Operational thresholds of the spatial resolution of the visual system and the contrast perception of objects

L. N. Aksyutov

Scientific Research Institute for Comprehensive Testing of Optoelectronic Devices, Sosnovy Bor, Leningrad Oblast

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Based on a model for predicting the probability of visually distinguishing/recognizing objects from an image and on the data of an experimental study, a method has been developed for analytically determining the operational thresholds of the spatial resolution of the visual system and of the contrast perception of a stimulus when the duration of its exposure does not affect perception. Previously unknown relationships that connect these quantities are established for wide ranges of the angular size of the stimulus and the adaptation luminance. The characteristic of the receptive field of the visual system corresponding to these relationships is obtained. © *2002 Optical Society of America*

The threshold characteristics of visual perception at various background luminances are of interest for psychophysics and the physiology of vision,[1] for solving applied problems, for instance, in illumination engineering,[2] and in estimating the possibilities of visually distinguishing small, low-contrast objects of a scene.

There are a large number of papers in the literature whose authors studied threshold quantities—the limiting distinguishable contrast and angular size of visual stimuli at various background luminances, with a description of the results in the form of an analytic function. The fact that these functions, given in Ref. 3, are so diverse and so numerous raises the question of how reliable they are. This question is associated with the fact that the limiting threshold values of these quantities are not invariant, but vary within rather wide limits in different observers.[4] Such smearing of the limiting thresholds of perception is explained by the fact that they depend not only on the psychophysiological features but also on the functional state of the subject of the activity.[5] Therefore, to increase the reliability of the description of the functions of visual perception, it is necessary to use the operational thresholds of visually perceptible quantities.

Reference 1 defines the threshold intensity of a stimulus of any modality as *operational* when it provides a level of perception sufficient for a 50% probability that it can be distinguished. This level is characterized by the balance of favorable and unfavorable factors that influence the discrimination of a stimulus, which corresponds to the maximum of the distribution of instantaneous fluctuations of the threshold of perception. Therefore, the operational threshold of a quantity that characterizes the perception of a stimulus determines the half-saturation level of the *S*-shaped psychometric function of its discrimination, regardless of the features of the observer's psychophysiology. For visual stimuli, such a quantity can be, for example, the contrast or the angular size.

The goal of this paper is to create a method for analytically determining the operational thresholds of the visually perceptible contrast of stimuli (objects) and of the angular resolution of the visual system in a wide range of adaptation luminance for an exposure time of the stimuli that prevents it from affecting the perception.

To achieve this goal, we chose the data of an experimental study carried out by Blackwell,[6] which is taken as classical,[7] and the main analytical relationships of a model for predicting the probability of the discrimination/recognition of objects from an image (the PRP model of Ref. 8), obtained theoretically in Ref. 9 on the basis of the main psychophysical law of perception (Fechner's law), retrieval theory, and the law of constancy of perception. These relationships are represented by

$$
\begin{aligned}
&P_p = 1 - 0.5\Psi^{-\eta_\nu} \quad \text{when} \quad \Psi > 1,\\
&P_p = 0.5 \quad \text{when} \quad \Psi = 1, \qquad (1)\\
&P_p = 0.5\Psi^{\eta_\nu} \quad \text{when} \quad \Psi < 1,
\end{aligned}
$$

where Ψ is an invariant of the information content of an image, which equals the ratio of any quantity that determines the intensity of a visual sensation (impression) from a perceptible stimulus to its operational threshold; η_ν is the confidence index of discrimination: $\eta_\nu = -\ln P_{\text{fa}}$, where P_{fa} is the false-alarm probability when solving a visual problem with probability P_p, as well as the formula that connects the *operational threshold of angular resolution* (OTAR) $\delta_{t,L}$, expressed in milliradians, of the visual system with the adaptation luminance L_{ad}:

$$\delta_{t,L} = \ln 2/(\log L_{\text{ad}} + 2.5). \qquad (2)$$

Equation (2) can be used for the range $-2.089 \leqslant \log L_{\text{ad}} \leqslant 3.535$, the limit of which, $\log L_{\text{ad}} = -2.089$, virtually coincides with the limit of variation of the characteristic of the threshold illumination of the pupil from back-

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TABLE I. Operational threshold of the angular resolution of the visual system ($\delta_{t,L}$) from Blackwell's data[6] and their discrepancy ($\Delta\,\delta_{t,L}$, %) with the calculated values from Eqs. (2) and (4).

δ_s arc min Ref. 6	δ_s mrad	log L_{ad} = 3.535	2.535	1.535	0.535	−0.465	−1.465	−2.465	−3.465	−4.465
		$\delta_{t,L}$, mrad								
18.2	5.29	—	—	—	—	—	—	—	—	8.82
9.68	2.81	—	—	—	—	—	—	2.21	4.43	8.86
3.60	1.05	0.130	0.146	0.172	0.229	0.362	0.743	2.15	4.44	8.89
0.595	0.173	0.111	0.130	0.161	0.217	0.348	0.726	2.13	4.41	8.63
Mean		0.120	0.138	0.167	0.223	0.355	0.734	2.16	4.43	8.80
Calculated from Eqs. (2) and (4)		0.115	0.138	0.172	0.228	0.340	0.670	2.18	4.36	8.70
$\Delta\delta_{t,L}$, %		4.3	0	−2.9	−2.2	+4.4	+9.5	−0.9	+1.6	+1.2

ground luminance (see Ref. 2, Fig. 1.49). However, we have not checked it against experimental data, because there are no such data in the literature.

The problem investigated in Ref. 6 was to determine the minimum contrast that ensures that a stimulus will be visually distinguished with probability $P_p=0.5$. According to what was said above, this minimum contrast, which we denote by the symbol K_t, corresponds to the *operational threshold of contrast perception* (OTCP).

Table VIII of Ref. 6 gives numerical values of $\log K_t$ for stimulus sizes of 360′, 121′, 55.2′, 18.2′, 9.68′, 3.6′, and 0.595′ for nine values of adaptation luminance L_{ad} from the range $-4.464\leqslant\log L_{ad}\leqslant 3.535$ that differ by an by order of magnitude.

According to Blackwell, the problem of the investigation is adequately solved within the limits of experimental error of $\pm 5\%$ when the time of perception of stimuli with positive and negative contrast is equal to 15 sec. He established that, regardless of the observation conditions, which are determined by the adaptation luminance L_{ad}, the contrast K_s (K_s is the differential or physiological contrast), and the time of perception of the stimuli, the psychometric function $P_p=f(Z=K_s/K_t)$ of distinguishing the stimuli, constructed from the experimental data, is satisfactorily described by an integral curve of a normal distribution.

This curve corresponds to Eqs. (1) with the following values of the parameters: $\eta_\nu=-3.2$ for $\Psi=Z>1$ and $\eta_\nu=1.8$ for $\Psi=Z<1$. For example, for $\Psi=1.62$, the discrepancy between the calculated discrimination probability $P_p=0.893$ and the probability $P_p=0.90$ indicated in Ref. 6 for $Z=1.62$ is less than one percent. With the same values of the η_ν parameters, the analogous function obtained in Ref. 10 for a perception time of visual stimuli of 0.3 sec is described, and this indicates that it is independent of the exposure time. The substantial difference of the quantitative description of the function $P_p=f(Z=K_s/K_t)$ by an integral curve of the normal distribution in Refs. 6 and 10 and by Eqs. (1) with the indicated values of parameter η_ν consists only of the fact that the calculated values of $P_p>0.9$ in the latter case converge to unity more slowly as $\Psi=Z$ increases.

Thus it is possible to use Eqs. (1) to predict by a calculational method the probability of visually distinguishing a stimulus with known contrast and size for any given observation conditions. However, to implement the method, data are needed on the OTAR of the visual system. Therefore, we present the experimental values of the OTCP not in the form of the dependence on the angular size of the stimuli, which is characteristic of earlier studies of the perception of their contrast,[2,3,11] but in the form of the dependence on the ratio

$$\delta_o=\delta_s/\delta_{t,L}, \tag{3}$$

where δ_s is the angular size of the stimulus, and $\delta_{t,L}$ is the OTAR, calculated from Eq. (2) for the adaptation luminance L_{ad} of the *visual system.*

For adaptation luminances from the range $-4.5\leqslant\log L_{ad}<-2.089$, the threshold $\delta_{t,L}$ of the visual system is determined from

$$\delta_{t,L}=\exp_{10}[-(0.3\log L_{ad}+0.4)], \tag{4}$$

which we obtained on the basis of Blackwell's data (see Table I).

Since the quantity $\log L_{ad}$ for the visual system has a functional value,[12] we present the data of Table VIII from Ref. 6 in Fig. 1 in the form of the dependence $\log K_t=f(\log\delta_o,\log L_{ad})$, a feature of which is that it contains linear and nonlinear sections.

The linear relation of the quantities $\log K_t$ and $\log\delta_o$, clearly expressed in Fig. 1 for the adaptation luminance from the indicated range for values of $\log\delta_o\leqslant\log\delta_o^*$, corresponds to the equality

$$\log K_t=-\log\delta_o^2. \tag{5}$$

We established that the quantity $\log\delta_o^*$ for an adaptation luminance from the range $-2.089\leqslant\log L_{ad}\leqslant 1.535$ is determined by Eqs. (1) for the invariant of the information content of an image $\Psi=\log L_{ad}+3.5/2.75$ and with the same values of parameter η_ν that correspond to the function considered above, $P_p=f(K_s/K_t)$:

$$\log\delta_o^*=1-\frac{1}{2}\left(\frac{\log L_{ad}+3.5}{2.75}\right)^{-3.2},$$

$$\text{if}\ -0.75\leqslant\log L_{ad}\leqslant 1.535, \tag{6}$$

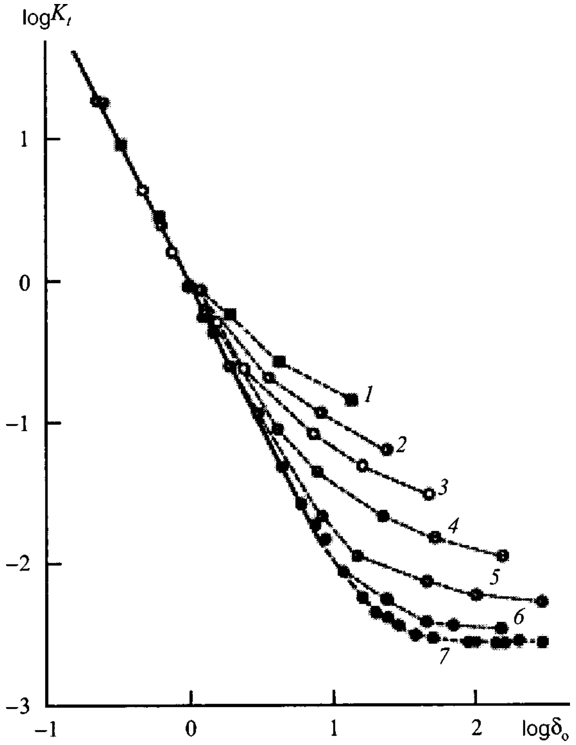

FIG. 1. Operational threshold K_t of visual contrast perception of stimuli as the function $\log K_t = f(\log \delta_o, \log L_{ad})$ from the data of Ref. 6: $L_{ad} = 3.43 \times 10^{-5}$ (*1*), 3.43×10^{-4} (*2*), 3.43×10^{-3} (*3*), 3.43×10^{-2} (*4*), 3.43×10^{-1} (*5*), 3.43×10^{0} (*6*), $3.43\times10^{1}-3.43\times10^{3}$ (*7*) cd/m^2.

$$\log \delta_o^* = \frac{1}{2}\left(\frac{\log L_{ad} + 3.5}{2.75}\right)^{1.8},$$

$$\text{if } -2.089 \leqslant \log L_{ad} < -0.75. \quad (7)$$

The value of $\log \delta_o^* = 0.928$ calculated from Eq. (6) for $\log L_{ad} = 1.535$ is also valid for adaptation luminances from the range $1.535 < \log L_{ad} \leqslant 3.535$, for which the experimental values of $\log K_t$ correspond to the dependence $\log K_t = f(\log \delta_o)$ shown by curve *7* in Fig. 1.

For $\log L_{ad} < -2.089$, we used the results of an analysis of Blackwell's data to obtain the expression

$$\log \delta_o^* = 0.14 \log L_{ad} + 0.442,$$

$$\text{if } -4.465 \leqslant \log L_{ad} < -2.089. \quad (8)$$

The formula $K_t \delta_o^2 = 1$ that corresponds to Eq. (5) when $\log \delta_o \leqslant \log \delta_o^*$ is substantially different from Wald's formula:[13]

$$LK\delta^x = k \quad \text{for } 0 < x \leqslant 2,$$

which, for a probability of 0.5 of visually distinguishing an object, connects its angular size δ and contrast K with background luminance L. It is emphasized in Ref. 13 that the use of Wald's formula, a particular case of which for $x = 2$ and $\delta < 7'$ is Ricco's law, assumes that it is necessary to make a preliminary measurement of parameters x and k under specific observation conditions.

Thus, Eq. (5), which assumes only that the adaptation luminance of the visual system is measured while an object with a known angular size is being observed, has obvious advantages over Wald's formula. One of them is as follows:

It is well known that the spatial resolution of any image-formation system, which it is customary to estimate as the square of its angular resolution, (see, for example, Ref. 11) determines the area of a resolution element (a pixel) of this system in the picture plane. Therefore, the value of δ_o^2 in Eq. (5) is equivalent to the number of pixels of the visual system per area of the visual projection of an object. In general, this number determines the information content of an image pattern of the object when solving the problem of recognizing it from the attributes of the parts and elements of the pattern that can be visually discriminated.[8,9] Therefore, Eq. (5) makes it possible to determine the OTCP that provides a given probability of recognizing the category to which an observed object belongs.

For values of δ_o that satisfy inequality $\log \delta_o < \log \delta_o^*$, we used Eqs. (5) and (3) and the K_t values obtained in Ref. 6 to calculate the OTAR of the visual system and the discrepancy $\Delta\delta_{t,L}$ of its value from that calculated from Eqs. (2) and (4). The results of the calculation are given in Table I.

Table I illustrates that the results of the calculation using the theoretically obtained dependence of Eq. (2) are in good agreement with the data of the independent experiment of Ref. 6, the more so that the $\delta_{t,L}$ values were not directly measured in this experiment. This fact is evidence of the reliability of Eq. (2) as well as of Eqs. (1), which are connected with it. Moreover, the data of Table I make it possible to regard the measurement of the OTCP of stimuli as a new, fairly accurate method of determining the operational threshold of spatial resolution of the visual system.

Analysis of the data of Table I shows that the factor that limits the spatial resolution during visual discrimination of the objects of natural scenes is not the scattering of light by the optical medium of the eye,[14] and not the physical size of the photoreceptor (Ref. 15, page 100), but the effective area of a pixel of the visual system that determines the receptor's photoresponse, determined by the excitation–inhibition processes of the neurons, forming the receptive fields of the visual system at the actual adaptation luminance.[12]

Now let us consider the nonlinear section of the $\log K_t = f(\log \delta_o, \log L_{ad})$ dependence when $\log \delta_o > \log \delta_o^*$ and $\log K_t < 0$ (see Fig. 1). To analyze it, we introduce the following notation:

$$Y = \log(K_t^*/K_t) \quad \text{and} \quad X = \log(\delta_o/\delta_o^*). \quad (9)$$

These coordinates are used in Fig. 2 to replot the data of Fig. 1.

Figure 2 displays a functional relationship that was unknown earlier: The $Y = f(X)$ dependence is described by a single curve not only for photopic levels of adaptation luminance ($\log L_{ad} \geqslant 1.5$), but also for its scotopic levels ($\log L_{ad} \leqslant -1.46$), at which rod vision predominates. For intermediate, mesopic levels of adaptation luminance, the $Y = f(X)$ function is determined by the numerical value of $\log L_{ad}$.

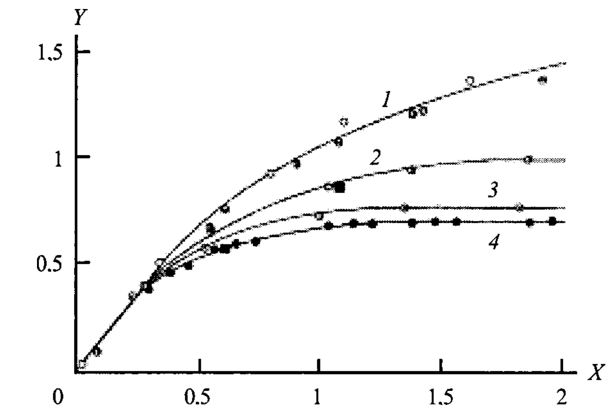

FIG. 2. The dependence $Y = \log(K_t^*/K_t)$ vs $X = \log(\delta_o/\delta_o^*)$ in the range of adaptation luminance $L_{ad} = 3.43\times10^{-5}$–$3.43\times10^{3}$ cd/m^2: the points show the data of Ref. 6 (symbols the same as in Fig. 1), and the curves show the calculated values, using Eqs. (10)–(14) for $L_{ad} = 3.43\times10^{-5}$–$3.47\times10^{-2}$ (*1*), 3.43×10^{-1} (*2*), 3.43×10^{0} (*3*), 3.16×10^{1}–3.43×10^{3} (*4*) cd/m^2.

The family of curves in Fig. 2 is described by the following relationships: When the inequality $0 < X \leqslant 0.20$ is satisfied for the adaptation luminance from the range $-4.465 \leqslant L_{ad} \leqslant 3.535$, the value of Y is determined from the equality

$$Y = 1.45X. \tag{10}$$

For $X > 0.20$, the values of $X_{rel} = X/X_m$ and $Y_{rel} = Y/Y_m$ are computed, where

$$\begin{cases} X_m = 1.40 - 0.78\log L_{ad}, & \text{if } 1.46 \leqslant \log L_{ad} \leqslant -0.11, \\ X_m = 1.48 - 0.48\log L_{ad}, & \text{if } 0.11 < \log L_{ad} \leqslant 1.5, \\ Y_m = 0.75X_m - 0.32. \end{cases} \tag{11}$$

The resulting value of X_{rel} is used to determine the Y_{rel} value from

$$\begin{aligned} Y_{rel} &= [A(X_{rel} - 0.05)]^{1/2} \\ &= [(1.6 + 0.23\log L_{ad})(X_{rel} - 0.05)]^{1/2}, \end{aligned} \tag{12}$$

$$\text{if } 0 < X_{rel} \leqslant 0.56;$$

$$\begin{aligned} Y_{rel} &= [1 - B(1 - X)]^{1/2} \\ &= [1 - (0.42 - 0.26\log L_{ad})(1 - X_{rel})]^{1/2}, \end{aligned} \tag{13}$$

$$\text{if } 0.56 < X_{rel} < 1.0.$$

This can be combined with the Y_m value to calculate the OTCP:

$$\log K_t = \log K_t^* - Y_{rel} Y_m. \tag{14}$$

In calculating $\log K_t$ from Eqs. (9)–(14), the parameters X_m, Y_m, A, and B were rounded to the second figure after the decimal point (see Table II). For adaptation luminances from the range $-4.465 \leqslant \log L_{ad} < -1.46$, the calculation uses the values of the parameters from the first row of Table II, whereas the fourth row is used for adaptation luminances from the range $1.5 < \log L_{ad} \leqslant 3.535$.

Table III shows the discrepancy $\Delta = [(K_{t,B}/K) - 1] \times 100\%$ between the values of the operational threshold $K_{t,B}$ from Table VIII of Ref. 6 and the threshold value K_t calculated from the relationships given above, using Eq. (14). The

TABLE II. Parameters for calculating the value of $\log K_t$ from Eqs. (9)–(14) in the range of adaptation luminance $-4.465 \leqslant \log L_{ad} \leqslant 3.535$.

$\log L_{ad}$	X_m	Y_m	A	B
−1.46	2.54	1.59	1.26	0.80
−0.465	1.76	1.00	1.49	0.54
0.535	1.44	0.76	1.72	0.28
1.5	1.36	0.70	1.72	0.28

discrepancies Δ in % enclosed by a frame in the lower part of Table III refer to the K_t values calculated from Eq. (5).

It can be seen from Table III that, for most of the calculated values of K_t, the discrepancy from the analogous data of Blackwell lies within the limits of the stated error $\pm5\%$. However, for the adaptation luminance $\log L_{ad} = -1.465$, the calculated K_t values proved to be systematically underestimated for all stimulus sizes δ_s with respect to the values obtained in experiment.

Considering the overall duration (up to 2.5 yr) of the study carried out by Blackwell, the reason of the discrepancy $\Delta > \pm5\%$ can probably be explained by the difference in the adaptation luminance indicated in Ref. 6 from its actual value, which corresponds to the experimental value of the OTCP. In order to avoid this, we calculated the value of $\log K_t$ for $\log L_{ad} = -1.556$, which, according to Eq. (2), corresponds to the mean value $\delta_{t,L} = 0.734$ mrad obtained for $\log L_{ad} = -1.465$ in Table I. The discrepancy between the K_t values calculated for $\log L_{ad} = -1.556$ in Table III and Blackwell's data for $\log L_{ad} = -1.465$ can be regarded as a confirmation of our assumption.

The results given in Table III make it possible to conclude that reliable values for the OTCP K_t calculated by the method that we proposed are obtained for adaptation luminances L_{ad} in kd/m^2 from the range $-4.465 \leqslant \log L_{ad} \leqslant 3.535$, and to recommend this method for practical application.

We now turn to the fact that the X_m and Y_m values for each adaptation luminance correspond to $\log \delta_{o,m}$ and $\log K_t$ values, with the latter remaining constant when $\log \delta_o > \log \delta_{o,m}$ (see Fig. 2). This fact agrees with the theoretically confirmed relationship of Ref. 12, according to which increasing the area of the *receptive field* (RF) of the visual system reduces the spatial summation of the responses of the neurons that forms this field, minimizing the threshold of perceptible contrast. Consequently, the value of $\log \delta_{o,m}$ corresponds to the angular size of the RF in which spatial summation completely terminates at the existing adaptation luminance.

It is established from the results of these calculations that the angular size δ_{RF} of the receptive field of the visual system in milliradians, corresponding to the total termination of spatial summation, is described by an *S*-shaped response $\log \delta_{RFc} = f(\log L_{ad})$, which in its representation by Eqs. (1) has the form

TABLE III. The discrepancy (Δ, %) between the operational threshold of contrast perception of visual stimuli from Blackwell's data[6] and the values calculated from Eqs. (5) and (9)–(14).

δ_s		$\log L_{ad}$									
arc min	mrad	3.535	2.535	1.535	0.535	−0.465	−1.465	−1.556	−2.465	−3.465	−4.465
		Δ, %									
360	104.6	−2.3	0	−1.1	−2.7	−0.4	+11	−1.4	+0.9	−3.6	−8.5
121	35.2	−1.1	+1.2	+0.7	−0.8	−0.5	+10	−2.7	−4.4	−8.2	−3.6
55.2	16.0	−0.3	−1.6	−1.2	+1.1	+5.1	+3.0	−9.3	−0.9	+1.1	+7.0
18.2	5.29	+9.5	−0.1	−4.3	−4.1	−3.3	+4.0	−9.4	+6.6	+1.0	+2.8
9.68	2.81	+2.6	−6.8	−3.7	−1.3	+0.7	+12	−4.4	+1.0	+4.2	−0.9
3.60	1.05	+23	+9.9	+0.7	+0.9	+13	+23	+2.6	−3.2	+4.0	0
0.595	0.173	−6.0	−11	−12	−9.6	+3.6	+17	−2.1	−5.6	+2.6	−1.1

$$\begin{cases} \log \delta_{\mathrm{RFc}} = 1.15\left[2-\left(\dfrac{8.3}{\log L_{\mathrm{ad}}+9.5}\right)^{-3.5}\right]+1.3, \quad \text{if} \\ \log L_{\mathrm{ad}} < -1.2, \\ \log \delta_{\mathrm{RFc}} = 1.15\left(\dfrac{8.3}{\log L_{\mathrm{ad}}+9.5}\right)^{6.2}+1.3, \quad \text{if} \\ \log L_{\mathrm{ad}} > -1.2. \end{cases} \tag{15}$$

Table IV shows the values of X_m, $\log \delta_{o,m}$, $\log \delta_o^*$, $\delta_{t,L}$, and $\log \delta_{\mathrm{RF}}$ obtained from Eqs. (2)–(11) for the range of adaptation luminance considered here and the discrepancy $\Delta = [(\delta_{\mathrm{RF}}/\delta_{\mathrm{RFc}})-1]\times 100\%$ of the values of δ_{RF} and δ_{RFc}.

The values in Table IV illustrate how the quantities that characterize the perception of visual stimuli depend on the adaptation luminance:

a) The value of $\log \delta_o^*$ is directly proportional and the values of $\log \delta_{t,L}$ and $\log \delta_{\mathrm{RF}}$ are inversely proportional to $\log L_{\mathrm{ad}}$.

b) The value of $\log \delta_{o,m}$ depends in a complex way on $\log L_{\mathrm{ad}}$: It is constant for photopic levels of adaptation luminance, increases for $\log L_{\mathrm{ad}} < 1.5$, reaching a maximum at $\log L_{\mathrm{ad}} \approx -1.46$, and decreases as the radiance decreases further.

Using Eqs. (15), it is easy to determine, for example, that, for an adaptation luminance $L_{\mathrm{ad}} = 500\ \mathrm{cd/m^2}$, corresponding to daytime illumination with a clear sky, the operational threshold of spatial resolution is $\delta_{t,L} = 0.133$ mrad and the angular size of the RF of the visual system that is responsible for this value is 25.5 mrad or about 1.5°, i.e., somewhat more than the angular size of the central field of vision. An important practical conclusion follows from this fact: In order to reliably estimate the probability of visual detection or recognition of small, low-contrast objects on natural backgrounds, it is necessary to adequately estimate the adaptation luminance, which determines the actual value of the operational thresholds of spatial resolution of the visual system

TABLE IV. The quantities that characterize the operational threshold of the angular resolution and the corresponding receptive field of the visual system.

$\log L_{ad}$	$\log\delta_o^*$	X_m	$\log\delta_{o,m}$	$\delta_{t,L}$, mrad	$\log\delta_{\mathrm{RF}}$	$\log\delta_{\mathrm{RFc}}$	Δ, %
	Eqs. (2)–(11)					Eqs. (15)	
−4.465	−0.183		2.357	8.70	3.30	3.40	−20
−3.465	−0.043		2.497	4.36	3.14	3.22	−17
−2.465	0.097		2.637	2.18	2.97	2.95	+5
−2.2	0.134		2.674	1.82	2.93	2.87	+15
−2.0	0.168	2.54	2.708	1.39	2.85	2.79	+15
−1.8	0.210		2.750	0.99	2.74	2.72	+5
−1.6	0.257		2.797	0.77	2.68	2.63	+12
−1.465	0.291		2.831	0.67	2.66	2.57	+23
−1.4	0.308	2.49	2.800	0.63	2.60	2.54	+15
−1.2	0.305	2.34	2.645	0.53	2.37	2.45	−7
−1.0	0.421	2.18	2.601	0.46	2.26	2.29	−7
−0.465	0.635	1.76	2.397	0.34	1.93	1.98	−11
0.535	0.853	1.44	2.293	0.228	1.65	1.65	0
1.535				0.172	1.52	1.50	+5
2.535	0.928	1.36	2.288	0.138	1.43	1.41	+5
3.535				0.115	1.35	1.37	−5

and of the perceptible contrast of objects in the zones over which the focal attention of the observer is distributed. The angular sizes of these zones along the horizon are 10°, 4°, and 1°, which ensure clear visibility of a scene, of segments of a scene, and of detailed differences of the segments, respectively.[16]

In conclusion, the following conclusions can be formulated:

1) Methods have been proposed for determining the operational thresholds of perceptible contrast of objects and of the spatial resolution of the visual system in the luminance range from 3.43×10^{3} to 3.43×10^{-5} cd/m^2. The quantities to be determined are reliable when adequate values of the adaptation luminance and the angular size of the observed object are measured.
2) A new approach to the analysis of the experimental data is used to develop the proposed methods, making it possible to establish previously unknown relationships of the perception of visual stimuli, which are represented in this article by analytical dependences.
3) The results of this work showed that the main formulas of a model for predicting the probability of the discrimination/recognition of objects (the PRP model) completely correspond to the relationships of visual perception, and this is evidence that the model is reliable.

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