

SUBJECTIVE BRIGHTNESS DURING DARK-ADAPTATION

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(Received 2 April 1962)

Abstract—The course of dark-adaptation was studied with threshold measurements and with measures of the luminance required to maintain a constant supraliminal brightness. A stimulus in the light-adapted right eye was matched in brightness to a stimulus presented to the left eye, which was dark-adapted. Two different methods were used and several levels were tested. The usual transition from cone to rod function observed in threshold measurements is also observed in curves of constant subjective brightness, provided the brightness is of the order of 1 bril, or a luminance in the dark-adapted eye of 40 dB (1.0 μ L).

The brightness function (operating characteristic) produced by light-adaptation plus recovery does not correspond identically to the characteristic produced by adaptation to a lower luminance, although the characteristic curves may be rather similar when only cone vision is involved.

Résumé—Le progrès de l'adaptation à l'obscurité a été étudié par des mesures de seuil et par des mesures de la luminance nécessaire pour maintenir une luminosité supraliminale constante. Un stimulus présenté à l'œil droit adapté à la lumière était égalisé en luminosité à un stimulus présenté à l'œil gauche qui restait adapté à l'obscurité. On a employé deux méthodes différentes et divers niveaux. Le point de transition de la vision des cônes à celle des bâtonnets que l'on constate d'habitude dans les mesures de seuil se retrouve aussi dans les courbes de luminosité subjective constante, pourvu que la luminosité soit de l'ordre de 1 bril, ou la luminance, dans l'œil adapté à l'obscurité, de 40 dB (1.0 μ L).

La fonction de luminosité (caractéristique opérationnelle) produite par l'adaptation à la lumière suivie de récupération ne correspond pas exactement à celle que produit l'adaptation à une luminance plus faible, quoique les courbes caractéristiques puissent être assez analogues quand la vision des cônes est seule en jeu.

Zusammenfassung—Der Verlauf der Dunkeladaptation wurde anhand von Schwellenmessungen und von Messungen der Leuchtdichte, die für eine konstante überschwellige Helligkeit notwendig ist, studiert. Ein Reiz im helladaptierten rechten Auge wurde bezüglich seiner Helligkeit mit einem Reiz, der dem linken dunkeladaptierten Auge geboten wurde, verglichen. Zwei verschiedene Methoden wurden benutzt und verschiedene Niveaus wurden untersucht. Das gewöhnliche Verhältnis zwischen den Funktionen für die Stäbchen und die Zapfen, das bei Schwellenmessungen beobachtet wird, tritt ebenfalls bei den Kurven konstanter subjektiver Helligkeit in Erscheinung, vorausgesetzt, dass die Helligkeit von der Grössenordnung 1 bril ist oder dass die Leuchtdichte für das dunkeladaptierte Auge etwa 1.0L beträgt.

Die Helligkeitsfunktion, die von der Helladaptation und der Erholung herrührt, entspricht nicht identisch jener Charakteristik, die von der Adaptation auf ein niedrigeres Leuchtdichtenniveau gewonnen wird, obgleich die charakteristischen Kurven sehr ähnlich zu sein scheinen, wenn nur das Zapfensehen in Betracht gezogen wird.

INTRODUCTION

THE course of dark-adaptation has been most often traced by means of threshold measurements. At supraliminal levels, the effects of light-adaptation have been studied by interocular comparison of the brightness seen in a light-adapted and a dark-adapted eye immediately after switching off the adapting field (STEVENS and STEVENS, 1960a; ONLEY, 1961). The purpose of the present work was to extend the interocular procedure to the determination of the subjective brightnesses of supraliminal stimuli as a function of the time following a given level of light adaptation.

¹ On leave with a NATO Science Fellowship from the Institute for Perception RVO-TNO, Kampweg 5, Soesterberg, The Netherlands. Supported in part by National Science Foundation Grant G-10716 and in part by the National Institutes of Health Grant B-2974 (PAR-269).

PROCEDURE

Interocular brightness-matching was used to trace the change in subjective brightness that takes place during dark-adaptation. The observer's left eye was dark-adapted and his right eye was light-adapted before each session. Under these circumstances a given luminance will appear less bright in the right eye than in the left eye, and in order to produce equal subjective brightnesses in the two eyes we must present a more intense stimulus to the right eye than to the left eye. The required difference in luminance decreases as the right eye becomes dark-adapted and reaches zero when both eyes have become equally adapted.

Once every 8 sec, two stimuli, 0.5 sec in duration and 6.5° in visual angle, were presented simultaneously to the observer, one in the light-adapted right eye, and the other in the dark-adapted eye.

In one series of experiments the luminance of the stimulus in the dark-adapted left eye was kept constant during a session. The luminance of the stimulus in the right eye was adjusted so that the observer saw a brighter stimulus in the left eye than in the right eye immediately after the adapting field was switched off. As the dark-adaptation of the right eye continued, the subjective brightness in this eye increased. The observer signalled which of the two stimuli, left or right, was brighter by pressing one of two switches. As soon as the stimulus in the right eye appeared brighter, the luminance of this stimulus was decreased by an amount sufficient to make the left-eye stimulus appear brighter again. This process was repeated according to a programme based on the results of preliminary experiments. The times at which the various luminances in the right eye appeared to match the constant luminance in the left eye were measured. In other words, a constant-subjective-brightness method was used to trace the course of dark-adaptation.

The foregoing experiments were complemented by another series in which the luminance of the right-eye stimulus rather than the left-eye stimulus was kept constant. During the course of dark-adaptation the subjective brightness of the constant right-eye stimulus increases. The luminance of the left-eye stimulus was increased as soon as the right-eye stimulus appeared brighter than the left-eye stimulus, and the times were measured. The half-second test flashes were delivered every 8 sec as in the first series. The constant-luminance method provides an additional description of the course of dark-adaptation.

Summarized, the constant-brightness method gives the relation between time and luminance necessary for the maintenance of a fixed subjective brightness; the constant-luminance method gives the relation between time and subjective brightness for a stimulus with fixed luminance.

This second method gives results that can be plotted against a subjective scale rather than against the luminance in the dark-adapted eye, because the values of subjective brightness in brils are known for the dark-adapted eye (STEVENS and STEVENS, 1960b). A bril is defined as the brightness seen by a dark-adapted observer when he views a luminance of 40 decibels (dB). The relation between the luminance in a dark-adapted eye and the subjective brightness in brils is shown in Fig. 2 by the left- and right-hand scales.

APPARATUS

The apparatus was a modification of that used for interocular brightness-matching by STEVENS and STEVENS (1960a). It consisted of two 150-W sources which were simultaneously switched on for 0.5 sec at 8-sec intervals. Each lamp illuminated a translucent target whose effective angular diameter was 6.5° .

The luminances were varied by means of neutral filters and a variable aperture. The attenuations of filters and apertures were calibrated and the luminances were expressed in dB above a reference level of 10^{-10} L, which is close to the human threshold (STEVENS, 1955). Filters with transmissions of 10 per cent and 50 per cent have attenuations of 10 dB and 3 dB. The value of a nit (1 cd/m^2) corresponds to 65 dB.

The diameter of the adapting field was about 60° . For most of the experiments, the luminance of the adapting field was 106.5 dB. This corresponds to approximately 14,000 nits or 4500 mL. Adapting luminances of 100 dB and 90 dB were used in one series of measurements.

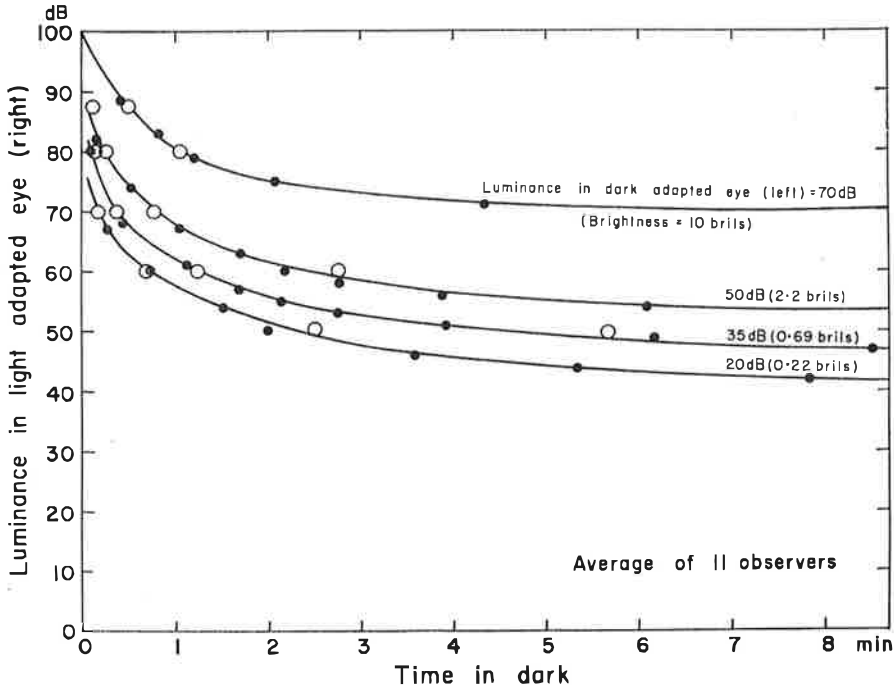


FIG. 1. Luminance in the light-adapted right eye necessary for a constant level of subjective brightness as a function of time in the dark. The fixed comparison stimulus was presented to the dark-adapted left eye. The filled points are averages for 11 observers. The unfilled points are derived from the curves in Fig. 2. Adaptation level = 106.5 dB for 2 min in right eye.

MEASUREMENTS

With constant subjective brightness of the stimulus in the left (dark-adapted) eye, the luminance needed to produce an equal brightness in the right (light-adapted) eye was determined as a function of time during the first 8 min of dark adaptation by 11 observers. The fixed luminances in the left eye were at one or another of the levels 20, 35, 50 or 70 dB. These levels correspond to subjective brightnesses of 0.22, 0.69, 2.2, and 10 brils. Before each session the observer's left eye was dark-adapted for about 25 min and the right eye exposed to the adapting luminance, 106.5 dB, for 2 min.

The results were averaged by calculating the geometric means of the times measured. Other methods of averaging, including the determination of the median values, gave results

that differed only slightly from the results of geometric averaging. The results of this first series of experiments are shown in Fig. 1.

The same 11 observers determined the luminance of the left-eye stimulus that was necessary to match the brightness of the stimulus in the (light-adapted) right eye. The luminance in the right eye was kept constant at one of the values 50, 60, 70, 80, or 87.5 dB. The results (geometric means) are shown in Fig. 2.

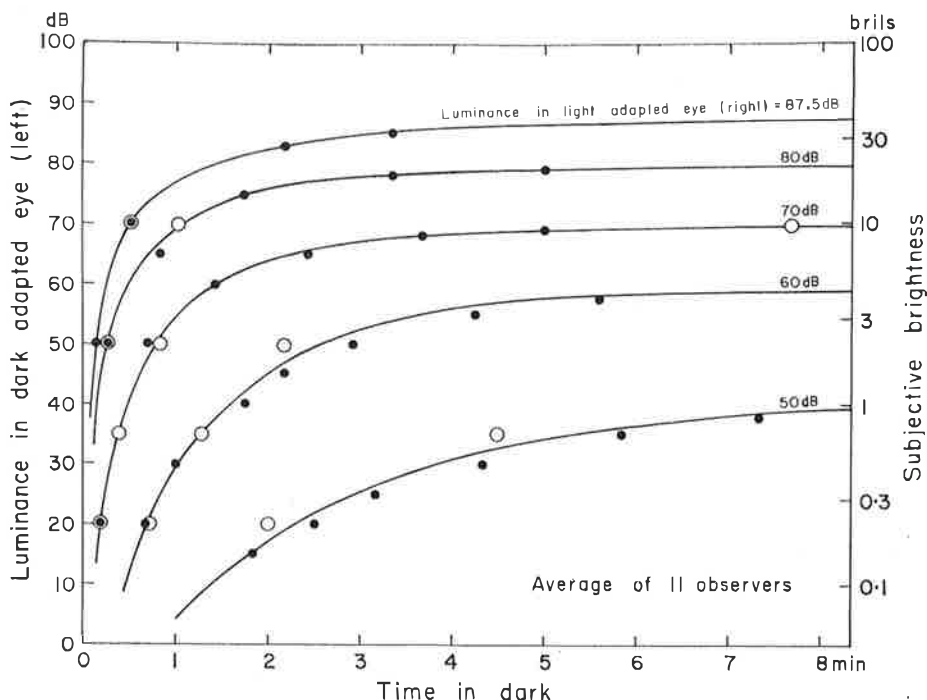


FIG. 2. Showing how the subjective brightness of different luminances grows in a light-adapted eye (right) as a function of time in the dark. The growth of brightness was tracked by matching to a variable stimulus in the dark-adapted left eye. The filled points are averages for 11 observers. The unfilled points are derived from the curves in Fig. 1. Adaptation level = 106.5 dB for 2 min in right eye.

Only the first 8 min of dark adaptation are shown by the curves of Figs. 1 and 2. Any difference between the filled and unfilled measuring points in connection with their location with respect to the curves in Figs. 1 and 2 must be caused by the fact that from the moment of switching off the adapting field the luminance conditions for the stimuli are different for the two methods (constant subjective brightness and constant luminance).

Because the two methods provide data which fit satisfactorily with the same curves, we may conclude that the presentation of the stimuli does not disturb dark-adaptation in the left eye and the process of dark-adaptation in the right eye.

In order to follow the dark-adaptation process over more of its time course, three observers, TA, SB, and JW, repeated the first experiments, but with longer durations. The "threshold" dark-adaptation curve was also measured. The threshold curve can be regarded as another constant-brightness function. In order to orient the observer during the threshold tests, a dim red point was placed 6° to the left of the centre of the target. The observers were

free, but not obliged to fixate this red point. The individual results for the longer measurements and their averages are given in Fig. 3.

The final experiment was designed to determine the influence of the brightness level of the adapting field. Observer TA repeated the observations shown in Fig. 3, but for levels of light-adaptation of 100 and 90 dB. The results are given in Fig. 4.

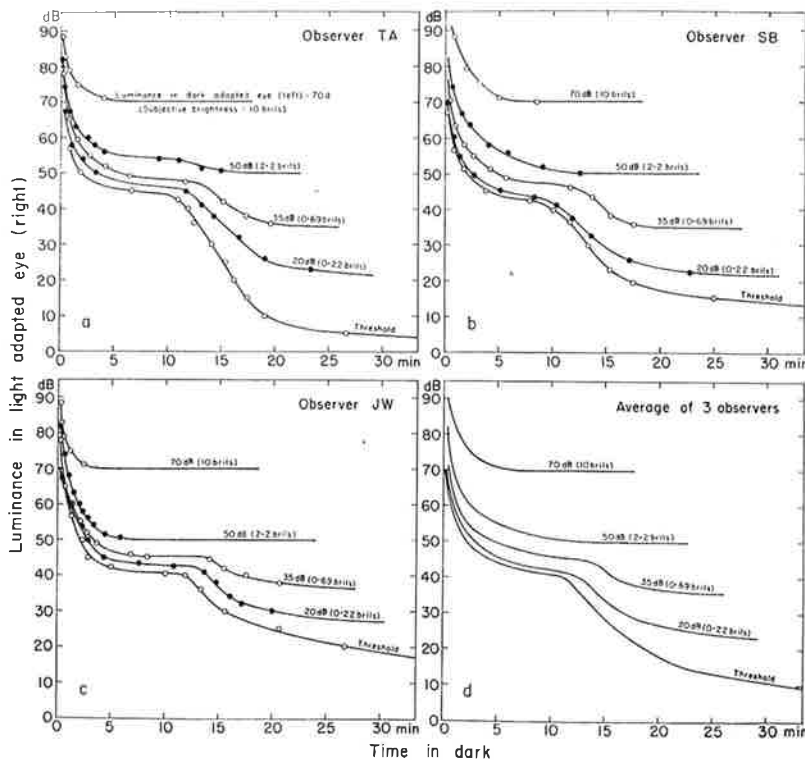


FIG. 3. The tracking of dark-adaptation by the constant-brightness method and the threshold method with three observers. At the end of about 10 min the threshold curve and the curves for the lower brightness levels plunge downward again. Adaptation level: 106.5 dB for 2 min in right eye.

DISCUSSION

A striking aspect of Figs. 3 and 4 is the appearance of two segments whenever the subjective brightness falls below a certain limit. This is the familiar form noted in threshold dark-adaptation curves, provided the adaptation level is sufficiently high to begin with (HECHT *et al.*, 1937). This dual feature of the curves is usually attributed to the change from cone function to rod function.

Evidently this transition occurs if the subjective brightness has a value such that the stimulus is observed with the rod system of a completely dark-adapted eye. The rod system is presumably in operation if the luminance in the dark-adapted eye is less than about 45 dB (0.01 cd/m²).

The influence of the initial level of adaptation is shown in Fig. 4. There we note that the cone-rod transition is present for an initial adaptation level of 100 dB, but almost absent for

an initial level of 90 dB. Again the threshold curves are in agreement with the results of HECHT *et al.* (1937).

The data in Fig. 3 can be plotted in a different way: luminance in light-adapted eye versus luminance in dark-adapted eye for equal subjective brightness, with time as the parameter. Such a plot is shown in Fig. 5. This plot also shows how the scale of subjective brightness—the “operating characteristic” (STEVENS, 1961)—changes as a function of time in the dark. It is interesting to compare these curves with those measured by STEVENS and STEVENS (1960a) as a function of the adaptation level (Fig. 6). (For a further description of these adaptation functions, see STEVENS, 1962.) The curves in Fig. 6 show subjective brightness as a function of luminance for different adaptation levels immediately after the adapting field is switched off.

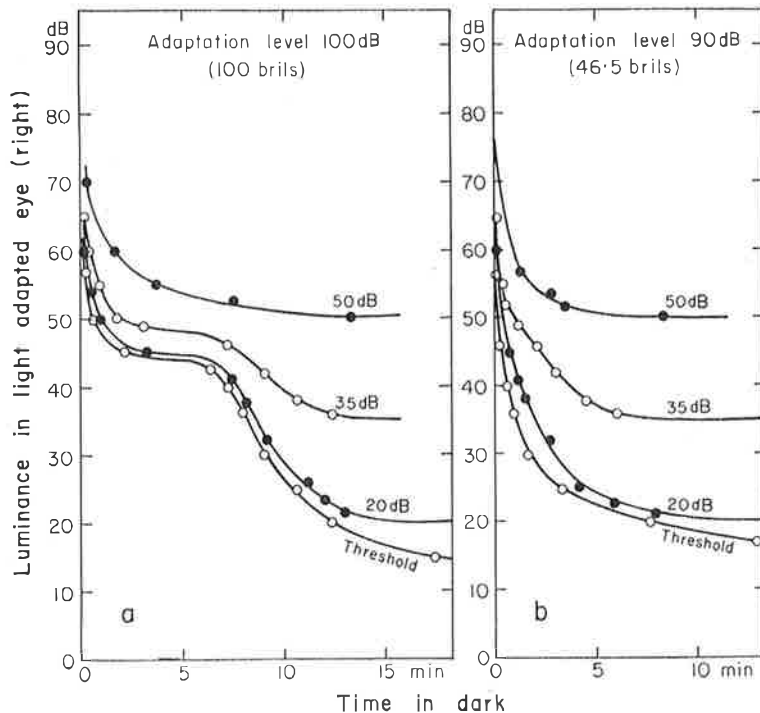


FIG. 4. The same as Fig. 3, but for observer TA, with adaptation levels of 100 dB and 90 dB for 2 min in right eye. At 90 dB the rod-cone transition is scarcely detectable.

Comparison of Figs. 5 and 6 throws light on an interesting question. Is the state of adaptation produced by a long exposure to a given luminance the same as the state produced by a higher luminance plus a period of time in the dark? The answer appears to be “no”. The eye that is partly recovered from an exposure to a bright field is not in the same state as an eye that has been adapted to a dimmer field. The difference is most striking when the recovery from exposure to the brighter field has proceeded to the point where rod function has begun to take control. There the brightness functions (Fig. 5) become markedly inflected. On the other hand, there is a fairly close agreement between Figs. 5 and 6 in the luminance range where cones are active. When, at other states of adaptation, the relation of subjective brightness to luminance differs from the relation that obtains under dark adaptation,

“recruitment” at higher luminance levels occurs in a comparable way. This suggests that there may be little difference at photopic levels between an eye partly recovered from a high-level exposure and an eye adapted to a lower level, so that, to some extent at least, time can be traded for level when the cones are involved. If there is a similarity of the luminance-brightness relation, at a certain time after exposure to a high level and immediately after exposure to a certain lower level, this does not mean that the two states of adaptation are equivalent. Generally the course of dark-adaptation during the time after this moment of similarity will be different in the two cases.

This difference, as well as the differences between the curves in Figs. 5 and 6 for low- and high-luminance levels, is probably due to the existence of two receptor systems.

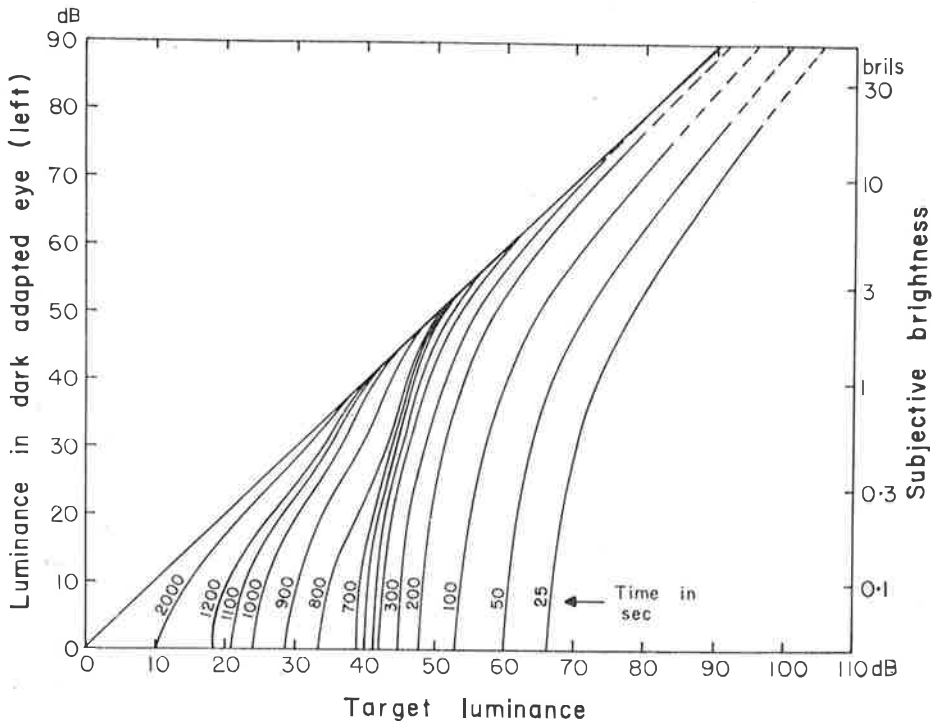


FIG. 5. Relation between luminance and subjective brightness after different periods of dark-adaptation. These brightness functions are derived from the average curves in Fig. 3. They show how an irregularity can be produced in the visual operating characteristic by means of a prior exposure to a bright light (106.5 dB for 2 min).

Acknowledgements—I want to express my gratitude to the Netherlands Organization for the Advancement of Pure Research (ZWO) for the assignment of a NATO Science Fellowship and for the hospitality of the Psycho-Acoustic Laboratory at Harvard University and for the help of Dr. S. S. STEVENS and other members of the staff. They aided these experiments with facilities and counsel.

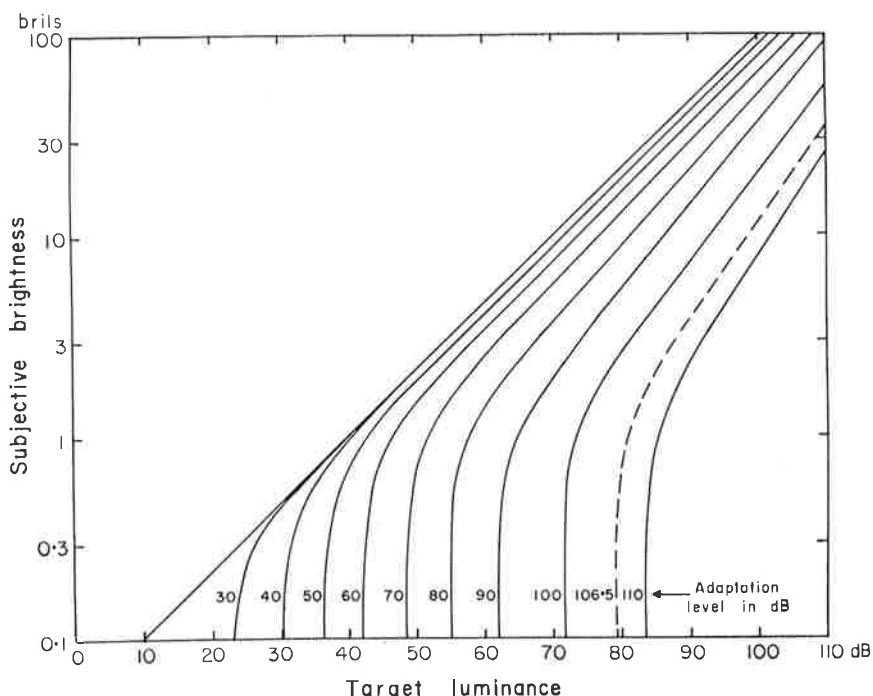


FIG 6. Operating characteristics produced by different levels of light-adaptation. The curves show the relation between luminance and subjective brightness immediately after the adapting field is switched off. The curves are power functions and follow the equation $\psi = k(B - B_0)^n$. The values of k , B_0 (threshold) and n are all affected by the adaptation level (STEVENS and STEVENS, 1960a).

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