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THE VISUAL ACUITY IN VIEWING SCALED OBJECTS ON TELEVISION COMPARED WITH THAT IN DIRECT VIEWING

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THE VISUAL ACUITY IN VIEWING SCALED OBJECTS ON TELEVISION COMPARED WITH THAT IN DIRECT VIEWING

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SUMMARY

The primary objective of this study was to establish a relationship between the visual acuity in viewing scaled objects on television monitors and that in direct viewing. An investigation of the acuity in viewing scaled objects on a closed-circuit television system was made. The data were compared with direct-viewing data taken in earlier studies. In both, the acuity was determined as a function of contrast and background luminance.

The results showed that the visual acuity in viewing scaled objects on television monitors was degraded. A technique employing human physiological data and television-system parameters was developed to predict the extent of this degradation and to predict the resulting visual acuity in direct viewing.

INTRODUCTION

For many years research has been conducted to further the understanding of the effects of the visual scene on the human ability to acquire visual information. A measurement index of these effects is the visual acuity, which is the inverse of the minimum visual angle in arc min. It is a function of the color, geometrical design, adaptation level, contrast, and background luminance of the visual scene – the latter two being the most convenient for laboratory measurements. Many researchers (including those of refs. 1, 2, 3, and 4) have studied the effects of contrast and background luminance in directly viewing scaled objects.

This paper presents an investigation of the effects of these two parameters in viewing scaled objects on a high-resolution, closed-circuit television system, CCTV. The data taken were compared with those from earlier, direct-viewing studies. To assure the validity of this comparison, subjects whose average visual acuity in direct viewing was the same as that of the subjects in the earlier studies were chosen for the CCTV study. In both, the visual scene was planar and perpendicular to the subject's line of sight so that size estimation and obliquity would not be factors in the study. In direct viewing, the additional factors of binocular viewing and retinal disparity were present, but these are not major parameters in detecting and resolving detail of the object. The significant parameters in each study were thus contrast and background luminance. The differences, within test error, between the data of the two studies were attributed to particular television characteristics – the vidicon response, picture-tube contrast ratio, television limiting resolutions, signal-to-noise ratio, phase shift, flux distribution, and critical flicker frequency – and to the subject and system variance. Explanations of how these parameters influenced the data are given.

This paper offers a technique employing the human physiological data and the television-system parameters to predict the visual acuity in viewing scaled objects on television monitors. The technique can also be used to predict the converse; that is, if the visual acuity in viewing television monitors is known, the acuity in direct viewing can be calculated.

SYMBOLS

C	contrast of Landolt ring with respect to background on slide, $\frac{I_b - I_o}{I_b}$, percent
C_a	actual contrast, contrast of Landolt ring with respect to background on monitor, percent
C_f	final contrast, contrast of Landolt ring with respect to background on monitor corrected for picture-tube contrast ratio, percent
d	distance of subject's eyes from visual scene, inches (meters)
f_{CF}	critical flicker frequency, hertz (1 hertz = 1 cps)
H	horizontal resolution, television line number
h	monitor screen height, inches (meters)
I_b	background luminance, foot-lamberts (candela/meter^2)
I_o	object luminance, Landolt ring luminance, foot-lamberts (candela/meter^2)
I_s	light-source luminance, foot-lamberts (candela/meter^2)
K	picture-tube contrast ratio

N	total number of discrete values of ϕ_m
R	vidicon response, percent of total response
T	slide transmissivity, percent of incident flux
T_b	transmissivity of background part of slide, percent of incident flux
T_o	transmissivity of Landolt ring part of slide, percent of incident flux
V	visual acuity, $1/\phi_m$, per arc minute
γ	gap width, angle subtended by Landolt ring gap, arc minutes
λ	probability of decay, per second
ρ	neutral density
σ	standard deviation of minimum visual angle, arc minutes
τ	time, microseconds
ϕ	visual angle, arc minutes
ϕ_m	average minimum visual angle, arc minutes
$\phi_{m,i}$	ith value of ϕ_m for $i = 1, 2, \ldots N$

EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 shows the experimental setup used in the television study. It consisted of test slides with a vision tester and a closed-circuit television system.

Test Slides

The test character chosen for measuring the visual acuity was the Landolt ring, a circle with a gap, the length of which equaled the boundary width of the circle. The gaps were randomly oriented at 45^o, 135^o, 225^o, and 315^o; the objective was to have the subject identify the gap orientation.

Arrays of these rings were arranged in "m" rows and "n" columns, producing matrices of Landolt rings. Each of the matrices was photographically reduced until the gaps subtended angles of 10.0, 7.5, 5.0, 3.5, 2.5, 2.0, and 1.5 arc min when viewed through the vision tester.

Slides, for which the transmissivity of the Landolt rings was less than that of the background, were made of these matrices. The printing of the rings was controlled so that they had a transmissivity relative to the background of the slide to provide the various contrast levels desired. Contrast levels of 99, 90, 82, 76, 69, 58, 49, 31, 24, and 14 percent were used. The contrast level was calculated from the following equations:

$$\rho = \log \frac{1}{T}$$

and

$$\frac{T_b - T_o}{T_b} = \frac{I_s\left(T_b - T_o\right)}{I_s T_b} = \frac{I_b - I_o}{I_b} = C$$

The neutral density was measured with a densitometer. Figure 2 shows a set of slides of the various Landolt rings for one contrast level. The slides were mounted in a commercial vision tester (fig. 3).

Television Equipment

The slides in the vision tester were viewed by a television camera with a 1.4 f-number and a 25-mm-focal-length lens. The lens occupied the same position that a subject's eyes would occupy if the subject had been looking directly into the tester. The subject viewed the rings on a television monitor with a horizontal resolution of 800 lines and with 675 scanning lines. The subject's eyes were positioned 2 ft (0.61 m) from the monitor in order for the subtended angles to have the values stated previously. (Additional specifications for the television monitor are given in table I.)

Study Procedure

Five subjects having normal vision participated in the study, which was conducted in a light-proof room. Each subject, in turn, was seated before the television monitor and given sufficient time to adapt to the background luminance on the monitor. The eight constant background luminances used were 150 (514), 120 (411), 94.5 (324), 75.0 (257), 60.0 (206), 48.0 (164), 28.5 (97.6), and 15.0 (51.4) ft-L (cd/m^2), the last seven being produced by placing neutral-density filters of 0.1, 0.2, 0.3, 0.4, 0.5, 0.7, and 1.0, respectively, over the monitor screen. For each constant background luminance, the sets of slides were presented to the subject in the order of decreasing contrast value.

RESULTS AND DISCUSSION

The minimum visual angle ϕ_m is defined in this study as the smallest angle for which at least 49 percent of the subject's answers were correct. In figure 4 the average of the minimum visual angles of the five subjects was plotted against contrast for a constant background luminance. Several results were seen in this plot. As the contrast increased, the minimum visual angle decreased. As the background luminance increased, the minimum visual angle decreased. For the highest contrast level, $C = 99$ percent, and the highest background luminance, $I_b = 150$ ft-L (514 cd/m^2), $\phi_m = 1.5$ arc min. This value suggested that the maximum resolution of the CCTV system at the fixed 2-ft (0.61-m) viewing distance was 1.5 arc min; this assumption was correct.

Also, for the lowest contrast level, $C = 14$ percent, a background-luminance change ΔI_b of 135 ft-L (462 cd/m^2) caused a variance of the minimum-visual-angle $\Delta\phi_m$ of 1.70 arc min. However, for $C = 65$ to 99 percent and this same $\Delta I_b = 135$ ft-L (462 cd/m^2), $\Delta\phi_m = 0.35$ arc min. This relative insensitivity of the minimum visual angle at $C = 65$ to 99 percent with $\Delta I_b = 135$ ft-L (462 cd/m^2) suggests that visual tasks in space operations would be feasible within this contrast-level and background-luminance region.

A further interpretation of the data was obtained from figure 5, where the logarithm of the visual acuity $\log V$ was plotted against the logarithm of the contrast $\log C$ for a constant background luminance. The solid lines represent the same data as in figure 4; and the dashed lines indicate the data of Shlaer (ref. 1) and of Hecht (ref. 2), both of whom also used Landolt rings. Shlaer's data, although taken with only two subjects, have been shown to be consistent with other investigators' findings. These data agree, in particular, with the efforts of Hecht (ref. 2) and of Jahn (refs. 3 and 4). Each of these three researchers showed that the visual acuity was a linear function of the contrast. In Shlaer's study an artificial pupil was used, whereas in the present study, it was not. Therefore, Shlaer's data are modified herein by employing Reeves' information (ref. 5) on pupil diameter as a function of light intensity. Three data points, each an average of the visual acuity in direct viewing for $I_b = 113$ ft-L (387 cd/m^2) of the five CCTV subjects, were plotted (fig. 5). These points suggested, within experimental error, that the average maximum visual acuity of the CCTV subjects was the same as that of the subjects in the earlier studies.

A comparison of the two sets of data in figure 5 for the high contrast levels showed that the minimum visual angle resolved in television viewing was 4 times larger than that resolved in direct viewing. For the low contrasts, the angle resolved with the television was only twice as large. Also, the visual acuity in the television viewing was more sensitive than that in the direct viewing to the background-luminance changes for all of the contrast levels. Therefore, the visual acuity in television viewing was not as good as that in direct viewing.

The greater differences between the data of the CCTV study and those of the direct-viewing studies were attributed to particular television characteristics, the most important being vidicon response and picture-tube contrast ratio. Less important television characteristics were limiting resolutions, signal-to-noise ratio, phase shift, flux distribution, and critical flicker frequency. Smaller differences were attributed to the subject and system variance.

Vidicon Response

The vidicon response R is defined as the capability of the tube's output signal to track an optical, square-wave input signal. Figure 6 is a characteristic plot, for the vidicon used in this study, of the vidicon response as a function of the required optical horizontal resolution H. For example, for the smallest Landolt ring, the gap width γ, the angle subtended by the gap, was equivalent to $H = 612$ lines; from figure 6, it was seen that the vidicon response to $H = 612$ lines was only 24 percent of that necessary to faithfully reproduce the change in luminance. For each gap width used, the required horizontal resolution was computed and the corresponding vidicon response was taken from figure 6. These values are listed in table II.

The contrast of the ring to the background of the slide was greater than the contrast of the gap to the ring. The contrast used in figure 5 was of the ring to the background, not of the gap to the ring. The difference between this contrast and the actual contrast C_a, the contrast on the monitor, accounted for most of the ordinate shift of the CCTV data from Shlaer's (ref. 1) and Hecht's (ref. 2) direct-viewing data (fig. 5). For an example of this shift, the ring for which $\gamma = 2.5$ arc min, which corresponds to $\log V = -0.398$, was studied. For the CCTV data (fig. 5, solid line), for this $\log V = -0.398$, and for $I_b = 150$ ft-L (514 cd/m^2), $\log C = -0.390$ ($C = 41$ percent). From table II, for $\gamma = 2.5$ arc min, $R = 49$ percent. Therefore, from the equation

$$\log C_a = \log C + \log R$$

the logarithm of the actual contrast $\log C_a$ was -0.699; that is, $C_a \approx 20$ percent. For the direct-viewing data (fig. 5, dashed line), for this same $\log V$ and I_b, $\log C = -0.765$ ($C = 17$ percent). This corresponds favorably to $C_a \approx 20$ percent, as predicted previously by employing the vidicon-response data. By applying the vidicon-response data to the CCTV data in this manner, a curve was obtained more like that found by Shlaer (ref. 1) and Hecht (ref. 2) for direct viewing. (See fig. 7.)

Ordinarily, it is not possible to add the logarithm of the contrast to the logarithm of the vidicon response. In the calculation of the contrast, the difference of the maximum and minimum luminances is normalized with respect to the maximum; and therefore, a normalized vidicon response must be added. In this particular study, the normalized response was identical to the true response because only two levels of luminance were on the monitor face, and most of this luminance was at the higher level. Therefore, in this study, the logarithm of the contrast could be added directly to the logarithm of the vidicon response.

Picture-Tube Contrast Ratio

The CCTV data adjusted for vidicon response could not be expected to exactly fit the direct-viewing data. (See fig. 7.) Besides the vidicon response, the picture-tube contrast ratio was also considered to have significantly affected the CCTV data. When light-level measurements of a half-black and half-white scene on a monitor face are taken, the black section is not entirely black but has a small finite luminance. For example, for such a hypothetical scene on the monitor, in the white section $I_s = 150$ ft-L (514 cd/m^2) and for the black section $I_s = 5$ ft-L (17.13 cd/m^2). The picture-tube contrast ratio in this example is the larger luminance divided by the smaller luminance, or 150/5 = 30. Two of the factors causing the black section to have this finite luminance are ambient light within the area of the television monitor falling onto the black section, and the light from the white section which is reflected from the protective glass onto the black section.

In the CCTV study, the black Landolt rings were not entirely black. Hence, the computed actual contrasts C_a of the black rings with respect to the white background on the monitor did not equal the true contrasts. A correction for the difference between the actual and the true contrasts was made by using the contrast ratio K of the system, which was 39.3. For each background-luminance level, a correction factor was obtained by dividing the background luminance by $K = 39.3$. For example, for $I_b = 150$ ft-L (514 cd/m^2), the correction factor was 150 ft-L/39.3 = 3.8 ft-L (514 cd/m^2/39.3 = 13.1 cd/m^2). Also for each background-luminance level, the luminances of the rings were computed from the actual-contrast values. (See fig. 7.) Then the correction factors were added to the respective ring luminances to give the actual luminances of the Landolt rings, that is, the luminances that appeared on the monitor. These actual luminances were then used with the corresponding background luminances to calculate the final contrasts C_f. The results of this correction are shown in figure 8.

The corrected CCTV data now almost match the direct-viewing data. (See fig. 8.) Except for minor effects from the remaining television-degradation factors, a subject's visual acuity when using this CCTV system can now be predicted from his direct-viewing data. In fact, this prediction would be possible when using any television system, given certain parameters. Before outlining this technique, however, the minor television-degradation factors will be discussed.

Minor Television Degradation Factors

Television limiting resolutions.- Two types of limiting resolution exist: One applies to vertical resolution; the other, to horizontal resolution. The smaller of the two is the limit of the system in question. As stated earlier, the CCTV system had a horizontal resolution of 800 lines and had 675 scanning lines. Hence, the vertical resolution was the limit of the system.

Of the 675 scanning lines, only 600 were available after blanking and synchronization. From studying a quality rectangle (a quadrangle centered on the monitor face and in which the scene had no recognizable distortion), the width of a single scan line was determined. At the 2-ft (0.61-m) viewing distance from the monitor, this line width subtended an angle of 1.5 arc min. Also at 2 ft (0.61 m) from the monitor, the smallest Landolt ring gap subtended an angle of 1.5 arc min. Since the angle subtended by the smallest Landolt ring gap was not larger than that subtended by the scan-line width, some of the gap information could possibly have been lost.

The horizontal resolution is dependent on the bandwidth response. The bandwidth was defined in reference 6 as "the portion of the frequency spectrum required to transmit the camera tube electrical signals that represent the optical image." The bandwidth response was then defined as the system's capability to reproduce the optical image. Only the bandwidth upper limit will be discussed. Bandwidth response becomes an important factor in the upper limit when the element of information is very small horizontally. The bandwidth response was analyzed for the CCTV system by using the method set forth in reference 6. The smallest Landolt ring gap was 0.017 inch (0.043 cm) for the CCTV system. This dimension was determined by dividing the minimum scan-line width of 0.012 inch (0.305 cm) by 0.707 (the Landolt ring gaps were oriented at 45° to the horizontal). Each scan line required 55 μsec with 45.21 μsec remaining for information presentation after blanking and synchronization. For the 9.8-inch (24.9-cm) monitor-tube width, the time required to present one gap was

$$\tau = 45.21\ \mu\text{sec}\ \frac{0.017}{9.80} = 0.0782\ \mu\text{sec}$$

This time corresponds to a bandwidth of 12.7 MHz, whereas the television had a bandwidth of 12.0 MHz. This borderline operation of the CCTV system caused some of the minor television degradation factors – the signal-to-noise ratio, flux distribution, and critical flicker frequency – to increase somewhat in significance.

Signal-to-noise ratio.- The signal-to-noise ratio is the magnitude of the signal normalized with respect to the base noise. At either the high or the low contrasts, the noise level might have been sufficient to mask the signal.

Phase shift.- The phase shift within the information signal is noticed in the black-to-white or white-to-black transitions. Filtering causes the constituents of the signal to become slightly out of phase. Hence, the response of the monitor was not a single pulse, but a series of temporally phased signals corresponding to the phase-shifted constituents. This response would have prevented exact resolution in the monitor, even if it would have otherwise been performing perfectly.

This resolution problem may be analyzed with Fourier integrals, as in reference 7. The analysis enables examination of the basic signal over a measured time period to determine the various frequencies composing the signal. The transform yields the amplitudes of the individual frequencies composing the signal.

Flux distribution.- The flux distribution within the electron beam impinging on the monitor face, especially since coupled with high-bandwidth requirements, further degraded the CCTV picture. In the CCTV system, the monitor's scanning spot had radial symmetry. From observation of the CCTV system's reproductions of the Landolt rings, the flux is seen to be considerably more dense at the center of the spot than at its edge. In chapter 5 of reference 7, it is indicated that the flux distribution is a problem in all television systems. It may be eliminated, for the most part, by a 50-percent overlap of the scanning lines to yield what is called a flat field.

Critical flicker frequency.- The critical flicker frequency f_{CF} is that frequency of a flashing light at which a subject first perceives that the light is flashing and not steady. Since the CCTV subjects were adapted to a particular background luminance and ring-gap luminance, they experienced sensations of the smaller ring gaps dancing about on the monitor. To understand this phenomenon, from figure 5 for $C \leqq 70$ percent ($\log C \geqq -0.1549$), it can be determined that the slope of the curve did not depend on the contrast but on the size of the ring gaps, which are related to the visual acuity when $\phi_m = \gamma$. The smallest Landolt rings used had gap widths of 2.5, 2.0, and 1.5 arc min, which correspond to $\log V = -0.40$, -0.30, and -0.18, respectively. In figure 5, the slope changed in the neighborhood of $\log V = -0.20$ to -0.31. For a visual angle $\phi = \gamma$ less than 2 arc min, the actual gap occupied only one scan line; for $\phi = \gamma$ greater than 2 arc min, the gap occupied two or more scan lines. This difference introduced the problem of critical flicker frequency because of the 2:1 interlace scan pattern of the television. If the gap occupied only one scan line, it occurred 30 times a second. However, for $I_b = 15$ to 150 ft-L (51.4 to 514 cd/m^2), $f_{CF} = 49$ Hz. Hence, for any gap occupying only one scan line, its frequency was 19 Hz less than the minimum required. Therefore, the subject perceived a dancing sensation of any particular element on which he concentrated.

The Landolt ring gaps that occupied only one scan line and for which the problem of critical flicker frequency occurred, were those for which $\gamma = 2.0$ and 1.5 arc min. In figure 5 the region of the data curve following the change in the slope was approximated by the percent of correct answers.

To closely inspect the region of the curve following the change in the slope and, thus, the problem of critical flicker frequency, very small step differences between gap sizes would have to be used. Measuring the effect of the critical flicker frequency and quantitatively applying the results to modify the data of figure 7 would in itself merit an independent investigation.

Subject and System Variance

In addition to the major and minor television-degradation factors already discussed, the subject and system variance also affected the CCTV data. As noted earlier, subjects whose average visual acuity in direct viewing was the same as that of the subjects in references 1 and 2 were chosen for the CCTV study. Also, throughout this investigation the entire system was continuously calibrated to maximize uniform operation. However, some subject and system variance still existed; its magnitude was apparent in the calculation of the standard deviations of the minimum visual angles. The standard deviation of the minimum visual angle was defined by

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \left(\phi_m - \phi_{m,i}\right)^2}$$

The standard deviations of the minimum visual angles as a function of the contrast values are given in table III. Except at the very high contrasts, as the contrast decreased, the standard deviation increased. A significant difference in data did occur at the small actual contrasts. (See fig. 7.)

METHOD OF TRANSFORMING VISUAL-ACUITY VALUES FROM TELEVISION-VIEWING DATA TO DIRECT-VIEWING DATA

The following is a condensation of the technique developed in this study to transform the visual-acuity values from television-viewing data to direct-viewing data.

(1) The contrast of the scene being viewed by the television camera was determined by

$$C = \frac{I_b - I_o}{I_b}$$

(2) The horizontal resolution of the monitor required to produce a particular minimum visual angle was determined by

$$H = \frac{h}{d \tan \phi_m}$$

(3) Corresponding to the horizontal resolution, the response of the particular vidicon used was determined from figure 6, a characteristic plot of the tube.

(4) The actual contrast was then determined by

$$C_a = RC$$

(5) The picture-tube contrast ratio is fixed for a particular television system. The luminance increase of a black section (Landolt ring) due to the brighter sections of the television scene was determined by

$$\Delta I_o = \frac{I_b}{K}$$

(6) The final contrast of the scene presented on the television monitor was expressed as

$$C_f = \frac{R\left(I_b - I_o\right) - \Delta I_o}{I_b} = C_a - \frac{\Delta I_o}{I_b}$$

PHOSPHOR DECAY

For a study involving moving objects, an analysis of phosphor decay must be included. The following discussion is in connection with the CCTV system used in this study.

The frame rate for the CCTV system was 30 Hz; therefore, any given element of the monitor face experienced an impingement every 33.3 msec. For the type of phosphor used, P4, the persistence was 36 msec; that is, in 36 msec, the phosphor emission level was reduced to 1 percent of its initial value. Hence, every 33.3 msec a particular electron's emission level was reduced to 1.4 percent of its value at the beginning of the decay cycle. Since the luminance is proportional to the excited elements, it is determined by the exponential-decay law:

$$I(t) = I(0)e^{-\lambda t}$$

where

$I(t)$	luminance as a function of time, ft-L (cd/m^2)

t	time, sec
λ	probability of decay, per sec

For the phosphor used in this study, $\lambda = 0.128$ msec^{-1}. The decay law is dependent on the type of phosphor used (ref. 7); however, for the initial part of the decay, the exponential form gives very reasonable results.

When a subject views a television scene, he may or may not scrutinize any particular part. How he views a scene depends on his task. If he is trying to detect a single point source of light, he may rapidly scan the scene, concentrating upon only a small part at any one time. If his task is general surveillance, he may scan and mentally integrate the entire scene simultaneously. For detection, he might want a slowly decaying phosphor so that the image would not be lost to the scene within one scan cycle. For surveillance, he might want a quickly decaying phosphor in order to prevent smearing, especially when a moving object is used. A short analysis of the time average of the luminance will show that for scan frequencies of or greater than the order of the critical flicker frequency, the eye actually integrates the luminance over the period of a single scan cycle. This is true for one scan line or a number of scan lines.

If exponential decay is assumed, two factors must be determined: How much luminance from the monitor is desired and how much smear can be accepted. In terms of the phosphor decay, these two factors correspond to the object luminance and to the probability of decay, respectively. The object luminance can be determined from the flux density of the impinging beam and from the atomic structure of the phosphor. From the probability of decay, the amount of smear in the dynamic situation, and also the time average of the luminance can be determined. Texts dealing with atomic structure will provide information for the determination of the object luminance and the probability of decay.

CONCLUSIONS

A study was conducted to establish a relationship between the visual acuity in viewing scaled objects on television monitors with that in direct viewing.

1. As was expected, the visual acuity in television viewing was not as good as that in direct viewing.

2. The vidicon response and the picture-tube contrast ratio of the subject television were the major degradation factors of those considered.

3. By using the vidicon response and the picture-tube contrast ratio, a method was developed for transforming the visual-acuity values from television-viewing data to direct-viewing data.

4. The critical flicker frequency affected the visual acuity at the high-contrast levels. This should be further investigated.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., September 24, 1969.

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TABLE I.- SPECIFICATIONS OF THE CLOSED-CIRCUIT TELEVISION SYSTEM

[Given by manufacturer]

Input:	
Voltage, V	100 to 130
Type of current	ac
Frequency, Hz	50 to 60
Power, W	185
Output impedance, Ω	75
Horizontal resolution, lines	800 or more
Signal-to-noise ratio	40:1 or higher
Scanning lines	675
Interlace ratio	2:1
Field rate, Hz	0.60
Automatic light-compensation ratio	6000:1
System bandwidth, MHz	12
Tolerable ambient noise level, dB	Up to 160
Camera:	
Dimensions, in. (cm)	4.5 × 10 × 6.56 (11.43 × 25.4 × 16.66)
Weight (mass), lb (kg)	9 (4.08)
Control unit:	
Dimensions, in. (cm)	17.37 × 5 × 19.62 (44.12 × 12.70 × 49.83)
Weight (mass), lb (kg)	4 (1.81)

TABLE II.- VIDICON RESPONSE CORRESPONDING TO GAP WIDTH

Gap width, γ, arc min	Required horizontal resolution, H, TV line number	Vidicon response, R, percent of total response
1.5	612.0	24
2.0	460.1	38
2.5	368.6	49
3.5	262.6	67
5.0	183.7	83
7.5	122.4	92
10.0	91.8	96

TABLE III.- STANDARD DEVIATIONS OF THE MINIMUM VISUAL ANGLES

C, percent	Log C	ϕ_m, arc min	σ, arc min
99	-0.0044	1.61	±0.200
90	-.0458	1.81	±.187
82	-.0862	1.83	±.150
76	-.1192	1.90	±.162
69	-.1612	1.97	±.200
58	-.2366	2.28	±.260
49	-.3098	2.76	±.384
31	-.5086	4.68	±.818
24	-.6198	6.48	±.885
14	-.8539	6.56	±.985

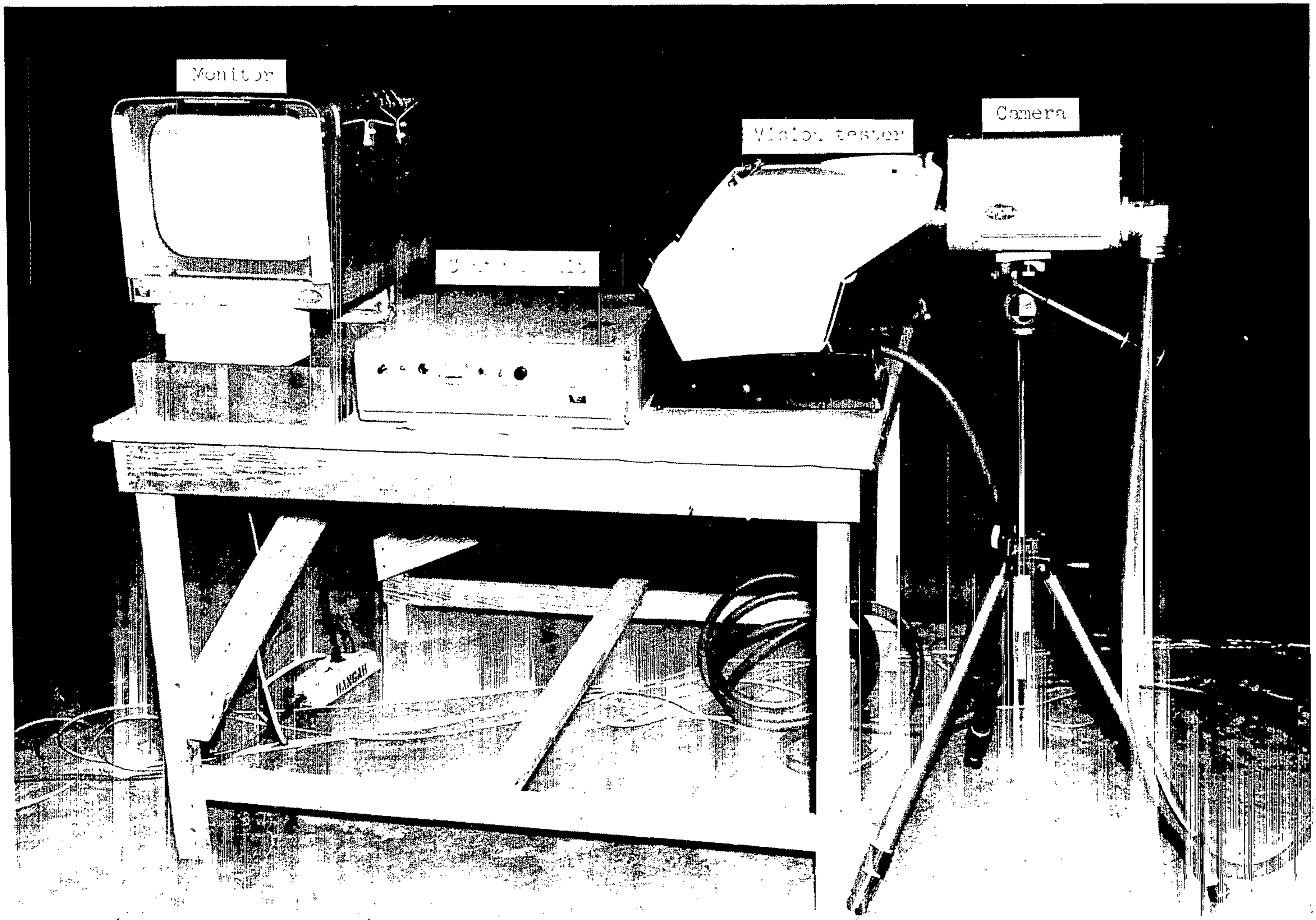

Figure 1.- Experimental setup.

L-66-7697.1

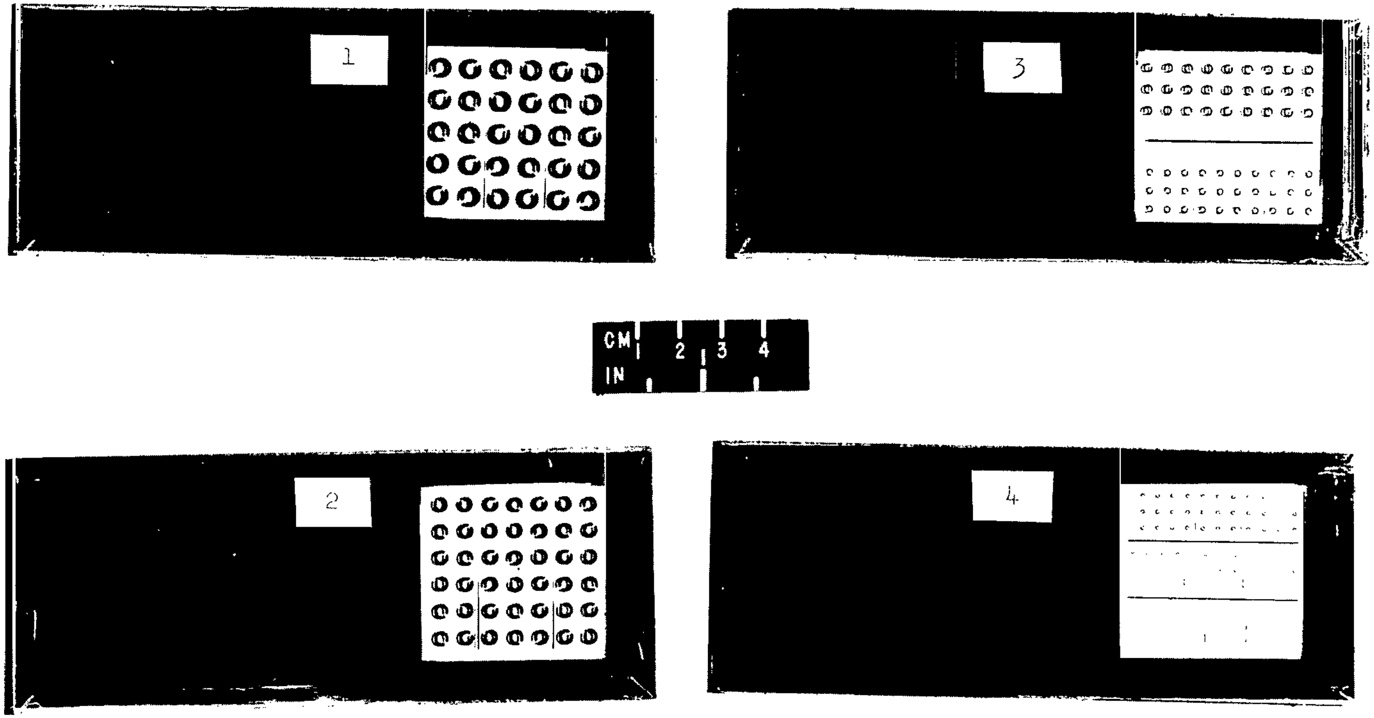

Figure 2.- Set of slides of the various Landolt rings for one contrast level. Transmissivity level, 99 percent. L-66-7599.1

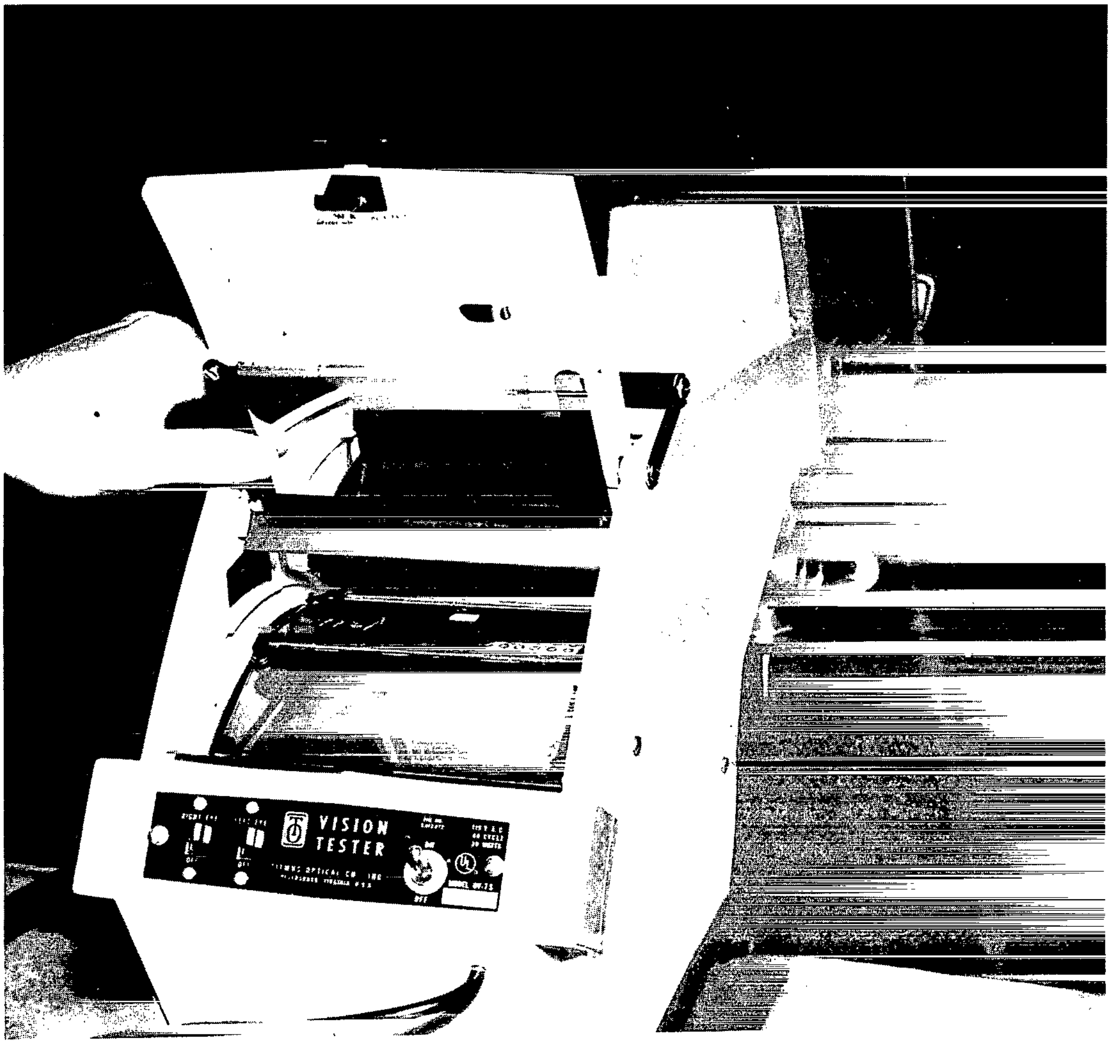

Figure 3.- Slide of Landolt rings mounted in vision tester.

L-66-7598

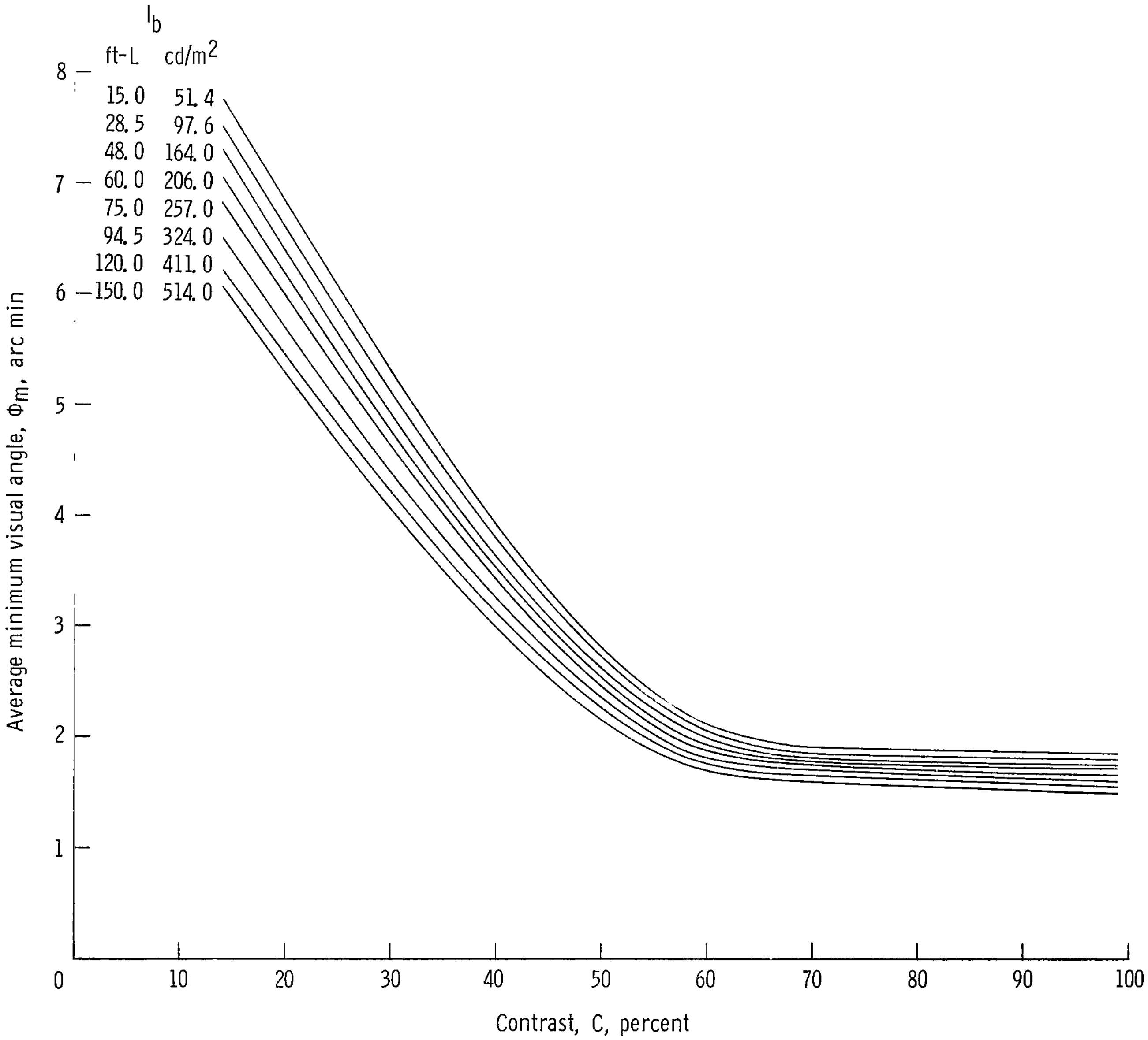

Figure 4.- Average minimum visual angle of subjects viewing CCTV.

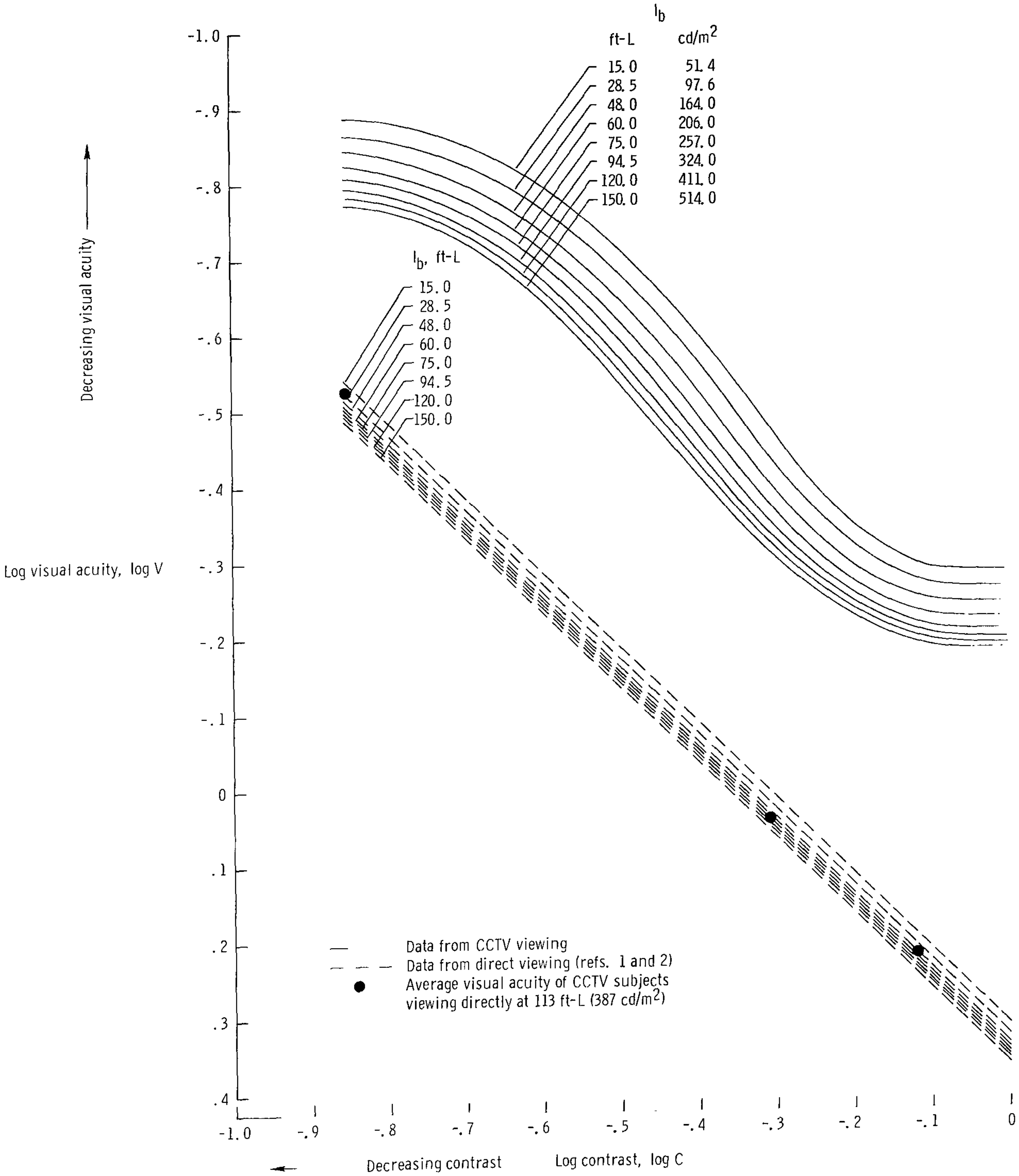

Figure 5.- Average maximum visual acuity of subjects.

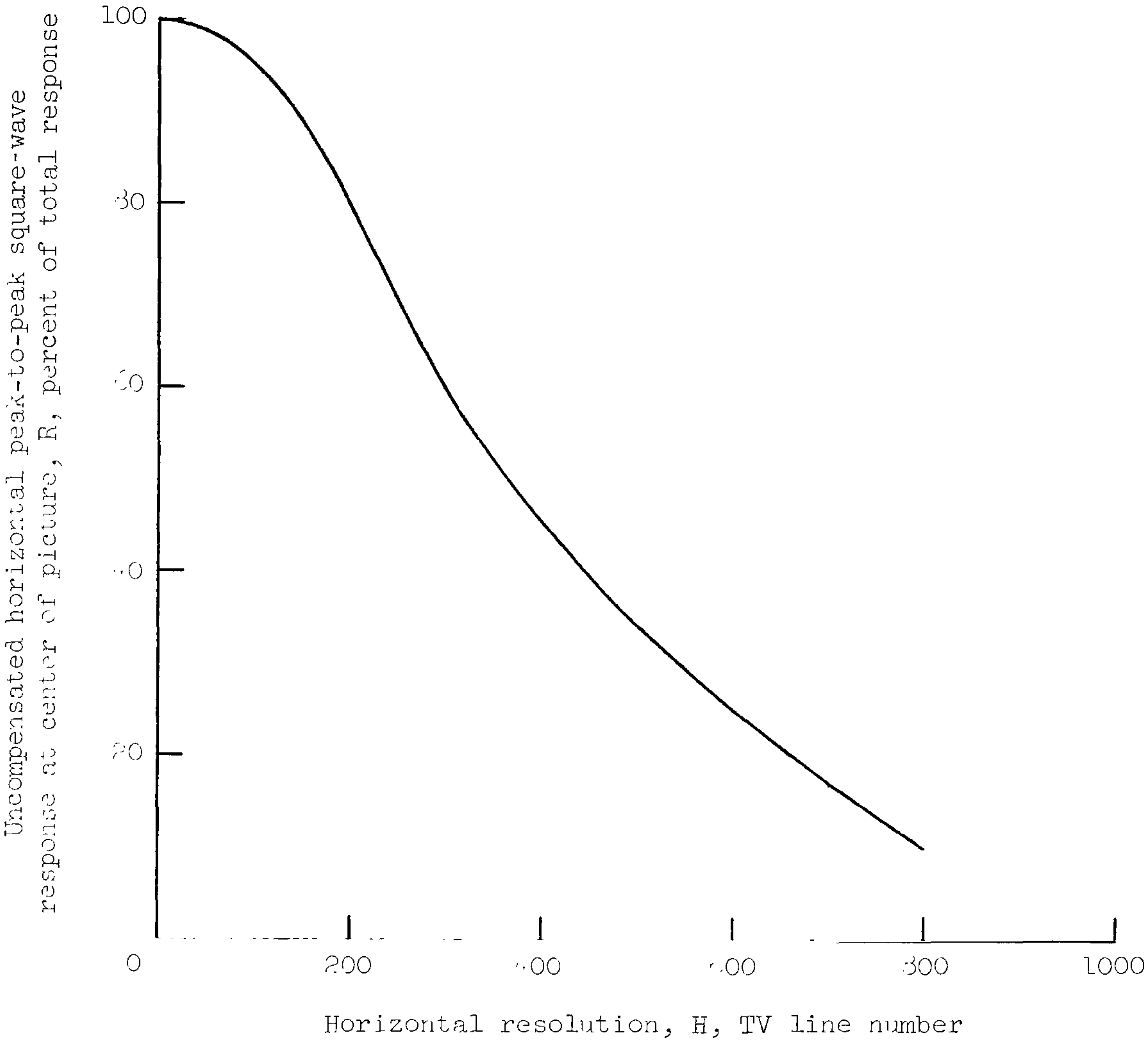

Figure 6.- Vidicon response as a function of horizontal resolution.

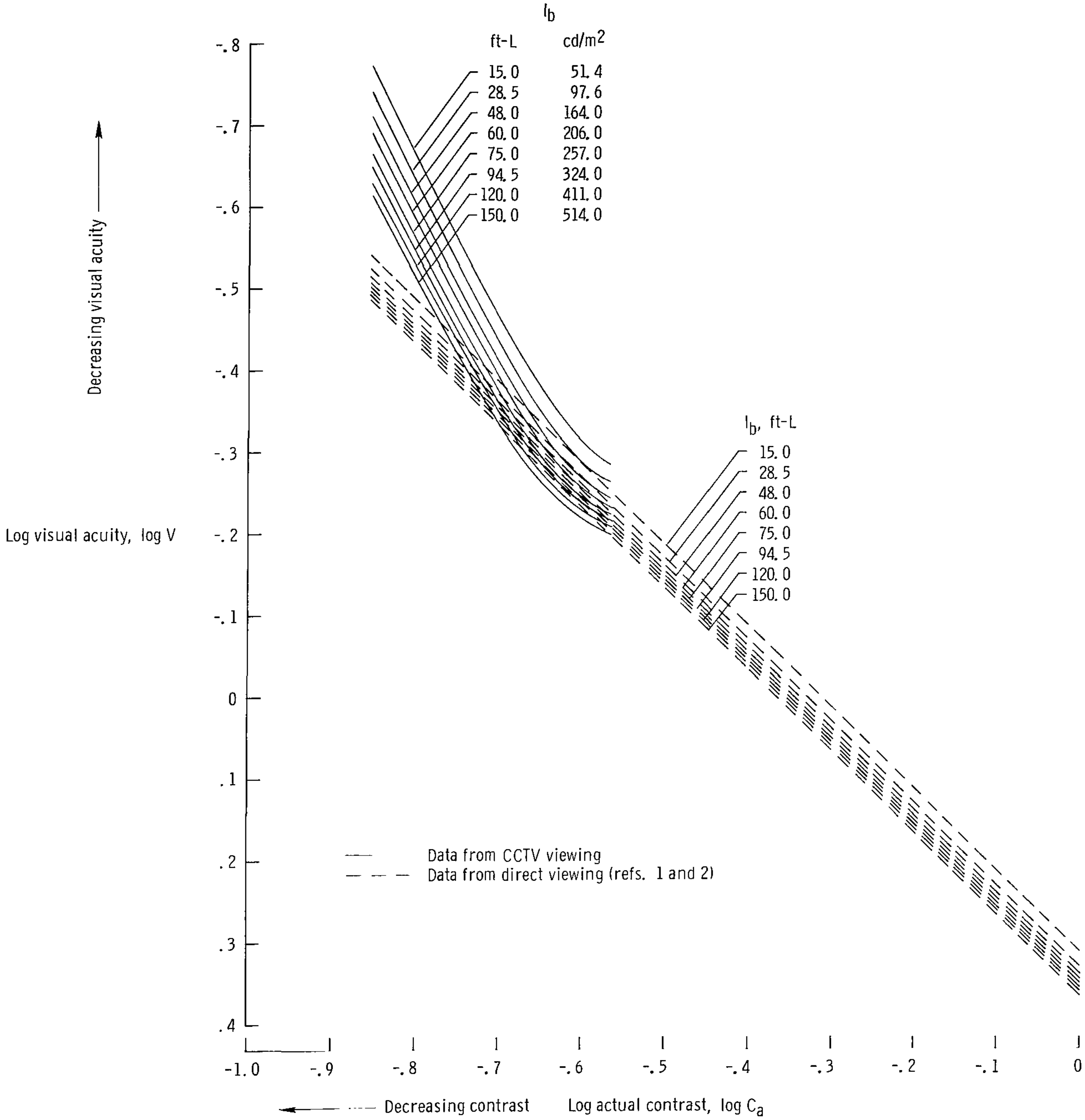

Figure 7.- Average maximum visual acuity of subjects, corrected for vidicon response.

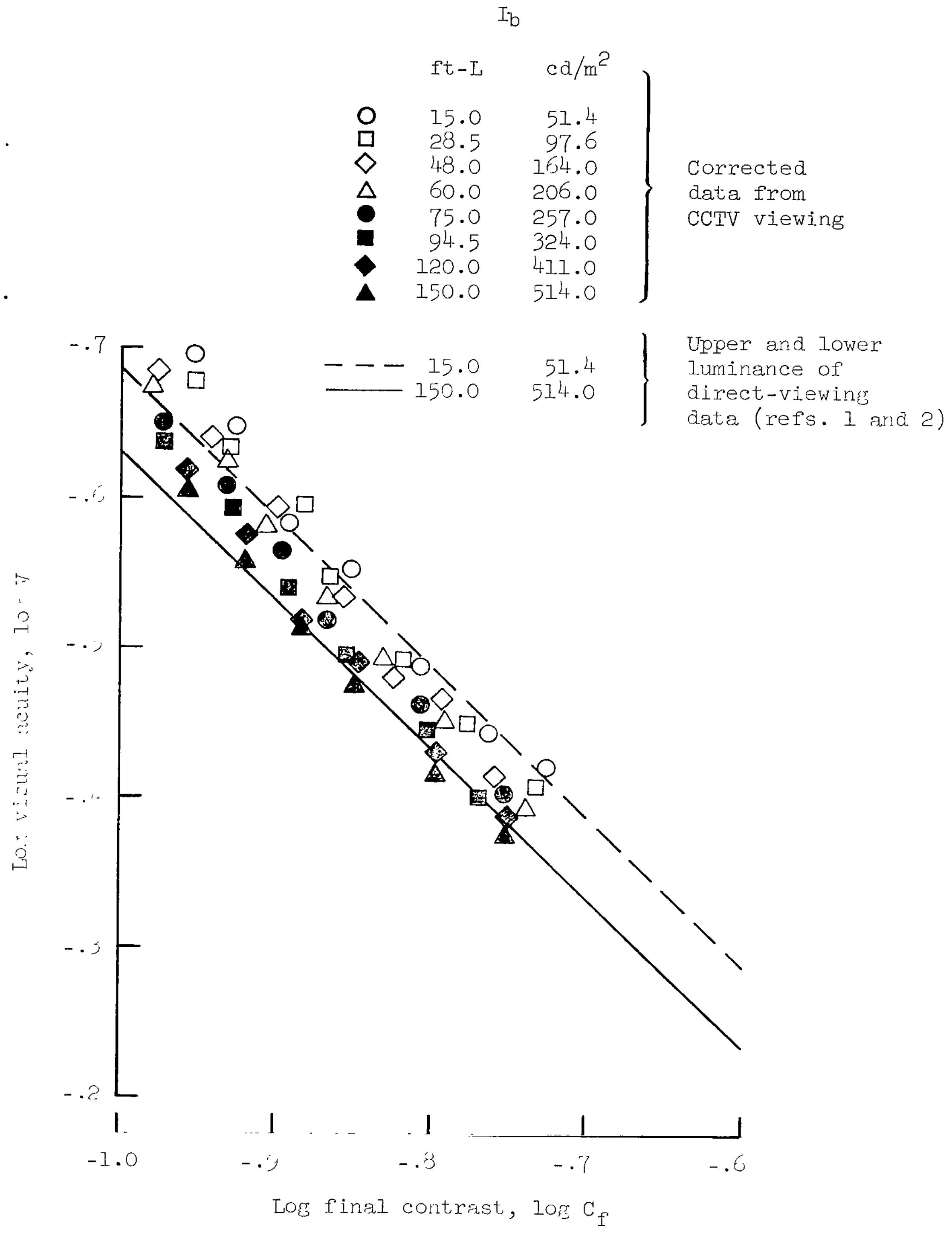

Figure 8.- Average maximum visual acuity of subjects, corrected for vidicon response and picture-tube contrast ratio.

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