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Contrast sensitivity, acuity, and the perception of 'real-world' targets

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SUMMARY A major assumption underlying the use of contrast sensitivity testing is that it predicts whether a patient has difficulty seeing objects encountered in everyday life. However, there has been no large-scale attempt to examine whether this putative relationship actually exists. We have examined this assumption using a clinic based sample of adults aged 20–77 years. Contrast thresholds were measured for both: (1) gratings of 0·5–22·8 cycles/degree; and (2) real-world targets (faces, road signs, objects). Multiple regression techniques indicated that the best predictors of thresholds for real-world targets were age and middle to low spatial frequencies. Models incorporating these variables accounted for 25–40% of the variance. Although acuity significantly correlated with thresholds for real-world targets, the inclusion of acuity as a predictor variable did not improve the model. These data provide direct evidence that spatial contrast sensitivity can effectively predict how well patients see targets typical of everyday life.

Over the past two decades contrast sensitivity testing has grown in popularity as a clinical tool for describing visual disturbances associated with various ophthalmic disorders.[1,2] Contrast sensitivity measurements can be particularly useful in diagnosis, since the shape and the height of the contrast sensitivity function (CSF) is vulnerable to pathological changes in the visual pathways. An assumption which often underlies the clinical use of the CSF is that it predicts whether a patient is likely to have difficulty in seeing visual targets typical of everyday life. Despite this widespread assumption, however, there has been no large-scale attempt to examine the validity of this putative relationship. The present study was designed to examine how contrast sensitivity measurements relate to the detection and identification of targets commonly encountered in daily experience.

There have been only a few earlier studies on contrast sensitivity and its predictive capacities. Typically these studies have centred on specific types of observers and have utilised relatively small samples. For example, Marron and Bailey[3] report that, for low-vision patients, contrast sensitivity could predict orientation and mobility on a test course. Ginsburg *et al.*[4] found that Air Force pilots' CSFs predicted the distance at which air-to-ground targets were detected in an aircraft simulator. And finally Evans and Ginsburg,[5] in a study on how aging relates to the visibility of road signs, found that contrast sensitivity was significantly correlated with the distance at which an observer could discriminate two highway signs.

These studies help to establish the validity of using contrast sensitivity as an indicator of the visibility of objects encountered in everyday life. Yet it would be helpful to know whether contrast sensitivity can be utilised in a clinical setting, where clinicians must make predictions as to what sorts of visual problems a patient might face in routine daily activities. In the present study we have used multiple regression techniques to examine this issue.

Subjects and methods

Patients (n=93) were recruited from the Primary Care Clinic and ranged in age from 20 to 77 years. As is evident from Table 1, each decade of age within this range was well represented in our sample. Binocular letter acuity, as measured by Sloan letters

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Table 1 *Age distribution of sample*

Age	*Sample size*
20–29	16
30–39	20
40–49	15
50–59	14
60–69	15
70–77	14

at a distance of 3 m, ranged from 20/15 to 20/50. Our subject sample represented a range of diagnoses, from excellent ocular health to early cataract and macular degeneration. Since we were interested in obtaining a range of visual performance levels, we did not restrict our sample on the basis of acuity or diagnosis. This was considered to be desirable because this is a correlational study, and we did not want to narrowly restrict the range of measured threshold values.

Testing was divided into two parts: (1) spatial contrast sensitivity testing, and (2) the measurement of contrast thresholds for real-world targets. The order of presentation of these tests was counterbalanced across subjects. Each subject gave written informed consent before testing was begun.

CONTRAST SENSITIVITY TESTING

Contrast sensitivity was measured for a series of vertical, sinusoidal gratings of the following spatial frequencies: 0·5, 1, 3, 6, 11·4, 22·8 cycles/degree (c/deg). Gratings were stationary. These patterns were generated by a CS2000 contrast sensitivity system (Nicolet) and displayed on a television monitor. Mean luminance of the screen remained constant at 100 cd/m^2 during testing; surround luminance was 5 cd/m^2. Maximum contrast of the gratings was 0·50. The display subtended a visual angle of 4·2×5·5° at a viewing distance of 3 m.

Contrast thresholds for each spatial frequency were measured by a method of increasing contrast which was under computer control. Prior to the actual testing for a specific spatial frequency the patients were shown a suprathreshold preview of the grating they would subsequently be tested for. During the threshold measurement task, gratings were initially presented at a randomly determined, near-zero, subthreshold contrast, and then contrast was gradually increased. The patient was asked to push a button when the grating first became visible. After doing so, contrast returned to a randomly determined subthreshold level, and a new trial began. Eight thresholds were measured for each spatial frequency. Threshold performance was defined as the geometric mean of these eight thresholds. Before any testing began we insured that patients understood the task by giving them practice at 0·5 c/deg and 6 c/deg. Since we were interested in the patients' performance under normal, everyday circumstances, they viewed targets binocularly with their habitual correction during contrast sensitivity testing and also during the task to be described below.

CONTRAST THRESHOLDS FOR REAL-WORLD TARGETS

Contrast thresholds were also measured for what we will refer to as 'real-world' targets. These targets were depicted on slides and were of three types: faces, road signs, and commonplace objects. Targets were relatively large, subtending from 4 to 6° of visual angle, and had an average luminance of 20 cd/m^2. Surrounding luminance was 5 cd/m^2.

The face targets were pictures of famous people, such as politicians and individuals in the entertainment media. The road signs were selected from the Alabama Motor Vehicle Study Book for drivers and consisted of frequently used signs such as the stop sign, pedestrian sign, and speed limit sign. The commonplace object targets consisted of objects fairly typical of our environment such as a lamp, a coffee cup, and a bicycle. Ten targets of each type were presented to patients.

Slides of these targets were projected through an optical system which allowed the subject to adjust the contrast of the target's image. This projection system, similar to one used in our earlier work,[6] consisted of two slide projectors (Kodak Ektagraphic) positioned so that their beams travelled through a beam splitter, and then combined on a rear-projection screen (Plexicat). Fixed linear polarisers were positioned in front of each projector but were in orthogonal positions. One projector contained the target slide; the other projector had no slide, only an open aperture. Neutral density filters were used to equalise the luminance of the two projectors. Another polariser intersected the combined beams before they reached the screen. This polariser could be rotated via a step motor and allowed us to control the amount of light which came from each of the two slide projectors. In this fashion the contrast of the image could be varied from zero contrast to 0·90. Within this range the contrast varied linearly with the position of the polariser. The mean luminance of the target remained approximately constant regardless of changes in contrast.

The patient sat 2 m from the rear-projection screen. Viewing was binocular. Each target was initially presented at a randomly determined, near-zero, subthreshold contrast. The patient's first task was to increase the contrast of the target until 'something was just detectable on the screen'. The patient did so by pressing a button which was connected to the step motor's controller. The experimenter recorded the controller's digital read-out which indicated the position of the rotating polariser. (Each read-out value corresponded to a particular contrast level.) The subject was then asked to continue to increase the contrast of the target until he/she could identify the target. Thus for each slide we measured a detection threshold and an identification threshold. This threshold measurement procedure was carried out for each of 10 slides in each target type (faces, signs, objects). A patient's detection performances and identification for each target type were represented as the mean of the contrast thresholds for the 10 slides of that type.

Since we measured threshold for identification, we had to ensure that all targets were familiar to each patient before testing began. Prior to testing, the patients were asked to identify a large set of pictures of faces and road signs. We noted which ones were identified correctly, and then a subset of those were included in the threshold measurement procedure. We assumed that all patients would be familiar with the commonplace objects we selected for threshold testing, since they were items frequently encountered in daily life.

Results

Fig. 1 is a log plot of mean contrast sensitivity as a function of spatial frequency. In order to display the data in some meaningful fashion we have graphed a separate function for each of three age groups—20–39 years, 40–59 years, and 60 years and over. Contrast sensitivity is defined as the reciprocal of contrast threshold.

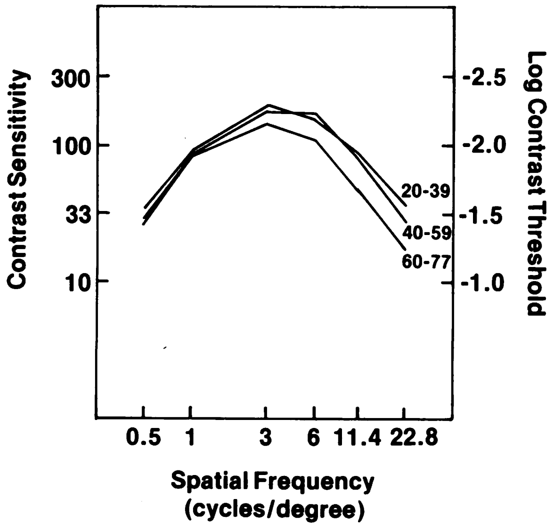

Fig. 1 *Mean contrast sensitivity as a function of spatial frequency. Results are plotted separately for the three age groups: 20–39 years, 40–59, and 60 and over.*

Sensitivity for the young and middle-aged patients was very similar, but the older age group had decreased sensitivity at intermediate and high spatial frequencies (at 6 c/deg, $F(5,87)=3{\cdot}54$, $p=0{\cdot}0058$; at 11·4 c/deg, $F(5,87)=5{\cdot}91$, $p=0{\cdot}0001$; at 22·8 c/deg, $F(5,87)=6{\cdot}66$, $p<0{\cdot}0001$). This general trend of a middle-to-high spatial frequency loss with increasing age during adulthood is in agreement with earlier work.[7-10] However, it is important to note that in the present study we have confounded the age variable with disease. That is, there was no attempt to exclude subjects of any age who had ocular disease, because, since this was a correlational study, we were interested in recruiting a sample with a wide range of visual threshold levels. Thus, these data are not strictly comparable to those from our earlier work on contrast sensitivity,[7] where we examined the effects of biological aging by carefully controlling variables such as disease and refractive error.

Fig. 2 displays how log contrast thresholds for detection and identification of real-world targets varied as a function of age. Panel A shows the results for the face targets, panel B for the sign targets, and panel C for the object targets. Fig. 2 illustrates that both detection and identification thresholds increase with increasing age in our sample (face detection, $F(5,88)=5{\cdot}53$, $p=0{\cdot}0002$; face identification, $F(5,88)=6{\cdot}39$, $p<0{\cdot}0001$; sign detection, $F(5,88)=8{\cdot}70$, $p<0{\cdot}0001$; sign identification, $F(5,88)=5{\cdot}06$, $p=0{\cdot}0004$; object detection, $F(5,88)=5{\cdot}89$, $p=0{\cdot}0001$; object identification, $F(5,88)=9{\cdot}50$, $p<0{\cdot}0001$).

MULTIPLE REGRESSION ANALYSES

The major question posed in this study is whether spatial contrast sensitivity measured in a clinic based sample can predict patients' contrast thresholds for real-world targets. To address this question we performed a stepwise multiple regression analysis (forward and backward stepping) on each dependent variable. This type of analysis reveals which independent variables best predict the obtained data. Table 2 lists the predictor (independent) variables that we evaluated. These variables included contrast threshold for each of the tested spatial frequencies (0·5, 1, 3, 6, 11·4, 22·8 c/deg). In addition two further variables were evaluated as predictors: acuity, since it is the traditional measure of pattern vision, and chronological age, since it is a readily available piece of information obtained when examining a patient. As discussed earlier, detection and identification contrast thresholds were measured for each of three types of targets—faces, road signs, and objects. We

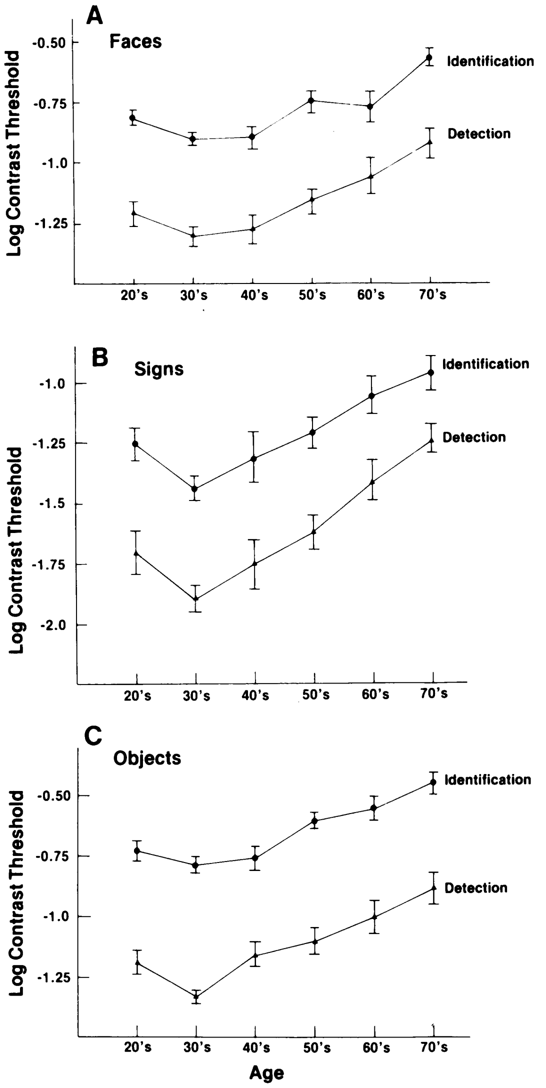

Fig. 2 *Mean contrast thresholds for detection and identification of real-world targets, plotted as a function of age. Panel A shows the results for face targets; panel B for signs; panel C for objects. Vertical bars indicate two standard errors above and below the mean.*

Table 2 *Independent variables evaluated*

Contrast threshold at:
0·5 c/deg
1·0 c/deg
3·0 c/deg
6·0 c/deg
11·4 c/deg
22·8 c/deg
Letter acuity
Age

therefore performed six separate multiple regression analyses to evaluate how effectively the independent variables listed in Table 2 predict each of the six dependent variables.

Table 3 lists the best-fitting model for each dependent variable. These are the models that emerged from a forward stepping technique in the regression analysis. (Backward stepping generated similar results.) The independent variables in each model are listed in order of their entry into the model. Also listed is R^2, the percentage of variance in the data accounted for by each model. If an independent variable is not listed as a part of the model, the inclusion of that variable in the model did not significantly improve the model as indicated by the F ratio (α=0·05 significance level).

There are a few important points to highlight. First, in the case of almost every dependent variable, 6 c/deg and age were the best predictors of contrast thresholds for the real-world targets. Adding further independent variables, such as higher or lower spatial frequencies did not significantly improve the model. The only exception to this general trend was the model for face detection, where age and lower spatial frequencies were the predictor variables. Secondly, a significant portion of the variance in each threshold task was accounted for by these models, ranging from 25% to 40% of the variance.

Thirdly, what is striking about these models is that they do not include acuity as a predictor, even though acuity is traditionally viewed as an important piece of information when assessing a patient's pattern vision. As displayed in Table 4, acuity did significantly correlate with all six of our contrast threshold measures for real-world targets. More specifically, poor acuity was associated with higher contrast thresholds. The question then is, why does acuity not appear as a predictor variable? It is important to note

Table 3 *Best-fitting model for each dependent variable*

Dependent variable	*Independent variable*	*R^2 for model*
Face detection	Age 3 c/deg 0·5 c/deg	0·29
Face identification	6 c/deg Age	0·25
Sign detection	6 c/deg Age	0·40
Sign identification	6 c/deg Age	0·30
Object detection	Age 6 c/deg	0·28
Object identification	Age 6 c/deg	0·40

Table 4 *Correlation between acuity and various dependent variables*

Dependent variables	*r*
Face detection	0·27
Face identification	0·31
Sign detection	0·38
Sign identification	0·28
Object detection	0·34
Object identification	0·41

Critical r (2-tailed, α=0·05)=0·21.

Table 5 *Best-fitting model for each dependent variable with age omitted as independent variable*

Dependent variable	*Independent variable*	R^2 *for model*
Face detection	3 c/deg 0·5 c/deg	0·19
Face identification	6 c/deg	0·18
Sign detection	6 c/deg Acuity	0·32
Sign identification	6 c/deg	0·25
Object detection	6 c/deg Acuity	0·21
Object identification	6 c/deg Acuity	0·31

that acuity is also highly correlated with age (r=0·54), which was an important predictor variable in the best-fitting models. It could be that once age has entered into the model, acuity adds very little additional information. Acuity may account for little variance beyond that already accounted for by the age factor. To evaluate this possibility we repeated the regression analyses on all six threshold measures for the real-world targets, but this time age was omitted as an independent variable. The best-fitting models emerging from these analyses are listed in Table 5. The general result was that acuity did emerge as a significant predictor in three out of the six threshold tasks, but it was never the first predictor (which was usually 6 c/deg). Furthermore, the models where acuity was forced into the model by excluding age as an independent variable accounted for less variance on average (24%) than the models which incorporated age as a predictor (32%).

Discussion

The results of this study indicate that spatial contrast sensitivity predicts whether patients are likely to have difficulty in seeing visual targets typical of everyday experience. In our study, if a patient had decreased sensitivity at middle-to-low spatial frequencies, that patient was also likely to have a decreased ability to see faces, road signs, and commonplace objects. It is important to note that the actual spatial frequency range which best predicts sensitivity for a real world target is likely to depend on the angular subtense (and thereby its spatial frequency content) of the real-world target in question. If our targets had smaller or larger visual angles (corresponding to greater or closer viewing distances in the real world), the spatial frequency range which best predicts their visibility would most likely be different than that reported here. The crucial point, however, is that spatial contrast sensitivity does systematically relate to the visibility of real-world targets such as those used in the present study. Clinicians can take advantage of this relationship by using contrast sensitivity testing to predict better the visual problems their patients are likely to encounter outside the clinic.

Since it was not the purpose of this study to identify the specific spatial frequencies involved in face perception, the spectral content of our stimuli were not measured. However, previous research has shown that lower spatial frequencies have a crucial role in face detection, while higher spatial frequencies are important in facilitating face identification.[11-13] Our data are consistent with this earlier work in that the best spatial-frequency predictors in face detection were 3 and 0·5 c/deg, whereas 6 c/deg was the best predictor in face identification.

In both the contrast sensitivity task and the threshold task for real-world targets, older adults tended on average to have higher thresholds than those of young adults. There has been some suggestion in the gerontological literature[14] that older adults may be more cautious in their responses to perceptual stimuli. In a psychophysical experiment this contention could be characterised in terms of an older person possibly having a more conservative criterion for stating that a sensory signal is present. Thus in this view higher thresholds in older adults may be due to cautiousness in responding rather than to a real visibility problem. For the following reasons we believe that it is doubtful whether the age-related declines in sensitivity in the present work can be accounted for in this fashion. First, in regard to age-related changes in the spatial CSF, the higher spatial frequency loss in older adults reported here has also been reported in other studies using several different psychophysical methods,[7-9 15] including a study using a criterion-free, forced-choice procedure.[10] Secondly, as regards the threshold measurement procedure for real-world targets, an earlier study[6] on age-related changes in face perception, using the same methodology as the present study, indicated that criterion effects had no role in older adults' elevated thresholds. This implies that the present results, generated through the same procedure, are not due to criterion differences between young and older adults.

The contrast sensitivity levels in the grating task are for the most part higher than those for the real-world target task. This is probably due to a combination of factors, such as lower target luminance for the real-world targets, the periodicity and simplicity of the sinewave gratings, and the 'preview' grating before threshold measurement in the grating task (which presumably reduced the observer's uncertainty about the test target).

It is interesting that chronological age by itself was a powerful predictor of patients' thresholds for real-world targets. It is true that, in terms of the experimental design of the present study, age is confounded with disease, since patients were not excluded on the basis of diagnosis. Yet it is important to note that our study indicates that a patient's age can be at least as important in predicting some visual problems as are more complicated clinical measurements. However, further regression analyses indicated that, even within a single age group, contrast sensitivity can identify patients who have difficulty seeing real-world targets, implying that age by itself is certainly not sufficient information for the diagnosis of contrast sensitivity problems.

Although acuity was significantly correlated with contrast thresholds for real-world targets, the inclusion of acuity as a predictor variable did not significantly enhance the model. This finding is in agreement with the increasing number of studies which indicate that acuity often fails to predict the day-to-day visual problems patients face.[6 16 17] Acuity measurements are particularly useful in carrying out refraction and in identifying difficulties in seeing detail, but much of our routine visual activity involves the detection and discrimination of larger objects in our environment. Spatial contrast sensitivity testing appears to be more useful to clinicians in identifying these latter problems.

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