TECHNICAL REPORT

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Ergonomics of human-system interaction —

Part 310: Visibility, aesthetics and ergonomics of pixel defects

Ergonomie de l'interaction homme-système —

Partie 310: Visibilité, esthétique et ergonomie des défauts de pixel

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Foreword

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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.

In exceptional circumstances, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example), it may decide by a simple majority vote of its participating members to publish a Technical Report. A Technical Report is entirely informative in nature and does not have to be reviewed until the data it provides are considered to be no longer valid or useful.

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ISO/TR 9241-310 was prepared by Technical Committee ISO/TC 159, *Ergonomics*, Subcommittee SC 4, *Ergonomics of human-system interaction*.

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 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 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 143: Form-based dialogues*

— *Part 154: Design guidance for interactive voice response (IVR) applications*

Requirements, analysis and compliance test methods for the reduction of photosensitive seizures and evaluation methods for the design of physical input devices are to form the subject of a future part 411.

Introduction

This part of ISO 9241 summarises information that ISO/TC 159/SC 4/WG 2, *Visual display requirements*, collected on pixel defects and their impact on aesthetics and ergonomics during preparation of ISO 13406 and other parts in the ISO 9241 “300” subseries. It uses terms and definitions from ISO 9241-302 and VESA FDPM[20].

It is based on research and reports that were available at the end of year 2005. The annexes contain information upon which the Working Group could not reach consensus, as well as some additional information, collected during the year 2006, that did not undergo the same review and analysis process as the earlier material.

Ergonomics of human-system interaction —

Part 310: Visibility, aesthetics and ergonomics of pixel defects

IMPORTANT — The electronic file of this document contains colours which are considered to be useful for the correct understanding of the document. Users should therefore consider printing this document using a colour printer.

1 Scope

This part of ISO 9241 provides a summary of existing knowledge on ergonomics requirements for pixel defects in electronic displays at the time of its publication. It also gives guidance on the specification of pixel defects, visibility thresholds and aesthetic requirements for pixel defects. It does not itself give requirements related to pixel defects, but it is envisaged that its information could be used in the revision of other parts in the ISO 9241 series.

2 Terms and definitions

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

2.1
pixel
smallest addressable spatial unit of a display that can show all the colours of the display

NOTE 1 Typical pixel heights for single-user displays range from 0,05 mm to 0,40 mm. Multi-user displays viewed from a distance use bigger pixel sizes.

NOTE 2 Adapted from ISO 9241-302:2008, definition 3.4.29.

2.2
subpixel
independently addressable unit of a pixel, the smallest addressable unit of a display, used for spatial dithering to change colour or luminance

2.3
pixel fault
defective pixel or subpixel that is visible under the intended context of use

[ISO 9241-302:2008]

2.4
pixel defect
pixels that operate improperly when addressed with video information

EXAMPLE A pixel addressed to turn black could remain white. If it never changes state, it is said to be a stuck pixel. If it changes state without the proper addressing signal, it could be intermittent.

[VESA FPDM 303-6]

2.5
stuck on pixel
bright pixel on a black background

NOTE A stuck on pixel can be observed using a black screen.

[VESA FPDM 303-6]

2.6
stuck off pixel
dark pixel on a white screen

NOTE A stuck off pixel can be observed using a white screen.

[VESA FPDM 303-6]

2.7
stuck dim pixel
grey pixel independent of a white or black background

NOTE A stuck dim pixel can be observed using a white and then a black screen.

[VESA FPDM 303-6]

2.8
defective column/row
complete column or row of pixel defects

[VESA FPDM 303-6]

2.9
partial
pixels or subpixels that have defective sub area of defects

EXAMPLE Part of the pixel is stuck on or off but the rest of the pixel works properly.

[VESA FPDM 303-6]

2.10
temporal and intermittent defect
(sub)pixel defect that exhibits temporal variations not related to any steady-state video input

NOTE Temporal defects can be intermittent, exhibit a sudden change of state, or be flickering. They can be observed using a white and/or a black screen.

[VESA FPDM 303-6]

2.11
defect cluster
more than one defect present in a cluster of pixels of a defined size, e.g. 5 × 5 pixels

[VESA FPDM 303-6]

2.12
fill factor
amount of the area producing useful luminance compared to the amount of the area allocated to the (sub)pixel

[VESA FPDM 303-3]

2.13
mura
Japanese word meaning blemish that has been adopted in English to provide a name for imperfections of a display pixel matrix surface that are visible when the display screen is driven to a constant grey level

NOTE Mura defects appear as low contrast, non-uniform brightness regions, typically larger than single pixels. They are caused by a variety of physical factors. For example, in LCD displays, the causes of mura defects include non-uniformly distributed liquid crystal material and foreign particles within the liquid crystal. Mura-like blemishes occur in CRT, FED and other display devices.

[VESA FPDM 303-8]

3 Review of research

3.1 Detection of spots

3.1.1 General

Detection of spots is somewhat different to detection of spatially periodic targets. The vision research on spatially periodic targets is more extensive than the research on spots. The main factors affecting the visibility of small spots are spot size, spot duration, interaction of size and duration, the oblique effect, light adaptation, location in the visual field and spatial uncertainty.

Reading research [25] showed that the human being has three contrast channels suitable for reading; luminance contrast, Red-Green contrast and Yellow-Blue contrast. In normal reading, the signal from the contrast channel with the strongest signal is used and the two other channels are ignored. Since reading is dependent on detection of character features, it can be assumed that the same mechanism is valid for spot detection.

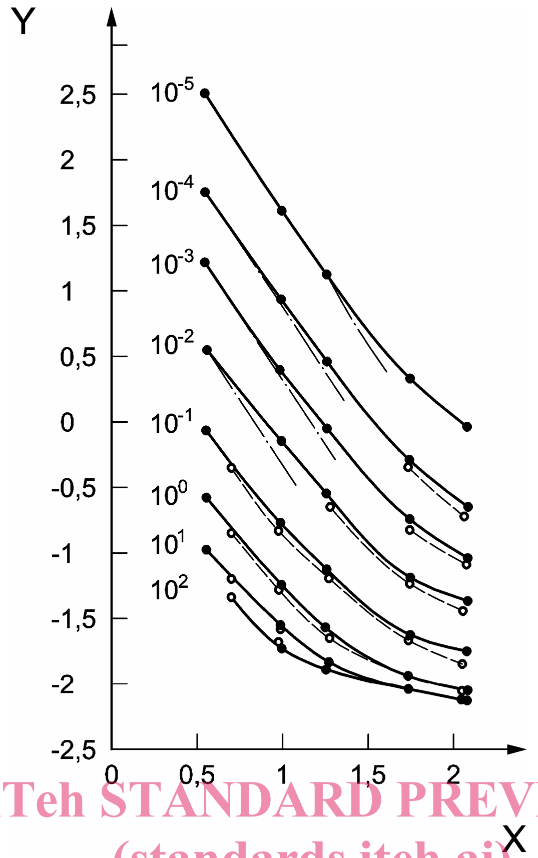
Effects of defect colour on spot detection can thus be analyzed for the three contrast channels separately and the spot will be visible if one or more of the three contrast channels produces a signal that exceeds contrast threshold.

3.1.2 Spot size

3.1.2.1 General

For small spots the visibility threshold decreases as the target area increases (spatial summation). There are five different types of spatial summation to consider in the study of pixel defects: Piper's Law, Ricco's Law, S-cones and M- and L-cones.

Spatial summation explains why stuck on defects on a black background are more visible than stuck off defects on a white background. On a black background the bright spot is summed with its black background and the contrast between the summed area and its background remains high enough to be visible. On a white background the black spot and its bright surround are summed and the contrast between the summed area and its background rapidly becomes less than threshold, when the size of the summed area increases.



Key

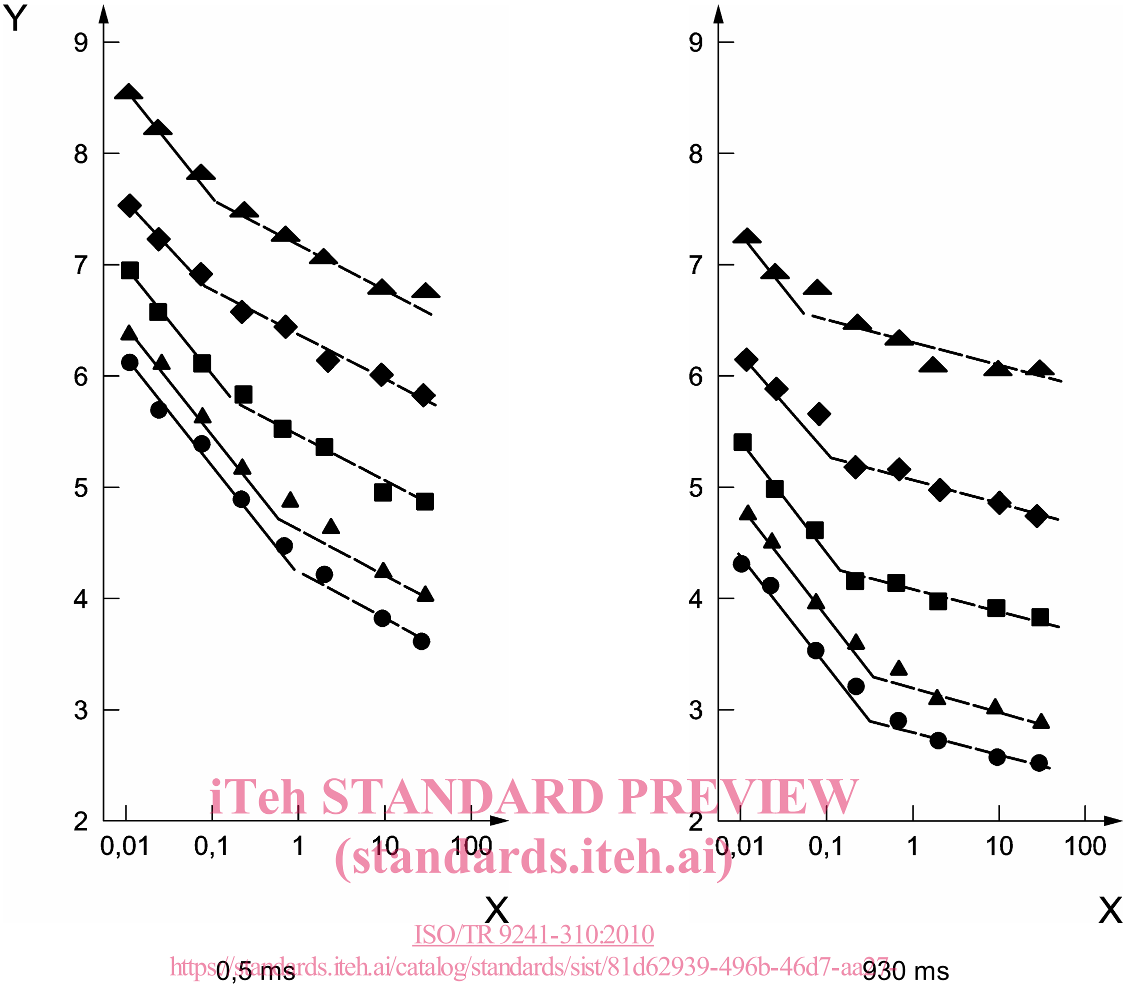
X log$_{10}$ stimulus diameter in min of visual angle

Y log$_{10}$ in $\Delta L / L_0$

NOTE Figure from Blackwell (1986) [29].

Figure 1 — Spatial summation as a function of target size and adaptation level

Log-increment (solid lines) and log-decrement (dashed lines) thresholds $\Delta L / L_0$ plotted as a function of log stimulus diameter for several adaptation levels. Complete summation (Ricco's Law) is given by a slope of -2. The area of complete summation decreases as mean luminance level increases. The test stimulus was a variable diameter circle (3,6 min to 121,0 min) presented for 6 s on a 10° background. Adaptation level, L_0, ranged from 10^{-5} to 10^2 cd/m^2. Observers were 19 women, 19 to 26 years old with normal vision. Each freely scanned the background from a distance of 18,2 m, so that viewing was probably parafoveal for the three lowest adaptation levels. The test spot could appear at one of eight positions projected on the circumferences of an imaginary 3° radius circle, and a spatial forced-choice detection task was used to estimate threshold. Threshold was taken to be the point at which the probability of a correct detection was 0,5, corrected for chance.



Key

X area of increment in deg^2

Y threshold in log quanta per second and deg^2

▲ background luminance (log quanta/s deg^2) 7,83

◆ background luminance (log quanta/s deg^2) 5,94

■ background luminance (log quanta/s deg^2) 4,96

▲ background luminance (log quanta/s deg^2) 3,65

● absolute thresholds

Figure 2 — Summation at cone level or Ricco's law is represented by the solid line with a gradient of −1

Log luminance (quanta/sec.deg^2 is a another method of expressing illuminance, similar to troland) as a function of area for two different stimulus duration. Spatial Barlow's data from Lamming D., Spatial Frequency Channels. Chapter 8. In: Cronly-Dillon, J., Vision and Visual Dysfunction, Vol 5. London: Macmillan Press, 1991. [http://webvision.med.utah.edu/]

3.1.2.2 Piper's Law (probability spatial summation)

Piper's law applies to large-sized spots which are close to visibility threshold: It can hold for up to 24° in size in the peripheral vision. The mechanism behind the summation is probability summation. It has been mathematically shown that the probability of detection increases with the square root of the number of retinal ganglion cells involved.

$$I\sqrt{A} = k_{\mathrm{p}} \qquad (1)$$

where

I is the intensity of the spot;

A is the area of the spot;

k_{P} is a constant.

When contrast and brightness are high, Piper's law has no impact on pixel visibility analysis.

3.1.2.3 Ricco's Law (neural spatial summation)

Ricco's law describes effects of neural-level spatial summation. If, close to detection threshold a spot is creating an image on the retina that covers several photoreceptors (cone cells), ganglion cells can be connected so that they receive stimuli from several photoreceptors and spatially integrate the signal from several photoreceptors.

In the fovea, the amount of spatial summation is small and neural spatial summation occurs mainly in the peripheral vision field. In the fovea, spatial neural summation can occur only up to 2' to 3'. In the parafovea, the summation can be up to 30'. For rod vision in the peripheral visual field, the summation can be up to 2°. The amount of spatial neural summation is dependent on the intensity of the stimuli.

$$I \times A = k_{\mathrm{R}} \qquad (2)$$

where

I is the intensity of the spot;

A is the area of the spot;

k_{R} is a constant.

When contrast and brightness are high Ricco's law has no impact on pixel visibility analysis, which is demonstrated by the fact that humans can, in good conditions, detect spots subtending as little as 0,5'.

3.1.2.4 Spatial summation in S-cones (PSF and spacing summation)

The S-cone is critical to the blue-yellow contrast signal. It has (for small spots) only a minor contribution to luminance contrast and no contribution to red-green contrast.

The human resolution to spots with short-wavelength light contrast is determined by the spatial spacing of the S-cones and the limitations of the optical system of the human eye (light scattering, chromatic aberration etc). The characteristics of the optical system can be quantified as the PSF (point spread function) of the eye. The spacing of S-cones in fovea is well aligned to the PSF for short wavelengths. The highest density of S-cones occurs not in the centre of the visual field, but at an excentrity of 0,35° to 1°. The peak density is slightly higher than 10 cones/°, which is equivalent to a spacing slightly denser than one cone per 6'. In the central visual field there is a zone with no S-cones at all. The diameter of this zone subtends about 0,35°.

If the spot is smaller than the S-cones spacing, then spatial summation will occur within the photoreceptor. When evaluating if the blue-yellow contrast of a spot exceeds visibility threshold, any spots or features smaller than this spacing shall thus be spatially summed for an area of subtending approximately 6'.

3.1.2.5 Spatial summation in M- and L-cones (PSF and spacing summation)

The M- and L cones contribute to all three contrast channels. These cones have the highest spatial resolution in the fovea of all photoreceptors and set the absolute limit for human visual acuity.

The maximum M- and L- cone density is about 120 cones/°, which is equivalent to a spacing of one cone per 0,5’. When evaluating if the luminance contrast or red-green contrast of a spot exceeds visibility threshold any spots or features smaller than this spacing shall thus be spatially summed for an area of subtending approximately 0,5'.

3.1.2.6 Ricco's area

Ricco's area is the area (in the spatial frequency domain) where only partial summation occurs. The broader between full and partial summation, as well as between partial and no summation depends on the wavelength, luminance and duration of the stimuli. For practical applications, Ricco's' area can thus be considered an approximative definition that adds uncertainty to any analysis of spot detection. See Figure 2.

The uncertainty of Ricco's area also explains some of the differences between reported research findings.

3.1.2.7 Spatial summation: Summary

When analysing spot visibility, the effect of spatial summation needs to be considered. For fovea vision, the spatial width of the summation will be at least 0,5' and at the most 2’ to 3’ for luminance contrast and red-green contrast and 6’ for blue-yellow contrast.

3.1.3 Spot duration

The highest detectable temporal frequency is slightly above 100 Hz, but for practical applications about 80 Hz. With lower average luminance, the maximum detectable frequency decreases towards about 40 Hz.

For frequencies higher than 10 Hz Bloch’s law is valid, according to which the luminance times the duration is constant:

$$I \times t = k_S \qquad (3)$$

where

I is the intensity of the spot;

t is the duration of the spot;

k_S is a constant.

For frequencies less than 10 Hz, the detection threshold is unaffected by the frequency.

3.1.4 Interaction of size and duration

Within Bloch’s law and spatial summation according to Ricco’s law and cone level spatial summation, the summation effects are additive. At lower spatial and temporal frequencies no simple relationship exists.

3.1.5 The oblique effect

At horizontal and vertical orientations, elongated targets have lower thresholds than round or square targets.

3.1.6 Light adaptation

The literature and popular literature about contrast dynamics state contradictory ratios for maximum contrast dynamics, e.g. 2,5:100, 1:100 and 1:1000. These are not in conflict with each other but refer to different reference situations.

For the purpose of this Technical Report, a normal luminance dynamics range of 3 log units in total is assumed, extending from 1,5 log units below adaptation luminance to 1,5 log units above adaptation luminance.

Threshold for light spots is dependent on the adaptation luminance. For adaptation luminances less than 0,1 cd/m², the adaptation luminance has no impact on visibility threshold. For adaptation luminances between 0,1 cd/m² and 10 cd/m², there is an increasing dependency on the adaptation luminance. For adaptation luminances above 10 cd/m², Weber's law is valid:

$$\frac{\Delta I}{I} = k_{\mathrm{A}} \tag{4}$$

where

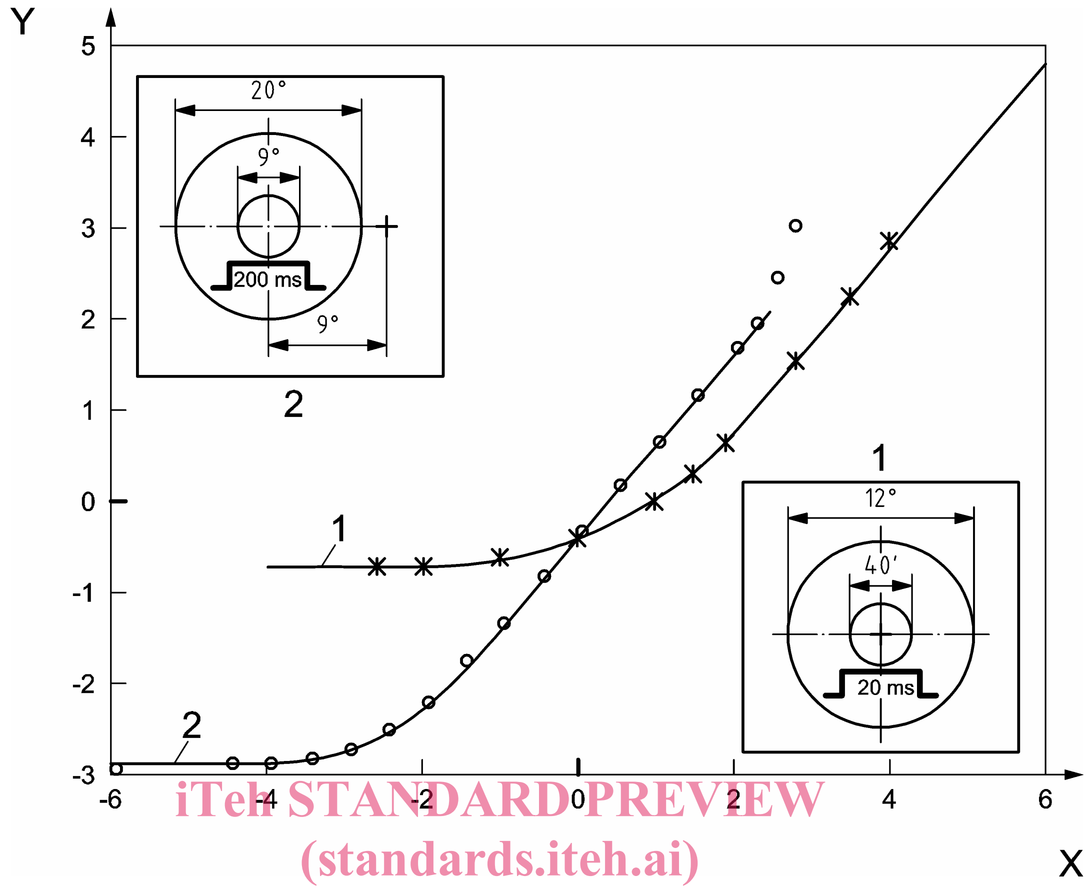
I is the intensity of the spot;

ΔI is the intensity difference threshold for detection;

k_{A} is a constant.

For normal usage situations $k \approx 100$

The size of the area determining the luminance adaptation is not covered in this report. Local luminance adaptation occurs concurrently and continuously for different areas of the field of view and could partially explain why a certain spot luminance can be clearly visible against a background, dimly visible in the neighbourhood of other patterns and not at all visible within the other luminance pattern.



Key

1 cones

2 rods

X log background luminance in cd/m^2

Y log threshold luminance in cd/m^2

Figure 3 — A psychophysical model of detection thresholds over the full range of vision; source: [26]