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CONTRAST AND VISIBILITY

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FOREWORD

The following members of Technical Committee TC 1-17 'Contrast Metric of Visibility', established in 1984, took part in the preparation of this Technical Report. The Committee comes under CIE Division 1 Vision and Colour.

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CONTRAST AND VISIBILITY

SUMMARY

The purpose of the present report is a study of literature related to analytical visual performance models and a discussion of various approaches with respect to a further development of a CIE contrast metric of visibility. It has been shown that many developments have taken place during the last 10 or 15 years which permit a much improved understanding of the multiparametric interactions in visual performance thresholds and in capability of predicting them. We have presented the concept of visibility lobes per glimpse which reveals a basis for evaluation of visual tasks and lighting conditions. An analytical function is discussed which includes foveal and extrafoveal vision, target-background interference, and information load. A critical point is the appropriate definition of contrast. It should be distinguished, for example, between inner and outer contrast. Furthermore, different filtering channels have to be taken into account if contrast sensitivity is measured. Contrast sensitivity as a function of spatial frequency must be determined for the prediction of detection and discrimination capabilities of observers. Priority of further work should be given to the investigation of visibility lobes as a function of target and background structures.

KONTRAST UND SICHTBARKEIT

ZUSAMMENFASSUNG

Das Ziel des vorliegenden Berichtes ist eine Auswertung von Literaturergebnissen zu Modellen, welche die Leistung bei visuellen Aufgaben quantitativ bewerten, sowie eine Diskussion der verschiedenen Ansätze für die weitere Entwicklung einer CIE Kontrast-Metrik für die Sichtbarkeit optischer Reize. Es wird gezeigt, daß in den vergangenen 10 bis 15 Jahren zahlreiche Entwicklungsschritte zu einem viel besseren Verständnis der komplexen Wechselwirkungen geführt haben, welche die visuellen Leistungsschwellen bestimmen, und daß darüber hinaus Verbesserungen bei der Vorhersage dieser Schwellen erzielt werden konnten. Wir stellen das Konzept der Sichtbarkeitsfelder pro Fixation vor, welches eine Basis für die Bewertung von Sehaufgaben und Beleuchtungsbedingungen darstellt. Es wird eine analytische Funktion diskutiert, welche neben fovealem und extrafovealem Sehen eine Ziel-Hintergrund Wechselwirkung sowie die Belastung des Beobachters durch Zusatzinformation berücksichtigt. Ein kritischer Punkt ist die geeignete Kontrastdefinition. Es sollte beispielsweise unterschieden werden zwischen innerem und äußerem Kontrast. Weiters müssen unterschiedliche Filterkanäle berücksichtigt werden, wenn die Kontrastempfindlichkeit gemessen werden soll. Die Kontrastempfindlichkeit als Funktion der Ortsfrequenz muß bestimmt werden, um die Beobachterleistung bei der Detektion und Unterscheidung von Reizen vorhersagen zu können. Schwerpunktmäßig sollten in Zukunft Sichtbarkeitsfelder als Funktion der Ziel- und Hintergrundstrukturen untersucht werden.

CONTRASTE ET VISIBILITÉ

RESUME

L'objet de ce rapport est de présenter une revue bibliographique des modèles analytiques relatifs à la performance visuelle. Le rapport contient par ailleurs une discussion de diverses approches en vue du développement futur d'une métrique CIE de la visibilité par contraste ("contrast metric of visibility"). Le présent travail montre que les nombreuses études effectuées pendant les 10 ou 15 dernières années ont permis d'améliorer nettement la compréhension des interactions entre les multiples paramètres qui interviennent dans les seuils de performance visuelle et dans la capacité de les prédire. Nous avons aussi introduit le concept de "lobes de visibilité" pour la vision instantanée ("visibility lobes per glimpse") qui constitue une base pour l'évaluation des tâches visuelles et des conditions d'éclairage. Une fonction analytique, tenant compte de la vision fovéale et extrafovéale, interactions entre l'objet et le fond et du contenu informatif, est présentée pour discussion. Un point critique concerne une définition appropriée du contraste où l'on devrait, par exemple, faire la distinction entre le contraste interne et le contraste externe. En outre, il est nécessaire de prendre en compte différents canaux de filtrage si l'on cherche à mesurer la sensibilité au contraste. La sensibilité au contraste, en fonction de la fréquence spatiale, doit être déterminée si l'on cherche à prédire les capacités de détection et de discrimination d'un observateur. La priorité, pour des travaux futurs, devrait être donnée à l'étude des "lobes de visibilité" ("visibility lobes") en fonction de la structure de l'objet et du fond.

1. INTRODUCTION

The report is divided into three parts. The first part is an introduction where the CIE contrast metric of visibility^{1.1} is discussed and some recent approaches are listed that can be used to characterize visual performance for near threshold and suprathreshold stimuli. One frequently used measure to describe quantitatively some properties of the human visual system is the visual modulation transfer function (MTF) as a filter of the spatial frequency components of the stimuli. The second part of the report therefore starts with an attempt to survey some important properties of the MTF. After that some models of early visual processing are considered which are based on results from psychophysics and neurophysiology and which might have consequences for further developments of a contrast metric of visibility. The third part of the report is essentially a discussion where the achievements and limitations of the various approaches are listed. We would like to emphasize that our understanding of visual information processing is far from complete. Due to the vast amount of literature on vision models we have had to confine ourselves to those models which could be easily related to the goals of CIE TC 1-17.

1.1 History and goals of the report

The CIE Publication No. 19.2 entitled "An analytical model for describing the influence of lighting parameters upon visual performance", was published in 1981 by the technical committee TC-3.1 "Visual Performance" under the chairmanship of H.R. Blackwell^{1.1}. There are some major achievements of this publication, but still there remain a number of practical and important questions to be solved as was explained very clearly by Inditsky, Bodmann, and Fleck^{1.2}. These authors outlined a path for a consistent development of CIE Publ. 19.2 by incorporating off-axis vision and ocular scanning strategies. Correspondingly an important element of visual performance appeared to be the visibility field per glimpse as related to the contrast and contrast threshold of a target. Further research by Voss^{1.3} and by Fleck^{1.4} has developed the quantitative basis of visibility fields per glimpse. So far it can be concluded that the "contrast metric of visibility" unifies lighting effects on the operation of the visual system at or near threshold performance. At supra-threshold levels a more appropriate visibility concept has to be established (Bodmann^{1.5}).

During the past 15-20 years the understanding of the physiology and neurophysiology of visual processes has improved dramatically and a number of attempts have been made to set up visual performance models based, at least to some extent, on this growing understanding. We think that these developments will lead in the near future to a clearer understanding of the first stages of visual information processing. Therefore CIE Division 1 decided in 1984 that the contrast metric of visibility ought to be confronted with the present state of knowledge on human visual system functions. In particular a review of the effects of contrast on visual detection and recognition tasks is needed as a first step for further developments of a CIE performance metric.

The CIE model as described and defined in CIE Publ. 19.2^{1,1} expresses the functional relation between overall performance and the level of reference luminance in terms of two classes of transfer functions. The first class of transfer functions is expressed in terms of the "relative contrast sensitivity" of the visual system provided by different levels of reference luminance including precise ocular fixation, target presentation for 0.2 seconds, uniform background luminance, etc. The second class of transfer functions relates overall performance to task visibility level. Thus, task visibility level is considered to be the "intervening" variable required to relate overall performance to reference luminance^{1,1}.

According to Inditsky, Bodmann and Fleck^{1,2} there are the following major achievements of CIE Publ. 19.2

- introduction of a contrast metric of visibility with the visibility level as unifying stimulus intensity,
- evaluation of lighting parameters as modifiers of the foveal visibility level of a target,
- a catalogue of empirical transfer functions relating foveal visibility levels to visual performance measures.

However, the metric developed was largely empirical and open to criticism because of the need to use it in conjunction with a number of auxiliary metrics. This was necessary in order to relate a variety of tasks and stimulus situations to a standard, well documented, threshold surface for pure detection of 4 min. of arc diameter disk stimulus. Some of the problems which remain to be solved for an extension of the present CIE model are the following^{1,2}

1. There is no accepted basis for a versatile and practicable prediction of foveal contrast thresholds.
2. There is no accepted device to measure visibility levels reducing contrast and nothing else.
3. Besides foveal visibility levels, off-axis vision and simple strategies of ocular scanning must be included in order to predict visual performance.

The first and third point are discussed in this report. Due to the complexity of visual perception we have to confine ourselves; we will not consider chromatic discrimination and temporal variation of stimuli.

1.2 Definitions of contrast

The contrast of a target is a measure of the difference in luminance between the target and its immediate surround or background. There exist different definitions of contrast depending on the shape of the targets. For simple, isolated targets on a uniform background, e.g. a disk or a Landolt ring, the (psychometric) contrast is given by the expression

$$C = \left| \frac{L_t - L_b}{L_b} \right| \quad (1.1)$$

where

- C = contrast
- L_t = target luminance
- L_b = background luminance.

Here the difference of neighbouring luminances is related to the background luminance to which the observer should be adapted. Eq. (1.1) has a physiological meaning for the detection of threshold contrasts in visual psychophysics where the just perceptible luminance increments are studied. In the Weber-Fechner region C is constant. The contrast definition in Eq. (1.1) leads to contrast values that range from 0 to infinity for targets brighter than their background and from 0 to 1 for targets that are darker than their background. The problem of an asymmetric range of contrast values is avoided if the difference between neighbouring luminances is related to their sum or mean (apart from a factor 2).

The relative contrast sensitivity

$$VL = \frac{C}{\bar{C}} \quad (1.2)$$

is designated as the visibility level. It would represent the ratio of actual contrast C and threshold contrast $\bar{C}$. The threshold contrast is usually taken as the contrast when $P = 0.5$ where P is the probability of the target being seen.

For spatially periodic stimuli like sine gratings, another contrast definition is commonly used:

$$m = \frac{|L_t - L_b|}{L_t + L_b} \quad (1.3)$$

which leads to contrasts that range from 0 to 1 for all conditions. In Eq. (1.3) L_t and L_b have the same meaning as above. The expression (1.3) has a physiological meaning if the adaptation luminance is governed by the mean luminance of target and background as could be possible for spatial periodic stimuli, e.g. a grating target. For such targets the expression (1.3) defines also the modulation.

Between Eq. (1.1) and Eq. (1.3) there exist the following relations

$$m = C/(2 + C) \quad \text{and} \quad C = 2m/(1 - m)$$

for targets brighter than their background,

$$m = C/(2 - C) \quad \text{and} \quad C = 2m/(1 + m)$$

for targets darker than their background.

The contrast of characters on active displays, e.g. VDU's, are usually defined by the ratio of two luminances^{1.6}

$$K = \frac{L_t}{L_b} \quad \text{for} \quad L_t > L_b \quad (1.4)$$

$$K = \frac{L_b}{L_t} \quad \text{for} \quad L_b > L_t \quad (1.5)$$

where L_t and L_b are defined as above. So far, there is no accepted specification of the location and spatial extent of the area where the target luminance L_t should be measured. The luminance modulation of rasters is theoretically and experi-

mentally analysed by Kokoschka^{1,6}, resulting in the definition of local inner, local outer and mean contrast of characters by the following expressions:

$$\text{outer contrast } K_a = \frac{L_m}{L_b} \quad (1.6)$$

$$\text{inner contrast } K_i = \frac{L_2}{L_1} \quad (1.7)$$

where

L_m = maximal luminance of a bright character
 L_2, L_1 = luminances of two adjacent raster points.

The inner contrast of critical detail is one of the determinants for the effect of contrast on visual identification tasks.

The size of the areas, where the luminances L_m , L_2 and L_1 should be measured, is only one picture element (pixel). The mean contrast K is defined by Eq. (1.4) and (1.5) where L_t is the mean luminance of the whole character. Fig. 1.1 shows an example of a raster character. The luminance profile through the middle part of the character M is depicted in the lower half of Fig. 1.1. Here the luminances L_1 , L_2 , L_m and L_b are localized. The mean contrast K is 15.

On the basis of detection, identification and search experiments on VDU's it is shown by Kokoschka^{1,6}, that the inner local contrast of characters is the determinant for the effect of contrast on visual performance and acceptance.

1.3 Detection probability per glimpse

The threshold contrast $\bar{C}$ in Eq. (1.2) has to be measured under reference conditions according to CIE Publ. 19.2^{1,1}. But one gets a fluctuation of the threshold contrast $\bar{C}$ from observation to observation. Therefore one has to assume a probability P of the target being seen. $P = 0.5$ usually defines the threshold contrast $\bar{C}$. For a presentation time of approx. 0.3 s a probability per glimpse P_g can be defined because this presentation time simulates a single fixational pause. A plot of P_g as a function of VL or $\log VL$ is usually called a frequency-of-seeing curve. The visibility VL is defined by Eq. (1.2). A great number of such frequency-of-seeing curves have

been measured over the years by Blackwell and co-workers^{1,7,1,8} as well as by others.

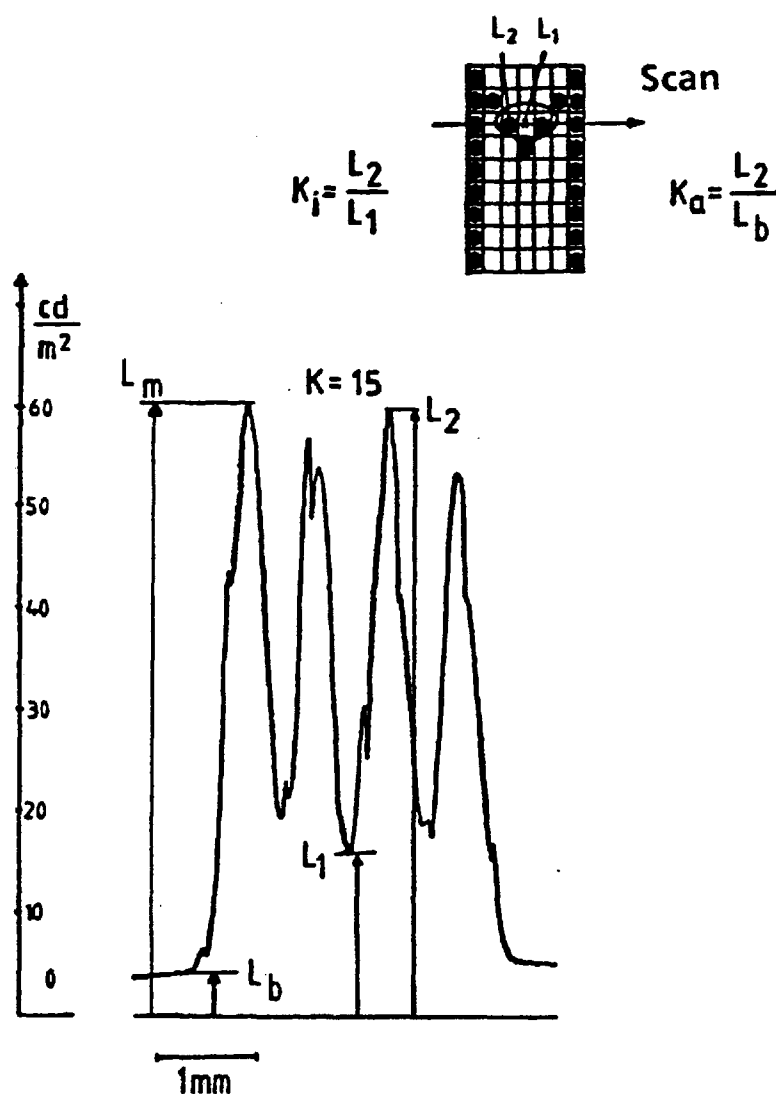


Fig. 1.1: Luminance profile of the complex details of the character "M" measured on a 15''-display. The scanned profile shows a typical configuration on "pixel of the character-gap-pixel of the character". The illuminance of the display was 12 lx (from Kokoschka^{1,6}).

The important conclusion from all the experiments is discussed with respect to Eq. (1.10) which is derived in the following from Eq. (1.8). For the mathematical description an equation is selected that has been suggested by several authors (Brindley^{1,9}, Quick^{1,10}, Robson & Graham^{1,11}, Voss^{1,3})

$$P_g(VL) = 1 - 2^{-VL^a_o} \quad (1.8)$$

The parameter a_0 determines the steepness of the frequency-of-seeing curve. Eq. (1.8) can be deduced from signal detection theory relating detection probability to signal-to-noise ratios for one biological detection channel if VL_2 is considered proportional to the signal-to-noise ratio^{1,3}.

Until now we have confined ourselves to on-axis vision. In order to include off-axis vision we have to consider visibility levels $VL_\beta = C/\bar{C}_\beta$ where β is the eccentricity angle and $\bar{C}_\beta$ the threshold contrast for a presentation of the stimulus at eccentricity β . Threshold contrast and visibility level measured under the reference conditions in CIE Publ. 19.2^{1,1} are designated as $\bar{C}_0$ and VL_0 to indicate "on axis" observation. By specifying a relative contrast threshold $R(\beta)$ according to

$$R(\beta) = \frac{C_\beta}{C_0} = \frac{VL_0}{VL_\beta} \quad (1.9)$$

one gets from Eq. (1.8)

$$P_g(VL_0, \beta) = 1 - 2^{-\left(\frac{VL_0}{R(\beta)}\right)^{a_0}} = 1 - 2^{-VL_\beta^{a_0}} \quad (1.10)$$

which is the detection probability per glimpse as a function of eccentricity and foveal visibility level of the target^{1,2, 1.3}.

However, it should be noted that in practice the function $R(\beta)$ in Eq. (1.9) is strongly dependant on such parameters as target size and image quality (that is, $R(\beta)$ is stimulus specific). Extreme care must therefore be taken in using this formula for the prediction of peripheral visual performance. One possible way of overcoming the problem of variability of $R(\beta)$ is to compute $\bar{C}_\beta$ directly from a multiparametric threshold model which includes effects of size, quality etc. (e. g. ORACLE - see Section 2.3), whence $VL_\beta = C/\bar{C}_\beta$ as in Eq. (1.2).

Fig. 1.2 shows an example for a frequency-of-seeing curve as measured by Fleck^{1,4} with forced choice experimentation, 0.3 second target presentation (eccentricity angle = $7^\circ \dots 27^\circ$), uniform background and a young population. The symbols mark experimental results for the detection of the characters O and D (size $36' \times 18'$) on a VDU. The full line is a plot of Eq. (1.10) with $a_0 = 3.44$.

From these, as well as from Blackwell's and other experiments, one arrives at an important conclusion.^{1,2} If plotted against VL_β , the frequency-of-seeing curve is

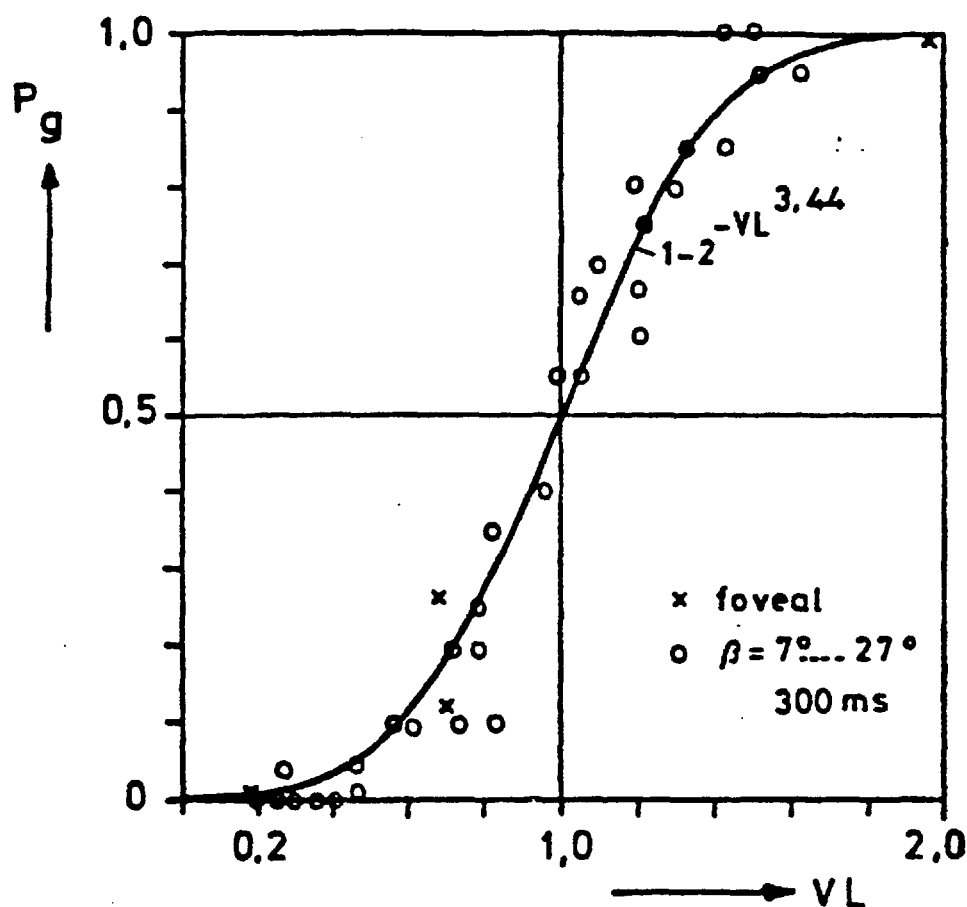


Abb. 1.2: Detection probability per glimpse p_g as a function of visibility level VL in the threshold zone for foveal (crosses) and peripheral vision (circles). The data have been measured by Fleck^{1,4}. The full line is a plot of the function defined by Eq. (10) for $a_0 = 3.44$.

much more independent of specific task conditions than any other function. This is the unifying power of the contrast metric defined by Eq. (1.2) although there are still variations of the gradient of the curve depending on the task and on the observer.

For pure detection tasks at very large visibility levels VL_β , the probability p_g reaches 100 % for every eccentricity β . The experimental results of Fleck^{1,4} however, showed that, for discrimination tasks (target sizes $20' - 30'$), $p_g = 100 \%$ could never be reached beyond eccentricities of $10^\circ - 12^\circ$, irrespective of actual contrast. Therefore Eq. (1.10) must be modified if discrimination tasks are to be considered. The reason for this is that for such tasks the value of $R(\beta)$ (Eq. (1.9)) tends to infinity for eccentricities of more than a few degrees and so VL_β can then never reach

high value. The tendency for $R(\beta)$ to approach infinity as the image position moves away from the fovea is, in fact, very generally true for discrimination tasks.

For small stimuli and high levels of discrimination such trends in $R(\beta)$ may well occur quite close to the fovea. Some typical trends of VL_β , as computed by ORACLE (Section 2.3), are presented in Fig. 1.3. For some high level discrimination tasks and small stimuli a related limitation applies even at the fovea. This latter effect is due to the existence, in such discrimination tasks, of a secondary probability function in the size domain (see, for instance, Biberman^{1,12} concerning the probability distribution of the Johnson criteria).

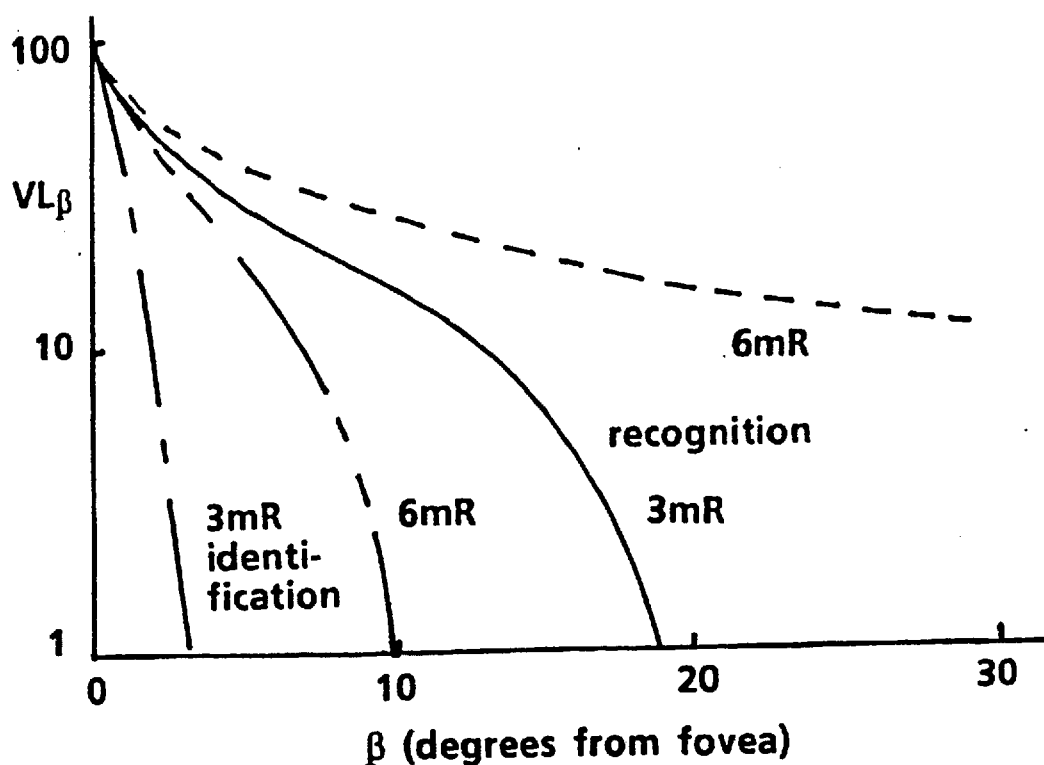


Fig. 1.3: Illustration of typical VL_β trends with retinal image position for two task levels and two sizes of disc stimulus. (Computed from ORACLE).

The detection probability $P_D(VL_0, \beta)$ as a function of β (or equivalent spatial coordinates) is termed the visibility lobe because it is directly linked to the present CIE metric of visibility. In general $R(\beta)$ depends on task conditions. It has been shown that different visual tasks must be compared on the basis of visibility lobes instead of visibility levels^{1,2, 1.4, 1.13, 1.14}.

1.4 Ocular scanning

Considering realistic visual tasks such as search or inspection work we have to combine visibility lobes per glimpse with a particular distribution of fixations in the time-space domain. There has been much discussion on the form that such a distribution of fixations should take. It is usually assumed that the distribution is either random or to a systematic pattern, although in practice it is likely to be between the two (see Morawski^{1,15} for a discussion).

It is assumed here that the fixations of duration T are randomly distributed over a field subtending a solid angle ω_f and that the fixations are independent events. The corresponding fixation pattern is called random search. The following paragraphs are presented as an introduction to search modelling. For the reader wishing to study the subject further an appendix is provided where some aspects are developed further.

For each trial (i.e. a randomly directed fixation) the probability of target detection is assumed constant and may be taken as P_{ge} which is defined by

$$P_{ge} = \frac{\omega_e}{\omega_f}, \quad \omega_e \ll \omega_f \quad (1.11)$$

Here an inspection field is considered subtending a solid angle ω_f and a target contained in ω_f having an effective visibility lobe size $\omega_e \ll \omega_f$. P_{ge} is the expected detection probability of the target per glimpse for an arbitrary viewing direction within ω_f . For situations where ω_e is not very much smaller than ω_f , see the appendix.

After n glimpses the probability that there is no detection is $(1-P_{ge})^n$ so that the probability P_d of at least one detection is given by: (further details are in Appendix A).

$$P_d = 1 - (1 - P_{ge})^n \quad (1.12)$$

Now for $\omega_e \ll \omega_f$, $P_{ge} \ll 1$. Therefore, substituting

$$(1 - P_{ge})^n = \exp [n \ln(1 - P_{ge})] \approx \exp (-nP_{ge})$$

and relating the number of glimpses n up to time t by $n = t/T$ one obtains

$$P_d(t) \approx 1 - \exp\left(-\frac{P_{ge}}{T}t\right) = 1 - \exp\left(-\frac{t}{t_e}\right) \quad (1.13)$$

where $P_d(t)$ represents the cumulative distribution of detection time with a mean value $t_e = T/P_{ge}$. The impact of visibility lobes on detection time is quantified by the following definition¹⁴

$$\omega_e = 2\pi \int_0^{\beta_{max}} P_g(VL_o, \beta) \sin\beta \, d\beta \quad (1.14)$$

where the probability profile $P_g(VL_o, \beta)$ is used as weighting function for eccentricity β . Substituting ω_e in Eq. (1.11) by Eq. (1.14) the impact of visibility lobes P_g on the probability P_{ge} of target detection and (using Eq. (1.13)) on the cumulative distribution P_d is quantified. For further discussion on the probability profile $P_g(VL_o, \beta)$ to be used in Eq. (1.14) see appendix A.

From a practical point of view the random search model has been widely used to fit the results of various search experiments. Surprisingly enough the cumulative distribution of detection time in many realistic search tasks is roughly consistent with random scanning. It can be shown that much more sophisticated strategies of scanning always yield exponential distributions of detection time^{1,14}. However, in many practical search experiments the search accumulators, although being of exponential form, fail to reach unity after a prolonged search time, whilst the "time constant" t_e is frequently found to be not well represented by the theoretical value of T/P_{ge} . A more generally applicable search accumulation equation has been found to be

$$P_d(t) = A(1 - \exp(-t/t_e)) \quad (1.14a)$$

where A takes a value between 0 and 1 and $t_e \propto T/P_{ge}$ rather than $t_e = T/P_{ge}$. Further discussion on this can be found in the appendix. The most important strategy related factor which significantly affects visual performance in realistic tasks was found to be extrafoveal guidance of saccades, and this will be discussed next.

So far it has been assumed that successive fixations are independent of each other. In fact this cannot be true for tasks with structured backgrounds. Once a potentially informative object is located by extrafoveal vision the following saccade will be directed to this object for more detailed examination by foveal vision. This extrafoveal guidance of saccades is a general principle of visual search and scanning behaviour.

A more general description of the corresponding search model can be found in Ref. 1.14 or 1.16. To simplify the mathematical treatment we presume a search field ω_F containing k randomly distributed objects, one of which is the target to be recognized. It is further assumed that all objects are fixated directly in a random order. The target can then be detected either foveally or extrafoveally while fixating one of the adjacent objects. This scanning strategy has been termed "quasi-random" search.

The probability of foveal detection ($\beta = 0$) per glimpse is $P_g(VL_o, O)/k$ and the corresponding probability for extrafoveal detection may be taken approximately as that for random search defined earlier. Together with some other assumptions an equation for the probability of target detection per glimpse P'_{ge} can be obtained^{1,2} which is analogous to Eq. (1.13)

$$P'_{ge} = 1 - \exp\left(-\frac{t}{t_e}\right) \quad (1.15)$$

The "gain" factor in terms of reciprocal search time is

$$\frac{t_e}{t'_e} = 1 + \left(\frac{\omega_F}{\omega_e} - 1\right) \frac{1}{k} \quad (1.16)$$

Thus with small numbers of objects and large search fields compared to ω_e there is a dramatic effect of extrafoveal guidance while for sufficiently large k values quasi-random search degenerates into perfect random search.

1.5 Modification of the visibility concept for highly suprathreshold stimuli

1.5.1 Visual performance. The term visual performance is used for a variety of performance scores such as frequency of seeing, detection time, detection distance, reaction time, speed and accuracy of visual work. Although each of these measures may be relevant for a specific task they may be interrelated and a more general quantity would be desirable^{1,5}.

It is the consensus of the committee that a crucial element of CIE Publ. 19.2 is the introduction of a contrast metric of visibility with the Visibility Level as a unifying stimulus intensity for the threshold zone of vision. Lighting parameters affect either the contrast or the contrast sensitivity, or both, and can thus be treated as modifiers of the Visibility Level.

At high suprathreshold levels of contrast the "perceived" visibility of a task and its CIE Visibility Level are not necessarily the same. Evaluations of perceived contrast, conspicuity, and readability of image quality all indicate that there is an optimum value of contrast above threshold. Studies directly measuring suprathreshold visual performance have shown that it will increase with both contrast and luminance^{1,17}. The model of visual performance (CIE Publ. 19.2) cannot predict the data of Rea^{1,18} which are obtained at a realistic, reading-writing task. The "relative visual performance (RPV)" model of Rea^{1,18} predicts that suprathreshold visual performance will increase only slightly with luminance when the contrast is high and more strongly when the contrast is low.

The RPV model of Rea is based on suprathreshold sensory compression, which has the following form, first employed by Naka and Rushton^{1,19}

$$\frac{R}{R_{\max}} = \frac{I^n}{I^n + k^n} \quad (1.17)$$

where

R	=	response
R _{max}	=	maximum response
I	=	stimulus intensity
n	=	exponent
k	=	stimulus intensity producing half of maximum response.

This expression is quite robust in describing visual responses to luminous modulations. The exact values of n, k and R_{max} in Eq. (1.17) will vary with the experiment.

With respect to the reading-writing task described in Rea^{1,18} a measure of visual performance VP is defined by the reciprocal of the time taken to read each reference list of a particular contrast at a particular adaptation luminance. Eq. (1.17) is rewritten in the following form

$$VP = \left[\frac{\Delta L^n}{\Delta L^n + k^n} \right] VP_{\max} \quad (1.18)$$

where: ΔL is the absolute value of a luminous increment or a luminous decrement from the threshold criterion at a given adaptation luminance, and $VP_{\max}$ the maximum performance.