INTERNATIONAL STANDARD

ISO 9241-303

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Ergonomics of human-system interaction —

Part 303: **Requirements for electronic visual displays**

Ergonomie de l'interaction homme-système —

Partie 303: Exigences relatives aux écrans de visualisation électroniques

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9241-303 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

This second edition cancels and replaces the first edition (ISO 9241-303:2008), of which it constitutes a minor revision. Together with ISO 9241-302 and ISO 9241-305, ISO 9241-303:2008 cancelled and replaced ISO 9241-8, and together with ISO 9241-302, ISO 9241-305 and ISO 9241-307, it cancelled and replaced ISO 9241-7 and ISO 13406-2, and partially replaced ISO 9241-3:

— terms and definitions related to electronic visual displays were transferred to, and collected in, ISO 9241-302;

— while the areas previously covered in ISO 9241 and by ISO 13406 remained essentially unchanged, test methods and requirements were updated to account for advances in science and technology;

— all generic ergonomic requirements were incorporated into ISO 9241-303;

— the application of those requirements to different display technologies, application areas and environmental conditions — including test methods and pass/fail criteria — is specified in ISO 9241-307.

ISO 9241 consists of the following parts, under the general title *Ergonomic requirements for office work with visual display terminals (VDTs)*:

— *Part 1: General introduction*

— *Part 2: Guidance on task requirements*

— *Part 4: Keyboard requirements*

— *Part 5: Workstation layout and postural requirements*

— *Part 6: Guidance on the work environment*

— *Part 9: Requirements for non-keyboard input devices*

— *Part 11: Guidance on usability*

— *Part 12: Presentation of information*

— *Part 13: User guidance*

— *Part 14: Menu dialogues*

— *Part 15: Command dialogues*

— *Part 16: Direct manipulation dialogues*

— *Part 17: Form filling dialogues*

ISO 9241 also consists of the following parts, under the general title *Ergonomics of human-system interaction:*

— *Part 20: Accessibility guidelines for information/communication technology (ICT) equipment and services*

— *Part 100: Introduction to standards related to software ergonomics* [Technical Report]

— *Part 110: Dialogue principles*

— *Part 129: Guidance on software individualization*

— *Part 143: Forms*

— *Part 151: Guidance on World Wide Web user interfaces*

— *Part 171: Guidance on software accessibility*

— *Part 210: Human-centred design for interactive systems*

— *Part 300: Introduction to electronic visual display requirements*

— *Part 302: Terminology for electronic visual displays*

— *Part 303: Requirements for electronic visual displays*

— *Part 304: User performance test methods for electronic visual displays*

— *Part 305: Optical laboratory test methods for electronic visual displays*

— *Part 306: Field assessment methods for electronic visual displays*

— *Part 307: Analysis and compliance test methods for electronic visual displays*

— *Part 308: Surface-conduction electron-emitter displays (SED)* [Technical Report]

— *Part 309: Organic light-emitting diode (OLED) displays* [Technical Report]

— *Part 310: Visibility, aesthetics and ergonomics of pixel defects* [Technical Report]

— *Part 400: Principles and requirements for physical input devices*

— *Part 410: Design criteria for physical input devices*

— *Part 411: Evaluation methods for the design of physical input devices* [Technical Specifiction]

— *Part 420: Selection of physical input devices*

— *Part 910: Framework for tactile and haptic interaction*

— *Part 920: Guidance on tactile and haptic interactions*

The following parts are under preparation:

— *Part 154: Interactive voice response (IVR) applications*

Human-centred design and evaluation methods, optical characteristics of autostereoscopic displays, and requirements, analysis and compliance test methods for the reduction of photosensitive seizures are to form the subjects of future parts 230, 331 and 391.

Introduction

This part of ISO 9241 addresses a large range of technologies, tasks and environments.

ISO 9241 was originally developed as a seventeen-part International Standard on the ergonomics requirements for office work with visual display terminals. As part of the standards review process, a major restructuring of ISO 9241 was agreed to broaden its scope, to incorporate other relevant standards and to make it more usable. The general title of the revised ISO 9241, “Ergonomics of human-system interaction”, reflects these changes and aligns the standard with the overall title and scope of Technical Committee ISO/TC 159, Subcommittee SC 4. The revised multipart standard is structured as series of standards numbered in the “hundreds”: the 100 series deals with software interfaces, the 200 series with human-centred design, the 300 series with visual displays, the 400 series with physical input devices, and so on.

See Annex A for an overview of the entire ISO 9241 series.

Ergonomics of human-system interaction —

Part 303: Requirements for electronic visual displays

1 Scope

This part of ISO 9241 establishes image-quality requirements, as well as providing guidelines, for electronic visual displays. These are given in the form of generic — independent of technology, task and environment — performance specifications and recommendations that will ensure effective and comfortable viewing conditions for users with normal or adjusted-to-normal eyesight.

This part of ISO 9241 does not address issues of accessibility for people with disabilities. However, it does take into account aspects of the eyesight of older people and could be of value to people dealing with issues of visual impairment in certain cases: the specification of essential characteristics for normal viewing can be used to gauge the severity of different visual abnormalities so that appropriate solutions can be identified.

NOTE In addition to the Bibliography, Annex F gives a selected bibliography of documents addressing the needs of people with disabilities, including people with poor, deteriorating or no eyesight.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 9241-302, *Ergonomics of human-system interaction — Part 302: Terminology for electronic visual displays*

ISO 9241-307, *Ergonomics of human-system interaction — Part 307: Analysis and compliance test methods for electronic visual displays*

3 Terms and definitions

For the purpose of this document, the terms and definitions given in ISO 9241-302 apply.

4 Guiding principles

For a satisfying human–display interaction, a number of different requirements have to be met at the same time in an appropriate balance. For the purposes of this part of ISO 9241, these requirements have been grouped into the following eight major areas:

— viewing conditions;

— luminance;

— special physical environments;

- visual artefacts;
- legibility and readability;
- legibility of information coding;
- legibility of graphics;
- fidelity.

NOTE For the attractivity of the image on the visual display, see Annex B.

5 Ergonomic requirements and recommendations

5.1 Viewing conditions

5.1.1 General

Many tasks require that the information presented on an electronic visual display be acted upon. Viewing the display such that this information can be taken up quickly, without error and with little effort, is thus highly important. A number of viewing conditions that are necessary, though not sufficient of themselves, can be specified for achieving fast, error-free and near-effortless viewing. These pertain to the design viewing distance and direction and to the needed gaze and head tilt angles of the viewer.

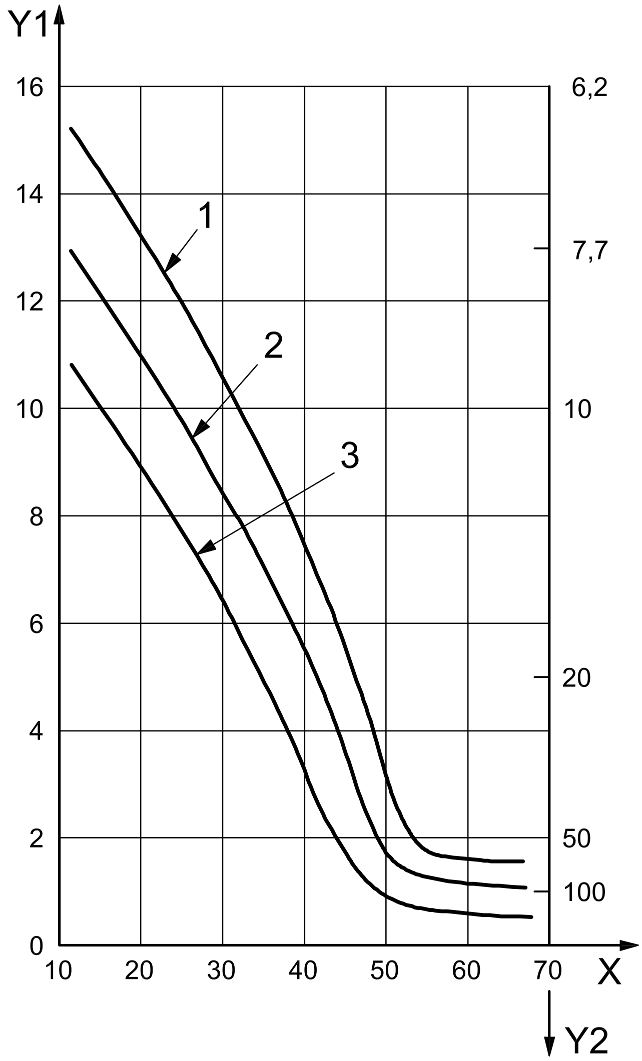
It is known that viewing distance and line-of-sight angle (gaze angle) need to be compatible with the user's vergence and accommodation capability and his or her capability to focus on short distances.

5.1.2 Design viewing distance

The design viewing distance is dependent on the task and on the electronic visual display and shall not be less than 300 mm, being the typical minimum comfortable viewing distance, or *near point*, for normal (emmetropic) eyes of adults. There is a physiologically determined relationship between the near point and the age of the user, shown in Figure 1, and between the near point and the luminance level; however, there is a large variance in this relation.

Shorter viewing distances, of between 200 mm and 300 mm, can be observed in children and (very) young adults, enabling them to see details (e.g. parts of characters) smaller than those that they could see at greater distances, provided that aspects such as display luminance, contrast and the sharpness are high enough. However, most adults as well as older people position their displays at a larger viewing distance, typically 300 mm and more.

For larger visual displays, such as those used in office tasks, the preferred viewing distance is longer — typically 400 mm to 750 mm. At this distance, the accommodative strain to the eyes is less than at shorter viewing distances; moreover, there is larger freedom of movement at larger viewing distances. For presentation tasks or projection, the preferred viewing distance is still larger (typically 2 m to 10 m).



Key

X age, in years

Y1 accommodation span, dioptres

Y2 near point of accommodation, centimetres

1 maximum

2 mean

3 minimum

Figure 1 — Accommodation span and near point in relation to age of user

5.1.3 Design viewing direction

For normal use in which the user moves his or her head, a display shall be legible from any angle of inclination up to at least 40° from the normal to the surface of the display, measured in any plane.

Depending on the task, other limit values are possible. For example, for tasks requiring privacy, such as display use in crowded environments, the display should be only legible to a maximum angle of inclination between 15° and 20°.

EXAMPLE People in wheelchairs wishing to withdraw cash from an automatic teller machine in privacy are obliged to read the ATM display from a fairly low viewpoint. Their requirements can be met by a display that is only legible to a maximum angle of inclination between 15° and 20° in the horizontal plane, but downwards to a larger angle, of at least 40°, in the vertical plane.

NOTE Some display technologies exhibit anisotropic optical properties, which means that the luminance, contrast and colour vary with viewing direction.

5.1.4 Gaze and head tilt angles

For a typical working environment with an approximately vertical position of the upper body, the work place and the visual display should permit the user to view the screen with a gaze angle from 0° to 40° and a head-tilt angle of from 0° to 25°.

NOTE These angle values can require the tilt of the display to be adjustable, so that perpendicular view can be obtained. In addition, the height (above floor level) of the display might have to be adjustable.

5.1.5 Displays for virtual images

The ergonomics of displays for virtual images are considered in Annex E, covering the ergonomics characteristics of binocular non-see-through displays and gives recommended values.

5.2 Luminance

5.2.1 General

In order for information symbols on a visual display screen to be visible, sufficient contrast with their background is necessary. Both symbols and screen background therefore need to be of a certain, different luminance and/or colour.

In most cases, there is a luminous environment to the screen that contributes to its luminance and colour; therefore, the contrast on the screen is changed by the luminous environment (for reflective displays such as paper, contrast on the display screen is even caused by the luminous environment). Since the environment’s luminosity generally cannot be controlled by the user, it is necessary to provide means of adjusting display luminance to obtain a proper luminance balance over a range of work environments.

5.2.2 Illuminance

The supplier shall specify the design screen illuminance, E_S.

NOTE If the application uses colours, their chromaticity coordinates, u',v', may change as a result of the colour of the design screen illumination.

5.2.3 Display luminance

In the ambient illumination for which the display is designed, the display luminance shall exceed the minimum value for obtaining a sufficient recognizability of the displayed information over the design viewing range and the intended lifetime of the visual display unit. Under night-time conditions, it should not be so high as to annihilate dark adaptation of the user’s eyes.

Annex D presents a treatise on basic concepts of contrast and luminance in visual perception. Equation (D.11) defines the minimum value of bright parts of a display taking into account the luminances of the dark parts and of diffuse and specular reflections on the display surface.

EXAMPLE For an office application having 500 lx illuminance (horizontally) of white paper with a reflectance of 80 % and positive display polarity, it is often recommended that the display luminance be in the range of 100 cd/m^2 to 150 cd/m^2.

5.2.4 Luminance balance and glare

a) The area average luminance of task areas that are frequently viewed in sequence while using the display (paper document, screen, etc.) should be between 0,1L and 10L, where L is the average luminance of the whole screen in the application used on the display in the design viewing direction. For a stationary visual field, a higher ratio of space average luminances between the task area and its surrounds (for instance, room walls), up to 1:10, has no adverse effect.

b) The design of the visual display screen and surrounding visible area of the product housing shall not contribute to disturbing glare by the environmental lighting. This holds especially for prolonged viewing in work environments.

The visual display screen shall be in accordance with 5.4.11. [The Member States of the European Union have adopted regulations related to glare and reflections on the workstation, including the display screen equipment based on Directive 90/270/EEC[23] (see NOTE 4).]

NOTE 1 Glare is defined by CIE (845-02-52; glare) as: “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 too extreme contrasts” (see Reference [22]). 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.

NOTE 2 Matt surfaces typically do not produce glare, whereas gloss surfaces can, depending on design aspects such as shape, colour, size and environmental lighting conditions. There are, however, cases where gloss is advantageous. For printed paper and displays, such as reflective colour displays, gloss is necessary for obtaining high colour fidelity, whereas the occurrence of disturbing glare can be avoided by changing the orientation of the paper or display with respect to the environmental light source.

NOTE 3 For prolonged viewing in work environments, the aim is to harmonize the visual display screen and surrounding area of the product housing with their environment and its lighting according to ISO 8995-1 and ISO 9241-6.

NOTE 4 Directive 90/270/EEC Annex, 2. (b) requires that “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” and Annex, 2. (c) requires that “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”.

NOTE 5 The issue of disturbing glare on the visible part of the screen housing is under discussion with regard to a future revision or amendment of this part of ISO 9241.

5.2.5 Luminance adjustment

For emissive displays, the luminance of the background and/or the contrast between the characters and their background shall be easily adjustable by the user. The emissive display shall be easily adjustable to ambient conditions over the range of luminances that can occur in the particular work environment.

5.3 Special physical environments

5.3.1 General

The following guidelines should be taken into consideration in the design of a display wherever it is expected that the display will be subjected to one or more of the environmental conditions described in 5.3.2 to 5.3.4.

5.3.2 Vibration

Vibration of the display with respect to the head and therefore the eyes (or *vice versa*) is an annoying effect that can even reduce visual performance, because

— vibration hampers eye movement control during reading by making it more difficult to determine the target of saccades, and causing image movement during a fixation pause, in which the centre of the visual field needs to be recognized,

— the contrast of small details is reduced because the zones along a border will have the average luminance of both sides of the border, and

— the rapid alternation of light and dark in an area of the visual field can create flicker effects.

The severity of these effects depends on the frequency and amplitude of the vibration. Frequencies above 0,5 Hz of the display are disturbing when their amplitude is more than a threshold value. Also, frequencies of the head above 6 Hz are disturbing when the amplitude is more than a threshold value. Such frequencies and amplitudes should therefore be avoided — for example, by embedding the display in appropriate damping material.

5.3.3 Wind and rain

Strong winds can cause vibrations of objects such as visual displays that are sufficiently exposed.

Rain drops falling on a display screen will distort the displayed image, to the point where text becomes illegible.

Visual displays that may be used outdoors should therefore be mechanically shielded from such weather effects.

5.3.4 Excessive temperatures

When operation of display devices is required in environments where temperatures are approaching 0 °C or + 40 °C, users should take equipment and personal precautions to ensure that they are able to complete their tasks satisfactorily and safely. Excessive temperatures will adversely affect the performance of most display devices, as well as the associated electronic circuitry and therefore affect user performance on the task. Consult the manufacturer's product specifications to find out the recommended operating range of temperatures for the device. If the environmental conditions are close to or beyond the recommended limits, the display device and the associated electronic circuitry may have to be heated or cooled to a temperature level within the manufacturer's specified range in order to ensure proper operation of the device(s).

5.4 Visual artefacts

5.4.1 General

Ideally, an electronic visual display will show only intended, high-quality information, in the form of text, graphics or images. However, display technology is usually not ideal, and reflected images of the outside world as well as unintended images due to visual perception phenomena cause *visual artefacts*, i.e. information competing with the intended information for the viewer's attention.

5.4.2 Luminance non-uniformity

For an intended uniform display luminance, the luminance non-uniformity, either step-wise or smooth, in ambient illumination shall not exceed the threshold for reduced visual performance, with a maximum of 1,7:1.

5.4.3 Colour non-uniformity

Any non-uniformity of the colour shall not create competing information content when evaluated at three locations on the screen. The maximum chromaticity difference shall be in accordance with Table 1.

Table 1 — Maximum chromaticity difference

$\frac{D_{active}}{D_{design\ view}}$	Chromaticity difference $\Delta(u',v')$	
	Applications using colour per default colour set	**Any primary colour** [a]
< 0,75	0,02	0,02
⩾ 0,75	0,03	0,03

D_{active} diagonal of active area of screen

$D_{design\ view}$ design viewing distance

[a] The primary colours are the unmixed colours, usually red, green and blue.

Colour uniformity refers to how well the colour remains constant over the surface of the screen. Conversely, non-uniformity of colour characterizes the manner in which the colour changes over the surface of the screen. The non-uniformity of colours is best specified by the maximum colour difference (using some colour difference metric) between any two points on the screen. Several colour different metrics and coordinates are in use today, including CIELAB, CIELUV and CIE 1931 (x, y).

For the purposes of this part of ISO 9241, the metric, u',v' colour difference, is used.

5.4.4 Contrast uniformity

Contrast uniformity can be important if proper recognition or presentation of information depends critically on proper scene or pattern rendering. It is expressed as a percentage: contrast uniformity = 100 %(C_{min}/C_{max}), where C_{min} and C_{max} are the minimum and maximum contrast, respectively, of the sampled contrast set on the screen (see ISO 9241-305). The contrast uniformity should be as high as possible and, in general, be commensurate to the user's task.

NOTE There are three different forms of contrast non-uniformity:

— variation in area average luminance contrast from the centre of a display to the edge of any portion thereof;

— variation of the peak contrast of character elements (dots or strokes) at different locations of the screen;

— variation of the peak contrast of character elements (dots or strokes) within a character.

The threshold for visual detection of contrast non-uniformity is higher than the threshold for measurable difference in task performance. Both thresholds are dependent on the following factors:

— target size;

— contrast sensitivity of the user;

— task;

— luminance of the target, background and surrounds.

There are other ways of expressing contrast uniformity that may be found to be useful, for example, the ratio of the "intended contrast", such as that between text characters and their background, to the contrast that is due to the contrast non-uniformity.

One way to ascertain the impact of contrast non-uniformity is to use a user performance test method (see ISO 9241-304). Test persons representing a sample from the intended user population most likely to suffer performance reduction should be used. In the test, the contrast uniformity shall be intentionally varied over the screen.

5.4.5 Geometric distortions

For different rows or columns of text, the difference of length shall not exceed 1 % of the length of that column or row.

The horizontal displacement of a symbol position relative to the symbol positions directly above and below shall not vary by more than 5 % of the character width. The vertical displacement of a symbol position, relative to the symbol positions to the right and left of it, shall not vary by more than 5 % of the character height.

5.4.6 Screen and faceplate defects

The electronic display should be free of screen and faceplate defects.

Regularly addressed displays should be free of pixel faults[1]. If not, the supplier shall specify the number of defective pixels and/or subpixels.

Depending on the task of the user, screen and faceplate defects or pixel faults can be disturbing, resulting in reduced performance in reading speed and reading errors or to reduced appreciation of an image and visual discomfort. Or they can present wrong information in images and their information content, leading to misinterpretation of the displayed content. Aesthetic and attractivity aspects can affect the user's acceptance regarding the displayed content in case of faults as well.

Therefore, screen and faceplate defects or pixel faults have to be examined from the point of view of their relevance to

a) ergonomics performance, and

b) acceptance by the users, given their tasks.

If a regularly addressed display meets the ergonomics performance criteria for pixel faults, these faults will not reduce reading speed, increase number of reading errors or cause visual discomfort symptoms such as red, sore, itchy or watering eyes, headaches or aches and pains associated with poor posture.

If an electronic display meets the acceptance criteria for pixel faults in a specified fault class, these pixel faults will probably not cause misinterpretations or insufficient acceptance by the users, related to the intended tasks.

NOTE If an electronic display has pixel faults, their number is not the only important factor, but rather, this number in relation to the size of both pixels and display. Also of importance is the material being displayed, task of the user, position on the display screen of the defective pixel and/or subpixel, etc. The exact ergonomic performance requirement level is not defined in this part of ISO 9241. Therefore, a display in any of the fault classes (0, I, II, III, IV) can meet the ergonomics performance and visual discomfort requirement level, depending on the context of use. Research is continuing to elucidate these issues and will be taken into account in future amendments of this part of ISO 9241.

5.4.7 Temporal instability (flicker)

The entire image area shall be free of flicker to at least 90 % of the user population.

Flicker is the perception of unintended temporal variations in luminance on the display, in a frequency range of a few hertz up to the critical flicker frequency. These unintended temporal variations can affect the comfort and performance of the user. The critical flicker frequency (CFF) is an upper frequency above which flicker is no longer perceived by the user. The perception of flicker increases with increasing luminance and increasing screen size.

NOTE 1 The eye is more sensitive to flicker in the lateral visual field than in the central visual field.

NOTE 2 The critical frequency decreases with age (*between individuals* factor) and with fatigue (*within individuals* factor) and with duration of exposure.

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[1] As defined in ISO 9241-302, “pixel fault” includes both defective pixels and *subpixels*.

5.4.8 Spatial instability (jitter)

The image shall be free of jitter in the intended display environment.

This can be accomplished by ensuring that the peak-to-peak variation in the geometric location of image elements does not exceed 0,000 1 mm per millimetre of design viewing distance for the frequency range of 0,5 Hz to 30 Hz.

5.4.9 Moiré effects

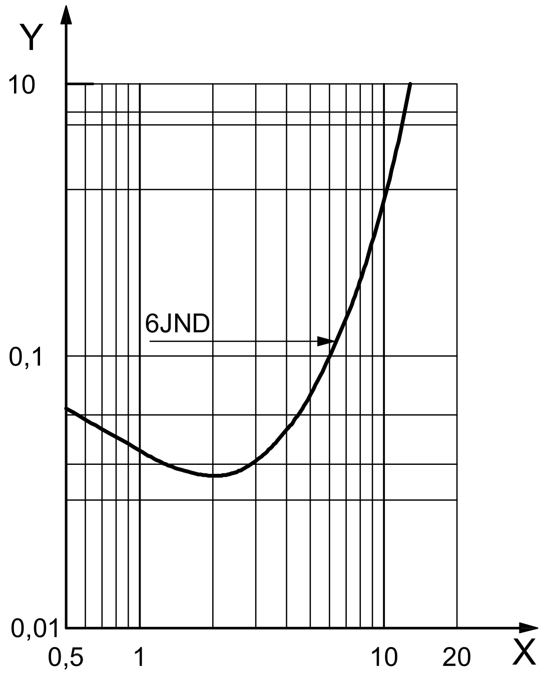
Moiré is a regular image superimposed on the intended image. Because the image is a structured pattern, it is often detected easily by users.

Moiré patterns are natural interference phenomena. They can appear as ripples, waves and intensity variations that are superimposed on the screen image.

For colour displays, moiré patterns, which resemble a periodic noise field overlying the screen image area, should not have more than 6 JND (just noticeable differences) (see ISO 9241-302) of modulation at their fundamental spatial frequency.

Moiré patterns with spatial frequency and modulation falling above the curve in Figure 2 are predicted to exceed 6 JND and therefore be clearly visible.

To minimize (decrease) the detection of moiré patterns by users, the fundamental spatial frequency and modulation of a colour display should be below the curve shown in Figure 2.



Key

X spatial frequency, cycles per degree

Y contrast

JND just noticeable difference

Figure 2 — Thresholds for visibility of moiré patterns

[From HFES 100[1] (reprinted with permission)]

5.4.10 Other instabilities

Electronic visual displays can exhibit unintended spatial and temporal luminance variations such as “swim” or “crosstalk”. In addition to the requirements specified in 5.4.6, 5.4.7 and 5.4.8, those for proper ergonomics design criteria should be used to minimize other unintended spatial or temporal artefacts that exceed the threshold for visual detection.

It is important to first analyse the context of use to verify whether or not the threshold for detection is exceeded. There are many artefacts that are visible through, for example, a magnifying glass, but not at the actual viewing distance.

EXAMPLE Technically speaking, a display can exhibit jitter that is spatially so small that it cannot be detected with the naked eye at normal viewing distance. From an ergonomics point of view, the display is jitter-free when used at that viewing distance. This jitter, however, will still have an effect on contrast of thin lines. So the conclusion will be that the display has, from an ergonomics point of view, reduced contrast in thin lines, technically caused by jitter. It will depend on the degree of contrast reduction whether or not corrective action, i.e. reduce or eliminate the jitter, is necessary.

5.4.11 Unwanted reflections

Disturbing and/or unwanted reflections that reduce contrast shall be avoided. If necessary, the screen shall have antiglare and/or antireflection treatment. Unavoidable reflections shall be as small as possible.

Specular reflections of ambient light sources (luminaires, lamps, windows, etc.) on a display screen are unwanted reflections. They reduce the contrast and thus the legibility of displayed information. Often, they are the cause of glare, leading to discomfort or inability to recognize the information for the user. Depending on the kind of visual display terminal, reflections can be one of the following types or combinations thereof:

a) Lambertian (reflected luminance constant for all directions) — paper for photocopiers is a good example of a Lambertian reflector;

b) specular (mirror-like) — a distinct image of the source of illumination is visible;

c) haze (peaked about the specular direction, but images are more or less blurred due to light scattering) — small light sources reflected by a hazy object are perceived as a non-distinct fuzzy circle of light around the specular direction.

Lambertian reflections reduce the contrast of the displayed information by lightening the dark state. Specular reflections, however, are often experienced as uncomfortable, due to the repeated focusing (accommodation) of the eye between the information displayed on the screen and the image of the light source. This continued re-focusing is the reason why many people rate a Lambertian reflection as less disturbing than a reflected distinct image of the same luminance. Distinct images of light sources can be experienced as so bright that the displayed information cannot be perceived and interpreted (i.e. causing disability glare).

NOTE 1 Displays with a transparent protection or CRT (cathode ray tube) and plasma displays can be well characterized by a superposition of Lambertian and specular reflectance components. The same characterization that omits the haze component leads to substantial errors in the evaluation of displays having a non-vanishing haze component.

NOTE 2 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.

NOTE 3 Many users find the type of reflection that produces a distinct image more objectionable than a diffused reflection of the same luminance.

5.4.12 Unintended depths effects

Spectrally extreme colours that produce unintended depth effects (chromostereopsis) shall not be presented for images intended to be continuously viewed or read.

5.5 Legibility and readability

5.5.1 General

For electronic visual displays, the presentation of legible characters and symbols for readable text is one of the most important issues. The characteristics and requirements are described in 5.5.2 to 5.5.11.

Older people experience a number of complex age effects on their eyesight, not all of which are presently known in detail, that in particular influence the recommendations for luminance contrast (5.5.2), image polarity (5.5.3) and character height (5.5.4). The consequences of these effects may be summarized as follows: for older people, avoid low contrast and low background luminances, and small character sizes.

5.5.2 Luminance contrast

In the ambient illumination for which the display is designed, the minimum luminance contrast of character details within or between characters that is relevant for legibility shall comply with the values derived from Figure D.3.

As an example, for applications with a display luminance of 20 cd/m^2, and taking any reflections in the display screen into account, the minimum contrast values shall be $C_\mathrm{m} = 0{,}5$ (contrast modulation), or $C_\mathrm{r} = 3{:}1$ (contrast ratio).

For a good visual performance and comfortable reading, especially over extended periods of time, the modulation depth or luminance contrast should preferably be higher than 0,5 or 3:1, respectively. This is particularly important for older users, especially above 80 years of age.

Annex D is a treatise on basic concepts of contrast and luminance in visual perception, leading to Equation (D.8).

5.5.3 Image polarity

Either dark characters on a brighter background (positive image polarity), or bright characters on a darker background (negative image polarity) are acceptable. If a display provides positive and negative polarities, it shall meet all the requirements of this part of ISO 9241 for each image polarity.

NOTE For most tasks, positive image polarity is preferable. Its advantages are

- reduction of bright to dark eye adaptation,
- less eye strain,
- improvement of legibility, owing to better recognition of characters at the same contrast,
- less detection of unavoidable reflections,
- better legibility for most older people, and
- in most cases, screen luminance in balance with walls of a normally lit room.

However, many people with low vision prefer negative image polarity.

5.5.4 Character height

The minimum Latin character height shall be 16′ of arc; it is required that the system have the capability of providing a character height from 20′ to 22′ of arc. Japanese characters shall have a minimum character height of 20′ of arc. Character heights subtending from 20′ to 22′ of arc for Latin characters and from 25′ to 35′ of arc for Japanese characters are recommended for most tasks.

The ultimate limiting factor for legibility is the human visual system: only characters that have been imaged sharply, with sufficient height, on the retina can be read well. Which height is "sufficient" will depend on the quality of the display and of the text displayed thereon, the age of the reader and the reading task. For an ideal visual display such as is approached by printed paper, the minimum character height is 10′ to 12′ of arc. Present electronic displays at best only approximate the ideal display. Limiting factors are pixel density or resolution, contrast and character font and matrix, as well as viewing distance.

For applications where legibility is incidental to the task, smaller characters may be used (for instance, for footnotes, superscripts and subscripts). For Latin characters, the character height should exceed 10′ of arc unless loss of legibility is acceptable (e.g. when showing page layout appearance).

For applications designed for a special group of users, generally young ones, a character height of 11′ of arc with a viewing distance of 250 mm (see 5.1.1) makes it possible to fit a chunk of legible information such as a timetable on the screen of hand-held devices. Such users then can read and combine this information, provided: firstly, that the pixel density of the display is at least 200 pixels per inch, secondly, that the contrast between characters and background is 3:1 or higher (depending on the technology), and thirdly, that the width-to-height character matrix is at least 7 × 9. However, the application should allow the characters to be displayed at a larger height for users with a lower visual acuity than those of the special group mentioned — albeit at the cost of fitting a smaller chunk of legible information on one screen.

The character height of lowercase characters without ascender and descender should be approximately 70 % of the character height (uppercase character without ascender). In instances where readability is important, the upper limit on character height should be 30′ of arc.

Older users need reading glasses for short viewing distances because they have lost some, and eventually all, of their accommodative power. For a viewing distance of 25 cm, this need can begin at approximately 35 years. However, the negative effect on recognition of characters not being imaged sharply on the retina can be compensated to a certain extent by increased contrast. Furthermore, contrast sensitivity and, therefore, character recognition increases with increasing background luminance. However, especially in situations such as outdoors, when people do not have their reading glasses immediately available, the use of letters that are not too small, i.e. larger than 16′ of arc, is recommended for displays such as public phones, cell phones or personal digital assistants (PDA).

NOTE 1 Small, or very small electronic displays such as are used in PDA or cell phones, with correspondingly small characters, typically are read at distances close to the near point, where the eyes' lenses are maximally accommodated (characters with a height of 1,4 mm subtend 16′ of arc at a viewing distance of 300 mm). Maintaining such a strong accommodation over a considerable time can be strenuous; it is unnecessary if larger characters that can be read at a larger viewing distance are used. However, with smaller characters, more information can be presented on one screen, without scrolling, thus making it easier for the user to survey, for instance, (part of) a timetable and quickly grasp its meaning.

NOTE 2 For character sets other than Latin or Japanese, such as Cyrillic, Chinese, Arabic or Korean, as defined in ISO/IEC 10646[2], appropriate character heights need to be specified.

5.5.5 Text size constancy

If text size constancy is important for the task, then the height and width of a specific character of a specific character font shall not vary by more than ± 5 % of the character height of that character set, regardless of where it is presented on the display surface.

EXAMPLE The difference in size between the 10 point and 11 point font sizes might be rendered as 11 pixels and 12 pixels. In a proofreading task, the user is required to find letters typed by error in 11 point size in the middle of a 10 point text. The difference between 12 pixels and 11 pixels is 9 %. If the text size constancy is not clearly better than 9 %, the task will be difficult or impossible to perform. In digital displays which are driven by analogue signals, and where the resolution of the input signal is different from the resolution of the digital display, the font size is rendered with ± 1 pixel accuracy due to the analogue-digital conversion.

5.5.6 Character stroke width

For Latin-origin characters, the stroke width shall be within the range of 10 % to 17 % of character height.

NOTE Values below this range can give the character a very thin vertical appearance (“spider-legs”).

5.5.7 Character width-to-height ratio

For considerations such as line length and proportional spacing, the width-to-height ratio shall be within the range 0,5:1 to 1:1. For optimum legibility and readability, a width-to-height ratio of 0,7:1 to 0,9:1 is recommended.

5.5.8 Character format

The following applies to Latin characters.

— A 7 × 9 (width-to-height) character matrix shall be the minimum used for tasks that require continuous reading for context, or where individual alphabetic character legibility is important for the task, such as proofreading. A 5 × 7 (width to height) character matrix shall be the minimum used for numeric and upper-case-only presentations.

— The character matrix shall be increased upward by at least two pixels if diacritics are used. If lower case is used, the character matrix shall be increased downward by at least two pixels, to accommodate the descenders of the lower case letters.

— For higher-density character matrices, the number of pixels used for diacritics should follow conventional designs for printed text. A 4 × 5 (width to height) character matrix shall be the minimum used for subscripts and superscripts, and for numerators and denominators of fractions displayed in a single character position. The 4 × 5 matrix may also be used for alphanumeric information not related to the operator’s task, such as copyright information.

For Japanese characters, a minimum matrix of 11 × 11 elements is recommended, while a matrix of 15 × 15 elements is preferred.

5.5.9 Between-character spacing

For character fonts without serifs, the between-character spacing shall be a minimum of one stroke width or one pixel. If characters have serifs, the between-character spacing shall be a minimum of one pixel between the serifs of adjacent characters. For other text presentations, horizontal spacing should be within the range of 25 % to a maximum of 60 % of character width.

5.5.10 Between-word spacing

The minimum number of pixels between words shall be the number of pixels in the width of an unaccented upper-case letter H. The number of pixels in the width of the letter N shall be used for proportionally spaced fonts.

5.5.11 Between-line spacing

For tasks that require continuous reading of text, a minimum of one pixel or one horizontal stroke width shall be used for spacing between lines of text. This area should not contain parts of characters, diacritics or underscores.

5.6 Legibility of information coding

5.6.1 General

A particular meaning can be attached to the information displayed on the screen by coding it such that it can be distinguished from the rest of the displayed information. Luminance, colour, symbol shape and blink rate can all be used for this coding.

5.6.2 Luminance coding

Areas coded by luminance only shall differ in display luminance with respect to each other by a ratio of at least 1,5:1. Luminance coding includes intended ambient illumination conditions and design viewing angles.

NOTE Previously, in ISO 9241, the term *absolute luminance coding* was used. All previous requirements related to *absolute luminance coding* are now covered by this subclause.

5.6.3 Blink coding

Where blink coding is used solely to attract attention, a single blink frequency of from 1 Hz to 3 Hz, with a duty cycle of 50 %, is recommended. Where readability is required during blinking, a blink rate of 0,33 Hz to 1 Hz, with a duty cycle of 70 %, is recommended. It should be possible to switch off the blinking of the cursor.

NOTE The maximum of 3 Hz is derived from the need to protect people with photosensitive epilepsy.

5.6.4 Colour coding

Because of the conspicuity of colour differences, colour coding is a powerful means of attaching a specific meaning to the targeted information. Colours used for coding should be easy to discriminate. Each colour used for information coding should only represent one meaning of information, for example, the colour red reserved for all messages indicating a dangerous status or situation. The colour code should be used consistently in the whole system; otherwise it loses its value through confusion. Colour should not be the only means of coding, and should at least be used with care, because 8 % to 10 % of the male population is colour anomalous, i.e. does not perceive colour correctly. Some form of redundancy in coding should be used.

5.6.5 Geometrical coding

Geometrical coding is a particular type of graphical coding. The distinction of different classes of information in a graph can be facilitated by the use of different geometrical shapes, such as triangles or circles. These shapes should be easy to distinguish, which means that their number should be limited.

NOTE For more information on coding, see ISO 9241-12[3].

5.7 Legibility of graphics

5.7.1 General

Information can be carried by graphical symbols. They may be simple geometrical configurations such as circles and squares or more complex ones, generally called icons. Graphs, i.e. configurations of straight or curvilinear lines, also carry information. This can be acquired by the user only if these graphical symbols and graphs have a sufficient legibility in terms of their size, contrast and colour.

5.7.2 Monochrome and multicolour object size

Icons should be designed so that they are easily discerned, discriminated and comprehended.

Icons should enable the user to relate the graphic of the icon to the function of the icon.

To accomplish this, critical details such as symbols or text within the icon should have a minimum height of 20′ of arc. Heights subtending 25′ to 35′ of arc are preferred.

For graphical objects and other small objects where legibility is the primary concern, refer to 5.5.2.

For isolated images where accurate colour identification is required, the image shall subtend 30′ of arc; 45′ of arc is preferred.

5.7.3 Contrast for object legibility

Where accurate identification of an isolated, multicolour image (e.g. a single character or a symbol) is required, the same conditions for screen luminance and contrast as those specified in 5.5.2 shall apply.

5.7.4 Colour considerations for graphics

Where accurate colour identification of strings of characters or symbols is required, their minimum size shall be at least 20′ of arc at the design viewing distance. Where accurate colour identification of an isolated image such as a character or symbol is required, the image should be at least 30′ of arc at the design viewing distance, preferably 45′ of arc.

a) Small images

In the case of a dark background, the use of spectrally extreme blue ($v' < 0{,}2$) should be avoided for images subtending less than 2°.

b) Isolated images

Where accurate colour identification of an isolated image such as a character or symbol is required, the image should subtend at least 30′ of arc at the design viewing distance, preferably 45′ of arc.

c) Default colour set

When an application requires the user to discriminate or identify colours, it shall offer a default set of colours. The default colour set should be based on an operating system and include at least

— the primary colours of red, blue and green,

— non-primary colours as combinations of primary colour pairs, red-blue, red-green and blue-green, and

— black and white.

For accurate identification, the default colour set should consist of no more than 11 colours. If the colours can be altered by the user, the default set of colours shall be retrievable and restorable.

d) Colour difference

Colour pairs that are to be discriminated shall have colour difference values of $\Delta E^*_{uv} > 20$.

NOTE 1 If viewers are to accurately discriminate colours, even ΔE^*_{uv} significantly larger than 20′ of arc does not necessarily guarantee satisfactory perceptual performance because of the effects of adjacency and size on colour appearance.

NOTE 2 The metrics of lightness difference, ΔL^*, red-green difference, $\Delta u'$, and yellow-blue difference, $\Delta v'$, predict perception differently for different conditions. For example, for colour images widely separated, ΔL^* overestimates colour difference perception. For small images, $\Delta v'$ overestimates colour-difference perception by a factor of 5 to 1 compared with $\Delta u'$.

NOTE 3 Small images composed of colours from the blue-green region of the visible spectrum are very difficult to identify and discriminate because of small-field tritanopia. It is thus best to assign blue to large images (greater than 20′ of arc) and avoid spectrally extreme blue for small images (less than 20′ of arc).

e) Negative polarity

For text, alphanumerics and symbols used in reading tasks that are presented in negative polarity:

— blue ($v' < 0{,}2$) on a dark background shall not be used;

— red ($u' > 0{,}4$) on a dark background should be avoided and shall not be used on a spectrally extreme blue ($v' < 0{,}2$) background.

f) Positive polarity

For text, alphanumerics and symbols used in reading tasks that are presented in positive polarity:

— spectrally extreme blue ($v' < 0{,}2$) shall not be used on a spectrally extreme red ($u' > 0{,}4$) background;

— spectrally extreme red ($u' > 0{,}4$) shall not be used on a spectrally extreme blue ($v' < 0{,}2$) background.

g) Depth effects

Spectrally extreme colours that produce depth effects shall not be presented for images intended to be continuously viewed or read.

h) Colour misconvergence

On multicolour shadowmask CRT and projected images for some projector technologies, colour misconvergence causes the appearance of colour fringes or double images along the edges of an image, and may reduce user performance. The level of misconvergence at any location on such CRT or projection screens shall not degrade visual performance during task execution.

5.7.5 Background and surrounding image effects

In order to better discriminate and identify colours, systems and applications should use an achromatic background behind chromatic foreground image colours, or achromatic foreground image colours on chromatic backgrounds.

5.7.6 Number of colours

5.7.6.1 Simultaneous colour presentation

The number of colours simultaneously presented on a display should be based on the performance requirements of the task. In general, the number of colours simultaneously presented should be minimized. For accurate identification, the default colour set(s) (including the achromatic white, grey and black) should consist of no more than 11 colours for each set; more colours will lead to discrimination problems between some of the pairs of colours.

EXAMPLE 1 Red, orange, yellow, yellow-green, green, green-blue (cyan), blue, blue-red (purple or magenta), black, white and grey.

EXAMPLE 2 Red, pink, orange, yellow, brown, green, blue, purple, black, white and grey.

5.7.6.2 Visual search for colour images

When a rapid visual search based on colour discrimination is required, no more than six colours should be used.

5.7.6.3 Conspicuity of colours

Users can be easily distracted from the information they want by conspicuous colours appearing nearby.

5.7.6.4 Colour interpretation from memory

If the meaning of each colour in a set of colours is to be recalled from memory, no more than six colours should be used. For software applications that require the meaning of each colour of a set of more than six colours to be recalled, the associated meaning of each colour shall be made accessible.

5.8 Fidelity

5.8.1 General

Fidelity is an attribute that is important when static or moving images from the real world have to be reproduced electronically. The greater the correspondence between these electronic images and their real-world examples, the higher the fidelity of the imaging process. However, it is not certain that images with the highest fidelity will be those preferred by the viewers.

5.8.2 Colour gamut and reference white

5.8.2.1 Colour gamut

Accurate colour rendering is required whenever objects or scenes taken from reality are visualized on an electronic visual display (electronic photography, television, video, etc.). Inadequate colour rendering can cause misinterpretation or missing recognition of the objects or scenes that are visualized (colour of human skin may indicate sickness, etc.). In order to assure a minimum performance with respect to colour rendering (task dependent), the electronic visual display shall be able to reproduce colours that form a minimum triangular area in a specified chromaticity space [e.g. u' and v' chromaticity coordinates CIELUV (1976) of the primary colours R, G and B]. The applicable minimum values are given in ISO 9241-307.

5.8.2.2 Reference white

In order to arouse “proper” colour sensations, i.e. those corresponding to the expectation of a user watching a reproduction of reality, it is desirable to have images of non-selective surfaces such as paper or white clothes always perceived as “white” — regardless of the illumination at the scene which is reproduced. This can be accomplished by (1) establishing a *reference white* on the visual display, and (2) adjusting the camera registering the scene and the communication channel between camera and receiving display in such a way that non-selective surfaces are reproduced in reference white [4]. For the FCC colour primaries [2)], the chromaticity of CIE Illuminant, C ($u' =$ 0, 201; $v' =$ 0,461) should be used as reference white for the display.

5.8.3 Gamma and grey scale

The gamma for each of the three primary colours shall be in the range of 2,0 ± 0,2.

As to the grey scale of a multichrome visual display capable of reproducing images from the real world, no special requirements in addition to those for faithfully reproducing colour are necessary, since the human eye is much more tolerant to luminance deviations than to chromaticity deviations for a particular visual scene. It should be realized that the gamma curve of an LCD depends on the viewing direction, which means that the colour and luminance distribution of an image can change substantially when the viewing direction changes.

2) US Federal Communications Commission standard.

5.8.4 Rendering of moving images

To render moving images properly, a display needs temporal fidelity. This temporal fidelity is influenced by four main parameters:

— rise time;

— hold time (time between end of rise time and beginning of fall time);

— fall time;

— sampling frequency.

The rise and fall time shall be short enough for the luminance signal to switch from one desired level to another, from frame to frame. Otherwise, this signal will not be able to change fast enough for fast-moving images. In the worst case, the motion will become undetectable (i.e. as on slow LCD screens without any compensation for this slowness).

The rise and fall times shall be short enough for proper rendering of the fastest moving image that will be shown on the screen. Otherwise, the edges and details of moving images will be blurred.

The hold time shall be the same or shorter than that required for the fastest moving image that will be shown on the screen. Otherwise, the edge and details of moving images will be blurred.

NOTE 1 If the hold time is too short compared to the sampling frequency, the user will perceive flicker.

The sampling frequency (refresh rate) shall be high enough to show all details of fast moving images. If the sampling frequency is too low, quick movements will not be visible. If the sampling frequency is very low, the movement will become jerky.

Apart from these four parameters, the signal-to-noise ratio of the signal shall be high enough so that fast movements are not lost in noise.

NOTE 2 The following steps might be taken to ensure the integrity of moving images:

a) analyse the intended moving image content and identify how high a sampling frequency will be needed in order not to loose intended movement details;

b) choose a display with a refresh rate that matches the sampling frequency;

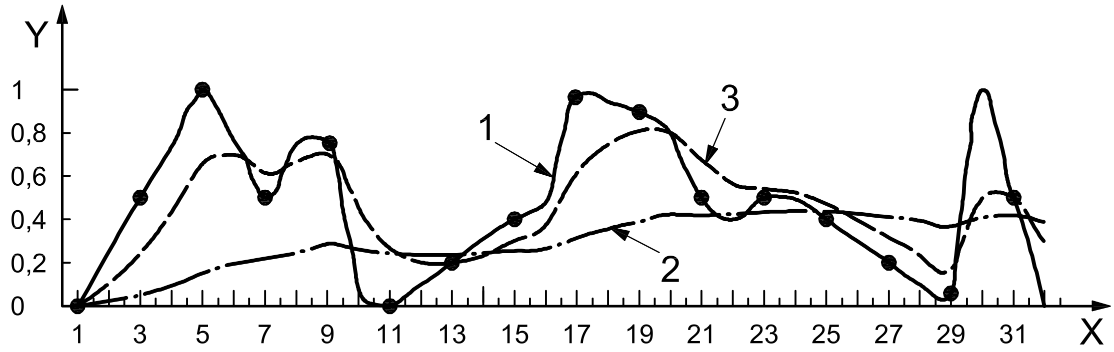
c) select the rise and fall times to be short enough not to blur moving images;

d) select the hold time to be short enough not to blur moving images;

e) verify that the combination of refresh rate and hold time does not create flicker.

Test the system to find out whether or not video signal processing is needed to compensate for any remaining artefact or system deficiency.

Figure 3 illustrates the effects of several rise, hold and fall times and a particular sampling frequency on the image of a moving object.



Key

X time (arbitrary unit)

Y intensity (arbitrary unit)

1 real image

2 STN–LCD (super twisted nematic–liquid crystal display) type display

3 TFT–LCD (thin film transistor–liquid crystal display) type display/CRT (cathode ray tube) display

Both the STN–LCD and TFT–LCD displays have not only a too-slow rise time and fall time, but also a too-long hold time for the moving image to be able to be shown properly. The user will perceive blur. The CRT is fast enough and has a short enough hold time to show the movements without blur. The sampling frequency, however, is not fast enough to avoid flicker and to sample the movement correctly (see time = 22 and time =31).

Figure 3 — Luminance–time graph of image moving with speed over small section of screen

5.8.5 Image formation time (IFT)

The IFT shall be short enough for the type of information shown. The time required for an image to form on an electronic visual display depends on the technical type of display. This image formation time can be too long for the application. For example, rendering realistic motion effects requires a short IFT. However, for displays that keep displaying each part of the image over a large part of the frame period, the duration of the frame period is a limiting factor. If the IFT or frame period duration is too long, while the display produces the image during a large part of the frame period, then blurred or jerky images will result, and contrast could be reduced.

For many flat panel display types, the time needed to switch from one luminance level to another — determinant for the IFT — depends on the values of these levels in a complex way. It also depends on the temperature of the display. The dependence is specific to the display type. As yet, not enough data are available to predict when the transition between two grey levels will be slowest, i.e. when the "worst case" in terms of IFT occurs. Switching from "black" to "white" could take less time than switching from, for instance, "dark grey" to "light grey". ISO 9241-307 gives an indication of the imaging consequences of a particular IFT.

5.8.6 Spatial resolution

Resolution of the display should enable a satisfying reproduction of the original image; that is the case with the normal horizontal and vertical resolution of TV imagery. Moreover, there should not be geometric distortions that reduce geometric imaging fidelity.

5.8.7 Raster modulation or fill factor

For displays having a raster modulation or fill factor of less than 30 pixels per degree at the design viewing distance, the luminance modulation in the direction perpendicular to adjacent pixel lines shall not exceed $C_m = 0,4$ for monochrome displays or $C_m = 0,7$ for multi-colour displays, when all pixels are in their high state.

For better legibility, C_m should not exceed 0,2 for either type of display.

5.8.8 Pixel density

For direct-view displays, the manufacturer shall specify the pixel density.

Pixel density is an important factor for properly rendering information.

6 Conformance

The procedures for determining conformance with this part of ISO 9241 shall be in accordance with ISO 9241-307.

Annex A
(informative)

Overview of the ISO 9241 series

The annex presents an overview of the structure of ISO 9241. For an up-to-date overview of its structure, subject areas and the current status of both published and projected parts, please refer to:

ISO 9241 series

The structure reflects the numbering of the original ISO 9241 standard; for example, displays were originally Part 3 and are now the 300 series. In each section, the “hundred” is an introduction to the section; for example, Part 100 gives an introduction to the software-ergonomics parts.

Table A.1 — Structure of ISO 9241 — Ergonomics of human–system interaction

Part	Title
1	Introduction
2	Job design
11	Hardware and software usability
20	Accessibility and human–system interaction
21-99	Reserved numbers
100	Software ergonomics
200	Human–system interaction processes
300	Displays and display-related hardware
400	Physical input devices — Ergonomics principles
500	Workplace ergonomics
600	Environment ergonomics
700	Control rooms
900	Tactile and haptic interactions

Annex B
(informative)

Attractivity, or subject visual quality

The attractivity of the image on a visual display is an important factor and there is no doubt that it influences well-being, fatigue and work performance.

In the case of a character font design, attractivity is a psychological factor that is a measure for acceptance by the user.

A unanimously agreed definition of *attractivity* has yet to be established. Nevertheless, the following contributing factors are considered to influence it (although the psychological correlation has not yet been shown).

Font styles

— character, word, line separations

— serifs

— bold, italic style

— under/overcut

— size

User factors

— education

— age

— reading environment

Non-scientific reading performance studies and opinion polls for printed text using different fonts have been carried out with a significant number of persons. The results definitely show a differentiation in attractivity ratings. For example, it is well known by book printers that certain fonts such as *Gatineau* are preferred by many people. It is not known, however, whether these experiences can be transposed to the characteristics of visual displays — be they CRT, LCD or other, new, technologies.

For the above reasons, neither a precise definition, measurement methods nor reference levels can be given. It can be recommended, however, that the factor of attractivity be considered by the manufacturer wishing to improve his design. In the absence of a scientifically proven methodology, it could also be helpful to question as many people as possible on their opinion and subjective rating of a presentation of various character sets, including the set intended to be used, applying the proven rules for performing opinion surveys.

Annex C
(informative)

Usability aspects of installation

C.1 Usability aspects

Usability is an important consideration in the design of products because it is concerned with the extent to which the users of products can work effectively, efficiently and with satisfaction. To determine the level of usability achieved, the performance and satisfaction of users working with a product should be measured. Key factors that should be addressed when assessing the usability of a product are the task to be performed, the context of use and the qualification of the user. An adequate usability test should be able to reveal discrepancies between the intended use (as defined by a designer) and actual use (as performed by a real user).

The installation and set-up of a product, such as a computer workstation, is one of the initial experiences that a user has with a product and that can influence initial user satisfaction.

For this reason, this annex provides an outline of one possible usability test for installation and the setting up of a product, such as a computer workstation.

C.2 Installation and set-up

As defined in this example, the task to be performed and the context of use is the installation of a product. Installation could comprise the following stages:

- unpacking;
- finding/identifying the installation procedure or manual;
- removal of protective means such as screws, shock absorbers and wrapping materials;
- coordination of hardware installation components including cables, plugs, bezels and screws;
- sequence and connection aids (e.g. colour coding of matching parts) to assemble installation components;
- installation of software components such as drivers, utilities and applications;
- registration;
- several start/restart sequences of the system.

The effectiveness and the efficiency of installation depends on the abilities, experience and training of the person in charge of the task. For this reason, the manufacturer should determine the type of installation: whether it is a user setup or an expert setup, or a plug-and-play versus a customized setup.

To determine the level of usability, a representative usability test in a suitable environment should be conducted. This environment can be simulated in a usability test lab.

The following measures have been shown to provide meaningful information:

a) time from unpacking to completion of installation;

b) time of identified individual sub-steps;

c) number of misinterpretations;

d) failures (fatal — i.e. abnormal stop — circumventable problems or minor):

   1) minor (temporarily impedes progress),

   2) major (substantially impedes progress),

   3) fatal (further progress is not possible);

e) number of questions to trained reference person;

f) number and quality of user feedback and recommendations for improvement;

g) relation of needed guidance compared to self-explaining steps.

C.3 Operation of product

In order to specify or measure usability of use, one needs to identify the goals and to decompose effectiveness, efficiency and satisfaction and the components of the context of use into subcomponents with measurable and verifiable attributes. Many situations may require the evaluation of the usability of the product-under-test within the complete system. This includes any hardware or software component that is relevant and representative of the actual work environment. The components and the relationships between them are illustrated in Figure C.1.

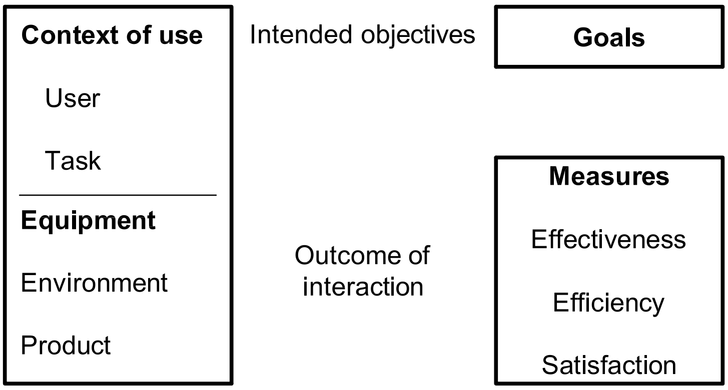


Figure C.1 — Usability framework

Annex D
(normative)

Basic concepts of visual perception for contrast and luminance of electronic displays

D.1 Contrast and luminance for electronic displays

This annex attempts to elucidate the phenomena behind the formation of images with a certain luminance and contrast on an electronic display, thus dealing with basic concepts of luminance and contrast in visual perception.

D.2 Symbols and abbreviated terms

For the purposes of this annex, the following symbols and abbreviated terms apply.

CR	contrast ratio
E	illuminance
g	uniformity of illumination
L_L	display luminance of low state
L_A	luminance of light source
L_r	reflected luminance
L_H	display luminance of high state
r	(subscript) reflected value
$S_A(\lambda)$	spectral distribution of light source
$S(\lambda)$	spectral distribution
T	correlated colour temperature
u',v'	CIE 1976 UCS values
X_r, Y_r, Z_r	tristimulus values of colour stimulus
Ψ	character height
γ	gamma value (electro-optical transfer function)

D.3 Illumination conditions

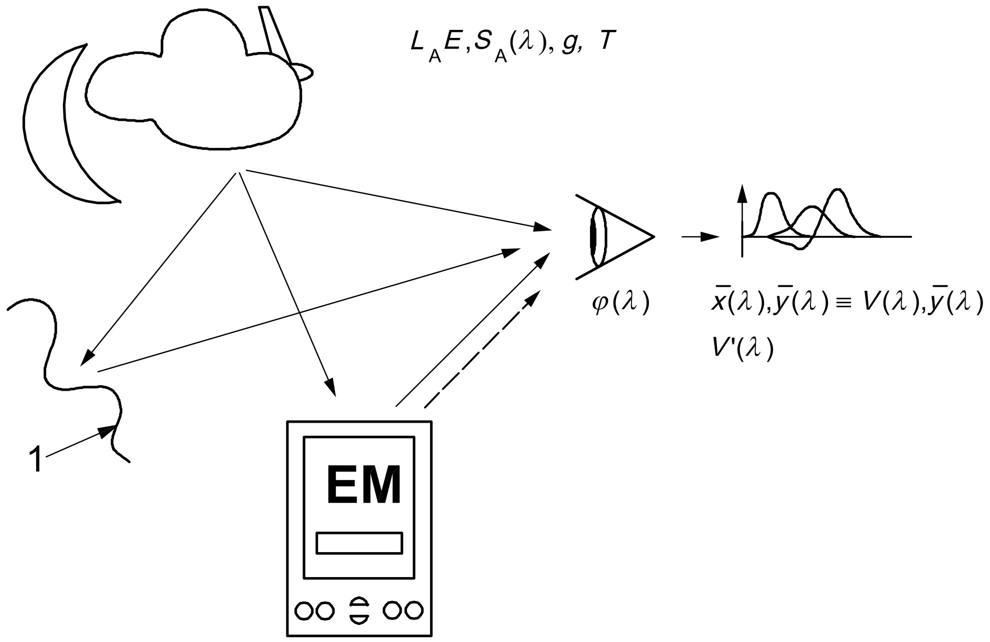
The typical use of a display is illustrated in Figure D.1. Elements of vision are symbolically drawn:

— different illumination conditions (natural, artificial sources) and their attributes;

— surrounding, which affects the adaptation of the eye;

— the display with its attributes;

— the eye with its attributes.



Key

1 physical surroundings

Useful information: $S(\lambda)$, L_H, L_L, CR, u', v', Ψ, γ, etc.
Disturbing information: X_r, Y_r, Z_r, (L_r), etc.

NOTE See D.2 for symbol meanings.

Figure D.1 — Use of displays

Useful information is given by the display to the user based on

— luminance, L_H, L_L,

— contrast, $CR = L_H/L_L$, and

— colour contrast, ΔE.

Due to reflection, the different illumination conditions result in disturbing information. The following are consequences of the disturbing information.

Reduction of contrast:

$$CR = \frac{L_H + L_r}{L_L + L_r} \quad (D.1)$$

Desaturation and change of hue:

$$\Sigma X = X + X_{\mathrm{r}}$$
$$\Sigma Y = Y + Y_{\mathrm{r}} \quad \text{(D.2)}$$
$$\Sigma Z = Z + Z_{\mathrm{r}}$$

Useful information is recognizable if the following conditions are met:

— minimum luminance;

— minimum contrast;

— minimum size;

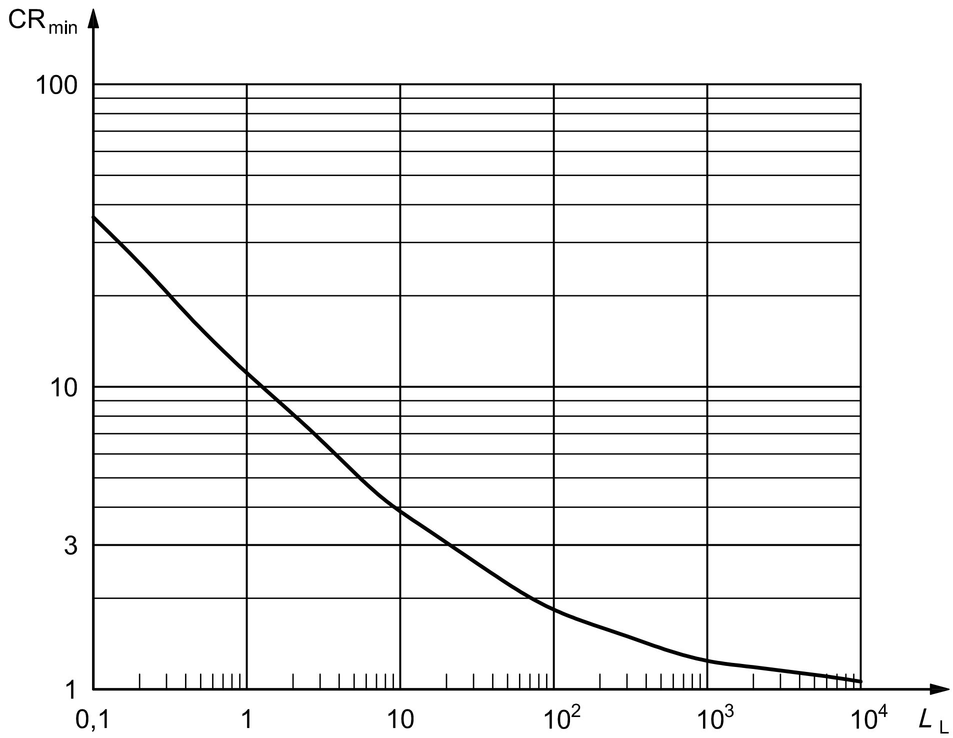
— adaptation of the eye to current luminance of field of vision;

— sufficient time of presentation of the object;

— reduction of unintended information, for example from reflections, so that the useful information can be prerceived and is minimally influenced.

D.4 Luminance contrast

A comparison of the different contrast requirements of ISO 9241-3[4] and ISO 13406-2[5] is shown in Figure D.2.



Key

L_{L} luminance, cd/m^2

$\mathrm{CR}_{\mathrm{min}}$ contrast threshold

Minimum contrast according to ISO 9241-3: CR = 3:1

Minimum contrast according to ISO 13406-2: $\mathrm{CR} = 1 + 10 \times L_{\mathrm{L}}^{-0,55}$

Figure D.2 — Minimum contrast of displays (according to ISO 9241-3/ISO 13406-2)

Comparison and discussion

Both curves cross at $L_\mathrm{L}^* \approx 18{,}7\ \mathrm{cd/m^2}$.

Below L_L^*, the requirement of ISO 9241-3 is too low when compared with ISO 13406-2.

Above L_L^*, the requirement of ISO 9241-3 is too high when compared with ISO 13406-2.

The contrast according to ISO 13406-2 strives to 1 with increasing L_L. This is unacceptable.

As an alternative to the differing contrast requirements of ISO 9241-3 and ISO 13406-2, for the purposes of this part of ISO 9241, another contrast requirement is specified.

Based on historical research, Kokoschka[15] carried out a mathematical evaluation of the visual contrast threshold, $\bar{C}$, giving a mathematical expression of $\bar{C}$ as a function of luminance, L_L, and angular extent, α, of the visual target:

$$\begin{aligned} \bar{C} &= \frac{L_\mathrm{H} - L_\mathrm{L}}{L_\mathrm{L}} = f(L_\mathrm{L}, \alpha) \\ \bar{C} &= \bar{C}_\mathrm{min} \times f_1 \times f_2 \\ \bar{C} &= 0{,}002\ 75 \times f_1 \times f_2 \end{aligned} \tag{D.3}$$

with

$$\begin{aligned} f_1 &= 1 + \left(\frac{L_\mathrm{L}}{0{,}158}\right)^{-0{,}484} \\ f_2 &= 1 + \left(\frac{\alpha_0}{\alpha}\right)^2 \\ \alpha_0 &= 7{,}5 + 133 \times \left[1 - \frac{1}{1 + \left(\frac{L_\mathrm{L}}{0{,}000\ 75}\right)^{-0{,}383}}\right] \end{aligned} \tag{D.4}$$

This expression is converted to express the contrast ratio, CR:

$$\mathrm{CR} = \frac{L_\mathrm{H}}{L_\mathrm{L}} = 1 + \bar{C} \tag{D.5}$$

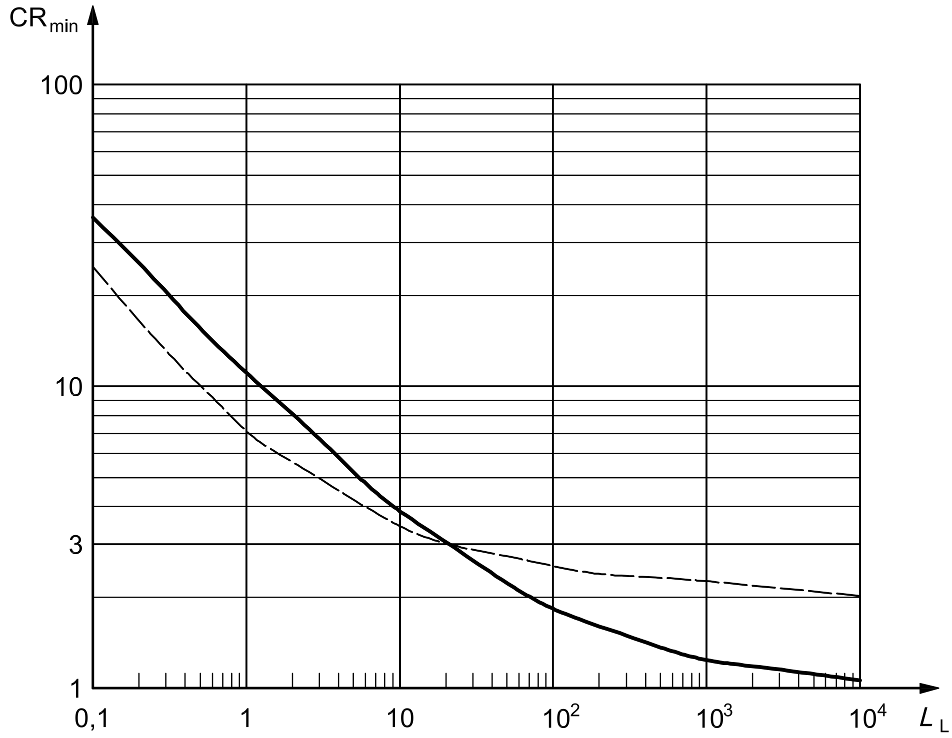
Depending on the size of the visual target, the visual contrast threshold, $\bar{C}$, shall be adjusted by a constant, k. Using an object size of $\alpha = 1'$ will lead to a constant k of:

$$\begin{aligned} \mathrm{CR} &= \frac{L_H}{L_L^*} = 3 = 1 + k \times \bar{C}, \quad (L_\mathrm{L}^* \approx 18{,}7\ \mathrm{cd/m^2}; \quad \alpha = 1') \\ k &\approx 6{,}3 \end{aligned} \tag{D.6}$$

In general:

$$\mathrm{CR} = \frac{L_\mathrm{H}}{L_\mathrm{L}} = 1 + 6{,}3 \times \bar{C}(L_\mathrm{L}; \alpha = 1') \tag{D.7}$$

The result is shown by the dotted line in Figure D.3.



Key

L_L luminance, cd/m[2]

CR_{min} contrast threshold

Figure D.3 — Required minimum contrast of displays

The (adjusted) visual contrast threshold for an object size of 1′ is proposed as the minimum contrast requirement for electronic displays.

Therefore, the required contrast shall be:

$$CR_{min} = 2{,}2 \times (1 + 2{,}2 \times L_L^{-0{,}65}) = 2{,}2 + 4{,}84 \times L_L^{-0{,}65} \quad (D.8)$$

Basic data for the above-mentioned contrast requirement were derived by experiments on young users. The required luminance contrast, CR, differs with the age of the users. For this reason, the introduction of a contrast multiplier, k_{age}, was suggested by Blackwell[16]:

$$CR_{min,age} = k_{age} \times CR_{min} \quad (D.9)$$

See Table D.1.

Table D.1 — Blackwell's age contrast multiplier

Age of user **years**	**Contrast multiplier** k_{age}
20	1,00
25	1,00
30	1,02
35	1,07
40	1,17
45	1,34
50	1,58
55	1,90
60	2,28
65	2,66

However, the combination of the data from Blackwell and Kokoschka needs to be regarded with caution. At the present time, Equation (D.8) represents the appropriate requirement (see also CIE 145[17]).

D.5 Display luminance

In addition to L_H, L_L, the luminance, L_r, reflected from the display or screen surface shall be considered in illuminated environments; L_r, considers luminance components, L_D and L_S:

— diffuse reflected luminance, $L_D = q \times E = R'_D \times E$;

— specular reflected luminance, $L_S = R'_S \times L_A$.

In general, the minimum contrast will be:

$$\mathrm{CR_{min}} = \frac{L_H + L_D + L_S}{L_L + L_D + L_S} = 2{,}2 + 4{,}84 \times (L_L + L_D + L_S)^{-0{,}65} \tag{D.10}$$

Solving Equation (D.10) to L_H, the minimum display luminance, $L_{H,min}$, is derived:

$$L_{H,min} = \left[2{,}2 + 4{,}84 \times (L_L + L_D + L_S)^{-0{,}65}\right] \times \left(L_L + L_D + L_S\right) - L_D - L_S \tag{D.11}$$

Therefore, $L_{H,min}$ is a function of L_L:

$$L_D = q \times E = R'_D \times E \tag{D.12}$$

$$L_S = R'_S \times L_A \tag{D.13}$$

This is illustrated in the following two examples:

Example 1

Typical CRT monitor as used in offices, where:

$L_L = 0,5 \text{ cd/m}^2$

$q = \frac{\rho}{\pi} \approx 2,5\ \%$

$R_{S,EXT} \approx 3\%$

$L_A = 0 \text{ cd/m}^2$

See Table D.2.

Table D.2 — Results of Equation (D.11) for Example 1

E lx	$L_{H,min}$ cd/m^2
1	**≈ 5**
10	**≈ 6**
100	**≈ 11**
1 000	**≈ 46**
100 00	**≈ 334**
100 000	**≈ 3 075**

Example 2

Typical laptop with TFT–LCD, where:

$L_L = 0,5 \text{ cd/m}^2$

$q = \frac{\rho}{\pi} \approx 0\ \%$

$R_{S,EXT} \approx 2\ \%$

L_A see Table D.3.

Table D.3 — Results of Equation (D.11) for Example 2

L_A cd/m^2	$L_{H,min}$ cd/m^2
1	≈ 5
10	≈ 6
100	≈ 10
1 000	≈ 39
100 00	≈ 272
100 000	≈ 2 470

Lower limit for $L_{H,min}$

$L_{H,min}$ shall exceed 3 cd/m^2. This minimum luminance is required in order to perceive colour images[18].

In the case of low illuminance, $L_{H,min}$ is also a function of the display size.

EXAMPLE In cinemas, $L_{H,min}$ should be about 50 cd/m^2.

Upper limit for L_H

Glare (disability glare or discomfort glare) shall not be produced by the display.

NOTE Glare depends on the state of the adaptation of the human eye.

Annex E
(informative)

Virtual display — Performance objectives

E.1 General

Use comfort is one of the key issues when head-worn or hand-held virtual displays are considered. The purpose of this annex is to provide a minimum set of ergonomical performance objectives for helping achieve a comfortable user experience with a virtual display. These are limited to non-see-through binocular or biocular displays.

E.2 Eye relief

Eye relief is the distance from the last physical surface of the virtual display optics to the exit pupil where the pupil of the eye is placed. Eye relief is constrained by two factors: the eye must be near enough to the lens that the whole display is visible, but far enough away from the display so that spectacles can be worn. To accommodate spectacles, the eye relief should be at least 25 mm[5][6][7].

E.3 Convergence demand

The vergence angle, α, is the angle between the visual axes of the left and right eye. See Figure E.1. It is expressed as:

$$\alpha = 2 \tan^{-1}(i/2D)$$

where

D is the distance from the nodal point of eye along the midsagittal plane to the fixated point, F, in space;

i is the interpupillary distance.

When the two displays of a binocular virtual display are in front of the eyes, the user has to converge the eyes in order to perceive the images and fuse them into a single percept. The convergence position of the eyes that is required for binocular fusion is the *convergence demand* of the binocular virtual display system.

The system should not cause a convergence demand that is in the divergent direction from the parallel visual axes, i.e. in the direction of the temples from optical infinity[5][8].

The convergence demand should be between 0° to10°, preferably between 2° to 10°[5][6].

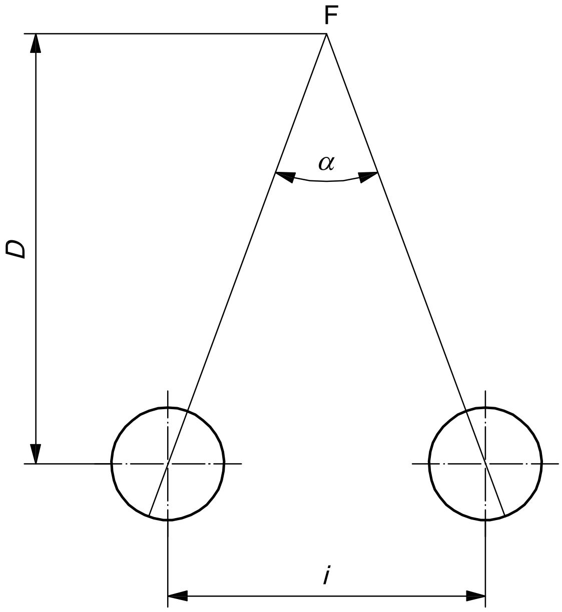


Figure E.1 — Convergence

E.4 Horizontal disparity

Horizontal disparity is the difference in the relative position of the visual images of an object on the two retinas. The horizontal image disparity in the retina of the fixation point, F, with respect to the point, P, is equal to the difference between the vergence angle required to fixate F and the vergence angle required to fixate P: the disparity between F and P = $\alpha_1 - \alpha_2$. Point P has a convergent or crossed disparity relative to point F, while point Q has a divergent or uncrossed disparity relative to point F. See Figure E.2.

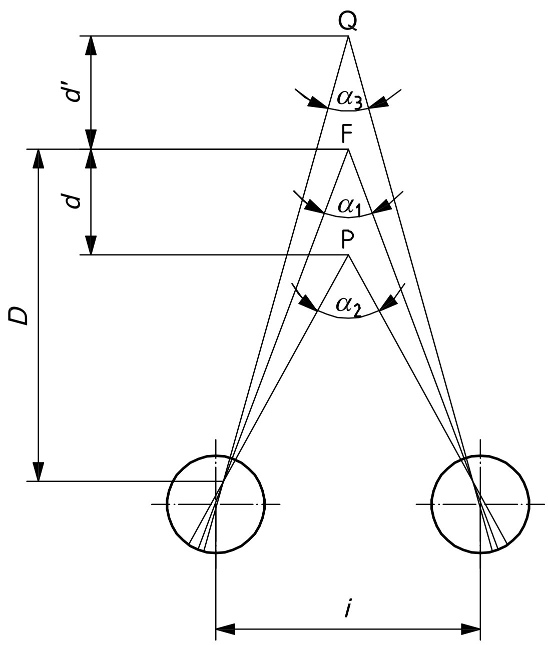


Figure E.2 — Horizontal disparity

If depth perception is to be avoided, disparities in the virtual display should be less than 20″ of arc[5].

If depth perception is the purpose of the display, the uncrossed horizontal disparity should not cause a convergence demand that is in the divergent direction from the parallel visual axes, i.e. in the direction of the temples from the optical infinity[5][8].

If the aforementioned limitation is taken into account and a non-see-through display is used, the crossed or uncrossed horizontal disparity relative to the point of fixation with over 200 ms presentation time should be ⩽ 2°[8][9] and ⩽ 15′ of arc[10], with a presentation time of less than 200 ms.

E.5 Vertical misalignment of the displays

Figure E.3 shows the vertical misalignment of a display.

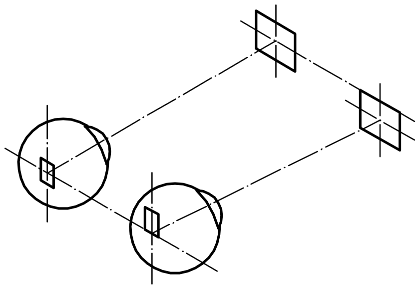


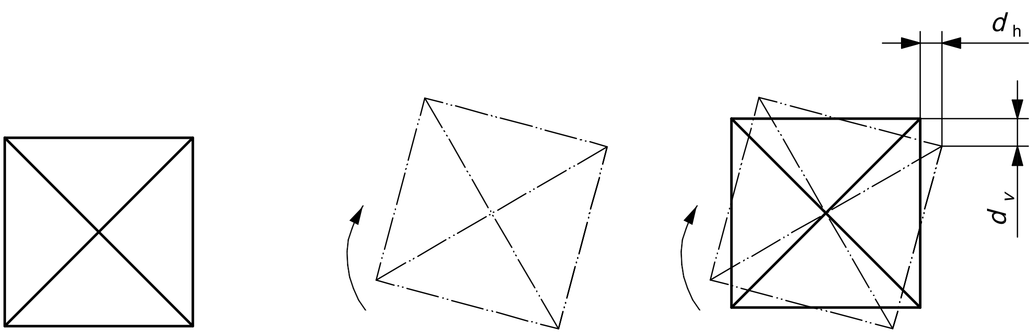
Figure E.3 — Vertical misalignment of display

Vertical misalignment refers to the vertical position of the two displays relative to each other. If there is no vertical misalignment and the user fixates exactly on corresponding points in the two displays, the visual axes define a plane. The amount of vertical misalignment is the total deviation of the visual axes from this plane.

The recommendations for appropriate vertical misalignment range from 3′ to 34′ of arc (see Reference [8] for a review). The different recommendations are based on different assumptions related to the device usage time and acceptable user experience. However, if comfort criteria are used and it is assumed that the binocular virtual displays are used for longer periods, the vertical misalignment of a binocular display should not exceed 8,6′ of arc[11].

E.6 Interocular rotation difference

This is a difference of rotation between two displays of a biocular or binocular virtual display. In Figure E.4, the solid rectangle represents the position of one display and the hatched rectangle that of a second display.



a) Left display **b) Right display** **c) Comparison**

Key

d_h horizontal misalignment

d_v vertical misalignment

Figure E.4 — Interocular rotation difference

If it is assumed that the visual fields of a binocular virtual display are totally overlapping. The maximum permitted rotation difference, R, in minutes of arc, is calculated from the maximum permitted vertical misalignment, V, and the total field of view, FOV, in degrees, and is expressed by[18][13]:

$$R = V \times \sin(\text{FOV}/2) \tag{E.1}$$

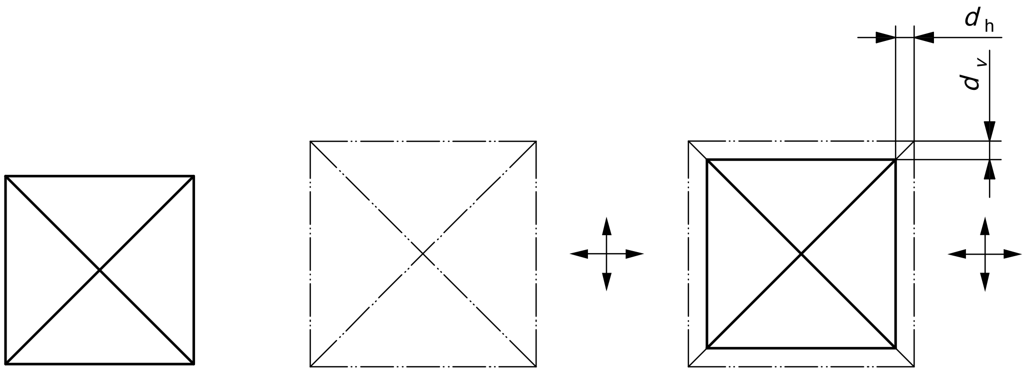
Table E.1 describes the resulting maximum rotation differences when the vertical misalignment of 8,6′ of arc is used as the maximum permitted vertical misalignment[12].

Table E.1 — Maximum permitted rotation differences

FOV degrees (°) of arc	**Maximum permitted rotation difference** minutes (′) of arc
30	49,53
40	33,23
50	25,14
60	20,35
70	17,20
80	14,99
90	13,38
100	12,16
110	11,23
120	10,50

E.7 Interocular magnification difference

This is a difference in magnification between the two displays of a biocular or binocular virtual display. In Figure E.5, the solid rectangle represents the position of one display and the hatched rectangle that of a second display.



a) Left display b) Right display c) Comparison

Key

d_h horizontal misalignment

d_v vertical misalignment

Figure E.5 — Interocular magnification difference

If it is assumed that the visual fields of a binocular virtual display are totally overlapping. The maximum permitted magnification difference, d, in percent, is calculated from the maximum permitted vertical misalignment, V, and the total field of view, FOV, in degrees, and is expressed by[6][12]:

$$d = 0{,}33V/\mathrm{FOV} \quad \text{(E.2)}$$

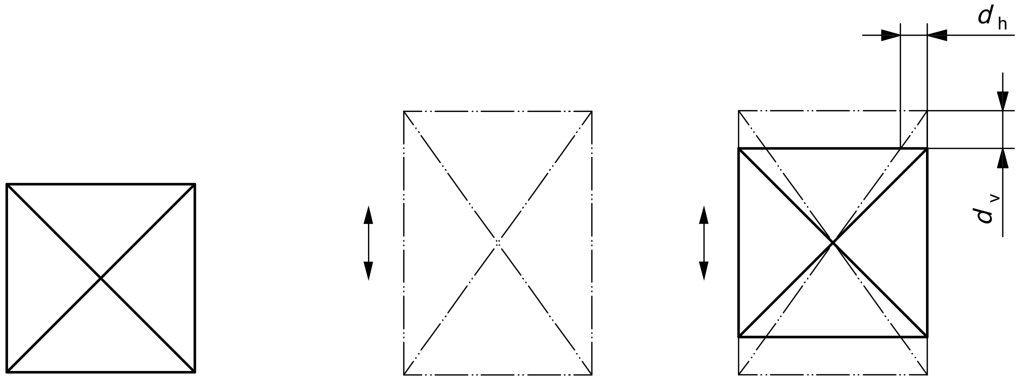
Table E.2 describes the resulting maximum magnification differences, when the vertical misalignment of 8,6′ of arc is used as a maximum permitted vertical misalignment[12].

Table E.2 — Maximum permitted magnification difference

FOV degrees (°) of arc	**Maximum permitted magnification difference** percent (%)
30	0,95
40	0,72
50	0,57
60	0,48
70	0,41
80	0,36
90	0,32
100	0,29
110	0,26
120	0,24

E.8 Interocular vertical magnification difference

This is a difference in vertical magnification between the two displays of a biocular or binocular virtual display. In Figure E.6, the solid rectangle represents the position of one display and the hatched rectangle that of a second display. The magnitude of vertical misalignment caused by the vertical magnification differences should not exceed 8,6′ of arc[11].



a) Left display   b) Right display   c) Comparison

Key

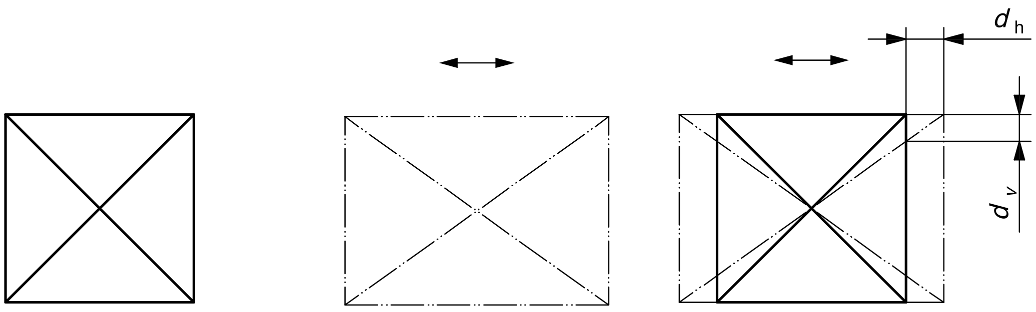
d_h horizontal misalignment

d_v vertical misalignment

Figure E.6 — Interocular vertical magnification difference

E.9 Interocular horizontal magnification difference

This is a difference in horizontal magnification between the two displays of a biocular or binocular virtual display. In Figure E.7, the solid rectangle represents the position of one display and the hatched rectangle that of a second display.



a) Left display **b) Right display** **c) Comparison**

Key

d_h horizontal misalignment

d_v vertical misalignment

Figure E.7 — Interocular horizontal magnification difference

The horizontal magnification difference between the displays should be such that the resulting disparity would not cause a convergence demand that is in the divergent direction from the parallel visual axes, i.e. in the direction of the temples from optical infinity[5][8].

If the aforementioned limitation is taken into account, the crossed or uncrossed horizontal disparity relative to the point of fixation with over 200 ms presentation time should be $\leqslant 2°$[8][9] and $\leqslant 15'$ of arc[10], with a presentation time $\leqslant$ 200 ms.

E.10 Interocular luminance difference

The luminance differences in the left and right eye views should not exceed 10 %[5][6].

E.11 Interocular focus difference

The focus differences in the left and right eye views should not exceed 0,25D[8].

E.12 Temporal asynchrony

The temporal asynchrony of stimuli presented to the left and right eye should not exceed 100 ms[8].

E.13 Focal distance

If a fixed focal distance is used, the focal distance should not be less than 40 cm. A distance of more than 100 cm is preferred[8].

E.14 Interocular distance

If the interocular distance is changeable, it should be at least 50 mm to 74 mm (this covers 98 % of the population[5]).

If the interocular distance is fixed, the following is recommended.

If the user's interpupillary distance does not match the interocular distance of the device, the eye's optical centres are not concentric with the system's optics, which could cause additional convergence demand. The convergence demand caused by the device's interocular distance should not be in the divergent direction from the parallel visual axes, i.e. in the direction of the temples from optical infinity[5][8].

The mismatch between the user's interpupillary distance and the system's interocular distance should not cause an anisoaccommodative demand greater than 0,25D[8].

The mismatch between the user's interpupillary distance and the system's interocular distance should not cause vertical misalignment larger than 8,6′ of arc[11].

E.15 Field curvature difference

The interocular difference in field curvature should not produce an anisoaccommodative focus demand greater than 0,25D[8].

Annex F
(informative)

Electronic visual display accessibility — Selected bibliography

F.1 General

The references listed in this annex should be viewed as a starting point for product designers, developers and users of electronic equipment who are planning to provide accessibility features in their products. These accessibility references are not intended to be complete or exhaustive. The area of accessibility is recognized as a world-wide challenge and is resulting in wide scale efforts — both political and technological. The listed references provide initial guidance and serve as a source of technical information.

F.2 References

URLs can be subject to change, and although the Web addresses given below were correct at the time of publication of this part of ISO 9241, the user is advised to check for accuracy. Some of the documents are available only through issuing agencies.

— The World Wide Web Consortium (W3C). The developer of interoperable technologies (specifications, guidelines, software and tools), the W3C is cited by many countries throughout the world as the core technical source for software accessibility:

http://www.w3.org/

— ISO/TS 16071:2003, *Ergonomics of human-system interaction — Guidance on accessibility for human-computer interfaces*. Available from ISO.

— HFES 200, Human Factors Engineering of Software User Interfaces (canvass draft 2006). Multi-part draft standard developed by the USA's Human Factors and Ergonomics Society, intended to be published as an expanded US version of the ISO 9241 software-related parts 10 to 17. One part deals with software accessibility, including Web access. See also Reference [1].

— US Section 508. Technical standards for Web-based applications, software and operating systems, telecommunications products, video and multimedia products, desktops and hardware. An official starting point for any developer to understand what needs to be done:

http://www.section508.gov/index.cfm?FuseAction=Content&ID=12

— UNE 139801, Aplicaciones informáticas para personas con discapacidad. Requisitos de accesibilidad al ordenador. *Hardware.* (*Computer applications for people with disabilities. Computer accessibility requirements. Hardware.*). Published by the Spanish Association for Standardisation and Certification (AENOR), Spanish version only available:

http://www.aenor.es/desarrollo/inicio/home/home.asp

— *Nordic Guidelines for Computer Accessibility*, second edition: Provides public and private procurers with accessibility requirements to be included in or referred to in calls-for-proposal for personal computer systems and similar systems. Published by the Nordic Cooperation on Disability:

http://trace.wisc.edu/docs/nordic_guidelines/nordic_guidelines.htm

— DIN TR 124, *Products in Design for All*. Deutsches Institut für Normung e. V. (DIN) Technical Report containing guidelines and recommendations for the development of technical products so that “as many people as possible can use the products as intended — if readily achievable.”

— ISO/IEC Guide 71, *Guidelines for standards developers to address the needs of older persons and persons with disabilities*. Available from ISO.

— CEN/CENELEC Guide 6, *Guidelines for standards developers to address the needs of older persons and persons with disabilities* (January 2002).

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3) US Human Factors and Ergonomics Society draft standard.

4) International Commission on Illumination.

[20] ISO 6385:2004, *Ergonomic principles in the design of work systems*

[21] ISO/CEI 8995-1:2002, *Lighting of work places — Part 1: Indoor*

[22] CIE 17.4:1989/IEC 50:1989, *International Lighting Vocabulary*[5)]

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5) International Commission on Illumination.

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