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Contrast Detection and Discrimination in Young and Older Adults

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ABSTRACT

Purpose. To determine if age differences in contrast detection thresholds extend to suprathreshold contrast discrimination. *Methods.* Psychophysical contrast detection and discrimination thresholds were determined in 56 adults ranging in age from 22 to 72 years. In experiment 1, thresholds were measured using a two-interval forced-choice procedure across a range of pedestal grating contrasts. In experiment 2, detection and discrimination thresholds were measured at two spatial frequencies and two luminance levels. *Results.* When normalized to the contrast detection threshold, contrast discrimination thresholds were similar in young and older adults. This result is akin to previous findings for clinical patients with contrast detection deficits. In addition, contrast discrimination in the elderly is independent of mean display luminance as has been found in young adults. *Conclusions.* Normalized contrast discrimination functions have the same shape in young and older adults and show no change with a 4-fold reduction in luminance.

Key Words: spatial vision, aging, contrast sensitivity, suprathreshold contrast, visual masking

Much research has been devoted to understanding low contrast processing in the aged visual system. Psychophysical measurements using both an external grating and laser interferometry have shown that older observers, who are free of ocular pathology, show deficits in contrast detection for intermediate and high spatial frequency patterns.[1–6] Comparatively little age-related research has been devoted to measurements of suprathreshold contrast discrimination.[7] We wished to determine if age-related changes in contrast detection extend to contrast discrimination measurements.

Contrast discrimination paradigms are useful for examining low and high contrast processing. In a typical contrast discrimination experiment, observers distinguish between two slightly different contrast stimuli. One stimulus is called the background, or pedestal, whereas the test stimulus is an increment in contrast that is added to the pedestal contrast. The contrast discrimination threshold is the lowest test contrast needed to discriminate between the pedestal stimulus alone and the pedestal plus test stimulus. Changes in test contrast threshold (c_t) at various levels of pedestal contrast (c_p) provide valuable information about visual filter characteristics as well as sources of noise in the visual system.[8–10]

Contrast discrimination curves (c_t vs. c_p) are dipper-shaped when the test and pedestal stimulus spatial and temporal characteristics are similar.[11–15] The test contrast detection threshold is measured at $c_p = 0$ (in the absence of a pedestal stimulus). At low pedestal contrasts (c_p slightly greater than the detection threshold), there is a facilitation in test stimulus visibility that may be caused by increased certainty about the test stimulus to be detected because the pedestal is slightly suprathreshold.[16] As pedestal contrast increases, test thresholds climb steadily, approximating Weber's law behavior.[14] That contrast discrimination follows a systematic increase with contrast permits precise predictions of how a background stimulus masks, or obscures, the visibility of low contrast patterns.

The contrast discrimination function shape may be predicted by the contrast detection threshold.[17] Detection thresholds are profoundly affected by such factors as the spatial frequency,[13, 17, 18] retinal illuminance,[17, 18] or eccentricity[17] of the stimulus. The relation between contrast detection and discrimination lies in the masking ability of the pedestal (c_p). Namely, the c_p's masking effectiveness is greater when detec-

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tion thresholds are low. Conversely, the c_p's effectiveness is less when the detection threshold is high.[17] The outcome is an apparent invariance of contrast discrimination thresholds at high contrasts across many stimulus variables. Normalization of contrast discrimination thresholds to the detection threshold results in superimposed contrast discrimination functions. Based upon these findings, we hypothesized that in the elderly (who show elevated contrast detection thresholds[1–6]) there would be a similar invariance in contrast discrimination thresholds at high c_p contrasts. Young and old contrast discrimination functions should be similar after normalization to their individual detection thresholds.

A second line of reasoning leads us to the same prediction of an age-related invariance in contrast discrimination. Although the locus of age-related elevation in contrast detection thresholds is still not clear, recent evidence suggests that optical factors are the main contributor to these threshold increases (e.g., see Burton et al.[6] for a brief review). The elevation in contrast detection thresholds with age would be expected to elevate the low contrast portion of the contrast discrimination function, but would have little effect on the high contrast portion of the curve. There is little reason to predict that the near-Weber relation ($\approx$ 0.7) seen in young observers would significantly change with age.

Using a contrast discrimination paradigm, Leat and Millodot[7] found that contrast discrimination thresholds for sinusoidal gratings were elevated in the elderly (N = 8). Older adults had higher Weber fractions (c_t/c_p), suggesting that the pedestal stimulus had greater masking power in elderly visual systems than in the young. They also found a greater relative increase in the Weber fraction of older observers to a higher contrast pedestal compared to the young observers. This suggests that the contrast discrimination function slope may change with age.

Leat and Millodot's[7] measurements were made at two contrast levels, 1.0 and 1.5 log unit above detection threshold, and were limited to spatial frequencies less than 3 cpd. In our first experiment we measure contrast detection and contrast discrimination thresholds in young and older adults across a large range of pedestal contrasts to determine if contrast discrimination is different in the aged visual system as suggested by the Leat and Millodot[7] data. Using a similar paradigm, our measurements were taken at 10 cpd, where age differences in contrast detection thresholds are evident.

Contrast *discrimination* thresholds in young adults are robust to the display mean luminance level.[17] Conversely, contrast *detection* thresholds are strongly affected by changes in mean luminance, particularly in the elderly.[19] In a second experiment, we measured contrast detection and discrimination thresholds as a function of display luminance in young, middle-aged, and older adults to determine if (unlike young adults) the display luminance is a salient factor at suprathreshold contrast levels in older observers. The combined results of the two experiments show that although contrast detection thresholds are elevated in our older observers (N = 22), there is little age-related difference in normalized contrast discrimination thresholds.

METHODS

Experiment 1

Sinusoidal grating stimuli (10 cpd) were generated using a Prisma VR 1000 Grating Generator (Millipede Electronic Graphics). The display had a mean luminance of 50 cd/m^2 and consisted of a circular opening subtending 2.5° visual angle from a viewing distance of 118 cm. We used a surrounding mask of the same color and similar mean luminance (33 cd/m^2) to the display. All tests were performed monocularly, using the eye with the better visual acuity. The other eye was occluded with a black patch. Viewing was foveal with a natural pupil.

Observers were instructed to allow their eye to wander over the screen between trials to reduce the formation of afterimages, but to look at the screen's center during a trial. Warning tones were used to signal each trial interval. Stimulus onset and offset were abrupt. To help minimize stimulus uncertainty effects, a stimulus preview was shown before each set of trials. Stimuli were presented for 500 ms, separated by an interstimulus interval of 1 s, during which the screen was blank but of the same mean luminance as the sine wave stimulus. Because there may be an age-related increase in stimulus persistence,[20] a pilot experiment was performed to determine an interstimulus interval duration that would not permit the two stimulus intervals to temporally overlap in the elders' visual systems. These measurements showed that interstimulus intervals of 500 and 1500 ms produced similar thresholds. Test thresholds were determined in the presence of pedestal gratings ranging from 0.0 to 64.0% contrast. The order of pedestal contrast testing was randomized.

We used a temporal two-interval forced-choice staircase tracking procedure to estimate thresholds. Within each trial, one interval contained only the pedestal stimulus (c_p), whereas the other interval contained the pedestal plus test stimulus ($c_p + c_t$). The interval containing the test stimulus was randomized. The observer's task was to indicate which interval contained the grating of higher contrast by depressing one of two response keys located on a hand-held response box. Auditory feedback was provided to inform the observer as to the higher contrast interval. On subsequent trials, the test stimulus contrast was adjusted according to the observer's performance. Specifically, test contrast was reduced after 3 consecutive correct responses and increased after 1 incorrect response, thus estimating the 84% correct threshold level.[21] A staircase was terminated after 12 reversals in contrast. This procedure provided percent correct scores for a range of test contrasts that were analyzed using Probit analysis,[22] which estimated the 75% correct threshold level. After at least 300 practice trials, 2 to 3 threshold estimates were made at each pedestal contrast. Reported thresholds are the geometric mean of the thresholds calculated using Probit analysis. Standard errors are based on the greater of the between- and within-staircase variances.

Nine young (age range 22 to 36 years; mean = 26.3 years) and 10 older (age range 62 to 72 years; mean = 67 years) adults participated in this study. The results of one older adult are not presented because he did not complete the experiment. Observers, recruited from the East San Francisco Bay area, were in excellent general health and were all living independently in the community. Ophthalmologic records were obtained from private ophthalmologists. Eye examinations, received within 8 months before the experiment, included indirect ophthalmoscopy, slitlamp examinations, assessments of intraocular pressure, near and far acuity, motility, and visual fields (Humphrey Field Analyzer, Program 30–2). These examinations indicated that all observers were in good ocular health showing no obvious signs of disease. Interocular pressures were less than 19 mm Hg. Older adults did not exhibit drusen, although they did exhibit subtle macular and lenticular density changes, which are common to aging individuals. If these macular and lenticular changes had been considered unusual by the attending ophthalmologist, that observer would not have been included in our data analysis. On an initial visit to our laboratory, refraction was performed to ensure best correction during experimental testing. Mean visual acuities (in logMar) were -0.02 for our young observers and 0.06 for the elderly, consistent with population age trends in acuity.[23]

A control experiment was performed to ensure that temporal uncertainty would not differentially impair the elderly because of the increased memory load of a *temporal two-interval* forced-choice design as compared to a *spatial two-alternative* design. Two older adults were tested. Temporal and spatial forced-choice designs were compared. The same sort of results were found for the spatial and temporal designs in these older adults.

RESULTS

We measured test contrast thresholds over a range of pedestal contrasts. Analysis of variance on the contrast detection and discrimination data showed a significant difference between the young and older observers' data [$F(1,16) = 104.55$, $p < 0.0001$]. That the interaction term between age and task (detection vs. discrimination) was not significant [$F(1,8) = 0.99$, $p > 0.05$] suggests that both detection and discrimination thresholds were elevated in the elderly.

Because there are age differences in the contrast detection threshold, we normalized each observer's discrimination data to their detection threshold to equate these visibility differences. Fig. 1 presents normalized contrast discrimination thresholds for young observers tested at 10 cpd. The normalized test contrast threshold is plotted against pedestal contrast (also normalized to the detection threshold). The observers' ages are shown in parentheses next to their initials. The horizontal dashed line indicates no facilitation or masking. As previously reported,[14] young observers show a dipper-shaped contrast discrimination function. There is facilitation near the contrast detection threshold, followed by a gradual increase in contrast discrimination thresholds as pedestal contrast increases.

Using a formula which originated from the transducer function discussed by Klein and Levi[10] and later modified by Beard et al.,[24] we fitted the raw (prenormalized) data with the function:

$$c_t = [(1 + c_p^{\,n}(1 + nw))^{1/n} - c_p]T_o \qquad (1)$$

where c_t is the test contrast threshold, c_p is the pedestal contrast, n is the transducer exponent, w is the intrinsic Weber fraction, and T_o is a detection threshold estimate. This function has the classic "dipper function"[14] shape, which specifies the test threshold across pedestal contrast. The amount of facilitation seen in the curve is expressed in 1/n. The intrinsic Weber fraction, where thresholds increase proportionally to pedestal contrast, is expressed by the parameter w. Although the term "Weber" implies a slope with exponent of 1.0, most contrast discrimination exponent estimates are around 0.7.[6] These fits are presented on the normalized data in Fig. 1 and are shown by the solid curve. The amount of facilitation differed among individuals within this young age group. Although the parameter T_o approaches unity, it differs from the detection threshold because it also depends upon discrimination thresholds at low pedestal contrasts.

Fig. 2 shows normalized contrast discrimination thresholds for the older observers. These data were also fitted with the model in equation 1. Individual differences are again evident where some elderly observers performed similarly to the young observers, whereas others appear to show no facilitation effect. These individual differences in thresholds point out the importance of looking at individual scores in geriatric studies and may help explain the small age effects typically found for averaged data.

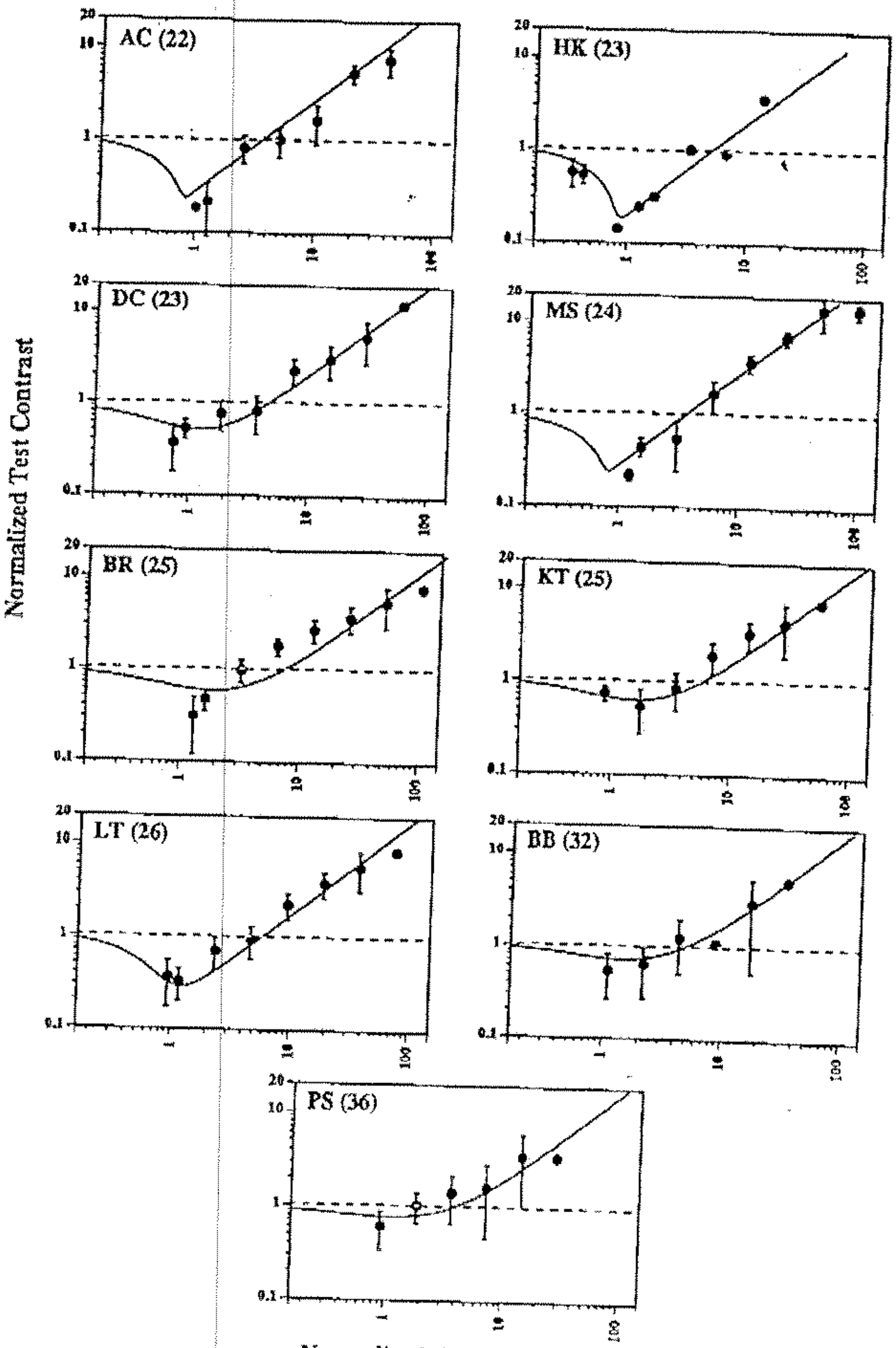

Figure 1. Normalized contrast discrimination thresholds for young observers tested at 10 cpd. Test contrast in contrast threshold units is plotted against pedestal contrast (also in contrast threshold units). The solid line represents a three-parameter model fitted to the data (see equation 1). The horizontal hashed line shows the contrast detection threshold. Standard error bars represent the greater of the between- and within-error estimates. Observer age is shown in parentheses.

To show more clearly the amount of facilitation and masking between the age groups, Fig. 3 presents a plot of the parameters n and w from the model given in equation 1 as a function of each observer's contrast detection threshold. These are the contrast detection thresholds used to normalize the data in Figs. 1 and 2. The reciprocal of parameter n, the transducer exponent, describes the amount of facilitation seen in test thresholds. The young observers' data are represented by circles and the older observers' data by triangles. The age difference in contrast detection threshold is immediately evident because the older observers' data are shifted to the right. In general, the

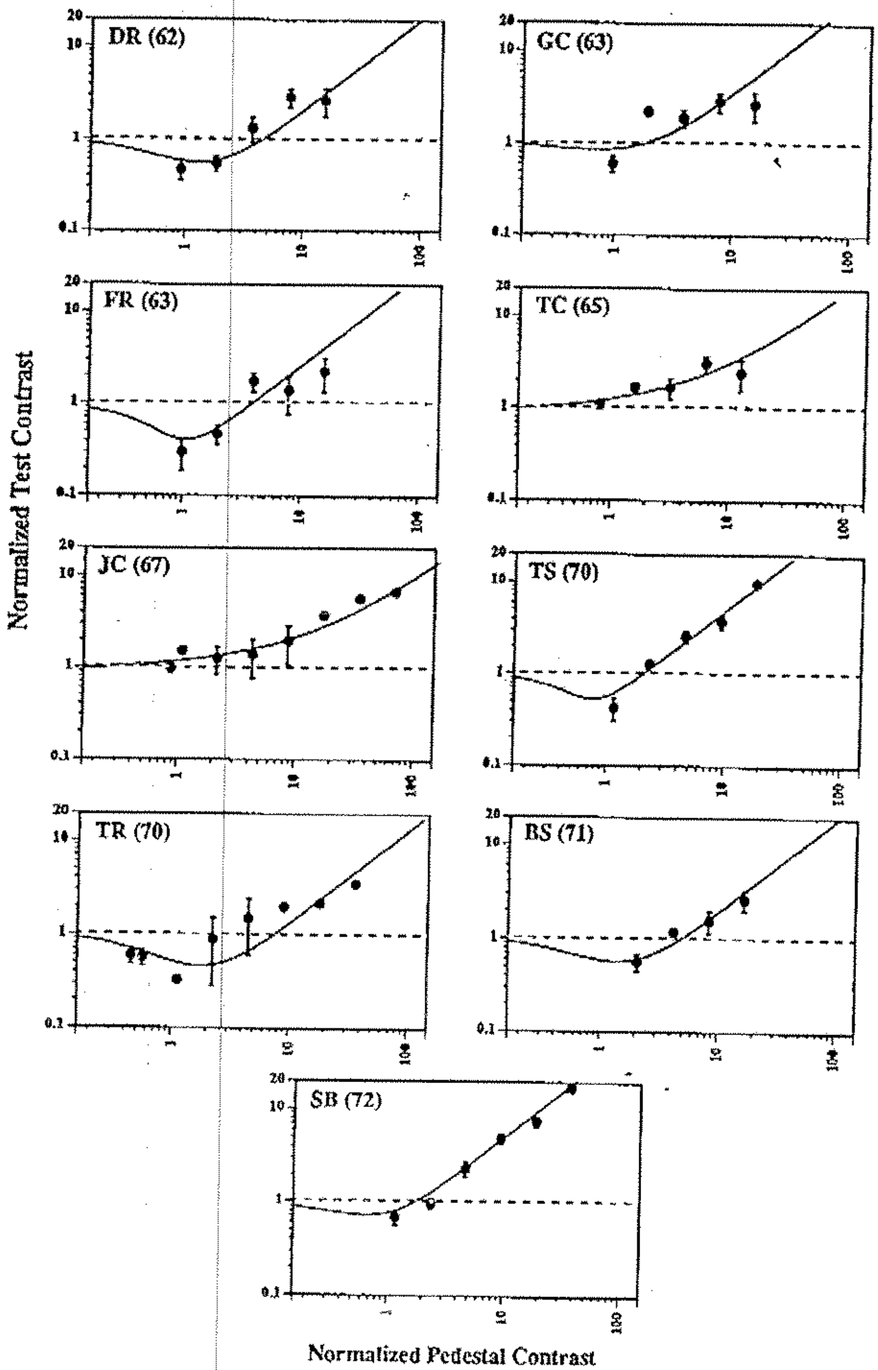

Figure 2. Normalized contrast discrimination thresholds for older observers tested at 10 cpd. All information is the same as in Fig. 1.

amount of facilitation is similar in the two age groups, suggesting that even at lower pedestal contrast levels, contrast discrimination is similar in young and older adults. The Weber fractions (bottom panel) are also similar in young and older adults.

Experiment 2

Our first experiment showed no age-related difference in normalized contrast discrimination for 10 cpd gratings at a mean screen luminance of 50 cd/m^2. Research has shown that contrast detection thresholds in the elderly are more greatly affected at lower luminances and high spatial frequencies than they are in the young.[19] In our second experiment we examine the effect of mean luminance level and spatial frequency on contrast detection and discrimination thresholds across the adult age span (38 adults ranging in age from 23 to 75 years). To show age trends in our data,

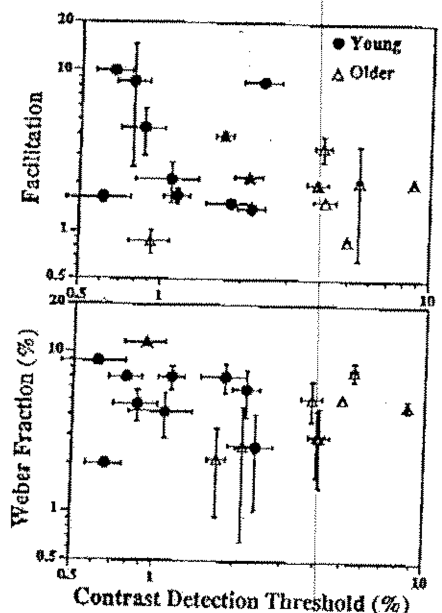

Figure 3. Plots of the parameter estimates from the model (equation 1) as a function of the contrast detection threshold. The upper panel presents estimates of the "dipper" or facilitation seen in the tvc curves for each observer. The lower panel shows estimates of the Weber fraction for each observer. Young (circles) and older (triangles) observers' data are shown in each panel. Error bars represent the error in the parameter fit using a least square algorithm. There are no age differences for either of these parameters.

observers were divided into three age groups. It is not known if increased age effects resulting from decreased luminance levels for contrast detection transfer to suprathreshold contrast levels, although previous research has shown contrast discrimination thresholds in young observers to be relatively invariant with the mean luminance level and display spatial frequency.[17]

To increase our chances of receiving full data sets on each observer, we limited measurements to contrast detection (c_p = 0%) and contrast discrimination thresholds (c_p = 30%) at two spatial frequencies and two mean luminance levels (8 conditions x 3 repetitions). Contrast discrimination thresholds were measured for vertically oriented antisymmetric Gabor patches with peak frequencies of either 2 or 10 cpd. For the Gabor patches centered at 2 cpd, there were 6 young (age range 23 to 39 years; mean = 30.1 years), 4 middle-aged (age range = 42 to 50 years; mean = 45.5 years), and 7 older observers (age range 61 to 75 years; mean = 65.4 years) tested. For Gabor patches centered at 10 cpd, there were 9 young (age range 23 to 39 years; mean = 29 years), 9 middle-aged (age range = 40 to 53 years; mean = 46.6 years), and 8 older observers (age range 63 to 70 years; mean = 66 years). Five of the young, 1 middle-aged, and 1 older observer were tested at both 2 and 10 cpd. Each observer practiced both detection and discrimination tasks for *at least* five trial blocks. Each block contained approximately 100 trials. Mean screen luminance was either 12.5 or 50 cd/m^2 with a darker surround. The lower luminance level (i.e., 12.5 cd/m^2) was achieved through the use of a 0.6 neutral density filter placed in front of the observer's eye. Frosted glass was used to occlude the untested eye allowing light, but not pattern, to pass through.

Stimuli were presented on a Tektronix 608 monitor (P31 phosphor). The display subtended a visual angle of 1.5 x 2.5° when viewed from a distance of 3.05 m held constant by a chin/forehead rest. Best correction for this distance was provided using trial lenses inserted into a fixed frame mount. All observers were given a thorough eye examination at the SUNY Optometric Center after study completion. Inclusion criteria were the same as those used in the first experiment. Two older observers (in the 10 cpd group) were excluded from data analysis because of diabetic retinopathy in 1 and Parkinson's disease in the other. Mean corrected visual acuities were -0.04 logMar for the young observers, -0.02 logMar for the middle-aged group, and 0.08 logMar for the older group.

For rapid threshold measurement we again used a two-interval forced-choice staircase technique. Both the 71 and 84% points on the psychometric function were estimated using two randomly interleaved staircases. The 84% staircase was as described above. For the 71% staircase, test contrast was reduced after two consecutive correct responses and increased after one incorrect response. Two to three threshold estimates were obtained for both the 71 and 84% correct threshold levels in all observers. The data for both 71 and 84% staircases were pooled and analyzed using Probit analysis. We analyzed the psychometric function slopes and found no significant difference between young and older observers,[25] suggesting that the amount of noise in the adult visual system is age-invariant.

The upper two panels of Fig. 4 present contrast *detection* thresholds (% contrast) at the lower mean luminance of 12.5 cd/m^2 as a function of detection thresholds (% contrast) obtained at the higher luminance of 50 cd/m^2 for 2.0 (left panel) and 10.0 cpd (right panel) Gabor patches. Observer age is again represented by different symbols (young = circles, middle-aged = squares, older = triangles). The oblique line passing through the data represents thresholds when there is no effect of luminance level. At 2 cpd, display luminance was not an effective variable for any age group. But, at 10 cpd the lower luminance resulted in increased threshold in some elderly and middle-aged observers, although analysis of variance for repeated measures revealed that this trend did not reach statistical significance [$F(2,32) = 0.95$, $p > 0.05$].

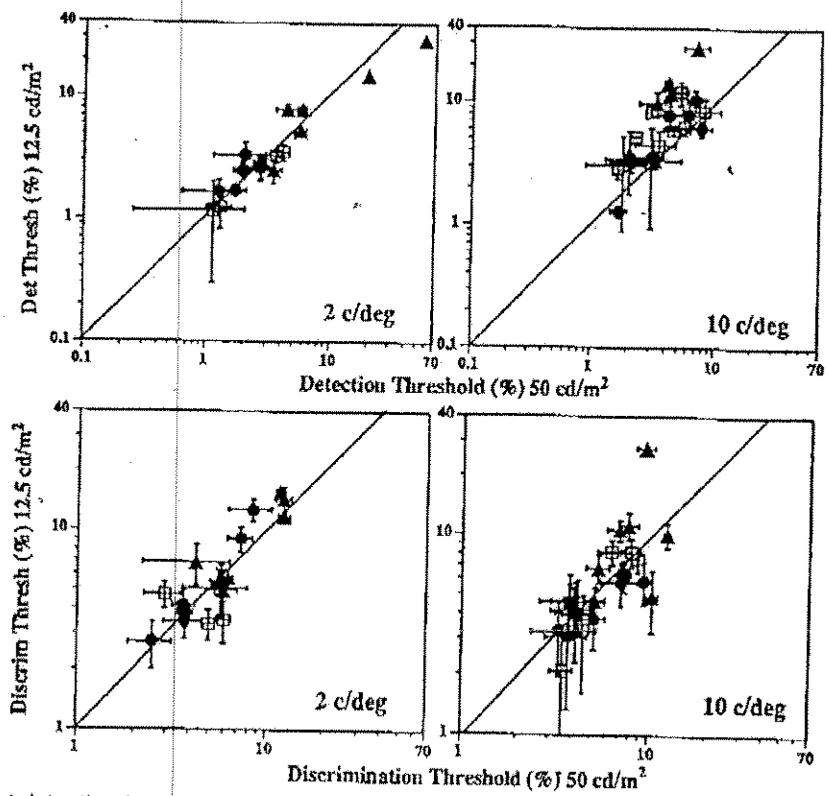

Figure 4. Contrast detection (upper panels) and contrast discrimination (lower panels) thresholds (% contrast) at 12.5 cd/m² as a function of thresholds at 50 cd/m². Two cycles per degree data are shown in the left panels and the right panels present 10 cpd data. Young (circles), middle-aged (squares), and older (triangles) are shown in each panel.

We wished to determine if the elderly show elevated thresholds relative to young observers at suprathreshold contrast levels when the display mean luminance is lowered. The lower two panels present contrast *discrimination* thresholds at the low vs. high display luminance levels at 2 and 10 cpd. For all age groups, luminance was not an effective variable at suprathreshold contrast levels.

DISCUSSION

In support of much previous literature, we found an age-related elevation in contrast detection thresholds in older adults who had no sign of ocular pathology and had visual acuities within the normal range. We extended these threshold measurements to suprathreshold levels of contrast using a contrast discrimination paradigm. When age differences in pattern contrast detection threshold were accounted for, little age-related difference in suprathreshold contrast discrimination was found. Our results suggest that although the detectability of contrast changes with age, contrast discrimination above threshold shows similar nonlinear characteristics in young and older adults.

Klein and Levi[10] and Beard et al.[24] have successfully tested a model of temporal contrast discrimination data in young observers. We used this model (equation 1) to compare contrast discrimination curves in adults ranging in age from 22 to 72 years. One parameter of this model relates to the amount of facilitation seen in the low pedestal contrast portion of the dipper-shaped curve. Although two elderly observers showed no facilitation effect, seven of the elderly showed facilitation similar to that seen in the young observers. A second model parameter relates to the Weber fraction at high pedestal contrasts. We found similar Weber behavior in the observers from both age groups. For both young and older adults, normalized contrast discrimination thresholds rise steeply on a log-log plot once the pedestal stimulus is slightly above the contrast detection threshold. Normalized contrast discrimination thresholds change little across the age span.

It has been suggested that contrast detection and discrimination may be mediated by different mechanisms.[26] Before normalization to the detection threshold, our older observers showed contrast discrimination curves which had a rightward shift and decreased facilitation. These characteristics are similar to those found under conditions where the stimulus detection threshold is increased, such as in the periphery[27,28] and in amblyopic observers.[17,29] Bradley and Ohzawa,[17] for example, found that the elevation in contrast detection thresholds found in amblyopic observers could predict the reduced facilitation and elevation seen in their contrast discrimination functions. Others have found that age-related contrast sensitivity losses may be compensated so that performance on a contrast matching task is relatively unimpaired.[30] The results of these experiments suggest that contrast sensitivity may set the gain control in a contrast discrimination task. Further work should explore the relation between contrast detection thresholds and suprathreshold contrast discrimination.

In the first experiment, there was a difference between the mean screen luminance and the white surround. For two reasons we do not think that this small luminance change at the edge of the sine wave gratings differentially affected our two age groups. First, the log of the ratio between the screen and surrounding mask was only 0.18. Second, in experiment 2, where we used spatially limited Gabor stimuli that did not approach the screen edge, we found results similar to those in the first experiment. For these two reasons, we do not think that the abrupt screen edges had a differential effect on our elderly observers' thresholds.

If contrast discrimination thresholds are affected by alterations in noise in the visual system,[31, 32] then the psychometric function slope would be flatter for the older observers than for younger observers. We have analyzed the slope of the psychometric function using Probit analysis and Quick's[33] formula and found that the slopes of the psychometric functions were not significantly different in young and older observers.[34] Thus, there is no evidence that increased noise in the aging visual system can account for their elevated (before normalization) contrast discrimination thresholds.

Our thresholds are comparable to those reported in the literature using similar visual stimuli. In our second experiment, contrast thresholds for antisymmetric Gabor patches were elevated as compared with other experiments using sine wave gratings.[3, 35] However, the detection thresholds for the Gabor stimulus were similar to those reported by Peli et al.,[36] who also measured thresholds for 2.0 cpd Gabor patches. It has been shown that contrast threshold increases when the number of stimulus cycles present in the visual display decreases.[37] Because Gabor stimuli have a limited number of cycles and therefore limited spatial extent, this could raise detection thresholds substantially. On the other hand, contrast discrimination thresholds for sine waves and Gabor patches in our two experiments were both similar to those obtained by Bradley and Ohzawa.[17] This can be explained by the finding that contrast processing above 10% contrast is invariant with number of grating cycles.[14]

There are several practical and clinical implications of this study. Previous studies have shown that individual differences in contrast detection thresholds may be used to better understand and predict complex object discrimination thresholds.[38] If so, then individual differences in contrast discrimination thresholds may relate to an individual's ability to see under high visibility conditions in everyday situations. Our results suggest that individuals showing deficits in contrast detection thresholds may not have deficits in contrast discrimination. Low visibility deficits in the elderly may be eliminated effectively through maximizing contrast in tasks such as reading. The results of these experiments may have important implications for older automobile drivers and the elderly in vision-intensive occupations. Because older adults show some luminance-dependent deficits in threshold contrast, driving under conditions of reduced contrast such as rain or fog might be safest for them during daylight hours (high luminance). Under high luminance conditions, some elderly may only be at a slight disadvantage.

In summary, these results suggest that when normalized to the contrast detection threshold, suprathreshold contrast discrimination is similar across the adult age span and shows no change with changes in mean luminance level. These results extend measurements of contrast detection threshold, providing a more comprehensive assessment of the aging visual system. If we assume that contrast discrimination functions reveal principles of vision such as contrast coding, then the coding process is similar in young and older adults.

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ANNOUNCEMENT

The British College Optometrists is holding their Centenary Conference (1895–1995) on April 5 to 8, 1995 in Cambridge, England at Churchill College.

The program contains a mixture of lectures and workshops covering topics including: Volk lenses, use of lasers, gonioscopy and punctum plugs, pediatric assessment, corneal foreign body removal, PRK surgery, contact lenses, and low vision aids.

Invited Lecturers will be discussing Myopia: Causation, assessment, correction and treatment; Shared Care: Experience and the future; Noninvasive investigation of visual function; Presbyopia: Causation, assessment and correction.

Possible topics on free papers include: Acquired color vision defects, Ocular motor issues, Ocular biometry, Environmental and ergonomic issues, Gender and ethno-specific ocular changes.

Professor N. McBrien will give The Fincham Medal Lecture and Mr. M. Jalie will give the Arthur Bennett Memorial Lecture.

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