so that their luminance and solid angle can be evaluated accurately.

The solid angle of the glare source helps to describe the perceived degree of glare according to the distance of the observer from the source and the size of the source. It was assumed that discomfort glare perception has a negative linear relationship with the distance from the window and a bell-shaped relationship with the size of the window (Boubekri and Boyer 1992). Recently, Rodriguez and Pattini concluded from an experiment with a simulated window that the source size had the same impact on perceived discomfort glare than the luminance of the source (Rodriguez and Pattini 2014). Recent studies also confirmed that an increased solid angle produced more discomfort from glare (Lin et al. 2014, Tyukhova 2015).

3.1.2.2. Position of the glare source as seen by the observer

To account for the difference in the perception of a glare source in relation to its position in the field of view, the position index P was introduced by Luckiesh and Guth in their study on discomfort glare from small sources (Luckiesh and Guth 1949). The index is a function of the vertical and angular displacement of the source from the line of vision of the observer. Although Petherbridge and Hopkinson did not refer to Guth position index in their experiments, they acknowledged the influence of the displacement of the source from the direction of view on discomfort glare perception (Petherbridge and Hopkinson 1950). Later, while Einhorn endorsed the position index as one of the four main variables influencing discomfort glare perception (Einhorn 1969, 1979), Hopkinson described it as a function of the angles between the direction of the light source and the observer's viewing direction (Hopkinson 1972). Whereas in Chauvel et al.'s DGI, the position index was determined thanks to the angles subtended by the glare source in the horizontal and vertical directions which were reported on a diagram (Chauvel et al. 1982). More recently, the vertical position of the glare source in the field of view was again acknowledged as influencing discomfort glare perception from laboratory studies (Chen et al. 2015, Eble-Hankins and Waters 2009, Huang et al. 2017, Lin et al. 2014, Tyukhova 2015). In road lighting as well, it was recognized that the larger the angle from the line of sight, the smaller the glare effect (Völker et al. 2017).

The PGSV index (Tokura et al. 1996) does not include the position index, which means that it only predicts discomfort glare perceived in the observer's line of sight. However, in a later study, Iwata and Tokura, investigated the difference between sensitivity to a glare source positioned above or below the line of vision (Iwata and Tokura 1997). They deduced, with the help of Einhorn, a new analytical equation applicable to glare sources located below the line of vision as they observed glare sensation was higher than when the source is in the upper part of the field of view. A modified position index was developed including two different expressions reflecting the upper and lower part of the field of view. The DGP index uses this modified position index (Wienold and Christoffersen 2006), namely Guth's position index for sources located in the upper part of the field of view and Iwata-Einhorn's for the lower part.

The glare source configuration, which, in the case of discomfort glare from daylight, might have been interpreted as the window configuration, should also be mentioned as a potential influencing factor. Although Chauvel et al. did not find an effect of windows shape on discomfort glare perception (Chauvel et al. 1982), Iwata et al. observed that a simulated rectangular window did not generate the same glare perception to the observers than a square simulated window, depending on the direction of the view (Iwata et al. 1992a). However, some years later, Hellinga confirmed that "*glare perception was not related to the different window configurations*" (Hellinga 2013).

The position of the glare source is considered as a factor influencing discomfort glare perception since existing literature agrees on the fact that the further the glare source from the line of vision, the less the perceived discomfort. Currently, Guth's position index is used in most existing glare metrics, for daylight and electric light. Further research on the combination of Guth's and Iwata-Einhorn's position index would be needed to confirm its validity. Recently, several laboratory studies (Kim et al. 2009, Kim and Kim 2010, 2011, Kim and Koga 2005) were conducted to develop a new position index in which the difference between sensitivity to a glare source positioned above or below the line of vision is implemented. However, there is an inconsistency between the formula and the graph published.

Table 2. Factors related to the interaction between the observer and the glare source having a potential influence on discomfort glare perception from daylight. *Author(s)/Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Size of the glare source as seen by the observer	Luckiesh & Guth	1949	10	50	V	A	**ALMOST CERTAIN**
	Petherbridge & Hopkinson	1950	6	?	V	A	
	Einhorn	1969/1979	R	R	V	A	
	Hopkinson	1972	R	R	V	A	
	Chauvel et al.	1982	R	R	V	A	
	Boubekri & Boyer	1992	40	40	V	A	
	Tokura et al.	1996	240	2400	V	A	
	Velds	2000	84	656	V	A	
	Wienold & Christoffersen	2006	76	349	V	A	
	Aries er al.	2010	333	S	V	A	
	Lin et al.	2014	12	864	V	A	
	Rodriguez & Pattini	2014	25	200	V	A	
	Tyukhova	2015	47	1692	V	A	
Position of the glare source as seen by the observer	Luckiesh & Guth	1949	10	270	V	A	**ALMOST CERTAIN**
	Petherbridge & Hopkinson	1950	6	?	V	A	
	Einhorn	1969/1979	R	R	V	A	
	Hopkinson	1972	R	R	V	A	
	Chauvel et al.	1982	R	R	V	A	
	Iwata & Tokura	1997	71	2130	V	A	
	Kim & Koga	2005	25	2400	V	A	
	Wienold & Christoffersen	2006	76	349	V	A	
	Eble-Hankins & Waters	2009	67	1608	V	A	
	Kim et al.	2009	27	1053	V	A	
	Kim & Kim	2010	32	2144	V	A	
	Kim & Kim	2011	8	1536	V	A	
	Lin et al.	2014	12	864	V	A	
	Chen et al.	2015	8	576	V	A	
	Tyukhova	2015	47	1692	V	A	
	Huang et al.	2017	18	324	V	A	
	Völker et al.	2017	R	R	V	A	

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

3.2. Related to the context

3.2.1. Environment characteristics

3.2.1.1. Spectrum and color temperature

As the spectral power distribution or the correlated color temperature of daylight can vary with the type of glazing, as well as the weather and time of the day, it is worth studying the influence of these parameters on discomfort glare perception.

As a matter of fact, it has been demonstrated several times that the color temperature of the light could have an impact on discomfort glare perception. In several experiments on car headlights and on LED lights, the glare source or the background color was shown to have a significant influence on discomfort glare perception, as blueish light was always perceived as more discomforting (Berman et al. 1995, Flannagan 1999, Kimura-Minoda and Ayama 2011, Sivak et al. 2005, Sweater-Hickcox et al. 2012, van Bommel 2015, Yang et al. 2016). Moreover, some authors have reinforced this observation by showing that glare sources with a large amount of short-wavelengths resulted in higher perceived discomfort glare (Akashi et al. 2013, Bullough 2009, Fekete et al. 2009, Sivak et al. 2005, Stringham et al. 2003, Yang et al. 2016). However, it has recently been demonstrated that metameric light sources, namely sources having different spectral power distributions but the same correlated color temperature, did not lead to different discomfort glare perceptions (Huang et al. 2017). This last observation implies that the spectral power distribution is not directly influencing discomfort glare perception, but the correlated color temperature is. The influence of the correlated color temperature of the light, namely the apparent color of the light, on discomfort glare has recently been demonstrated again in several studies (Chen et al. 2015, Lin et al. 2014, Völker et al. 2017, Wei et al. 2014, Zhang et al. 2013). But one study from Ko and Choi could not observe an influence of the color temperature of the glare source on discomfort glare perception (Ko and Choi 2017).

Subsequently, glazing that filters some parts of the daylight spectrum causing it to appear colored, such as electrochromic glazing, might have an influence on discomfort glare perception. More research is required to extend the results of these studies on artificial glare sources for discomfort glare from filtered daylight.

3.2.1.2. View direction and position

By changing our view direction or our position, the luminance distribution across the field of view is altered. Some researchers currently focus on integrating this new variable by developing either view-independent or gaze-driven glare evaluation methods. The influence of view direction and position of the subject on his or her discomfort glare perception has indeed already been observed (Hirning et al. 2016, Sekihara et al. 2016).

The first step to take into account view direction into discomfort glare evaluation was made by Jakubiec and Reinhart with the 'adaptive zone' (Jakubiec and Reinhart 2011). They concluded that for one workplace, only one glare prediction should be considered, which is the lowest glare prediction in either of all directions. This is due to the fact that an occupant will select the least disruptive view direction and position within the adaptive zone to minimize the occurrence of discomfort glare for a particular workplace (Jakubiec and Reinhart 2016). Another study, using only simulations and no subjective glare evaluations, proposed a new glare evaluation method which should yield comparable results to the DGP-based approach (Torres and Lo Verso 2015). This new evaluation is based on the cylindrical illuminance, namely the average of all vertical illuminances in all directions around a considered point, and has therefore the advantage of making the glare analysis view-independent. Vasquez et al. looked at the time spent by a subject in several view directions and the corresponding glare metrics values (Vásquez et al. 2016). Although they could not find any relationship between the two –probably due to the other factors influencing the view direction such as the visual interest–, they observed that the subject seemed to alternate the sight between more and less stressful view scenarios. At last, a study from Sarey Khanie et al. used a more sophisticated method with a mobile eye tracker and 270° HDR images in order to derive a gaze-centered luminance map (Sarey Khanie et al. 2017). A significant difference was noticed between the gaze-driven and fixed-gaze glare evaluation method when participants' gaze was exploring the surroundings independently of the task. In the case of a scene with high luminance values, the view seems to avoid extreme regions containing discomfort glare. At last, a recent study from Iwata et al. showed that there was no difference in discomfort glare perception according to the position of the subjects towards the window –facing or perpendicular– (Iwata et al. 2017a).

As these studies are quite recent, more insight is needed on the influence of gaze and position on discomfort glare perception. Also, a comparison between gaze-driven or view-independent glare evaluation methods would be necessary as it was acknowledged in the case of road lighting that glare evaluation methods with a fixed view lead to higher glare rating than methods with a free view (Völker et al. 2017).

3.2.1.3. Attractiveness of the view through the window

As mentioned years ago, the view through the window affects the judgment of discomfort glare from windows (Chauvel et al. 1982). "*There is an underlying conflict in making an assessment in a highly glaring situation if the window has a pleasant view or one with a great deal of interesting information*" (Hopkinson 1972).

One of the first authors who showed a real effect of the view through the window on discomfort glare perception is Osterhaus (Osterhaus 2001). During a study conducted to identify the factors playing a role in the assessment of visual comfort in daylit office spaces, it was deduced from the results that discomfort glare might be less of an issue when there is an appealing view through the window. Likewise, Tuaycharoen and Tregenza conducted a large study on the effect of the view on perceived discomfort glare from windows (Tuaycharoen and Tregenza 2005). Their experiments showed that the tolerance to discomfort glare is increased when the source is an interesting image rather than a blank screen, and especially increased when the view contains elements of natural scenes instead of urban or man-made views. In order to validate their results, they conducted their experiments with real windows and under real daylighting conditions (Tuaycharoen and Tregenza 2007). They concluded that the best ranked view, namely the most attractive one, is significantly less glaring than the last ranked one which, in turn, is less glaring than the blank view. Moreover, views with natural scenes appeared to be significantly less glaring than urban views and views with only one 'distance layer' produced more glare than views with three 'distance layers'. A last experiment of Tuaycharoen at Naruesan University in Thailand produced similar conclusions (Tuaycharoen 2011).

More authors studied the influence of window views on discomfort glare perception. Shin et al. observed from an experiment with a simulated window that tolerance to discomfort glare was higher for distant views including the sky layer than for near views and, surprisingly, lower for natural views than for man-made or urban views (Shin et al. 2012). From these observations, a new model to predict discomfort glare was suggested in which four characteristics of the view were included (Kim et al. 2012). Hellinga concluded in her PhD thesis that "*the outside view might only affect the perceived amount of glare if it is very good or very bad, because otherwise other variables play a more important role*" (Hellinga 2013) as no statistically significant correlation was found between occupant's subjective impression of an outside view and their sensation of glare. Similarly, in two other studies on discomfort glare under daylight conditions (Hirning et al. 2014, Iwata et al. 2017a), no statistically significant correlation was found with the view attractiveness. Since many subjects were satisfied with their view content, this lack of expected result could be interpreted in the same way as in Hellinga's thesis, which means that the view through the window only influences discomfort glare sensation when it is very good or very bad.

What should also be considered is the impact that the view through the window can have on the subject's acceptance towards discomfort glare. Wienold noticed during his PhD experiment that the acceptance of discomfort glare could increase in order to maintain the view although discomfort glare perception remains the same (Wienold 2009a). Therefore, shading controls strategies should be implemented in such a way that blinds do not block the view to the outside in order for the observers to keep a visual contact with the exterior (Iwata et al. 2017b).

To conclude, the view through the window has a direct influence on the acceptance and perceived degree of discomfort glare, especially when the observer has a strong opinion about it. Nonetheless, two characteristics of the view should be taken into account: the interest and the extent of the view.

3.2.1.4. Room temperature

To date, only one study focuses on the influence of thermal comfort on discomfort glare perception in office environments. The results of this experiment (Yamin Garretón et al. 2015) showed that the subjects had a different tolerance towards discomfort glare when they were outside their thermal comfort zone. In a study on the interaction of comfort parameters (Laurentin et al. 2000), no influence of thermal conditions on visual discomfort could be found in the case of daylighting. However, the lack of effect might be due to the fact that the maximum temperature in the study was only 3°C above the thermal comfort zone (Inkarojrit 2005).

Our perception of discomfort glare could also be influenced by other discomfort parameters such as humidity or noise. More research is needed to define these interactions properly.

Table 3. Factors related to the environment characteristics having a potential influence on discomfort glare perception from daylight. *Author(s)/Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Spectrum and color temperature	Berman et al.	1995	12	1080	V	A	**MORE LIKELY**
	Flannagan	1999	12	288	V	A	
	Stringham et al.	2003	3	33	V	A	
	Sivak et al.	2005	12	540	V	A	
	Bullough	2009	67	934	V	A	
	Fekete et al.	2009	10	2200	V	A	
	Kimura-Minoda & Ayama	2011	15	1395	V	A	
	Sweater-Hickcox et al.	2012	10	200	V	A	
	Zhang et al.	2013	18	180	V	A	
	Lin et al.	2014	12	864	V	A	
	Wei et al.	2014	26	S	V	A	
	Chen et al.	2015	8	576	V	A	
	van Bommel	2015	R	R	V	A	
	Yang et al.	2016	20	960	V	A	
	Huang et al.	2017	18	324	V	A	
	Ko & Choi	2017	176	1760	X		
	Niedling & Völker	2017	36	648	V	A	
	Völker et al.	2017	R	R	V	A	
View direction and position	Jakubiec & Reinhart	2015	194	S	V	A	**INCONCLUSIVE**
	Hirning et al.	2016b	49	68	V	?	
	Khanie et al.	2016	97	97	V	A	
	Sekihara et al.	2016	20	240	V	?	
	Vasquez et al.	2016	1	12	V	B	
	Iwata et al.	2017	146	584	X		
	Völker et al.	2017	R	R	V	A	
Attractiveness of the view through the window	Hopkinson	1972	R	R	V	A	**INCONCLUSIVE**
	Chauvel et al.	1982	R	R	V	?	
	Osterhaus	2001	83	S	V	A	
	Tuaycharoen & Tregenza	2005	32	1152	V	A	
	Tuaycharoen & Tregenza	2007	168	600	V	A	
	Wienold	2009a	76	349	V	A	
	Tuaycharoen	2011	76	752	V	A	
	Shin et al.	2012	48	2400	V	A	
	Hellinga	2013	558	S	X		
	Hirning et al.	2013a	468	493	X		
	Iwata et al.	2017	146	584	X		
Room temperature	Laurentin et al.	2000	20	180	X		**INCONCLUSIVE**
	Yamin Garretón et al.	2015	19	57	V	A	

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

3.2.2. Glare experiment characteristics

3.2.2.1. Time of the day

Depending on the time of the day, our sensation of discomfort glare might be fluctuating. It was first demonstrated by two studies conducted under artificial lighting conditions that as the day progresses, tolerance towards discomfort glare increases (Altomonte et al. 2016a, 2016b, Kent et al. 2015a, Kent et al. 2015b). On the opposite, a study conducted by Borisuit et al. revealed no evolution of perceived glare sensation for a period of eight hours (Borisuit et al. 2015). However, no neutral basis was defined to compare the subjective glare evaluations made during the day in this last study as daylight might have been changing but no discomfort glare index was calculated. Recently, Kent et al. conducted another study under daylighting conditions to confirm the effect of time of day on discomfort glare perception (Kent et al. 2017a). They concluded that the time of the day could be one of the causes explaining the large variability between subjects' discomfort glare perception, since a statistically significant influence of this factor was observed.

3.2.2.2. Season

A seasonal effect on discomfort glare perception means that depending on the season and its related daylight characteristics, tolerance towards discomfort glare might vary.

Some authors have already suggested that subjects have a higher acceptance of the presence of sunlight in winter than in summer (Christoffersen et al. 2000, Nicol et al. 2006). In one of Van Den Wymelenberg's experiments on discomfort glare, participants were significantly more sensitive to glare source brightness during fall than during summer, with a difference of approximately 100 cd/m² in glare source luminance (Van Den Wymelenberg 2012). This effect could, however, also be attributed to post-awake sunlight availability, namely a smaller or larger amount of daylight prior to the experiment.

Since only one study could find an influence of seasons on discomfort glare perception, and since the seasonal influence might overlap with previous luminous environment (§ 3.*iii*.a), more research is required to conclude on the influence of this factor.

3.2.2.3. Task difficulty

Quite often, attention tasks, such as the Stroop test (MacLeod 1991), are used to assess the influence of the visual environment on workers' productivity and concentration. However, some studies (Flannagan et al. 1990, Sivak et al. 1989) have shown that the task required while rating the visual environment could impact this rating. It is thus important to determine whether the perceived discomfort glare is influenced by the presence and the difficulty of a task, or the other way around.

Sivak et al. concluded from an experiment on the influence of a visual task on discomfort glare ratings (Sivak et al. 1989) that more difficult tasks resulted in more discomforting glare responses, and that the effect was more noticeable at low levels of glare. Flannagan et al. conducted another experiment to extend these findings (Flannagan et al. 1990). Besides reinforcing Sivak et al.'s results on task difficulty, they showed that when subjects have to accomplish a visual task, perceived discomfort glare tends to be higher than when no task is required. On the opposite, Osterhaus and Bailey observed in a study on the effects of large area glare sources on discomfort glare perception that when a task was required, subjects tended to be less sensitive towards discomfort glare (Osterhaus and Bailey 1992). A recent study from Altomonte et al. demonstrated that the more difficult the visual task was, the higher the glare sensation was perceived (Altomonte et al. 2016a, 2016b). This effect was noticed to be more significant at earlier sessions during the day, although the authors warned on the potential interaction between temporal variables which could have affected the variation of glare response as the day progresses since a direct relationship was also found between fatigue and glare response. In road lighting, the influence of the task difficulty on discomfort glare perception has been recognized, although it is not yet sure whether more difficult tasks generate higher or lower discomfort glare perception (Völker et al. 2017).

In the mentioned studies, glare assessments usually take place after the subjects have finished their task – not during the task itself. In addition to the need for further research on the influence of task difficulty on discomfort glare perception, discomfort glare assessments acquired from subjects while they are performing a task should be investigated against others acquired after the task.

3.2.2.4. Glare rating scales and experimental design

Discomfort glare is almost never assessed objectively – its evaluation is, up to now, mainly relying on feedback by the use of questionnaires. The subject is asked to evaluate his or her perception of discomfort glare through rating scales, such as the De Boer scale (De Boer 1967), Hopkinson's scale (Hopkinson 1971) or the Glare Sensation Vote (Iwata et al. 1992a). Several distortions can occur due to these rating scales or to the way the experiment is designed:

- bias towards higher glare assessments

Scales used to evaluate discomfort glare might lead the subject to acknowledge the presence of glare since "no glare" is often not a choice in the available responses on the rating scale (Fotios 2015). Subjects' answers are thus biased as the reported stimulus is somehow imposed. Moreover, when asking questions about glare itself, the attention is drawn on it, forcing the glare option (Van Den Wymelenberg 2014). The act of asking subjects to rate their discomfort glare may incite them to acknowledge something they would not have considered in other conditions.

- interpretation of scale labels

The various labels of existing rating scales may be interpreted in different ways, either between different subjects participating in a survey or between researchers using the scale labels differently (Fotios 2015, Kent and Fotios 2017, Osterhaus 2008, Rea 1982, Van Den Wymelenberg 2014). For instance, a survey on the de Boer glare rating scale showed that the descriptor “Satisfactory” was most of the time misunderstood (Gellatly and Weintraub 1990). Another study showed a significant difference in interpretation between the perceived discomfort rating and the acceptance rating of glare (Geerdinck 2012). According to the results, a setting that is acceptable is not necessarily comfortable, suggesting that these two concepts should not be merged in a single scale such as in the De Boer scale.

- number of scale response points

Due to the abundance of existing glare rating scales, the amount of response points is not fixed. Rating scales can have three (Osterhaus and Bailey 1992), four (Fisekis et al. 2003), five (Tuaycharoen and Tregenza 2007), six , seven , eight (Shin et al. 2012), nine (Carlucci et al. 2015), ten (Stringham et al. 2011) or even more response points. The high variation in rating scale formats might have an influence on subject’s assessment (Fotios 2015), as this issue has already been covered in the literature for other research fields (Garland 1991, Weijters et al. 2010).

- stimulus range bias

The stimulus range available to the subject has a significant influence on his or her evaluation (Kent and Fotios 2017). Depending on the stimulus range presented, a situation might be rated as comfortable in one experiment and uncomfortable in another one. This is due to the fact that subjects make relative evaluations, which should not be generalized as absolute evaluations. For instance, from several experiments on visual preferences, it was observed that the mean preferred illuminance always lies in the middle of the available range of illuminances (Fotios and Cheal 2010, Fotios et al. 2011, Logadóttir et al. 2011, Logadóttir et al. 2013). The effect of range bias on discomfort glare perception was first demonstrated by Lulla and Bennett (Lulla and Bennett 1981). This bias was then also reported by Geerdinck et al. as the potential cause to a discrepancy in the results of an experiment on discomfort glare perception (Geerdinck et al. 2014).

- anchor effect

The sequence in which glare situations are presented to the subject has a direct influence on his or her evaluation of discomfort glare (Kent and Fotios 2017). If glare situations are presented with an increasing discomfort and the first situation is overrated by the subject, every following situation tend to be over-rated as well. This is especially true in the case of a Hopkinson-like multiple-criterion adjustment method, as it has been recently demonstrated (Kent and Fotios 2017, Kent et al. 2017b). This anchor effect can be avoided by randomizing the sequence of stimuli presented to the subject.

- learning effect

The learning effect appears when the same subject is asked to do the same task several times. The more he/she will perform the task, the greater the learning effect will be as the subject will get bored and tried to complete the task as quickly as possible. Therefore, if several glare assessments from the same subject are needed, the learning effect can affect the subject’s responses and cause bias in the results. This effect can be avoided by randomizing the stimuli, or at least verified by using a null condition (Fotios 2015).

- laboratory versus field experiment

When asking subjects about discomfort glare perception, it seems like they have a different tolerance towards discomfort glare whether the experiment takes place in a laboratory environment or in the field. It has indeed been acknowledged for road lighting that discomfort glare is assessed more critically in a laboratory test than in the field (Völker et al. 2017). DGP and DGI thresholds appear to be diverging as well between laboratory (Wienold 2009a) and field (Hirning et al. 2013) studies, although in this case, subjects seem to be less tolerant towards discomfort glare in the field.

For all these reasons, special attention should be paid when designing an experiment on discomfort glare involving subjects. Design recommendations, such as the use of a control situation with no discomfort glare or the sequence randomization, should be adopted (i.e. (CIE 2014)) to reduce the probability of bias in the results. Moreover, more research is required to study the influence of glare rating scales on discomfort glare perception. For instance, a comparative study on the performance of various glare rating scale formats would be very useful to suggest a universal glare rating scale, which should be adopted by CIE and used by all subsequent studies.

Table 4. Factors related to the glare experiment characteristics having a potential influence on discomfort glare perception from daylight. *Author(s)/Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Time of the day	Borisuit et al.	2015	25	400	X		**SOMEWHAT LIKELY**
	Kent et al.	2015a/b	30	480	V	A	
	Altomonte et al.	2016a/b	20	960	V	A	
	Kent et al.	2017	40	720	V	A	
Season	Van Den Wymelenberg	2012	93	1488	V	A	**SOMEWHAT LIKELY**
Task difficulty	Sivak et al.	1989	12	1080	V	A	**SOMEWHAT LIKELY**
	Flannagan et al.	1990	24	4320	V	A	
	Osterhaus & Bailey	1992	26	?	V	B	
	Altomonte et al.	2016a/b	20	960	V	A	
	Völker et al.	2017	R	R	V	?	
Glare rating scales and experimental design	Lulla & Bennett	1981	20	360	V	NA	**MORE LIKELY**
	Rea	1982	6	36	V	NA	
	Gellatly & Weintraub	1990	26	?	V	NA	
	Garland	1991	448	?	V	NA	
	Osterhaus	2008	P	P	V	NA	
	Weijters et al.	2010	1433	?	V	NA	
	Fotios et al.	2011	57	?	V	NA	
	Geerdinck	2012	42	840	V	NA	
	Geerdinck et al.	2014	42	668	V	NA	
	Van Den Wymelenberg	2014	R	R	V	NA	
	Fotios	2015	R	R	V	NA	
	Kent et al.	2017	22	264	V	NA	
	Kent & Fotios	2017	R	R	V	NA	
	Völker et al.	2017	R	R	V	NA	

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

3.3. Related to the observer

3.3.1. General characteristics

3.3.1.1. Gender

The gender of a person as a factor influencing glare perception has already been examined in various studies (Iwata et al. 1992a, Kent et al. 2015c, Pulpitlova and Detkova 1993, Saur 1969, Shin et al. 2012, Sivak et al. 1989, Tuaycharoen and Tregenza 2007). They all came to the conclusion that the perception of discomfort glare is the same whether the subject is a man or a woman. A large survey on Indoor Environmental Quality has, however, suggested that women are more likely to complain about indoor comfort factors than men (Kim et al. 2013). It can still be assumed that gender does not influence the perception of discomfort glare.

3.3.1.2. Age

The subject's age is quite a controversial factor in the assessment of discomfort glare. As with a growing age, absolute sensitivity to light, contrast sensitivity and amount of light reaching the retina are reduced, several authors (Boyce 2014, Karwowski 2006, Mainster and Turner 2012, Narisada and Schreuder 2004) believe age should have an influence, even a small one, on our perception of discomfort glare. Bennett was the first to develop a short formula to assess the Borderline between Comfort and

Discomfort (BCD) level according to the subject's age, since a significant correlation was found between age and BCD level in one of his experiments (Bennett 1977):

$$BCD = \frac{80000}{Age\ (in\ years)} [cd/m^2] \quad (6)$$

Flannagan (Flannagan 1999) reinforced the hypothesis that older subjects give generally higher discomfort ratings than younger subjects in a study with artificial glare sources. Iwata and Tokura also noticed a difference between young and elderly subjects while developing the new position index (Iwata and Tokura 1997). Laboratory and field studies from Kuhn et al. on discomfort glare from daylighting have also suggested that the age effect exists but its statistical significance is very low (Kuhn et al. 2013). Völker et al. reinforced the hypothesis, suggesting that older people are less tolerant towards discomfort glare but that this difference is very small (Völker et al. 2017). On the opposite, a study from Wolska and Sawicki asserted that younger people were more sensitive to discomfort glare than older people (Wolska and Sawicki 2014). This was reinforced by a recent study on the glare effect, which observed that glare thresholds were higher for the "aged" group (Facchin et al. 2017).

But in several other studies, the age effect on perceived discomfort glare is refuted. Saur did not observe any effect of the subjects' age in his study on the physiological aspects of discomfort glare for car users (Saur 1969). No relation was either found between age and ratings in Vos and Van Bergem's study on subjective reactions to emitted light of greenhouses (Vos and Van Bergem-Jansen 1995). Furthermore, neither Osterhaus (Osterhaus 2001), Shin et al. (Shin et al. 2012) nor Hirning et al. (Hirning et al. 2014) found a statistically significant relationship between people's age and the level of glare experienced in their respective experiment or survey. Although in one experiment, older subjects self-reported as statistically more sensitive to brightness, the measured sensitivity to brightness, which was assessed by asking the subject to rate discomfort glare from artificial glare sources, did not reveal a significant difference between age groups neither (Van Den Wymelenberg 2012). Kent et al. studied the age effect as a personal factor influencing glare sensation (Kent et al. 2015a) but could not demonstrate any statistically significant influence of the age on individual glare sensation.

More recently, a study of Akashi et al. suggested that, compared to a group of younger subjects, there was a large deviation in glare sensitivity between older subjects (Akashi et al. 2017). They explained that this large deviation depended on the visual characteristics of the observers since these visual characteristics can cause the subject to be more sensitive to one of the two types of glare –absolute or relative.

From all these studies, it can be concluded that if there is an effect of age on discomfort glare perception, this effect might be weak, or even negligible, and depending more on the visual characteristics of the observer than on his or her age.

3.3.1.3. Culture

The culture of a subject is 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 behavior towards this indoor environment and his expectations about it. In consequence to this definition, people from North America would be treated as a different cultural group than people from Asia as they did not experience the same environment in the past. Several observations made in the last thirty years suggest that culture could be a factor influencing discomfort glare perception.

The first observation was made by Subova et al. while they were conducting a laboratory experiment on the subjective response to discomfort glare in Slovakia (Subova et al. 1991). From the results of their study, a difference in subjective discomfort glare levels was noticed between the Slovak subjects and the subjects of a similar study carried out in the USA (MacGowan et al. 1988). It was hypothesized that the difference "*might be caused by a greater sensitivity of the population in Middle Europe adapted to lower luminance conditions*". Iwata et al. made a similar assumption regarding the difference in tolerance towards discomfort glare between Japanese and British subjects (Iwata et al. 1992a). Japanese subjects were reported in the study as being tolerant to higher levels of discomfort glare than British subjects from a study of Hopkinson (Hopkinson 1971, Petherbridge and Hopkinson 1950). This observation should, however, be tempered since the procedures between Hopkinson and Iwata et al.'s studies were not exactly the same. Pulpitlova and Detkova carried out another study in Slovakia based on Hopkinson's discomfort glare scale (Pulpitlova and Detkova 1993). The mean luminance values evaluated by the Slovakian subjects for each discomfort glare level were similar to those evaluated by American subjects (MacGowan and Emery 1986), but differed from the ones evaluated by Japanese subjects (Iwata et al. 1992a). Lee and Kim reinforced the assumption that Asians have a different tolerance towards discomfort glare compared to Caucasians (Lee and Kim 2007). The DGI thresholds proposed by Hopkinson and the ones obtained from their study with Asian subjects were compared, and indicated a significant difference suggesting that at high glare source luminance, Caucasians felt more discomfort glare than Asians. However, in Kent et al. study on factors influencing discomfort glare perception, the subject's ethnicity was not correlated with the individual glare perception (Kent et al. 2015a). This might be explained by the fact that even if the subjects in this study came from various ethnicities, they were all accustomed to the same climatic and environmental conditions as they lived in the same country. Therefore, this ethnicity effect cannot be incorporated in the culture effect as described earlier. Recently, Huang and Wang developed the DGI_{China} on the basis of the DGI to provide a discomfort glare index consistent with Chinese people's visual characteristics (Huang and Wang 2016). The thresholds of the DGI_{China} scale have been set higher than those of the usual DGI scale, which implies that Chinese people might tolerate higher discomfort glare than Hopkinson's study subjects. Similarly, a field study conducted in Indonesia (Mangkuto et al. 2017) evaluated new thresholds for the DGP index, which are much lower than the original thresholds developed by Wienold et al. for European populations (Wienold and Christoffersen 2006). This last observation might, however, be related to the difference in tolerance towards discomfort glare between laboratory and field studies, as mentioned above. A study by Ko and Choi also investigated the difference in UGR glare thresholds between Caucasian and Korean subjects (Ko and Choi 2017). A modified version of the Unified Glare Rating (UGR) index was developed since it was observed that Korean subjects tolerated higher levels of discomfort glare than Caucasian subjects. At last, a field experiment was conducted by Pierson and others (Pierson et al. 2017) in Belgium and in Chile to compare discomfort glare perception in these two countries. From the results, it was hypothesized that current glare indices might not be relevant for every cultural background, since Chileans appear to perceive discomfort glare differently than Belgians.

These studies imply that culture, as defined in this paper, could have an influence on discomfort glare perception. Until now, discomfort glare indices have been developed through experiments involving particular populations: i.e. British subjects for DGI (Hopkinson 1971), Japanese subjects for PGSV (Tokura et al. 1996), German and Danish subjects for DGP (Wienold and Christoffersen 2006). No study has examined that these indices could be used analogously for subjects having different cultures, namely subjects experiencing different climates and having different sensitivities towards daylight. Since the observer's culture might influence his or her discomfort glare perception, a deeper understanding of the effect of culture is required.

3.3.1.4. Chronotype

The chronotype of a person is the behavioral manifestation of his or her circadian rhythm which is regulated by daylight. The behavioral manifestation of the circadian rhythm means our propensity to fall asleep at a certain time during the 24-hours loop. An early chronotype person will therefore fall asleep early in the evening and wake up early in the morning.

As tolerance to glare source luminance became smaller with the progression of subjects' chronotype from early to late type, Kent et al. concluded that earlier chronotype subjects, namely the subjects waking up early in the morning, tolerate higher levels of discomfort glare (Kent et al. 2015a, Kent et al. 2015c). But as mentioned before, and despite the promising results of Kent et al.'s experiment, more than one significant correlation is needed to acknowledge the influence of chronotype on discomfort glare perception.

3.3.1.5. Self-assessed glare sensitivity

The glare sensitivity is a characteristic that subjects could potentially determine for themselves. By asking ourself whether we often wear sunglasses in sunny weather can help us figure it out. The self-assessed glare sensitivity, or the self-reported sensitivity to brightness, was already compared to the measured sensitivity to brightness (Van Den Wymelenberg 2012). Although the correlation between the self-assessed and measured sensitivity to brightness was rather low, it seemed to hold at the extreme. This means that the subjects could not judge on a multiple-points scale their level of sensitivity but could classify themselves into the sensitive or non-sensitive categories.

First in 1969, Saur demonstrated that self-assessed glare sensitive subjects have a decreased tolerance of discomfort glare (Saur 1969). This assumption was confirmed in a survey for which a growing relationship between the average glare experienced and the perceived sensitivity to glare was observed (Osterhaus 2001). The self-assessed glare sensitivity was also studied as one of the criteria in window-blind control models as it was assumed that this factor could partly explain the wide variability between subjects' discomfort glare perception (Inkarojrit 2005). However, from the field study, no statistically significant correlation could be observed between the self-reported glare sensitivity and discomfort glare perception. More recently, Rodriguez and Pattini (Rodriguez and Pattini 2014) observed that when the glare source lies in the central vision, glare-sensitive people perceived higher discomfort glare than the others. However, this observation could not be confirmed in a second experiment (Rodriguez et al. 2016). A study from Kent et al. reinforced the assumption that self-assessed glare sensitivity is not a factor influencing discomfort glare perception (Kent et al. 2015a, Kent et al. 2015c).

The influence of the self-assessed glare sensitivity on discomfort glare perception is not clear as recent studies tend to reject the effect. More research is needed to determine if the subjective evaluation that a person makes of his or her own sensitivity to glare has an impact on his or her perception of a discomfort glare stimulus.

Table 5. Factors related to the observer's general characteristics having a potential influence on discomfort glare perception from daylight. *Author(s)/Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Gender	Saur	1969	35	70	X		**ALMOST CERTAINLY NULL**
	Sivak et al.	1989	12	1080	X		
	Iwata et al.	1992a	40	480	X		
	Pulpitlova & Detkova	1993	57	456	X		
	Tuaycharoen & Tregenza	2007	168	600	X		
	Shin et al.	2012	48	2400	X		
	Kim et al.	2013	38257	S	X		
	Kent et al.	2015a/c	30	480	X		
Age	Saur	1969	35	70	X		**INCONCLUSIVE**
	Bennett	1977	199	1393	V	A	
	Vos & Van Bergem-Jansen	1995	400	S	X		
	Iwata & Tokura	1997	71	2130	V	A	
	Flannagan	1999	12	288	V	A	
	Osterhaus	2001	83	S	X		
	Shin et al.	2012	48	2400	X		
	Van Den Wymelenberg	2012	93	1488	X		
	Hirning et al.	2013a	468	493	X		
	Kuhn et al.	2013	45	270	V	A	
	Wolska & Sawicki	2014	50	100	V	B	
	Kent et al.	2015a/c	30	480	X		
	Akashi et al.	2017	24	192	V	A/B	
	Facchin et al.	2017	50	4950	V	B	
	Völker et al.	2017	R	R	V	A	
Culture	Subova et al.	1991	32	256	V	?	**SOMEWHAT LIKELY**
	+ MacGowan et al.	1988	?	?			
	Iwata et al.	1992a	40	480	V	A	
	+ Petherbridge & Hopkinso	1950	6	?			
	+ Hopkinson	1971	?	?			
	Pulpitlova & Detkova	1993	57	456	V	A	
	+ MacGowan & Emery	1986	?	?			
	+ Iwata et al.	1992a	40	480			
	Lee & Kim	2007	42	630	V	A	
	+ Hopkinson	1971	?	?			
	Kent et al.	2015a/c	30	480	X		
	Huang & Wang	2016	R	R	V	A	
	Ko & Choi	2017	176	1760	V	A	
	Mangkuto et al.	2017	86	86	V	?	
	+ Wienold & Christofferse	2006	76	349			
Chronotype	Kent et al.	2015a/c	30	480	V	A	**SOMEWHAT LIKELY**
Self-assessed glare sensitivity	Saur	1969	35	70	V	A	**INCONCLUSIVE**
	Osterhaus	2001	83	S	V	A	
	Inkarojrit	2005	25	83	X		
	Rodriguez & Pattini	2014	25	200	V	A	
	Kent et al.	2015a/c	30	480	X		
	Rodriguez et al.	2015	32	64	X		

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

3.3.2. Vision characteristics

3.3.2.1. Optical correction

The optical correction factor expresses whether a person wears glasses, contact lenses or nothing. The wearing of glasses or lenses could influence discomfort glare perception as a modification is brought to the eyes of the subject.

First, in a study on physiological aspects of discomfort glare, no relationship was found between the perceived discomfort glare of a subject and its vision correction level (Saur 1969). In their work on discomfort glare from large sources, Iwata et al. did not detect any significant difference between subjects wearing glasses or lenses and those who did not (Iwata et al. 1992a, Iwata and Tokura 1997). Although Sivak et al. could show a tendency for subjects with optical correction to report more glare than subjects without correction, this difference in discomfort glare perception in road lighting was not statistically significant (Sivak et al. 1997). No difference in discomfort glare perception between subjects wearing glasses and subjects without could be found in other studies (Shin et al. 2012, Tuaycharoen and Tregenza 2007). More recently, Hirning et al. investigated this effect amongst others in a large survey and observed no statistically significant influence on perceived discomfort glare (Hirning et al. 2014), which confirms the assumption that the wearing of glasses or lenses does not affect the glare sensation.

3.3.2.2. Iris pigmentation

Iris pigmentation is the characteristic giving the eye its color. A popular belief is to think that according to their eye color, namely the iris pigmentation, people perceive glare differently. This belief seems to be based on unfounded assumptions since the iris pigmentation does not play any role in the mechanism of vision, and therefore probably not in the glare one either.

Nonetheless, some studies have examined the influence that iris pigmentation could have on perception of discomfort glare. In a study on discomfort glare for road safety, no correlation could be found between the eye color and the luminance level at which subjects feel discomfort glare (Saur 1969). Contrariwise, in a survey conducted by Osterhaus, a slight indication suggested that "*workers with lighter eye colors might, on average, perceive to be slightly more sensitive to glare and might be experiencing slightly higher levels of glare*" (Osterhaus 2001). But this information was not verified against lighting measurements, and it could as well be linked to the fact that subjects with light eyes are biased by the popular belief as they consider themselves as more sensitive to glare. Another similar trend of iris pigmentation influencing glare perception was reported in an experiment with an artificial glare source, as subjects with dark eyes reported lower discomfort glare perception (Bennett 1977). However, the effect was later refuted in an experiment to determine the effect of retinal pigment on visual discomfort (Stringham et al. 2011). It was concluded from the last that the iris pigmentation has no statistically significant influence on the perceived visual discomfort despite a visible trend. Recently, Rodriguez et al. (Rodriguez et al. 2016) noticed that more light-eyed volunteers were found in the glare-sensitive group than in the glare-insensitive group in one of their experiments. But no statistically significant difference in discomfort glare perception could be found in the study between glare-sensitive and glare-insensitive subjects.

Despite tendencies indicating that light-eyed people could be more sensitive to discomfort glare, there is so far no statistically significant evidence that iris pigmentation influence discomfort glare perception. Additional experiments focused on this particular matter should be conducted to confirm or infirm this hypothesis.

3.3.2.3. Macular pigment optical density

The macular pigment optical density (MPOD) is the level of density of protective pigment in the macula. The macula is a small area located in the retina where cones, which are the photoreceptors mainly responsible for the photopic vision, have the highest density. The yellow macular pigments are derived from carotenoids and deposited in this photoreceptor axon layer. A high MPOD level protects the retina as the macular pigments absorb high-energy short-wavelength light.

The effect of MPOD on visual discomfort, and specifically on discomfort glare, has been studied several times. From a study on the relationship between individuals' discomfort glare thresholds and spatial distribution of macular pigments (MP) in the retina (Stringham et al. 2004), it was assumed that MP acted as a spatially integrated filter against short-wavelength light and that a person with a relatively high MP level perceived less discomfort glare in the central viewing. Another experiment from Stringham et al. showed that subjects with broader MPOD spatial distribution would perceive less discomfort glare (Stringham et al. 2011). They made therefore the hypothesis that subjects having relatively high MP levels would tolerate more intense lights. The assumption that macular pigments reduce discomfort glare by absorbing short-wavelength light was endorsed by Lien and Hammond (Lien and Hammond 2011). However, Loughman et al. conducted another experiment on the role of MPOD, and concluded that visual performance under glare conditions was not related to MPOD (Loughman et al. 2010).

No definitive conclusion can be drawn from these studies on the effect of MPOD on discomfort glare perception, as the MPOD mechanism towards discomfort glare is not well understood.

3.3.2.4. Cortical hyperexcitability

The 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 vision. The neurons actually mediate communications of the nervous system by propagating electrical signals generated by their excitable membrane.

A study has shown that the cortical hyperexcitability of a person, meaning the degree to which his or her neuronal activity can arise, influences his or her sensitivity to discomfort glare (Bargary et al. 2015). The authors observed that the glare-sensitive subjects showed significantly greater activity in the visual cortex. Moreover, the data suggested a positive correlation between the magnitude of the neuronal response and individual's sensitivity to discomfort glare.

This neuronal effect on discomfort glare perception could explain the difference existing between glare-sensitive and glare-insensitive person. These two factors, namely the neuronal effect and the self-assessed glare sensitivity, might therefore overlap. Only one of them should be taken into account as a new variable of discomfort glare models. The self-assessed glare-sensitivity, despite its lack of accuracy, might be easier to implement than the cortical hyperexcitability.

3.3.2.5. Contrast sensitivity

With the ability to resolve fine details, namely the visual acuity, contrast sensitivity is the other important visual characteristic that refers to the ability of the eye to detect a difference in luminance between an object and its background (Karwowski 2006). Contrast sensitivity depends on the spatial frequency, namely the frequency of the contrast pattern in the field of view, and the level of contrast.

Several studies have investigated the relationship between contrast sensitivity and disability glare as people often have a loss in contrast sensitivity when there is light scattering in the eyes (Arranz et al. 2014, Bach et al. 2008, Bühren et al. 2006, Paulsson and Sjostrand 1980, Siah et al. 2017). Similarly, contrast sensitivity could have an influence on discomfort glare perception. As the contrast sensitivity curve of the human visual system peaks at a particular frequency and drops on either side of that peak frequency (Hilz and Cavonius 1974), the discomfort glare perception was observed to behave exactly inversely (Eble-Hankins 2008). From subjects' evaluations of discomfort glare, discomfort is minimized at the spatial frequency where contrast sensitivity peaks, and increases on either side of that minimum frequency. Contrast sensitivity could thus be an interesting variable to study as it could improve our knowledge of the mechanism of discomfort glare.

Table 6. Factors related to the observer's vision characteristics having a potential influence on discomfort glare perception from daylight. *Author(s)/Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Optical correction	Saur	1969	35	70	X		**ALMOST CERTAINLY NULL**
	Iwata et al.	1992a	40	480	X		
	Iwata & Tokura	1997	71	2130	X		
	Sivak et al.	1997	16	1600	X		
	Tuaycharoen & Tregenza	2007	168	600	X		
	Shin et al.	2012	48	2400	X		
	Hirning et al.	2013a	468	493	X		
Iris pigmentation	Saur	1969	35	70	X		**INCONCLUSIVE**
	Bennett	1977	199	1393	V	A	
	Osterhaus	2001	83	S	V	A	
	Stringham et al.	2011	26	468	X		
	Rodriguez et al.	2015	32	64	X		
Macular pigment optical density	Stringham et al.	2004	4	O	V	A	**SOMEWHAT LIKELY**
	Loughman et al.	2010	142	O	X		
	Lien & Hammond	2011	R	R	V	A	
	Stringham et al.	2011	26	468	V	A	
Cortical hyperexcitability	Bargary et al.	2015	28	280 + O	V	A	**SOMEWHAT LIKELY**
Contrast sensitivity	Eble-Hankins	2008	67	1608	V	A	**SOMEWHAT LIKELY**

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

3.3.3. Present state

3.3.3.1. Previous luminous environment

The previous luminous environment stands for the lighting conditions that a subject experienced during the period preceding the assessment of glare, whether it is the previous hours, day, week or even longer.

A first statistically significant correlation was found between one's occupation environment type, namely whether a person works inside or outside, and the BCD level (Bennett 1977). Bennett observed that subjects experiencing a lot of daylight at work, and therefore during the days preceding the glare evaluation, have a higher tolerance towards discomfort glare. Similarly, another laboratory experiment suggested that whether a subject had spent the last day in a shadowed or overlit environment, his or her discomfort glare thresholds were significantly different (Pulpitlova and Detkova 1993). Kent et al. also observed in their experiment that subjects having experienced daylight in the morning tolerated slightly higher degree of discomfort glare but this effect could not be demonstrated as statistically significant (Kent et al. 2015a, Kent et al. 2015c). A direct trend between discomfort glare perception and prior light exposure was deduced from a similar experiment, especially on glare evaluations made in the evening (Altomonte et al. 2016a, 2016b).

No strongly significant evidence towards higher tolerance of discomfort glare for people having previously experienced daylight could be presented, although a tendency was observed. Additional research is needed to determine whether this effect is real and whether short-term, post-awake, previous days, or previous weeks sunlight availability is more influent on discomfort glare perception.

3.3.3.2. Physical state

Since physical conditions such as diseases, head pain, back pain, etc., can reduce the perceived comfort, these could impact the visual comfort of a subject and influence his or her discomfort glare perception in a negative way.

When asking subjects about their current physical state in a survey on discomfort glare sensitivity, no influence could be found of the physical state on discomfort glare perception (Osterhaus 2001). However, only one survey investigated this factor and the subjective results were not compared to measures of the lighting environment or glare indices. More research is therefore required to confirm that the way a person feels physically does not influence his or her perception of glare.

3.3.3.3. Emotional state

The current emotional state of a subject could affect his or her perception of discomfort glare in the sense that positive emotions such as joy, serenity, pride or amusement could lead the subject to be less critical of the luminous conditions. The opposite could be true for negative emotions.

Similarly to the physical state, when asking subjects about their current emotional state and their sensitivity to discomfort glare, no correlation could be found with frequency of discomfort glare perception (Osterhaus 2001). However, a small influence was observed in another study establishing that, surprisingly, subjects in a better mood would experience slightly higher discomfort from glare (Altomonte et al. 2016a, 2016b). More research is needed to ascertain the assumption that subject's emotional state has an influence on discomfort glare perception.

3.3.3.4. Caffeine ingestion

When associated with bright light exposure, caffeine ingestion has an effect on melatonin secretion and therefore on the circadian rhythm (Wright et al. 1997). Caffeine ingestion could also have an influence on discomfort glare perception.

Two studies investigated the temporal factors influencing discomfort glare perception, amongst which the caffeine ingestion (Altomonte et al. 2016a, 2016b, Kent et al. 2015a, Kent et al. 2015c). According to the statistical analyses, there is a tendency for the subjects not having ingested caffeine to report discomfort glare at higher levels of glare source luminance. More results going in this direction are requested to confirm this hypothesis.

3.3.3.5. Food ingestion

Since circadian rhythms can be entrained by time-dependent schedules of light exposure, caffeine, and food intake (Kent 2016), the food ingestion prior to the glare evaluation has also been studied for its influence on discomfort glare perception. No statistically significant influence could be found in Kent et al.'s study (Kent et al. 2015a, Kent et al. 2015c). A significant difference was observed in another study between subjects having ingested food or not, although this difference was below the threshold of practical relevance (Altomonte et al. 2016a, 2016b).

The influence that food ingestion could have on discomfort glare perception is not evident, and further experiments should be conducted to dismiss or endorse this factor.

3.3.3.6. Fatigue

Fatigue could influence discomfort glare perception as tired subjects could be less tolerant towards discomfort glare in their field of view (Kent 2016).

From two laboratory experiments, some fatigue effects of small but relevant size were detected, such as a higher tolerance to luminance levels for less tired subjects (Altomonte et al. 2016a, 2016b, Kent et al. 2015a, Kent et al. 2015c, Kent 2016). These small fatigue effects do not allow, however, to draw conclusions on the influence of subjects perceived levels of fatigue on the discomfort glare sensation. Moreover, it is well likely that fatigue and time of the day are dependent factors. Attention should thus be paid to these factors so that they do not overlap each other.

Table 7. Factors related to the observer's present state having a potential influence on discomfort glare perception from daylight. *Author(s)/Year* = authors having studied the factor, classified by chronological order; *Subjects* = number of subjects having participated in the study; *Evaluations* = number of glare evaluations made during the study; *Influence* = detection or not of an influence of the factor on discomfort glare perception in the study; *Influence direction* = direction of the influence of the factor (increase or decrease of discomfort glare perception) –should be used to evaluate the agreement rate between studies–; *Influence indicator* = likelihood of the influence of the factor on discomfort glare perception.

Factor	Author(s)	Year	Subjects	Evaluations	Influence	Influence direction	Influence indicator
Previous luminous environment	Bennett	1977	199	1393	V	A	**INCONCLUSIVE**
	Pulpitlova & Detkova	1993	57	456	V	?	
	Kent et al.	2015a/c	30	480	X		
	Altomonte et al.	2016a/b	20	960	V	B	
Physical state	Osterhaus	2001	83	S	X		**SOMEWHAT UNLIKELY**
Emotional state	Osterhaus	2001	83	S	X		**INCONCLUSIVE**
	Altomonte et al.	2016a/b	20	960	V	A	
Caffeine ingestion	Kent et al.	2015a/c	30	480	V	A	**SOMEWHAT LIKELY**
	Altomonte et al.	2016a/b	20	960	V	A	
Food ingestion	Kent et al.	2015a/c	30	480	X		**SOMEWHAT UNLIKELY**
	Altomonte et al.	2016a/b	20	960	X		
Fatigue	Kent et al.	2015a/c	30	480	V	A	**SOMEWHAT LIKELY**
	Altomonte et al.	2016a/b	20	960	V	A	

R = literature review S = survey O = objective glare rating P = authors' point of view ? = information not available X = no influence of the factor V = influence of the factor

4. Conclusion

Factors potentially influencing discomfort glare perception from daylight are listed and reviewed. This literature study categorizes the influence of these factors on discomfort glare perception by introducing an influence indicator based on the amount of studies, the sample size of these studies, and the agreement between them. The suggested categories rate a factor influence as "almost certain", "more likely", "somewhat likely", "inconclusive", "somewhat unlikely", "less likely", or "almost certainly null". The magnitude of the influence of each factor can, however, not be determined from the data available in the literature.

From Tables 1 to 7, it can be observed that some factors – the gender of the observer and the optical correction – have almost certainly no influence on discomfort glare perception. Others – the food ingestion and the physical state of the observer – should not have any influence, even though additional studies are required to confirm it. On the other hand, it can be seen as well that a large number of factors are expected to be influencing discomfort glare perception. Amongst these factors, some – the saturation effect, the spectrum and color temperature of light– would just need one or two large studies to validate their influence, while others – the time of the day, the task difficulty, the culture, the chronotype, the MPOD, the cortical hyperexcitability, the contrast sensitivity, the season, the caffeine ingestion, and the fatigue – still need considerable investigation before drawing any conclusion on their influence on discomfort glare perception. The glare rating scales and experimental design factor includes several subfactors, which explains the non-applicability of the *Influence direction* information in Table 4. This considerable factor is also believed to influence discomfort glare perception, but several studies are still required to assert the influence of all subfactors. Moreover, the literature existing on several factors – the view direction and position of the observer, the attractiveness of the view through the window, the room temperature, the age, the self-assessed glare sensitivity, the iris pigmentation, the previous luminous environment, and the emotional state of the observer – was inconclusive about their influence on discomfort glare perception. As it can be recognized in the tables, the uncertainty is due to the fact that the studies having investigated these factors are either not agreeing on an influence of the factor or on the effect of this influence on discomfort glare perception. Also, precaution should be taken as some factors might interact. For instance, fatigue and time of the day are two factors closely linked. Therefore, the correlation found between fatigue and perceived discomfort glare should not be directly related to the influence of fatigue since the time of the day could also have played a role. The self-assessed glare sensitivity and the cortical hyperexcitability also seem to be related. For that reason, more research is necessary to clarify the influence of these factors. At last, factors having an almost certain influence in the mechanism of discomfort glare are, as expected, the luminance of the glare source, the adaptation level, the contrast effect, the size and the position of the glare source as seen by the observer.

From this work, it can be generally concluded that more work is needed to explain the high variability existing between individuals' discomfort glare perception, since there are a lot of factors potentially influencing discomfort glare perception. This literature review helps defining which factors have to be deeper investigated and to what extent. As a result, discomfort glare models might be adapted in the future according to the newly found influencing factors. Although it is recommended that each researcher defines his or her own prioritization list of factors requiring more investigation, some recommendations can be drawn from the tables and the influence indicator.

First efforts should be directed towards factors classified as more or less likely. For instance, a large experiment should be conducted on the perception of discomfort glare from filtered daylight to confirm the influence of the spectrum of light on discomfort glare perception. This will be very useful as new glazing types, such as electrochromic windows, are currently being developed. Another study should focus on validating the proposition that discomfort glare can be due to two main effects, the saturation and the contrast glare, so that both effects are included in discomfort glare models in the future. Last but not least, studies on the influence of glare rating scale and experimental design on the collection of subjective perceptions are greatly needed. This will ensure that the knowledge that is being built in the field of visual discomfort is not based on biased results. Then, factors of which the influence is classified as somewhat likely or unlikely should be further investigated. The influence probability of these is usually based on a small number of studies proving or denying the effect, or one study presenting opposite results questions the overall trend. Therefore, these factors require larger studies and stronger evidence to support or reject their influence on discomfort glare perception. Lastly, factors having an inconclusive influence should be looked at. These are generally controversial factors as different studies results do not agree. This suggests that either the influence of these factors is very small and maybe not significant, or the method used to study the factor is not always adequate. As an example, the attractiveness of the view through the window was believed to considerably influence discomfort glare perception due to the results of several laboratory experiments mainly using simulated windows. However, recent field studies have been challenging this assumption as this effect could not be observed from the results with real window views. It was therefore concluded that when the view implies no strong attraction or revulsion, its influence on discomfort glare perception is somehow largely reduced.

Nonetheless, the fact that physiological and psychological factors might influence discomfort glare perception brings a different perspective on discomfort glare indices. Glare in the field of view actually produces a sensation to the observer, who perceives it as more or less discomforting according to several psychological factors and some of his or her own physiological characteristics. The reason why the term ‘discomfort glare perception’ was used instead of ‘discomfort glare’ is due to the authors’ interest in the visual discomfort as perceived by the observer. Strong and statistically significant correlations could therefore be found between discomfort glare perception and physiological and psychological factors like the MPOD or the emotional state of the observer. As subjective perception matters in the case of discomfort glare, indices should not be made exclusively of physical quantities. Moreover, as it has already been suggested in 1950 (Petherbridge and Hopkinson 1950), a discomfort glare index should not rate on a numerical scale an assessment of a subjective effect, as it will naturally be interpreted arithmetically. A “percentage of people who would be disturbed” could be a more appropriate and better interpreted method to rank a certain discomfort glare stimulus.

No exact correlation should be expected between discomfort glare assessed by an index and perceived by a subject though. There are two reasons for this:

- on the one hand, because, besides the here listed psychological or physiological factors, some unknown others could be involved in the discomfort feeling. That is the reason why there is such a large spread amongst people when assessing discomfort due to glare;
- on the other hand, because the intensity of influence and interaction of the factors involved in the glare process cannot be precisely understood and explained, hence the uncertainty of existing discomfort glare models based on statistics.

However, a close approach of the perceived discomfort glare could be obtained by controlling, or at least monitoring, as many factors as possible. The set up and the questionnaire of an experiment aiming to collect subjective assessments of discomfort glare is thus of major importance.

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References

Akashi Y, Asano S, Kakuta Y, Fujita T. 2013. Visual mechanisms of discomfort glare sensation caused by leds. CIE Centenary Conference. Paris, France. April 12-19, 2013.

Akashi Y, Kojima S, Aoki T, Inatani M. 2017. Ageing effects on discomfort glare sensation and their mechanisms. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.

Altomonte S, Kent MG, Tregenza PR, Wilson R. 2016a. Task difficulty, temporal variables and glare response. PLEA 2016. Los Angeles, USA. July 11-13, 2016.

Altomonte S, Kent MG, Tregenza PR, Wilson R. 2016b. Visual task difficulty and temporal influences in glare response. Building and Environment. 95:209-226. doi:10.1016/j.buildenv.2015.09.021.

Aries MBC, Veitch JA, Newsham GR. 2010. Windows, view, and office characteristics predict physical and psychological discomfort. Journal of Environmental Psychology. 30(4):533-541. doi:10.1016/j.jenvp.2009.12.004.

Arranz I, Matesanz BM, Issolio L, Menendez JA, Mar S, Aparicio JA. 2014. Light adaptation in letter contrast sensitivity: The influence of optical and neural mechanisms. Lighting Research & Technology. 46:476–488. doi:10.1177/1477153513484633.

Bach M, Wesemann W, Kolling G, Buhren J, Krastel H, Schiefer U. 2008. Photopic contrast sensitivity. Local contrast perception. Ophthalmologe. 105(1):46-48, 50-49. doi:10.1007/s00347-007-1605-y.

Bargary G, Furlan M, Raynham PJ, Barbur JL, Smith AT. 2015. Cortical hyperexcitability and sensitivity to discomfort glare. Neuropsychologia. 69:194-200. doi:10.1016/j.neuropsychologia.2015.02.006.

Bellia L, Cesarano A, Iuliano GF, Spada G. 2008. Daylight glare: A review of discomfort indexes. Visual quality and energy efficiency in indoor lighting: today for tomorrow, international workshop. Rome, Italy. March 31-April 02, 2008.

Bennett CA. 1977. The demographic variables of discomfort glare. Lighting Design and Application. 7:22-24.

Berman SM, Bullimore MA, Bailey IL, Jacobs RJ. 1995. The influence of spectral composition on discomfort glare for large-size sources. The 1995 IESNA Annual Conference. New York, USA. July 30-August 02, 1995. doi:10.1080/00994480.1996.10748131.

Borisuit A, Linhart F, Scartezzini JL, Münch M. 2015. Effects of realistic office daylighting and electric lighting conditions on visual comfort, alertness and mood. Lighting Research & Technology. 47(2):192-209. doi:10.1177/1477153514531518.

Boubekri M, Boyer LL. 1992. Effect of window size and sunlight presence on glare. Lighting Research & Technology. 24(2):69-74. doi:10.1177/096032719202400203.

Bourassa CM, Wirtschafter JD. 1966. Mechanism of binocular increase of discomfort to high luminance. Nature. 212:1503–1504.

Boyce PR. 2014. Human factors in lighting - third edition. Boca Raton, USA: Taylor & Francis Group. 690p.

Bühren J, Terzi E, Bach M, Wesemann W, Kohnen T. 2006. Measuring contrast sensitivity under different lighting conditions: Comparison of three tests. Optometry & Vision Science. 83(5):290–298. doi:1040-5488/06/8305-0290/0.

Bullough JD. 2009. Spectral sensitivity for extrafoveal discomfort glare. Journal of Modern Optics. 56(13):1518-1522. doi:10.1080/09500340903045710.
Bülow-Hübe H. 2008. Daylight in glazed office buildings - a comparative study of daylight availability, luminance and illuminance distribution for an office room with three different glass areas. Lund, Sweden: Lund University. No. EBD-R--08/17. 98p.
Cai H, Chung T. 2012. Evaluating discomfort glare from non-uniform electric light sources. Lighting Research & Technology. 45(3):267-294. doi:10.1177/1477153512453274.
Cantin F, Dubois M-C. 2011. Daylighting metrics based on illuminance, distribution, glare and directivity. Lighting Research & Technology. 43(3):291–307. doi:10.1177/1477153510393319.
Carlucci S, Causone F, De Rosa F, Pagliano L. 2015. A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. Renewable and Sustainable Energy Reviews. 47:1016-1033. doi:10.1016/j.rser.2015.03.062.
CEN. 2011. Light and lighting - basic terms and criteria for specifying lighting requirements. Brussels, Belgium: Comité Européen de Normalisation. No. EN 12665:2011. 55p.
Chaiwiwatworakul P, Chirarattananon S, Rakkwamsuk P. 2009. Application of automated blind for daylighting in tropical region. Energy Conversion and Management. 50(12):2927-2943. doi:10.1016/j.enconman.2009.07.008.
Chan Y-C, Tzempelikos A. 2013. Efficient venetian blind control strategies considering daylight utilization and glare protection. Solar Energy. 98(Part C):241-254. doi:10.1016/j.solener.2013.10.005.
Chauvel P, Collins JB, Dogniaux R, Longmore J. 1982. Glare from windows: Current views of the problem. Lighting Research & Technology. 14(1):31-46. doi:10.1177/096032718201400103.
Chen P-L, Liao C-H, Li H-C, Jou S-J, Chen H-T, Lin Y-H, Tang Y-H, Peng W-J, Kuo H-J, Sun P-L et al. 2015. A portable inspection system to estimate direct glare of various led modules. International Conference on Optical and Photonic Engineering. Singapore, Singapore. April 14-16, 2015. doi:10.1117/12.2189599.
Christoffersen J, Johnsen K, Petersen E, Valbjorn O, Hygge S. 2000. Windows and daylight - a post-occupancy evaluation of danish offices. Lighting 2000. York, UK. July 09-11, 2000.
CIE. 1983. Discomfort glare in the interior working environment. Vienna, Austria: Commission Internationale de l'Eclairage. No. 55:1983. 52p.
CIE. 1995. Discomfort glare in interior lighting. Vienna, Austria: Commission Internationale de l'Eclairage. No. 117:1995. 41p.
CIE. 2014. Guidance towards best practice in psychophysical procedures used when measuring relative spatial brightness. Vienna, Austria: Commission Internationale de l'Eclairage. No. 212:2014. 65p.
Clear RD. 2013. Discomfort glare: What do we actually know? Lighting Research & Technology. 45(2):141-158. doi:10.1177/1477153512444527.
De Boer JB. 1967. Public lighting. London, UK: Cleaver-Hume. 693p.
Donners MAH, Vissenberg MCJM, Geerdinck LM, van den Broek-Cools JHF, Buddemeijer-Lock A. 2016. A psychophysical model of discomfort glare in both outdoor and indoor applications. CIE 2016 "Lighting Quality and Energy Efficiency". Melbourne, Australia. March 3–5, 2016.
Dubois M-C. 2001. Impact of shading devices on daylight quality in offices - simulations with radiance. Lund, Sweden: Lund University. No. TABK--01/3062. 162p.
Eble-Hankins ML. 2008. Subjective impression of discomfort glare from sources of non-uniform luminance [PhD dissertation]. [Lincoln, USA]: University of Nebraska (UNL). 385p.
Eble-Hankins ML, Waters CE. 2005. Vcp and ugr glare evaluation systems: A look back and a way forward. The Journal of the Illuminating Engineering Society. 1(2):7-38. doi:10.1582/leukos.2004.01.02.001.
Eble-Hankins ML, Waters CE. 2009. Subjective impression of discomfort glare from sources of non-uniform luminance. The Journal of the Illuminating Engineering Society. 6(1):51-77. doi:10.1582/LEUKOS.2009.06.01003.

Einhorn HD. 1969. A new method for the assessment of discomfort glare. Lighting Research & Technology. 1(4):235-247. doi:10.1177/14771535690010040201.
Einhorn HD. 1979. Discomfort glare: A formula to bridge differences. Lighting Research & Technology. 11(2):90-94. doi:10.1177/14771535790110020401.
Facchin A, Daini R, Zavagno D. 2017. The glare effect test and the impact of age on luminosity thresholds. Frontiers in Psychology. 8:1132. doi:10.3389/fpsyg.2017.01132.
Fekete J, Sik-Lanyi C, Schanda J. 2009. Spectral discomfort glare sensitivity investigations. Ophthalmic and Physiological Optics. 29:1-6. doi:10.1111/j.1475-1313.2009.00696.x.
Fisekis K, Davies M, Kolokotroni M, Langford P. 2003. Prediction of discomfort glare from windows. Lighting Research & Technology. 35(4):360-371. doi:10.1191/1365782803li095oa.
Flannagan MJ. 1999. Subjective and objective aspects of headlamp glare: Effects of size and spectral power distribution. Ann Arbor, USA: University of Michigan. No. UMTRI-99-36. 19p.
Flannagan MJ, Weintraub DJ, Sivak M. 1990. Context effects on discomfort glare : Task and stimulus factors. Ann Arbor, USA: University of Michigan. No. UMTRI-90-35. 30p.
Fotios S. 2015. Research note: Uncertainty in subjective evaluation of discomfort glare. Lighting Research & Technology. 47(3):379-383. doi:10.1177/1477153515574985.
Fotios S, Cheal C. 2010. Stimulus range bias explains the outcome of preferred-illuminance adjustments. Lighting Research & Technology. 42:433–447. doi:10.1177/1477153509356018.
Fotios S, Logadóttir Á, Cheal C, Christoffersen J. 2011. Using adjustment to define preferred illuminances: Do the results have any value? CIE 27th Session 2011. Sun City, South Africa. July 09-16, 2011.
Galasiu AD, Veitch JA. 2006. Occupant preferences and satisfaction with the luminous environment and control systems in daylit offices: A literature review. Energy and Buildings. 38(7):728-742. doi:10.1016/j.enbuild.2006.03.001.
Garland R. 1991. The mid-point on a rating scale: Is it desirable? Marketing Bulletin. 2(3):66-70.
Geerdinck LM. 2012. Glare perception in terms of acceptance and comfort [Master's thesis]. [Eindhoven, The Netherlands]: Eindhoven University of Technology (TUE). 74p.
Geerdinck LM, Van Gheluwe JR, Vissenberg MCJM. 2014. Discomfort glare perception of non-uniform light sources in an office setting. Journal of Environmental Psychology. 39:5-13. doi:10.1016/j.jenvp.2014.04.002.
Gellatly AW, Weintraub DJ. 1990. User reconfigurations of the de boer rating scale for discomfort glare. Ann Arbor, USA: University of Michigan. No. UMTRI-90-20. 23p.
Goovaerts C, Descamps F, Jacobs VA. 2017. Shading control strategy to avoid visual discomfort by using a low-cost camera: A field study of two cases. Building and Environment. 125:26-38. doi:10.1016/j.buildenv.2017.08.030.
Hansen P, Sarey Khanie M, Kuhn TE, Christoffersen J, Wienold J, Andersen M. 2016. Glare caused by contrast between task and immediate surround: An evaluation of luminance distribution in the field of view. CIE 2016 "Lighting Quality and Energy Efficiency". Melbourne, Australia. March 3–5, 2016.
Hellinga HI. 2013. Daylight and view - the influence of windows on the visual quality of indoor spaces [PhD dissertation]. [Delft, The Netherlands]: Technische Universiteit Delft (TUD). 376p.
Hilz R, Cavonius CR. 1974. Functional organization of the peripheral retina: Sensitivity to periodic stimuli. Vision Research. 14(12):1333-1337. doi:10.1016/0042-6989(74)90006-6.
Hirning MB, Isoardi GL, Cowling I. 2014. Discomfort glare in open plan green buildings. Energy and Buildings. 70:427-440. doi:10.1016/j.enbuild.2013.11.053.
Hirning MB, Isoardi GL, Coyne S, Garcia Hansen VR, Cowling I. 2013. Post occupancy evaluations relating to discomfort glare: A study of green buildings in brisbane. Building and Environment. 59:349-357. doi:10.1016/j.buildenv.2012.08.032.
Hirning MB, Isoardi GL, Garcia-Hansen VR. 2017. Prediction of discomfort glare from windows under tropical skies. Building and Environment. 113:107-120. doi:10.1016/j.buildenv.2016.08.005.

Hirning MB, Lim GH, Reimann GP. 2016. Discomfort glare in energy efficient buildings: A case study in the malaysian context. CIE 2016 “Lighting Quality and Energy Efficiency”. Melbourne, Australia. March 3–5, 2016.
Hopkinson RG. 1957. Evaluation of glare. Illuminating Engineering. 52:329-336.
Hopkinson RG. 1971. Glare from windows - using the glare index in daylighting design. Construction Research Development. 3:23-28.
Hopkinson RG. 1972. Glare from daylighting in buildings. Applied Ergonomics. 3(4):206-215. doi:10.1016/0003-6870(72)90102-0.
Hopkinson RG, Petherbridge P, Longmore J. 1966. Daylighting. London, UK: Butterworth-Heinemann Ltd. 640p.
Huang WJ, Yang Y, Ronnier Luo M. 2017. Discomfort glare caused by white leds having different spectral power distributions. Lighting Research & Technology. doi:10.1177/1477153517704996.
Huang YC, Wang T-H. 2016. Automatic calculation of a new china glare index. Building Simulation & Optimization 2016. Newcastle, UK. September 12-14, 2016.
Inkarojrit V. 2005. Balancing comfort: Occupants’ control of window blinds in private offices [PhD dissertation]. [Berkeley, USA]: University of California (UC). 277p.
Inoue Y, Itoh K. 1989. Methodological study of dynamic evaluation for discomfort glare. Journal of Architecture, Planning and Environmental Engineering. 398:9-19.
Iodice M, Jost S, Dumortier D, Gronfier C. 2017. An experimental protocol to objectively characterize discomfort glare using physiological measurements. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.
Iwata T, Imai M, Hagiwara H, Akiyama Y, Sekihara M. 2017a. Effects of task and views on discomfort glare from windows. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.
Iwata T, Kimura K-I, Shukuya M, Takano K. 1990. Discomfort caused by wide-source glare. Energy and Buildings. 15(3/4):391-398. doi:10.1016/0378-7788(90)90013-9.
Iwata T, Nagayoshi K, Osterhaus WKE. 2011a. Discomfort glare index for automated blind control. International Student Energy Summit 2011. Vancouver, Canada. June 09-11, 2011.
Iwata T, Osterhaus W. 2010. Assessment of discomfort glare in daylit offices using luminance distribution images. CIE 2010 "Lighting Quality & Energy Efficiency". Vienna, Austria. March 14-17, 2010.
Iwata T, Osterhaus WKE, Itoh HE. 2011b. Assessment of discomfort glare from windows with venetian blinds using luminance distribution images. CIE 27th Session 2011. Sun City, South Africa. July 09-16, 2011.
Iwata T, Shukuya M, Somekawa N, Kimura K-i. 1992a. Experimental study on discomfort glare caused by windows: Subjective response to glare from a simulated window. Journal of Architecture, Planning and Environmental Engineering. (432):21-33.
Iwata T, Taniguchi T, Sakuma R. 2017b. Automated blind control based on glare prevention with dimmable light in open-plan offices. Building and Environment. 113:232-246. doi:10.1016/j.buildenv.2016.08.034.
Iwata T, Tokura M. 1997. Position index for a glare source located below the line of vision. Lighting Research & Technology. 29:172-178. doi:10.1177/14771535970290030801.
Iwata T, Tokura M. 1998. Examination of the limitations of predicted glare sensation vote (pgsv) as a glare index for a large source: Towards a comprehensive development of discomfort glare evaluation. Lighting Research & Technology. 30(2):81-88. doi:10.1177/096032719803000205.
Iwata T, Tokura M, Shukuya M, Kimura K-i. 1992b. Experimental study on discomfort glare caused by windows: Subjective response to glare from actual windows. Journal of Architecture, Planning and Environmental Engineering. (439):19-31.
Jakubiec JA, Reinhart CF. 2011. The ‘adaptive zone’ – a concept for assessing discomfort glare throughout daylit spaces. Lighting Research & Technology. 44:149-170. doi:10.1177/1477153511420097.

Jakubiec JA, Reinhart CF. 2016. A concept for predicting occupants' long-term visual comfort within daylit spaces. The Journal of the Illuminating Engineering Society. 12(4):185-202. doi:10.1080/15502724.2015.1090880.
Karwowski W. 2006. International encyclopedia of ergonomics and human factors - volume 1. Boca Raton, USA: CRC Press. 3652p.
Kent M, Altomonte S, Tregenza P, Wilson R. 2015a. Time of day, temporal variables and personal factors in the subjective evaluation of glare sensation. PLEA 2015. Bologna, Italy. September 09-11, 2015.
Kent M, Altomonte S, Tregenza PR, Wilson R. 2015b. Discomfort glare and time of day. Lighting Research & Technology. 47:641-657. doi:10.1177/1477153514547291.
Kent M, Altomonte S, Tregenza PR, Wilson R. 2015c. Temporal variables and personal factors in glare sensation. Lighting Research & Technology. 48(6):689-710. doi:10.1177/1477153515578310.
Kent M, Altomonte S, Wilson R, Tregenza PR. 2017a. Temporal effects on glare response from daylight. Building and Environment. 113:49-64. doi:10.1016/j.buildenv.2016.09.002.
Kent M, Fotios S. 2017. Using adjustment to evaluate discomfort glare. Lux Europa 2017. Ljubljana, Slovenia. September 18-20, 2017.
Kent M, Fotios S, Altomonte S. 2017b. Discomfort glare evaluation: The influence of anchor bias in luminance adjustments. Lighting Research & Technology. doi:10.1177/1477153517734280.
Kent MG. 2016. Temporal effects in glare response [PhD dissertation]. [Nottingham, UK]: University of Nottingham. 390p.
Kim J, de Dear R, Cândido C, Zhang H, Arens E. 2013. Gender differences in office occupant perception of indoor environmental quality (ieq). Building and Environment. 70:245-256. doi:10.1016/j.buildenv.2013.08.022.
Kim JT, Shin JY, Yun GY. 2012. Prediction of discomfort glares from windows: Influence of the subjective evaluation of window views. Indoor and Built Environment. 21(1):92-97. doi:10.1177/1420326X11423157.
Kim W, Han H, Kim JT. 2009. The position index of a glare source at the borderline between comfort and discomfort (bcd) in the whole visual field. Building and Environment. 44(5):1017-1023. doi:10.1016/j.buildenv.2008.07.007.
Kim W, Kim JT. 2010. A distribution chart of glare sensation over the whole visual field. Building and Environment. 45(4):922-928. doi:10.1016/j.buildenv.2009.09.013.
Kim W, Kim JT. 2011. A position index formula for evaluation of glare source in the visual field. Indoor and Built Environment. 20(1):47-53. doi:10.1177/1420326x10389267.
Kim W, Kim JT. 2012. A prediction method to identify the glare source in a window with non-uniform luminance distribution. Energy and Buildings. 46:132-138. doi:10.1016/j.enbuild.2011.10.037.
Kim W, Koga Y. 2004. Effect of local background luminance on discomfort glare. Building and Environment. 39(12):1435-1442. doi:10.1016/j.buildenv.2004.05.003.
Kim W, Koga Y. 2005. Glare constant gw for the evaluation of discomfort glare from windows. Solar Energy. 78(1):105-111. doi:10.1016/j.solener.2004.05.020.
Kimura-Minoda T, Ayama M. 2011. Evaluation of discomfort glare from color leds and its correlation with individual variations in brightness sensitivity. Color research and application. 36:286 – 294.
Ko JK, Choi SY. 2017. Contents development for office smart lights. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.
Konis K. 2014. Predicting visual comfort in side-lit open-plan core zones: Results of a field study pairing high dynamic range images with subjective responses. Energy and Buildings. 77:67-79. doi:10.1016/j.enbuild.2014.03.035.
Kuhn T, Wienold J, Moosmann C. 2013. Daylight glare : Age effects and their impact on glare evaluation. 8th Energy Forum on Solar Building Skins. Bressanone, Italy. November 05-06, 2013.

Laurentin C, Bermtto V, Fontoynont M. 2000. Effect of thermal conditions and light source type on visual comfort appraisal. Lighting Research & Technology. 32(4):223-233. doi:10.1177/096032710003200406.
Lee ES, Clear RD, Fernandes L, Ward G. 2007. Commissioning and verification procedures for the automated roller shade system at the new york times headquarters, new york, new york. Berkeley, USA: Lawrence Berkeley National Laboratory (LBNL). 112p.
Lee JS, Kim BS. 2007. Development of the nomo-graph for evaluation on discomfort glare of windows. Solar Energy. 81(6):799-808. doi:10.1016/j.solener.2006.09.006.
Lien EL, Hammond BR. 2011. Nutritional influences on visual development and function. Progress in Retinal and Eye Research. 30(3):188-203. doi:10.1016/j.preteyeres.2011.01.001.
Lin Y, Liu Y, Sun Y, Zhu X, Lai J, Heynderickx I. 2014. Model predicting discomfort glare caused by led road lights. Optics express. 22(15):8056-8071. doi:10.1364/OE.22.018056.
Linney AS. 2008. Maximum luminances and luminance ratios and their impact on users' discomfort glare perception and productivity in daylit offices [Master's thesis]. [Wellington, New Zealand]: Victoria University of Wellington. 186p.
Logadóttir Á, Christoffersen J, Fotios S. 2011. Investigating the use of an adjustment task to set the preferred illuminance in a workplace environment. Lighting Research & Technology. 43(4):403-422. doi:10.1177/1477153511400971.
Logadóttir Á, Fotios S, Christoffersen J, Hansen SS, Corell DD, Dam-Hansen C. 2013. Investigating the use of an adjustment task to set preferred colour of ambient illumination. Color research and application. 38(1):46–57. doi:10.1002/col.20714.
Loughman J, Akkali MC, Beatty S, Scanlon G, Davison PA, O'Dwyer V, Cantwell T, Major P, Stack J, Nolan JM. 2010. The relationship between macular pigment and visual performance. Vision Research. 50(13):1249-1256. doi:10.1016/j.visres.2010.04.009.
Luckiesh M, Guth SK. 1949. Brightnesses in visual field at borderline between comfort and discomfort (bcd). National Technical Conference of the Illuminating Engineering Society. French Lick, USA. September 20-23, 1949.
Lulla AB, Bennett CA. 1981. Discomfort glare: Range effects. The Journal of the Illuminating Engineering Society. 10(2):74-80. doi:10.1080/00994480.1980.10748591.
MacGowan D, Aspinall P, Newman P, Russell T, Lakowski R. 1988. Visual quality characteristics of the working environment. Glasgow, UK: Inter-Institutional Research Programme.
MacGowan D, Emery AF. 1986. Window architectonics in the automated office. 10th Triennial Congress of the International Council for Building Research. Washington, USA. September 22-26, 1986.
MacLeod CM. 1991. Half a century of research on the stroop effect: An integrative review. Psychological Bulletin. 109(2):163-203. doi:10.1037/0033-2909.109.2.163.
Mainster MA, Turner PL. 2012. Glare's causes, consequences, and clinical challenges after a century of ophthalmic study. American Journal of Ophthalmology. 153(4):587-593. doi:10.1016/j.ajo.2012.01.008.
Mangkuto RA, Kurnia KA, Azizah DN, Atmodipoero RT, Soelami FXN. 2017. Determination of discomfort glare criteria for daylit space in indonesia. Solar Energy. 149:151-163. doi:10.1016/j.solener.2017.04.010.
Mochizuki E, Iwata T. 2005. Discomfort glare caused by a window screen with non- uniform luminance distribution. Lux Pacifica 2005. Cairns, Australia. July 24-26, 2005.
Narisada K, Schreuder D. 2004. Light pollution handbook. Groningen, The Netherlands: Springer Netherlands. 966p.
Nazzal AA. 2005. A new evaluation method for daylight discomfort glare. International Journal of Industrial Ergonomics. 35(4):295-306. doi:10.1016/j.ergon.2004.08.010.
Ngai P, Boyce P. 2000. The effect of overhead glare on visual discomfort. The Journal of the Illuminating Engineering Society. 29(2):29-38. doi:10.1080/00994480.2000.10748315.
Nicol F, Wilson M, Chiancarella C. 2006. Using field measurements of desktop illuminance in european offices to investigate its dependence on outdoor conditions and its effect on

occupant satisfaction, and the use of lights and blinds. Energy and Buildings. 38(7):802-813. doi:10.1016/j.enbuild.2006.03.014.
Osterhaus WKE. 2001. Discomfort glare from daylight in computer offices: What do we really know? Lux Europa 2001. Reykjavik, Iceland. June 17-20, 2011.
Osterhaus WKE. 2008. Analysis of luminance histograms for the assessment of discomfort glare in daylit offices. Balkan Light 2008. Ljubljana, Slovenia. October 07-09, 2008.
Osterhaus WKE. 2009. Design guidelines for glare-free daylit work environments. Lux Europa 2009. Istanbul, Turkey. September 09-11, 2009.
Osterhaus WKE, Bailey IL. 1992. Large area glare sources and their effect on discomfort and visual performance at computer workstations. 1992 IEEE Industry Applications Society Annual Meeting. Houston, USA. October 04-09, 1992.
Paulsson L-E, Sjostrand J. 1980. Contrast sensitivity in the presence of a glare light - theoretical concepts and preliminary clinical studies. Investigative Ophthalmology & Visual Science. 19(4):401-406. doi:0146-0404/80/040401+06$00.60/0.
Petherbridge P, Hopkinson RG. 1950. Discomfort glare and the lighting of buildings. Lighting Research & Technology. 15(2):39-79. doi:10.1177/147715355001500201.
Pierson C, Piderit MB, Wienold J, Bodart M. 2017. Discomfort glare from daylighting: Influence of culture on discomfort glare perception. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.
Pulpitlova J, Detkova P. 1993. Impact of the cultural and social background on the visual perception in living and working perception. International Symposium on Design of Amenity. Fukuoka, Japan. October 05-09, 1993.
Rea MS. 1982. Calibration of subjective scaling responses. Lighting Research & Technology. 14(3):121-129.
Rodriguez RG, Pattini A. 2014. Tolerance of discomfort glare from a large area source for work on a visual display. Lighting Research & Technology. 46(2):157-170. doi:10.1177/1477153512470386.
Rodriguez RG, Yamín Garretón JA, Pattini AE. 2016. Glare and cognitive performance in screen work in the presence of sunlight. Lighting Research & Technology. 48(2):221-238. doi:10.1177/1477153515577851.
Sarey Khanie M, Jia Y, Wienold J, Andersen M. 2015. A sensitivity analysis on glare detection parameters. BS2015-14th International Conference of the International Building Performance Simulation Association. Hyderabad, India. December 07-09, 2015.
Sarey Khanie M, Stoll J, Einhäuser W, Wienold J, Andersen M. 2017. Gaze and discomfort glare, part 1: Development of a gaze-driven photometry. Lighting Research & Technology. 49(7):845-865. doi:10.1177/1477153516649016.
Saur RL. 1969. Influence of physiological factors on discomfort glare level. Optometry & Vision Science. 46(5):352-357.
Scheir GH, Hanselaer P, Bracke P, Deconinck G, Ryckaert WR. 2015. Calculation of the unified glare rating based on luminance maps for uniform and non-uniform light sources. Building and Environment. 84(0):60-67. doi:10.1016/j.buildenv.2014.10.027.
Scheir GH, Hanselaer P, Ryckaert WR. 2017. Pupillary light reflex and receptive field calculation of visual discomfort for different spatial frequencies and luminance steps. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.
Sekihara M, Imai M, Hagiwara H, Akiyama Y, Taniguchi T, Iwata T. 2016. Effect of task on discomfort glare from windows. 9th CJK Lighting Conference. Busan, Korea. August 18-19, 2016.
Shen E, Hu J, Patel M. 2014. Energy and visual comfort analysis of lighting and daylight control strategies. Building and Environment. 78:155-170. doi:10.1016/j.buildenv.2014.04.028.
Shin JY, Yun GY, Kim JT. 2012. View types and luminance effects on discomfort glare assessment from windows. Energy and Buildings. 46:139-145. doi:10.1016/j.enbuild.2011.10.036.

Siah WF, O'Brien C, Loughman JJ. 2017. Macular pigment is associated with glare-affected visual function and central visual field loss in glaucoma. British Journal of Ophthalmology. doi:10.1136/bjophthalmol-2017-310215.
Sivak M, Flannagan MJ, Ensing M, Simmons CJ. 1989. Discomfort glare is task dependent. Ann Arbor, USA: University of Michigan. No. UMTRI-89-27. 18p.
Sivak M, Flannagan MJ, Traube EC, Kojima S. 1997. The influence of stimulus duration on discomfort glare for persons with and without visual correction. Ann Arbor, USA: University of Michigan. No. UMTRI-97-23. 22p.
Sivak M, Schoettle B, Minoda T, Flannagan MJ. 2005. Short-wavelength content of led headlamps and discomfort glare. The Journal of the Illuminating Engineering Society. 2(2):145-154. doi:10.1582/LEUKOS.2005.02.02.006.
Stone PT, Harker SDP. 1973. Individual and group differences in discomfort glare responses. Lighting Research & Technology. 5(1):41-49. doi:10.1177/096032717300500106.
Stringham JM, Fuld K, Wenzel AJ. 2003. Action spectrum for photophobia. Journal of the Optical Society of America. 20(10):1852-1858. doi:10.1364/JOSAA.20.001852.
Stringham JM, Fuld K, Wenzel AJ. 2004. Spatial properties of photophobia. Investigative Ophthalmology & Visual Science. 45(10):3838-3848. doi:10.1167/iovs.04-0038.
Stringham JM, Garcia PV, Smith PA, McLin LN, Foutch BK. 2011. Macular pigment and visual performance in glare: Benefits for photostress recovery, disability glare, and visual discomfort. Investigative Ophthalmology & Visual Science. 52:7406-7415. doi:10.1167/iovs.10-6699.
Subova A, Kittler R, MacGowan D. 1991. Results of ongoing experiments on subjective response to discomfort glare. Journal of the illuminating Engineering Institute of Japan. 75(Appendix):129-130. doi:10.2150/jieij1980.75.Appendix_129.
Sweater-Hickcox K, Narendran N, Bullough JD, Freyssinier JP. 2012. Effect of different colored background lighting on led discomfort glare perception. Twelfth International Conference on Solid State Lighting and Fourth International Conference on White LEDs and Solid State Lighting. San Diego, USA. August 12-16, 2012. doi:10.1117/12.968192.
Tashiro T, Kawanobe S, Kimura-Minoda T, Kohko S, Ishikawa T, Ayama M. 2015. Discomfort glare for white led light sources with different spatial arrangements. Lighting Research & Technology. 47:316–337. doi:10.1177/1477153514532122.
Tokura M, Iwata T, Shukuya M. 1996. Experimental study on discomfort glare caused by windows: Development of a method for evaluating discomfort glare from a large light source. Journal of Architecture, Planning and Environmental Engineering. (489):17-25.
Torres S, Lo Verso VRM. 2015. Comparative analysis of simplified daylight glare methods and proposal of a new method based on the cylindrical illuminance. Energy Procedia. 78:699-704. doi:10.1016/j.egypro.2015.11.074.
Tuaycharoen N. 2011. Windows are less glaring when there is a preferred view. Built-Environment Sri Lanka. 9-10(1-2):45–55.
Tuaycharoen N, Tregenza PR. 2005. Discomfort glare from interesting images. Lighting Research & Technology. 37(4):329-338. doi:10.1191/1365782805li147oa.
Tuaycharoen N, Tregenza PR. 2007. View and discomfort glare from windows. Lighting Research & Technology. 39(2):185-200. doi:10.1177/1365782807077193.
Tyukhova YI. 2015. Discomfort glare from small, high luminance light sources in outdoor nighttime environments [PhD dissertation]. [Lincoln, USA]: University of Nebraska - Lincoln. 295p.
van Bommel W. 2015. Road lighting: Fundamentals, technology and application. Cham, Switzerland: Springer International Publishing. 343p.
Van Den Wymelenberg K. 2012. Evaluating human visual preference and performance in an office environment using luminance-based metrics [PhD dissertation]. [Washington, USA]: University of Washington (UW). 346p.

Van Den Wymelenberg K. 2014. Visual comfort, discomfort glare, and occupant fenestration control: Developing a research agenda. The Journal of the Illuminating Engineering Society. 10(4):207-221. doi:10.1080/15502724.2014.939004.
Van Den Wymelenberg K, Inanici M. 2014. A critical investigation of common lighting design metrics for predicting human visual comfort in offices with daylight. The Journal of the Illuminating Engineering Society. 10(3):145-164. doi:10.1080/15502724.2014.881720.
Van Den Wymelenberg K, Inanici M. 2016. Evaluating a new suite of luminance-based design metrics for predicting human visual comfort in offices with daylight. The Journal of the Illuminating Engineering Society. 12:113-138. doi:10.1080/15502724.2015.1062392.
Van Den Wymelenberg K, Inanici M, Johnson P. 2010. The effect of luminance distribution patterns on occupant preference in a daylit office environment. The Journal of the Illuminating Engineering Society. 07(02):103-122. doi:10.1080/19401493.2015.1058421.
Vásquez NG, Ruttkay Pereira FO, Pires MO, Moraes LN. 2016. Investigating a method to dynamic assessment of glare using the hdr technique. PLEA 2016. Los Angeles, USA. July 11-13, 2016.
Veitch JA, Newsham GR. 2000. Preferred luminous conditions in open-plan offices: Research and practice recommendations. Lighting Research & Technology. 32(4):199-212. doi:10.1177/096032710003200404.
Velds M. 2000. Assessment of lighting quality in office rooms with daylighting systems [PhD dissertation]. [Delft, The Netherlands]: Technische Universiteit Delft (TUD). 231p.
Völker S, Freyer M, Raphael S, Meyborg M. 2017. Influence factors for discomfort glare of headlamps and a new model for its estimation. CIE 2017 Midterm Meeting. Jeju, South Korea. October 21-28, 2017.
Vos J, Van Bergem-Jansen PM. 1995. Greenhouse lighting side-effects: Community reaction. Lighting Research & Technology. 27(1):45-51. doi:10.1177/14771535950270010301.
Ward G. Radiance findglare program. 1993. [accessed September 27, 2017]. http://radsite.lbl.gov/radiance/man_html/findglare.1.html.
Waters CE, Mistrick RG, Bernecker CA. 1995. Discomfort glare from sources of nonuniform luminance. The Journal of the Illuminating Engineering Society. 24(2):73-85. doi:10.1080/00994480.1995.10748120.
Wei M, Houser KW, Orland B, Lang DH, Ram N, Sliwinski MJ, Bose M. 2014. Field study of office worker responses to fluorescent lighting of different cct and lumen output. Journal of Environmental Psychology. 39:62-76. doi:10.1016/j.jenvp.2014.04.009.
Weijters B, Cabooter E, Schillewaert N. 2010. The effect of rating scale format on response styles: The number of response categories and response category labels. International Journal of Research in Marketing. 27(3):236-247.
Wienold J. 2009a. Daylight glare in offices [PhD dissertation]. [Freiburg, Germany]: Universität Karlsruhe (TH). 136p.
Wienold J. 2009b. Workshop glare analysis of hdr images. 8th International Radiance Workshop. Boston, USA. October 21-23, 2009.
Wienold J, Christoffersen J. 2006. Evaluation methods and development of a new glare prediction model for daylight environments with the use of ccd cameras. Energy and Buildings. 38(7):743-757. doi:10.1016/j.enbuild.2006.03.017.
Wirtschafter JD, Bourassa CM. 1966. Binocular facilitation of discomfort with high luminances. Archives of Ophthalmology. 75:683–688.
Wolska A, Sawicki D. 2014. Evaluation of discomfort glare in the 50+ elderly: Experimental study. International Journal of Occupational Medicine and Environmental Health. 27(3):444-459. doi:10.2478/s13382-014-0257-9.
Wright KPJ, Badia P, Myers BL, Plenzler SC, Hakel M. 1997. Caffeine and light effects on nighttime melatonin and temperature levels in sleep-deprived humans. Brain Research. 747(1):78-84. doi:10.1016/S0006-8993(96)01268-1.

Yamin Garretón J, Rodriguez R, Pattini A. 2015. Effects of perceived indoor temperature on daylight glare perception. Building Research & Information. 44(8):1-14. doi:10.1080/09613218.2016.1103116.
Yang Y, Ronnier Luo M, Huang WJ. 2016. Assessing glare, part 3: Glare sources having different colours. Lighting Research & Technology. doi:10.1177/1477153516676640.
Yang Y, Ronnier Luo M, Ma SN. 2017. Assessing glare. Part 2: Modifying unified glare rating for uniform and non-uniform led luminaires. Lighting Research & Technology. 49:727–742. doi:10.1177/1477153516642622.
Zhang J, Tu Y, Liu L, Wang L, Peng S, Heynderickx I. 2013. Effect of the correlated color temperature of light on overhead glare in offices. SID Display Week. Vancouver, Canada. May 19-24, 2013.