Effect of luminance on suprathreshold contrast perception

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Perceived contrast was measured under natural viewing conditions with the use of contrast-matching and magnitude-estimation paradigms and found to be independent of luminance over a range of luminances from 37.5 down to 8 cd/m^2. However, this contrast constancy broke down when the dimmer target was below 8 cd/m^2. The perceived contrast of the dimmer target then fell below that expected from contrast constancy. The extended range of contrast constancy previously reported [J. Physiol. **252,** 627 (1975); Vision Res. **16,** 1419 (1976)] has been thought to imply neural mechanisms with unlimited constancy, but these researchers permitted differential adaptation to the brighter and dimmer targets, which were seen haploscopically (by different eyes). As our natural-viewing procedure ensured that both bright and dim targets were presented to retinal areas in a roughly constant state of adaptation, our failure to find extended contrast constancy implies an important limitation on the neural processing of contrast.

INTRODUCTION

Contrast is considered to be a relatively invariant perceptual attribute.[1] Experience suggests that the perceived contrast of objects in the environment is largely independent of size or spatial frequency (viewing distance). Indeed, two suprathreshold patterns generally match in apparent contrast when their physical contrasts are equal, despite large differences in the contrast thresholds for the two patterns.[2] This phenomenon, termed contrast constancy, has been shown to hold, within the limits imposed by threshold and resolution, over a wide range of spatial frequencies.[2–4] When the test and the standard have different spatial frequencies but equal mean luminances, contrasts are matched with near constancy whether they are presented to different eyes, that is, dichoptically,[3] or presented side by side to both eyes.[2,4] Our question is whether contrast constancy also holds over variations in luminance when spatial frequency is held constant.

The degree of constancy obtained over changes in luminance for the same spatial frequency was measured previously only dichoptically.[2,3] In the studies reported in Refs. 2 and 3 one eye was dark adapted, and the grating seen with this eye was matched to a grating of the same frequency presented to the other eye. For the long periods of adaptation used (1 h and 5 min, respectively, in the studies reported in Refs. 2 and 3), contrast constancy did hold. Only a small deviation from constancy was noted when the period of dark adaptation was shortened to a few seconds.[2] These results commonly have been held to demonstrate contrast constancy, but, since they were obtained with dichoptic presentations, they do not necessarily apply to more natural viewing conditions in which both eyes view the same scene and therefore have similar levels of adaptation.

Some suggestion that contrast is a critical variable in normal free viewing comes from the printer's rule of thumb that contrast matters more than luminance for the correct appearance of images.[5] Also, when observers matched a test target to a standard in both contrast and mean luminance, sensitivity to contrast was as much as 25 times greater than sensitivity to luminance.[5]

Many brightness-induction experiments[6–8] have been conducted with binocular dichoptic viewing (where the test and the comparison patterns were seen through different eyes). This was done to separate possible brightness-induction effects from any effects caused by the interaction of the two patterns on the same retina. However, contrast constancy, the invariance of perceived contrast over variations in illumination, should be distinguished from brightness induction, in which the perceived brightness of one area depends on the luminance of the surrounding area.[6–9] Whether induction occurs or not, the question remains whether the perceived contrast between the center and surround is independent of luminance.

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The current study was designed to determine the effect of changes of luminance in the image on contrast constancy in free-viewing conditions, for which the two patterns are presented side by side and an observer can move his or her eyes freely between them. The range of luminance levels tested was limited to those commonly available on video display monitors, which span the low photopic to the mesopic range. In analyzing contrast perception in complex images, Peli[10] assumed that contrast constancy holds above threshold at all frequencies, retinal eccentricities, and luminance levels. This assumption was combined with a definition of local band-limited contrast in complex images in simulations of the appearance of images to observers.[10] Contrast constancy above threshold levels also was assumed by Cannon and Fullenkamp.[11] The results of the current study were needed to determine whether and to what extent this assumption should be modified in consideration of luminance variations across the image.

We used Gabor-type patches of 1-octave bandwidth as stimuli, because we believe that these are more appropriate for the analysis of pattern perception than more extended grating stimuli.[12] Repeated, continuous cycles at any frequency are rare in natural scene images. Thus the sensitivity added by spatial summation is unlikely to be representative of visual perception of images other than gratings. The use of localized stimuli believed to match the impulse response of simple cortical cells is a natural way to obtain contrast-sensitivity functions that minimize the effects of spatial summation.

Two experiments are described below. The results of experiment 1 showed much poorer contrast constancy under changes in luminance than that found in previous experiments using dichoptic presentation, and experiment 2 showed that this effect was due to a deficiency in perceiving contrast at low luminance.

EXPERIMENT 1: CONTRAST MATCHING

Method

The stimuli to be matched were presented on a 19-in. (48.26-cm) 60-Hz, noninterlaced video monitor (U.S. Pixel, Framingham, Mass.) at a viewing distance of approximately 2 m (80 in.). At this distance the whole screen spanned 8°. The spatial inhomogeneity across the screen was 5% at mean luminance in the area in which the stimuli were presented. Linearity of the display response was obtained with the use of a 10-bit lookup table. The calibrated screen provided a linear response over 3 log units, and stimuli were limited to the range of luminances that could be presented accurately. The stimuli, two Gabor patches of different mean luminances, were separated by 4° from center to center (Fig. 1). The background luminance changed abruptly halfway between the patches. The screen appeared white.

The standard and the test grating patches were presented randomly at the right or left of the screen. In each session the standard patch luminance and contrast were fixed. Four test luminance levels were randomly interleaved. Test contrast was variable (see below). In a forced-choice paradigm, subjects were asked to decide which side had lower contrast, ignoring any luminance differences. All the subjects reported understanding the concept of contrast. Each session started with a 2-min dark adaptation followed by a 1-min light adaptation to a uniform field with the mean luminance of the standard. Before each trial, two uniform backgrounds appeared on the screen. When a subject pressed the ready button, the patches emerged abruptly from the backgrounds (without change of mean luminance) and remained on. After a response, both patches disappeared, and two different uniform backgrounds appeared on the screen at the intensity levels of the next trial.

The psychophysical procedure was a hybrid method consisting of three steps.[12] The first was a staircase procedure. After the second reversal of direction, data were collected and analyzed on line with the method of parameter estimation by sequential testing,[13] but, during this second phase, stimuli presentation was still controlled by the staircase. When an initial threshold estimate was determined within a confidence interval of 40%, stimulus control was switched to parameter estimation by sequential testing. This modification prevented long random walks that occur occasionally at the beginning of a parameter estimation by sequential testing routine.[14] After termination, a psychometric function (Weibull) was fitted to the data to obtain matching contrasts and standard deviations.

The luminance distribution of each Gabor patch can be written as

$$g_i(x,y) = L_i(1 + m_i \exp\{-[(x - x_i)^2 + (y - y_i)^2]/2\sigma^2\} \times \cos 2\pi f(y - y_i))\,, \tag{1}$$

where the subscript i can be 1 or 2, with 1 representing the standard patch and 2 the test patch. L and m are the mean luminance and the nominal physical contrast, respectively. The coordinates (x_i, y_i) were the center positions of the two patches. In the experiments the patches were side by side, $y_1 = y_2$. The distance between centers,

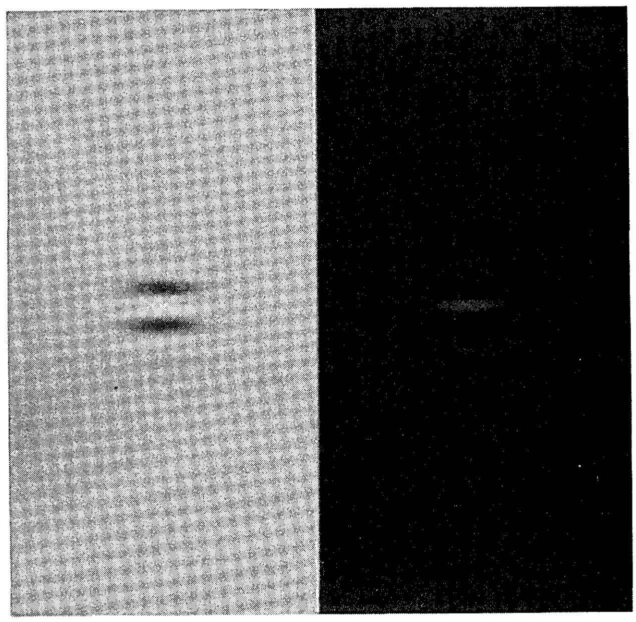


Fig. 1. Stimuli used in contrast-matching experiment [Eq. (1)]. The subject's task is to indicate which one of the two Gabor patches presented on two different backgrounds has lower contrast.

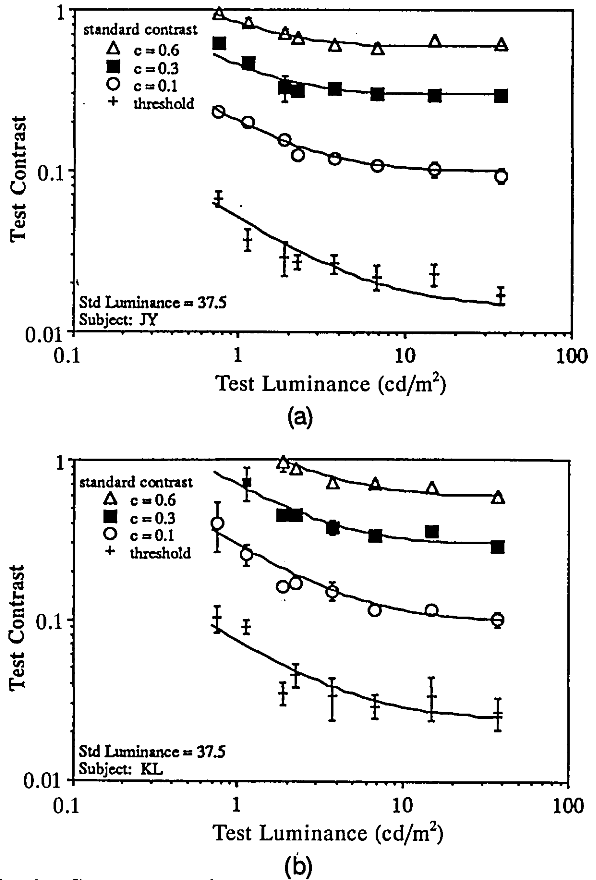


Fig. 2. Contrast-matching results for two subjects. The standard patch was always presented with a mean luminance of 37.5 cd/m^2. Standard contrasts used were 0.1, 0.3, and 0.6. The curve at the bottom represents contrast-detection threshold. The curves fitted to the data are tracings of the Stiles threshold-versus-intensity (TVI) curves.[15]

$x_1 - x_2$, was 4°. The mean spatial frequency f was set at 2 cycles per degree for both patches. The bandwidth in the spatial-frequency domain was set to 1 octave (Fig. 1), which was obtained by setting σ in Eq. (1) to

$$\sigma = \frac{3}{\sqrt{2}\,\pi f} = \frac{0.675}{f}. \tag{2}$$

Four subjects with normal corrected vision, ages 20–35 years old, participated in the experiment. Subject JY, one of the authors, had practiced for many sessions; the other three subjects were paid volunteers and were naïve to the objectives of the experiment. EF and KL ran through the experiments twice and ZW once. The standard mean luminance L_1 was fixed at 37.5 cd/m^2 throughout the experiments. The standard contrast m_1 was set at one of three levels (0.1, 0.3, or 0.6). Contrast levels were changed in steps of 0.02 log unit. For each standard patch, eight levels of L_2, the mean luminance of the test patch, were chosen over a 1.7-log-unit range of from 37.5 to 0.75 cd/m^2. Only four test patches could be interleaved in one session, so matched contrast data in each curve (Fig. 2) were obtained in two separate experimental sessions (one session with L_2 of 37.5, 6.75, 2.25, and 0.75 cd/m^2 and another with L_2 of 15, 3.75, 1.88, and 1.13 cd/m^2).

Contrast-detection thresholds were measured with the same stimuli and method of presentation but with the standard contrast m_1 set to zero. Thus test thresholds were measured in stimulus conditions comparable with those of the matching experiment. Since the standard was almost always brighter, the test and the standard then became obviously different. Therefore the forced-choice method had to be abandoned, and instead, a Yes–No staircase was used to determine the value of m_2 at threshold.

Results

Physical contrast of test targets is commonly measured with either the Michelson formula or the Weber fraction.[10] The nominal contrast m defined in Eq. (1) is used to measure the contrast of Gabor patch targets. The Michelson contrast of a patch approaches the value of m asymptotically for narrow-bandwidth patches (multiple cycles). On the other hand, for wideband, spatially narrow Gabor patches the values of m and the Weber contrast coincide. Since all our data were obtained with patches of one bandwidth (1 octave) m differs from both Weber and Michelson contrast, but all these measurements of contrast maintain a fixed ratio between their values.

Matching results are shown in Fig. 2 for subjects JY and KL, respectively, as functions of log L_2. Each set of data (one symbol) represents the mean matches to one standard contrast level interpolated from the Weibull psychometric function in which the value of m_2 was judged lower than that of m_1 half the time. The results for two other subjects are similar. The curves drawn through the data are tracings of the Stiles threshold-versus-intensity (TVI) curves.[15] We have transformed the TVI curves to our format by defining Weber contrast c as $c = \Delta I/I$. The curves then were moved parallel to the axes to give the best fit. The lowest curve represents the contrast detection threshold (no standard). Successively higher curves correspond to higher standard contrast matches. As can be seen, all data sets were well fitted by the TVI curve. Because of the limited luminance range available on the display, our curves could not be followed down to the −1 slope predicted by the Stiles template at the low-luminance end.

Variability, as indicated by standard error bars in Fig. 2, was greater at low luminances than at high. A few data points are missing, either because the subjects attempted to set the contrast m_2 higher than 1 or because the psychometric data were too erratic for the fitting program to obtain a reasonable fit.

As the results for the four subjects were similar, the average results are plotted in Fig. 3. Here too, the curves fitted are the transformed Stiles TVI curves. Thus, under natural viewing conditions, we did not find the extent of contrast constancy reported by Georgeson and Sullivan[2] and Kulikowksi[3] for dichoptic presentations. The matched contrasts m_2 show only a small deviation from the standard contrast m_1 when the test luminance L_2 was higher than 8 cd/m^2. However, when L_2 was decreased further, the matching contrast m_2 required was much higher, up to more than double m_1 over the range studied. In contrast, in dichoptic conditions the deviation from constancy decreases noticeably only with over 2 log units of reduction in luminance[3] (filled symbols, Fig. 3). An additional difference between our and earlier results is seen in Fig. 3. Figure 3(a) is plotted on a linear contrast

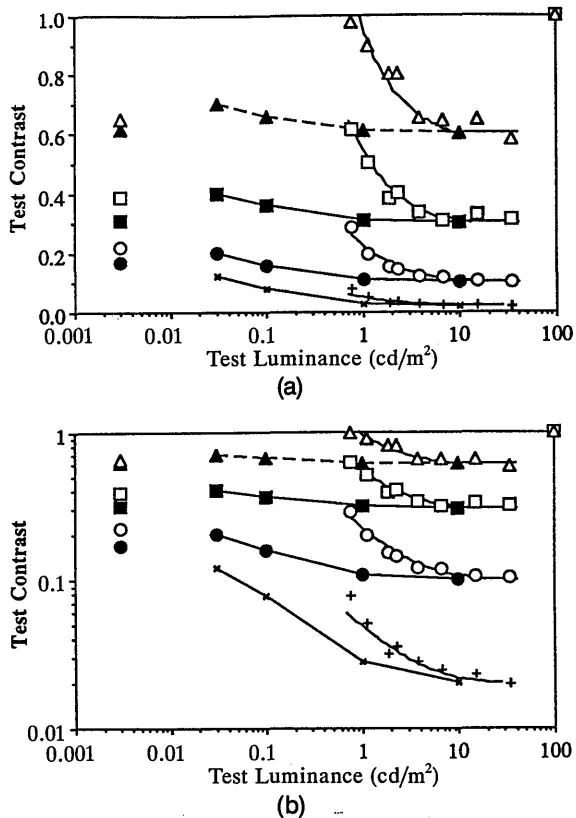


Fig. 3. Average results for four observers in the contrast-matching paradigm. The results of this study (open symbols on solid curves, the Stiles TVI curves) are compared with results from two other studies: closed symbols on curves from Kulikowski[3] and separate symbols at the left from Georgeson and Sullivan.[2] Results are presented twice: (a) linear contrast scale, (b) logarithmic contrast scale. Results illustrate test contrast as a function of test luminance, which was matched in our experiment to the appearance of a standard grating patch with a mean luminance of 37.5 cd/m^2. The standard contrasts were 0.1, 0.3, and 0.6, represented by circles, squares, and triangles, respectively. Detection threshold data from the Kulikowski[3] study (×) and ours (+) are represented by the two lower curves. Our data were obtained under free-viewing conditions in which the test and the standard were presented side by side. Data from the other two studies were obtained by dichoptic presentation; for both, the standard luminance was 10 cd/m^2. In the Kulikowski[3] study the dark-adapted eye was adapted for at least 5 min before testing. The dashed curve for 0.6 contrast represents extrapolation of the Kulikowski results, which were obtained only up to a contrast of 0.5. In the study by Georgeson and Sullivan,[2] the filled symbols show results with long adaptation of 1 h, and the open symbols show results with a short adaptation period of a few seconds before test. A 3.8-log-unit neutral-density filter was used over one eye.

axis to illustrate that the Kulikowski[3] results (filled symbols) are represented by a single curve shifted vertically on such a presentation. In comparison, our data below the luminance range over which constancy holds [Fig. 3(b)] appear to approach a single curve shifted vertically on a log-contrast plot. Thus the Kulikowski data, taken in dichoptic conditions, represent a change of contrast perception as a function of luminance that is independent of contrast level, while ours (taken in free viewing) represent approximately a fixed ratio of contrasts as a function of luminance.

Discussion

The results of experiment 1 suggest that, under normal viewing conditions, contrast constancy is maintained over somewhat more than a log-unit range of luminance on the display. However, when luminances differ by more than this, the contrast of the lower mean-luminance pattern is perceived to be lower than that of the higher mean-luminance pattern. The results suggest that an object in the light can appear to have higher contrast than the same object seen in a deep shadow, which agrees with our daily experience.

The mechanisms for this luminance effect, however, are not yet clear. Three causes may be postulated: First, contrast perception may be deficient at low luminances, just as thresholds are elevated at lower luminances.[16] Second, the retinal area, which normally viewed the dim region, may have been desensitized by the bright area, since free eye movements were permitted. However, the brighter patches were presented randomly to either side to minimize any slow adaptation effects. Moreover, in extensive preliminary experiments (on two subjects) we found that results were hardly altered whether fixation was free or controlled. (Controlled meant that fixation was either limited to the midpoint between the patches or switched regularly every second between the two targets.) Third, the field of bright light generated by the standard patch might have reduced effective contrast in the dim

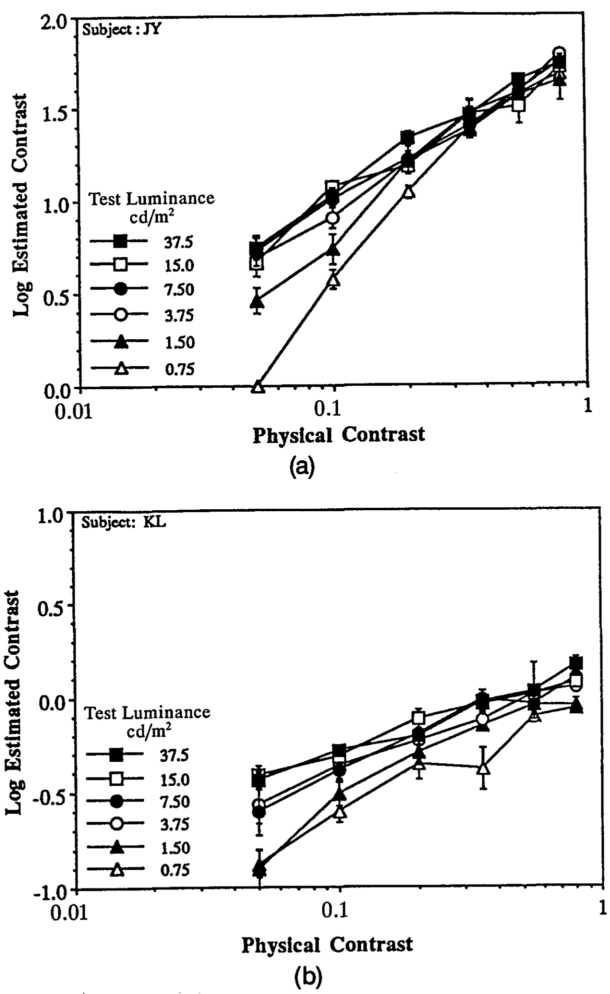


Fig. 4. Contrast-estimation results for two subjects. Each curve represents the results of contrast estimation at one mean luminance. All data points were obtained in one experimental trial, and the luminance was changed from one stimulus presentation to the next.

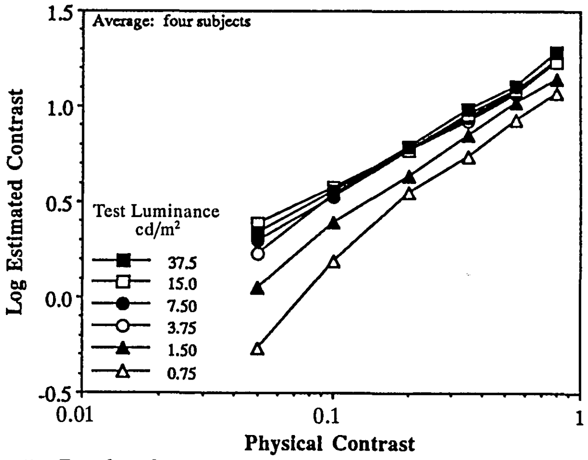


Fig. 5. Results of contrast estimation averaged (geometric mean) for four subjects and two durations of adaptations.

region by glare or by neural interactions. To test this, we carried out similar measurements but with the bright standard light turned off. In this case the contrast-matching method cannot be used, and so we employed a magnitude estimation procedure. Other research has generally found that estimation gives results closely comparable with matching.[17]

EXPERIMENT 2: CONTRAST ESTIMATION

Method

In this experiment subjects saw only one patch at a time and were instructed to estimate the suprathreshold contrast by giving a rating number on an arbitrary scale. This is the free-modulus technique, commonly employed in magnitude estimation.[4,12,18]

The video display was the same as that used in experiment 1. In each trial there was only one Gabor patch at the center of the screen. Between trials the mean luminance and the contrast of the patch changed. In each session there were six contrast levels (0.05, 0.10, 0.20, 0.35, 0.55, 0.8) and six mean luminance levels (0.75, 1.5, 3.75, 7.5, 15, 37.5 cd/m^2) totaling 36 stimuli. Each stimulus was repeated five times, presented in blocked random sequence. In each block, the 36 stimuli were presented in random order, but there were no repeats of the same stimuli within a single block. Subjects were instructed to assign an arbitrary number to the contrast of the first stimulus. In later trials subjects compared the contrast of the present patch with the previous ones and then assigned a corresponding number. In half the sessions, there was a 5-s adaptation period before each trial during which a uniform field with the mean luminance of the trial to come was presented immediately following a response.

The geometric means of the five repetitions at each level were used as the measure of the estimated perceived contrast for each subject.

Results

Figure 4 shows how estimated (perceived) contrast varies with physical contrast for two subjects when the adaptation duration was 5 s. As there were only small, irregular differences between the 0- and 5-s adaptation conditions, the results then were averaged over these two conditions. The data in Fig. 5 are the geometric means across repetitions, all four subjects, and the two adaptation durations.

In agreement with previous research,[4,12] the contrast-magnitude estimation results were well fitted by power functions of the physical contrast minus the threshold contrast. We estimated the threshold contrasts from the threshold data obtained in experiment 1 for each mean luminance. The exponents for the power functions at each mean luminance were between 0.60 and 0.68, which indicates that mean luminance has little effect on the exponents of the power function, as found by Gottesman *et al.*[18] and Biondini and de Mattiello.[19]

To compare the results of experiments 1 and 2, we converted the contrast estimation results to a form comparable with the matching results. In this form physical contrasts that produce the same perceived contrast are plotted against mean luminance. In Fig. 6 each horizontal line represents a locus of constant perceptual contrast for the independent variables of mean luminance and physical contrast. To match the standard ($L_1 = 37.5$ in experiment 1), the data in experiment 2 were converted as follows: To convert data at the lowest luminance (△), first select a luminance of 37.5 cd/m^2 and a physical contrast of, for example, 0.1. Second, draw a horizontal

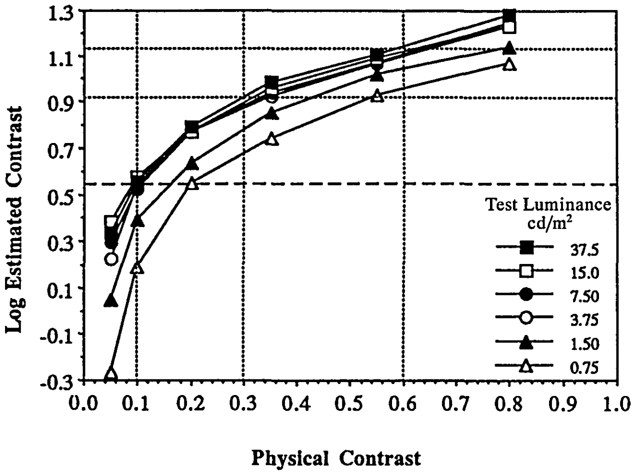


Fig. 6. Method of transforming contrast-estimation results to the format of contrast-matching results (Fig. 3). See text.

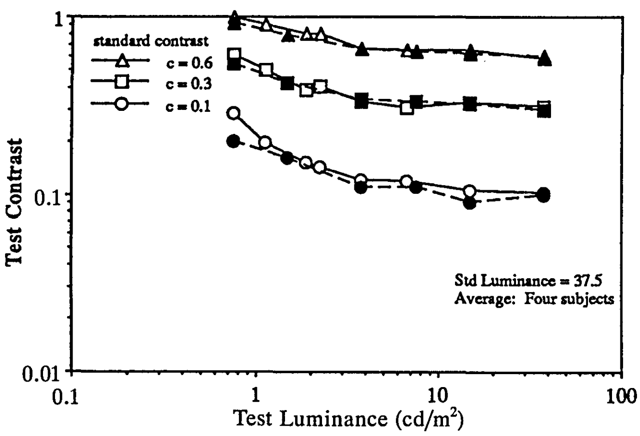


Fig. 7. Comparisons of averaged contrast-matching results (open symbols, solid curve) with the transformed results of contrast-estimation experiments (filled symbols, dashed curve). Except for the lowest-luminance level, the agreement is excellent, and the difference between the curves is not significant.

dashed line through the 37.5 cd/m^2 curve (■) at 0.1 contrast and extend it to the low-luminance curve (△). The intersection of this horizontal line with the curve is taken as the matching physical contrast (in the example, 0.2). This value (0.2) is plotted in Fig. 7 at the lowest luminance for the 0.1 contrast (● leftmost point). The results obtained in the two experiments are shown in Fig. 7; the filled symbols are the transformed estimation results and the open symbols the matching results. The agreement is excellent, and the differences between the results are not statistically significant. The combined p values for linear and quadratic comparisons were 0.23, 0.19, and 0.46 for the 0.1, 0.3, and 0.6 contrast levels, respectively.

Discussion

Experiments by others[18,19] and the ones reported here have shown little effect of luminance on the exponent of the power function relating perceived contrast to physical contrast. This fact is not evidence for contrast constancy, because intercepts of these functions change with luminance. In the experiments of Gottesman *et al.*[18] and Biondini and de Mattiello[19] the mean luminance was fixed in each session. Therefore both the subjects' state of adaptation and their strategies may have changed across sessions and made derivation of the relation between perceived contrast and luminance from their results problematic. In our experiment luminance was changed from trial to trial in an attempt to minimize these problems.

The similarity of the results in the contrast-matching and contrast-magnitude estimation experiments show that we cannot account for the effect of luminance on contrast perception seen in experiment 1 by assuming spatial interactions between standard and test; only the test was present in experiment 2. This result further supports our preliminary finding that the contrast matches are not affected by eye movements between the targets or by the presence of a brighter area in the visual field. Instead, we conclude that the results of both experiments represent a primary deficiency of contrast perception at low luminance, perhaps because of purely local gain-control effects.[1]

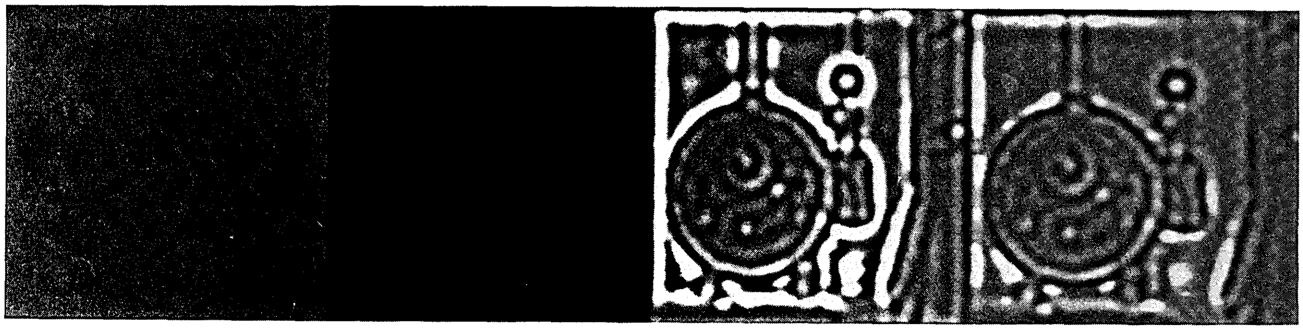
Furthermore, magnitude estimations in 0- and 5-s adaptation periods did not differ and suggested that any short-term changes of adaptation resulting from scanning eye movements had little effect on the results. Much longer adaptations, however, may reduce the luminance effects that we found. Such long-term adaptation may explain the differences between our results and those of Kulikowski.[3]

Like us, Whittle and Challands[8] found that contrast-matching data could be fitted by the Stiles curves; however, several differences exist between this study and ours. Our presentation was binocular; theirs, dichoptic. In their paradigm the two patches are presented on retinally different but perceptually fused backgrounds; in our paradigm the patches are on backgrounds that are distinct both retinally and perceptually. They claim that their subjects matched brightnesses, not contrasts. Finally, their data are photopic; ours reach down into mesopic levels. Despite these differences, both sets of data fitted onto the Stiles TVI curves, demonstrating the utility of their function and possibly pointing to a common mechanism.

Whittle and Challands[8] argued that the shape of the TVI curves is determined by the local retinal gain control. They believed that their suprathreshold constant-brightness curves reflect the action of the same retinal gain control on the response to a luminance increment. Whittle and Challands[8] found that the same results were obtained with 200-ms test flashes and with steady test patch lights. In both cases the steady background light was modified from trial to trial. The length of this period of adaptation to the background was not specified[8] but is likely to have been no longer than a few seconds. Similar results were reported with the surrounds of the left- and right-eye patches presented side by side rather than overlapping.[7] We also found that changing the adaptation period up to 5 s did not change the results. Thus the longer period of adaptation remains the most plausible explanation for the discrepancy between our results and those of Georgeson and Sullivan[2] and Kulikowski.[3] Another possible explanation may be related to the different spatial extent of the stimuli. Our stimuli were small localized patches. The other studies used extended grating stimuli that may span peripheral retinal areas and stimulated more rods and thus demonstrated increased sensitivity in the dark.

For darker-luminance levels than we have tested, i.e., for scotopic conditions, contrast constancy is incomplete and compensates only in part for changes in threshold as a function of spatial frequency.[2]

Fig. 8. Comparison of the band-limited local contrast in a typical video image calculated with and without accounting for the effect of local luminance on the apparent contrast: (a) a bandpass-filtered version (16 cycles per face) of (b), (b) the original image, (c) the local contrast for this band,[10] (d) the luminance modified local contrast. Here the contrast in every point is reduced depending on the local-luminance mean with the data from Fig. 3. Note that (c) and (d) are almost identical since, for most of the image, the local-luminance mean is too high to result in substantial reduction of apparent contrast.



(a) (b) (c) (d)

Fig. 9. The same comparison as in Fig. 8 but for the boiler image in which many areas of low luminance containing fine details exist. Here the apparent contrast shown in (d) is lower than the physical contrast calculated in (c). These differences may account for the difficulty in one's seeing the details in the original and may explain the ability of enhancement algorithms to improve the visibility of these details substantially.

All our experiments were carried out with stimuli of one spatial frequency, 2 cycles per degree. Van Nes and Bouman[16] have shown that the shape of the contrast-sensitivity-function curve is highly dependent on luminance, especially for the critical frequencies straddling the peak of the contrast-sensitivity curve (0.5–8 cycles per degree). This dependence implies that the relation between threshold modulation and luminance (the TVI curve) depends on spatial frequency. It is not known whether the same dependence on spatial frequency is found for supra-threshold contrast matching.

Implications for Video Imaging and Processing

Image-processing literature frequently treats the signal amplitude (at various frequencies) as the relevant visual variable. Peli[10] pointed out that the same local variations (amplitude) will result in larger contrast when they occur over an area of low mean luminance in the image. Therefore both the local-amplitude and the local-luminance means should be considered in determining local contrast. Our results here suggest that, for low-luminance levels, not only is the contrast detection threshold elevated but also the apparent contrast of suprathreshold features should be reduced. To determine the effect of such changes on the perceived contrast in images, we have incorporated this reduction in apparent contrast in our calculation of local band-limited contrast.[10] We used the averaged results (Fig. 3) in the implementation.

For most common video images (Fig. 8), the changes in local contrast resulting from reduced local luminance mean is small. Most images contain few areas with very low luminance (less than 3 cd/m^2). When such areas exist, they rarely contain much detail. One image frequently used to demonstrate the effectiveness of image-enhancement algorithms[20–22] is different in this regard. This image of a boiler inside a dark shed (Fig. 9) contains a large area of low-luminance levels that contain many details. Most of the details in the dark area around the boiler are not easily visible in the original image. Accounting for the reduction of contrast perception at low-luminance levels in this case, Fig. 9 clearly demonstrates the substantial reduction in local contrast, which may explain the poor visibility of details in the dark area. We have found only one more image that demonstrates a similar effect in a package of images frequently used in image-processing studies.[23] Thus it appears that the reduction of contrast at low-luminance levels may have a significant effect on the perception of video images. This effect is limited to a few images and, when it occurs, may be easily recognized by the atypical dark appearance of parts of the image. It should also be noted that luminance levels at which sensitivity is significantly reduced (more than a factor of 1.5) generally can occur only when a video display is observed in a dark room. Such situations occur more frequently with increased use of video displays for critical evaluation of images such as in radiology and in various military applications. At the ambient level of illumination in an office, the luminance of the unlit screen usually will be brighter than 8 cd/m^2, where we find that contrast constancy holds.

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