TECHNICAL REPORT

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Unwanted reflections from the active and inactive areas of display surfaces visible during use

Réflexions non désirées des zones actives et inactives des surfaces de l'écran visibles durant l'utilisation

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Foreword

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The committee responsible for this document is ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

Unwanted reflections from the active and inactive areas of display surfaces visible during use

1 Scope

This Technical Report provides users a summary of the existing knowledge about ergonomics requirements for unwanted reflections on electronic displays. The document furthermore provides some guidance on specification of unwanted reflections.

NOTE ISO 9241 contains normative requirements related to unwanted reflections. It is possible that the information contained in this Technical Report will be used for a future update of ISO 9241.

2 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1
asthenopia
weakness or tiring of the eyes accompanied by pain, headache, and dim vision

Note 1 to entry: Symptoms include pain in or around the eyes; headache, usually aggravated by using the eyes for close work; fatigue; vertigo; and reflex symptoms such as nausea, twitching of facial muscles, or migraine.

[SOURCE: Taber's Medical Dictionary]

2.2
disability glare
glare that impairs the vision of objects without necessarily causing discomfort

2.3
direct glare
glare caused by self-luminous objects located in the visual field, especially near the line of sight

2.4
discomfort glare
glare that causes discomfort without necessarily impairing the vision of objects

2.5
glare
condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or by extreme contrasts

2.6
glare by reflection
glare produced by reflections, particularly when the reflected images appear in the same or nearly the same direction as the object viewed

2.7
gloss (of a surface)
mode of appearance by which reflected highlights of light sources of objects are perceived as superimposed on the surface due to the directionally selective properties of that surface

2.8
glossmeter
instrument for measuring the various photometric properties of a surface giving rise to gloss

2.9
reflectometer
instrument for measuring quantities pertaining to reflection

2.10
specular gloss
ratio of the luminous flux reflected from an object in the specular direction for a specified source and receptor angle to the luminous flux reflected from glass with a refractive index of 1,567 in the specular direction

2.11
veiling glare (imaging)
light, reflected from an imaging medium, that has not been modulated by the means used to produce the image

3 Unwanted reflections within the context of the ISO 9241-3xx series

3.1 Glare and unwanted reflections

At various places in the ISO 9241-3xx series, we specifically adopt the CIE definition of glare, which includes both discomfort glare and disability glare. We note that the CIE defines discomfort glare verbally as:

> "glare which causes discomfort without necessarily impairing the vision of objects",[11]

and disability glare as

> "glare that impairs vision".[13]

Glare is commonly classed as direct glare, in which the eye is directly illuminated by some object, such as a display, a luminaire or the sun, and indirect glare, in which the eye is illuminated by light reflected from a surface such as that of a display screen.

3.2 Direct glare in the context of the ISO 9241-3xx standards series

ISO 9241-6 discusses two types of glare in the context of office working environments. Direct glare is described thusly:

> "Direct glare from daylight can typically be caused by a direct view of the sun or clouds and by their reflections on adjacent buildings.",[2]

and

> "Direct glare from artificial lighting can be caused by luminaires or illuminated room surfaces with high luminance".

Clearly, direct glare is seen to be associated with reflections as well as luminance sources directly in the user's line of sight.

In general, room lighting as a source of direct glare has been studied extensively and appropriate designs are well specified. However it is important to note that the recent introduction of new technologies such as luminaires composed of Light Emitting Diodes (LED) has stimulated reconsideration of both the concept of comfortable lighting,[14] and questions about the applicability of existing standards to environments illuminated by LEDs.[14][15] Although we will not discuss direct glare in detail in this paper, the specification of limits for the ambient illuminance for office computer workplaces in standards such as EN 12464-1 overlaps with the discussion of unwanted reflections from the inactive and active areas of displays that are visible during use.

Moreover, there is at least one specification within the ISO 9241-3xx series that deals specifically with the issue of direct glare as defined and discussed by CIE and ISO 9241-6:1999, 3.9, 5.4, Clause 10 and Annex A.

ISO 9241-303:2011, D.5 states a requirement regarding the upper limit for LH, display screen luminance:

> "Glare (disability glare or discomfort glare) shall not be produced by the display". Clearly this refers to a limit on direct glare resulting from an excessively high luminance of a self-luminous object (the display) located in the visual field, especially near the line of sight, exactly satisfying the definition of direct glare.

3.3 Glare by reflection

The second type of glare discussed in ISO 9241-6 is glare by reflection:

> "Glare by reflection can occur in vertical, horizontal and intermediate planes. It can impair visual perception and/or cause discomfort. Disturbing glare caused by reflection on working surfaces and work equipment (for example, visual displays, printed documents, keyboards) should be prevented by suitable design and positioning of the work equipment and the lighting."

The majority of the discussion on glare within the context of the ISO 9241-3xx series pertains to indirect glare resulting from reflections from display surfaces. The context of use for the great majority of the current standards content in the ISO 9241-3xx series is in regard to displays in the office computer workplace, however, this may be expanded in the future to include the home and other environments. It will be critical to maintain distinctions between specifications developed for different environments or contexts of use. It is also important to determine what is meant by the term "disturbing glare", as this term is not defined by the CIE and does not appear to be used outside of Europe.

4 Visual discomfort and glare while using computer displays

4.1 Asthenopia

Visual discomfort while viewing displays is commonly referred to as computer vision syndrome or asthenopia while viewing computer displays. Asthenopia complaints from computer users are common, with estimates of current symptom prevalence ranging as high as 90 % of all computer users.[16] It is an issue well known and documented since the introduction of personal computers.[17]

Sheedy, et al. list potential causes for asthenopia:[18]

> "Direct glare from lighting, anomalies of binocular vision, accommodative dysfunction, uncorrected refractive error, compromised quality of the viewed image, less than optimal viewing angles, flickering visual stimuli such as CRT computer displays, and dry eye".

Sheedy further classifies asthenopic symptoms into two groups, internal and external, based on a principle components analysis of the responses made by subjects during a study of asthenopia. The external symptom factor included eye symptoms such as burning, irritation, and dryness. These symptoms were associated with inducing conditions such as glare, upward gaze angle, flicker, font size, and reduced blink rate.

The internal symptom factor included symptoms such as eyestrain, headache and eye ache, they were associated with inducing conditions such as astigmatism and close viewing distance.

Consequently, while glare is an important causal factor for asthenopia occurring in the office computer workplace, it is important to note that it is one of many causal factors.

5 Unwanted reflections from displays

5.1 General

The question currently before ISO TC 159/SC4 technical committee is that of glare from the inactive areas of the display, such as housings, that are visible during use. It has been proposed that a limit should be set on the reflectivity (specular gloss) of equipment housings visible during use. In order to more fully understand the issue of glare, this paper first reviews current regulations, technical standards and research findings pertinent to unwanted reflections (glare) from the active and inactive areas of displays.

5.2 Glare and unwanted reflections on screens in the ISO 9241-3xx series

The ISO 9241-3xx series of ergonomic standards addresses the issue of unwanted reflections (glare) on display screens, with regard to the effect on the computer user's comfort and his or her visual performance. The terms "glare" and "unwanted reflections" are used interchangeably within the ISO 9241-3xx series. We will adopt the usage of the term "unwanted reflections" in this paper, with the understanding that it is used to mean both glare and unwanted reflections.

NOTE ISO 9241-305 also uses the term "glare" to refer to a noise source during measurement and unwanted reflections to refer to reflected light interfering with human visual performance.

6 Pertinent regulations regarding glare and unwanted reflections

6.1 European Directive 90-270 — On the minimum safety and health requirements for work with display screen equipment

EU Directive 90-270,[19] which has the force of law for members of the European Union, offers several statements regarding glare and unwanted reflections on screens.

> "The screen shall be free of reflective glare and reflections liable to cause discomfort to the user."

> "Possible disturbing glare and reflections on the screen or other equipment shall be prevented by coordinating workplace and workstation layout with the positioning and technical characteristics of the artificial light sources."

> "Workstations shall be so designed that sources of light, such as windows and other openings, transparent or translucid walls, and brightly coloured fixtures or walls cause no direct glare and no distracting reflections on the screen."

6.2 The meaning of disturbing glare within the ISO 9241-3xx series

6.2.1 General

Glare by reflection has been defined by the CIE; however, it is not clear what is meant within the context of EU Directive 90-270 by the term "disturbing glare" as it is not defined by the CIE and does not appear to be in common use outside of Europe.

ISO 9241-307 addressed this issue by equating "disturbing glare", as used in EU Directive 90-270, to the CIE definition of glare with the following statement:

> "Disturbing glare thus is a condition of vision in which there is a disturbing degree of visual discomfort or/and a noticeable reduction in the ability to see details or objects."

thus explicitly referencing and adopting the CIE definition of glare:

> "Condition of vision in which there is discomfort or a reduction in the ability to see details of objects, caused by an unsuitable distribution or range of luminance, or too extreme contrasts".

6.2.2 CIE definitions of discomfort glare and disability glare

The CIE[20] defines discomfort glare verbally as

> "glare which causes discomfort without necessarily impairing the vision of objects",

and quantitatively, in the context of direct glare caused by indoor lighting, by means of the Universal Glare Rating (UGR) formula.[12]

The CIE defines disability glare verbally as

> "Disability glare is glare that impairs vision.",[13]

and quantitatively by means of the CIE General Disability Glare Equation.[13] The CIE general formula for discomfort glare caused by indoor lighting is

$$UGR = 8\log_{10}[(0{,}25/L_B)\sum L^2\omega/\rho^2] \quad (1)$$

where L_B is the background luminance and may be defined as E/π, where E is the indirect illuminance at the eye of the observer and is measured in lux, ω is the solid angle of the glare source, L is the luminance of the source luminaire in the direction of the user's eye, and ρ is the Guth position index.

Although the original Guth position index was described only for the upper half of the visual field, it has been extended by Kim, et. al. over the entire visual field.[21] For the visual angles typical of a computer viewer (about 20° above, below and to the side of the line of sight), it is approximately 1,[21] which is smaller than the value suggested by Luckliesh and Guth,[22] which is about 1,5 for the overlapping regions.

While the CIE discomfort glare rating was developed in the context of direct glare, Howarth and Hodder[23] have examined whether it can be used to estimate the value of a single source luminance that will create an unacceptable reflectance. They note that it required a source luminance many times that which would be expected in the work environment in order to produce a reflection that would have an unacceptable UGR rating.

6.2.3 Unwanted reflections as currently specified and limited in ISO 9241-303, 9241-305 and 9241-307 for the active area of displays (screens)

Currently, ISO 9241-307 specifies maximum acceptable levels of unwanted reflections on the screen (the active area of the display) in terms of contrast ratios, which incorporate diffuse and specular reflection components. It is important to note that both ISO 9241-305 and ISO 9241-303 emphasize the importance of correctly dealing with the haze component.

In ISO 9241-303 we find the following note:

> "Typical LCD (liquid crystal display) monitor screens, for example, comprise only haze components with varying width of the intensity distribution of reflected light; in this case, specular and Lambertian components can be neglected."

ISO 9241-305 emphasizes the necessity to account for any haze component in the determination of the specular component of glare luminance. In the case that

> "...examination of the appearance of the reflected light of the lamp from the position of the LMD showed that the virtual image is distinct but there is substantial luminance reflected beyond the virtual image of the source or no virtual image is observable except for a "fuzzy ball of light", then calculate the small-source specular reflectance, ρ_{small}, while attempting to subtract the diffuse background from the specular component using the luminance factor, ρ_D, obtained from 6.5.6."

It further cautions that this:

"...is an approximate attempt to account for the non-specular reflectance by subtracting it from the specular component. The method specified [in this case] is correct for reflective surfaces for which only a specular and diffuse (Lambertian) component of reflection exists. It does not properly subtract the haze contribution from the reflection. It is a naïve model and can generate confusing results, owing to the assumption by its users that they have the correct specular reflectance and can begin using the form $\mathbf{L = \rho_{small} Ls}$ with impunity."

6.3 Interaction between specular, diffuse and haze reflection components

6.3.1 General

Attention is called to the distinctness or sharpness of the reflected image, noting that the more distinct an image is, the more noticeable and disturbing the image becomes.[24][25][26][27] However, it is noted in Reference [27] that haze reflection counteracts the effect of specular reflectance.

> "The effect from haze reflection relates positively to [the acceptable magnitude of the source luminance] because the haze reflection helps blur the edge and lower the peak luminance of the reflection. Both actions contribute to the reduction of perceived contrast. With less perceived contrast and blurred edges, the source of the reflection can have a higher luminance before being considered disturbing."

Reference [27] describes a source luminance that is on the borderline between acceptable and disturbing as

$$\mathrm{Log10}(L_A) = 3{,}013 - 10{,}668\ \rho_S + 0{,}43\ H + 0{,}001\ L_B - 4{,}550\ \omega \quad (2)$$

where L_A is the source luminance creating the disturbance, ρ_S is the specular reflectance associated with angular size of the light source, H is the haze reflection, L_B is the background luminance of the screen, and ω is the solid angle that the reflected light source subtends at the viewing position.

6.3.2 Recognition of the interaction of unwanted reflection components in the ISO 9241-3xx series

The ISO 9241-3xx series specifically recognizes the interaction between specular and diffuse reflection components in determining the point at which unwanted reflections are unacceptable. For example, both ISO 9241-305 and ISO 9241-307 limit the allowable reflection luminances for positive polarity screens displaying artificial information as

$$(L_H / (L_D + L_S)) \geq 1{,}2 + 4{,}84(L_D + L_S)^{-0{,}65} \quad (3)$$

and

$$(L_H + L_D + L_S)/(L_H + L_D) \leq 1{,}25 \quad (4)$$

where L_H is the luminance of the display at its high state, L_D is the luminance due to diffuse reflection and L_S is the luminance due to the specular reflection.

7 Luminance balance

ISO 9241-307 recommends that:

> "In work environments, the luminance of the task areas, Ltask, area, that are frequently viewed in sequence while using the visual display (document, covers, etc.) should be between 0,1 × Ltask, area ≤ LEa, HS ≤ 10 × Ltask, area, where LEa, HS is the area average luminance of the visual display."

8 Glare and the ambient illumination in the office-working environment

8.1 Ambient illuminance

ISO 9241-307 defines the intended context of use of emissive flat-panel displays. As a part of the Environment of the Context of Use, the design screen illuminance, ES, is specified as:

> "vertical 250 lx + 250 lx × cos(α) in offices, where α is the screen tilt angle",

or a maximum of 500 lx. An illumination range between 200 lx and 500 lx is recommended.[10]

Similarly, European Standard EN 12464-1:2011 requires that the minimum average maintained ambient illuminance on the work (reference) surface for Display Screen Equipment work environments to be 500 lx and that the UGR rating at 19 or less. It is important to note that the CIE specifies that, in order to obtain a UGR of 19 or less, the ambient illuminance must be 1 000 lx or less.

8.2 Arrangement of the computer work area

Both EU Directive 90-270 and EN 12464-1 call attention to the sources of glare, including attention to window location, window treatments and the arrangement of luminaires as a means of avoiding glare.

> "Workstations shall be so designed that sources of light, such as windows and other openings, transparent or translucid walls, and brightly colored fixtures or walls cause no direct glare and no distracting reflections on the screen."[19]

> "Reflections in the DSE and, in some circumstances, reflections from the keyboard can cause disability and discomfort glare. It is therefore necessary to select, locate and arrange the luminaires to avoid high brightness reflections."[8]

8.3 Surface finishes (reflectivity)

8.3.1 General

EN 12464-1, EU Directive 90-270, ISO 9241-411, ISO 9241-5, ISO 9241-6 and DIN 5035-7 refer to surface finish properties.

EN 12464-1 lists surface finish as one option to control veiling reflections and reflected glare.

> "High brightness reflections in the visual task may alter task visibility, usually detrimentally. Veiling reflections and reflected glare may be prevented or reduced by the following measures:
>
> — arrangement of luminaires and work places;
>
> — surface finish (matt surfaces);
>
> — luminance restriction of luminaires;
>
> — increased luminous area of the luminaire;
>
> — bright ceiling and bright walls."

EU Directive 90-270 requires that:

> "The keyboard shall have a matt surface to avoid reflective glare",

and

> "The work desk or work surface shall have a sufficiently large, low- reflectance surface and allow a flexible arrangement of the screen, keyboard, documents and related equipment."

ISO 9241-5 recommends that work surfaces and input device surfaces, respectively, should not exceed 45 gloss units or a reflectometer value of 20 or greater. ISO 9241-411 requires that input device surfaces must not exceed 45 gloss units or a reflectometer value of 20 or greater.

DIN 5035-7 provides recommendations for both reflectivity and gloss of various surfaces. For work tables, writing desks, factory benches, machines, display screen housings, keyboards and document holders, the recommended total reflectivity, RT, should range between 0,20 and 0,50 and the gloss should be ≤ 20 gloss units.

NOTE Although it has been suggested that DIN 5035-7 refers to diffuse reflectance, not total reflectance, this is not clear in the original text.

According to DIN 5035-7, the measurement of the reflectivity is to be accomplished by using an integrating sphere. However, the wording of the standard is not clear as to whether it refers to total reflectivity, diffuse reflectivity or specular reflectivity.

8.3.2 Conversion of specular gloss values to specular reflectance values

We can simplify specular gloss values to an equivalent specular reflectance. Gloss units can be converted to specular reflectance through use of the Fresnel equations,[28] producing the following relationships:

> "The black gloss reference used in gloss measurement has a specular reflectance of 0,100 at 60°, 0,049 at 20° and 0,619 at 85°. A perfect mirror has a gloss value of 1 000. By definition, the 60° gloss value of the black reference standard is 1 000 × 0,100 = 100".[29]

9 Literature review of research regarding unwanted reflections from the bezel, screen housing, or other inactive areas of the display visible during use

9.1 General

A comprehensive search using Google Scholar produced a few articles in the technical literature that directly examine the ergonomic effects of glare from screen bezels or housings.[30][31][32][33][34]

9.2 Bezel gloss

9.2.1 Howarth and Hodder, 2004

In their 2004 paper, Howarth and Hodder[31] report a study in two parts. In the first, they examined the effect of bezel gloss on letter identification, reporting no difference in performance as a function of bezel gloss for six subjects. They also applied the CIE discomfort glare formula, noting that high source luminances, much higher than those typically found in office work areas, appear necessary in order to produce glare ratings in excess of the limit of 19.

In the second part, they collected the subjective opinions of 20 subjects with regard to reading from displays with bezels of varying gloss. Each individual read text for two, 20-min sessions on six flat-panel displays and two cathode ray tube displays. The eight display bezels' glossiness varied between matt and mirror-like, and gloss measurements were taken using both 20° and 60° protocols. Howarth and Hodder note that the subjects' responses regarding discomfort and disturbingness, etc. are not correlated with bezel glossiness.

9.2.2 Béland and Andrén

Béland and Andrén[30] sought to determine what levels of front frame gloss and diffuse reflectance were acceptable to users. They presented 12 bezels with five different combinations of gloss, three levels of diffuse reflectance and three different colours to 31 subjects in three different settings; a control room (average surface luminance for surfaces of 113 cd/m^2, a dark room (average luminance for surfaces of 22 cd/m^2) and a light room (average luminance for surfaces of 900 cd/m^2). Each subject viewed each frame for approximately two minutes.

9.2.3 Howarth and Hodder, 2013

In their second study,[34] Howarth and Hodder studied subjective response to different bezels: three bezel colours (white, silver, black) and two gloss levels (matt or glossy). There are at least two important aspects with regard to the design of this study.

First, it was conducted in working offices, rather than in a laboratory. Each subject used each bezel combination for a period of one week, rather than for a few minutes or hours, as in previous studies. Second, the subjects were unaware of the purpose of the study; hence they were less likely to be inadvertently biased in regard to their response. Finally, the study was sponsored solely by Loughborough University.

Howarth and Hodder report that:

> "With the possible exception of the glossy black surround, there was no evidence of significantly increased visual discomfort, indicative of eyestrain, as a result of high or low bezel reflectance, or of high glossiness."

9.3 Bezel reflectance

9.3.1 General

Some of the studies identified report the effect of varying bezel reflectances.

9.3.2 Hunter, et al.

Hunter et al.[32] studied the effects of bezel reflectance, font size and time of day on the performance of 19 subjects. Performance on a numerical verification task, a data entry task and a naturalistic reading task was assessed for each subject. Each of the tasks was performed for approximately one hour in the morning and one hour in the afternoon. Each subject performed the tasks for one day at displays with varying bezel reflectivity and colour: 0,07 (black), 0,51 (pearl white) and 0,87 (high-reflectance white matt). Relative to the wall behind them, the three monitors had luminance ratios of 11:1, 1,4:1 and 0,88:1 respectively. Ambient illuminance was 500 lx on the work plane. No data were furnished regarding the luminance on the active screen areas. Statistical analysis found no difference in performance of any of the tasks as a function of bezel reflectance or time of day; larger font size (12 pt vs 6 pt) was associated with better performance. Finally, eye blinks and eye movements were tracked for six subjects. No difference was seen between bezel reflectance and either eye blinks or eye saccades; however, there was an increase in saccades between the morning and afternoon sessions, which the authors suggest may be related to fatigue.

Çakir and Çakir are critical of the Hunter et al. study, particularly in regard to its conclusions, which Çakir and Çakir report as:

> "… there is no scientific basis for a lower bound on the reflectance of monitor bezels",[24]

and that:

> "Organizations that recommend computer monitor bezel reflectances should consider raising their upper bound on reflectance to at least 0,87, … if upper bounds exist in their recommendations."[24]

Çakir and Çakir feel that Hunter et al. missed the point regarding reflectances, drawing attention to the end goal of creating a specified range of luminance ratios.

> "The reflectances specified are merely to serve as the means to this end. As the situations examined are definitely still in the range of the luminance ratios taken as being admissible, this study was unsuitable in terms of its approach to disprove the provisions of the regulations and standards."[24]

Unfortunately, neither Hunter et al. nor Çakir and Çakir define what they mean by the term "reflectance". Specifically, it is not clear whether it is meant to mean diffuse reflectance, specular reflectance or some combination of the two. Çakir and Çakir reference standards such as DIN 5035-7, which recommends a range of acceptable reflectance values for screen bezels of 0,2 to 0,5. Again, however, it is not clear whether the term reflectance is meant to refer to specular, diffuse or total reflectance.

9.3.3 Soderston, et al.

Soderston et al.[33] examined the effect of bezel colour and reflectivity on performance and discomfort, using the same bezel and display combinations used by Hunter et al. (black, total reflectivity of 0,07, pearl white, total reflectivity of 0,51, extreme white, total reflectivity of 0,87). In their study, subjects completed three tasks on each of three successive days: a 45-min data entry task, a 45-min web search task and a 45-min reading comprehension task. Each subject used a different bezel and display combination on each day. The study reports a finding of no effect of bezel colour or reflectance on performance or on visual metrics. Subjective discomfort was significantly greater for the extreme white bezel than for the other two combinations of bezel and display. They report that about two-thirds of their subjects expressed a preference for the black bezel and display combination.

9.3.4 Béland and Andrén

As the Béland and Andrén[30] study is the only one to suggest an inverse relationship between bezel gloss and acceptability of bezel gloss to users, we examined that study more closely. Béland and Andrén asked subjects to adjust the glare source illuminance to an acceptable level for each frame and report the per cent of subjects who set the incident illuminance at zero (no reflectance) as a function of frame gloss. Figure 2 from the Béland and Andrén study is reproduced below.

If the gray coloured bezels are ignored, there is an inverse linear relationship between frame gloss and the per cent of subjects who set the acceptable reflection at zero. The per cent of subjects who found the bezel reflectance acceptable is about equal to 100 minus the gloss rating, e.g. 90 % at 10 gloss units, 80 % at 20 gloss units, 70 % at 30 gloss units, etc.

Although this appears to suggest that high gloss leads to low acceptance, the acceptability of the high gloss gray bezels hints at a more complex relationship between bezel reflectivity and acceptability. Gray frames 7 and 8 in the Béland and Andrén study have relatively high gloss levels, 45 GU and 73 GU respectively (0,045 specular reflectance and 0,073 specular reflectance), yet they are acceptable to 55 % and 65 % of the users, respectively.

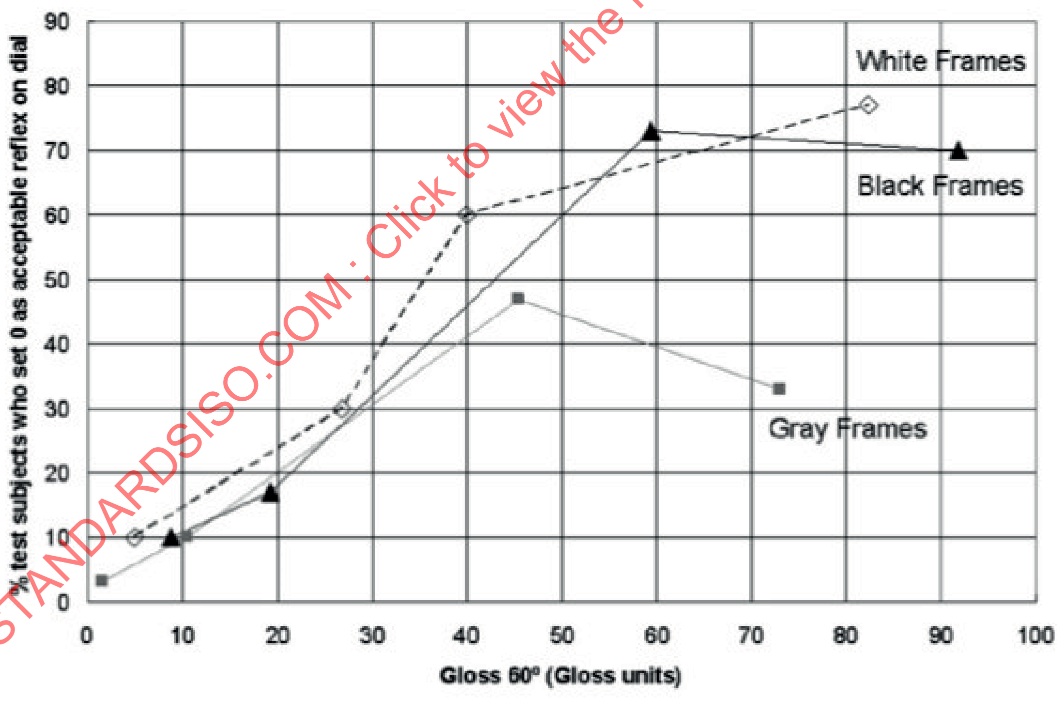

Figure 1 — Reproduction of Béland and Andrén Figure 2

Gloss level is important in determining the acceptability of screen and housing reflectivity, but it must be considered in terms of its interaction with diffuse reflectance and possibly with haze reflectance as well.

We examined the total reflectance of the bezels as described by Béland and Andrén, where the total reflectance is defined as the specular reflectance added to the diffuse reflectance. The specular reflectance was obtained by converting the gloss values to specular reflectance values as described in 8.3.1. The bezels were grouped by their total reflectance values into three groups according to the reflectance values suggested in DIN 5035-7, that is, one group had a total reflectance of 0,20 or less, a second group a total reflectance between 0,20 and 0,50, and the third group had a total bezel reflectance greater than 0,50. As Figure 2 clearly shows, the group of bezels for which the total reflectance was in the range of 0,20 to 0,50 was more acceptable to the users than were the other groups.

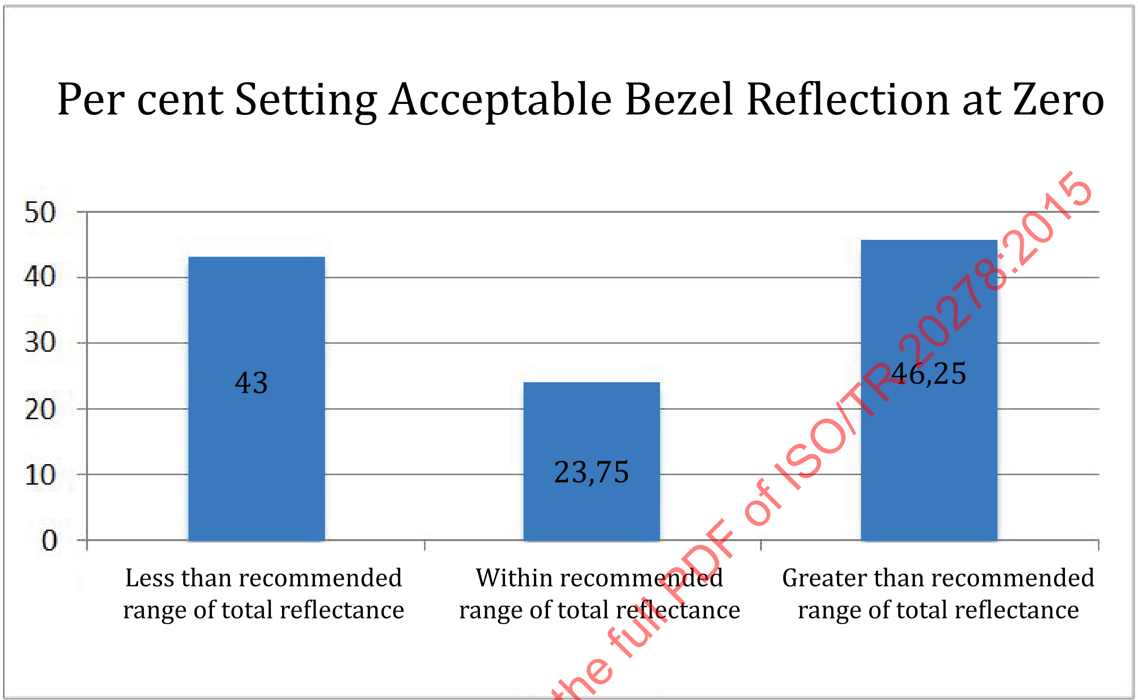

Figure 2 — Per cent of subjects in Béland and Andrén setting reflectance at zero as a function of conformance to DIN-5035-7 recommended range of total reflectance (0,20 to 0,50)

9.3.5 Howarth and Hodder

Howarth and Hodder[34] discuss bezel reflectance as well as bezel gloss in their 2013 study. They conclude that:

> "Finally, it is quite clear from our results that, in the context of acceptability, reflectance and gloss are not independent. The black, white and silver glossy bezels all had similar gloss values, but very different acceptability. It is to be expected that the higher the reflectance the more acceptable a given amount of gloss will be because the contrast between any reflection and the portion of the bezel surrounding it will be lower. Thus, reflections that are obvious in a glossy black bezel may be quite inconspicuous in a glossy white, or silver, one".

9.3.6 Conclusions from the literature regarding bezel gloss and reflectance

In summary, gloss level is important in determining the acceptability of screen and housing reflectivity, but its role appears to be that of a descriptor of specular reflectance. The acceptability of bezel gloss and reflection appears to be dependent on an interaction of specular reflectance and diffuse reflectance.

10 A review of the literature regarding eyestrain due to vergence and accommodative demands of glare reflections

10.1 Accommodative stress

It has been suggested that reflections on the bezel can cause the eye to repetitively change focus between the screen and the reflected image, which appears to be some distance behind the bezel. This