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An Anticipated Threshold Technique for Measuring Contrast Sensitivity

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ABSTRACT

A new psychophysical procedure for assessing contrast sensitivity rapidly and reliably is reported. The technique consists of increasing the contrast of a conventional sine wave grating according to the parameters set in a computer implemented algorithm. During the first half of a trial, the contrast increases quickly to a point just below an expected threshold, and in the second stage the contrast increases slowly until a threshold is reached. Details and advantages of the algorithm are presented as well as a comparison of data generated by this and other techniques.

Key Words: contrast sensitivity measurement, clinical diagnosis, psychophysical technique

Many psychophysical procedures exist that can be used to assess contrast sensitivity. Two alternative forced choice tasks, the method of limits and the method of constant stimuli, have often been used, but the most widespread technique for measuring contrast sensitivity seems to be the method of adjustment. With this procedure an observer manipulates the contrast of a grating until it is just visible (during an ascending trial), or just disappears (during a descending trial). Although this method has the advantage of speed, it requires observers to be highly experienced in order for stable data to be obtained.[1]

The assessment of contrast sensitivity in clinical populations has placed additional constraints on the utility of many of the classical procedures. For example, most patients are inexperienced psychophysical observers and are unlikely to give stable data if the method of adjustment is used. Also, physical disabilities, fatigue, and short attention spans necessitate the use of rapid psychophysical procedures with simply mastered task demands. Arden and Jacobson[2] have recently proposed a method that involves the presentation of photographic plates to an observer. Each plate contains a sine wave grating of a given spatial frequency whose contrast increases from top to bottom. The experimenter or clinician simply moves a card over the plate, systematically exposing higher contrasts, until the observer or patient reports the presence of a grating. Repeating this procedure at various spatial frequencies (i.e., a number of plates) allows the experimenter to plot the observer's contrast sensitivity function (CSF).

Dobson and Davison[3] describe a related technique in which a range of spatial frequencies is displayed across the face of a cathode ray tube. In this case the contrast increases logarithmically from the top to the screen. For the few cycles of each spatial frequency displayed, the observer is asked to adjust the swept contrast so that it is at a threshold level at midscreen.

Both of these procedures present simple tasks to the observer and provide a rapid assessment of a CSF. However, it is not clear to what extent these two techniques can generate data that are comparable to each other, or comparable to data collected with more conventional grating stimuli. In the conventional display a grating is presented whose contrast is uniform within the entire viewing area. In both of these procedures the amount of the grating that is actually at a

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threshold level of contrast represents only a small proportion of the total height of the display. However, it has been reported[4,5] that the height of a grating can directly influence contrast sensitivity. In addition, Dobson and Davison's[3] technique presents only a limited number of bars at each spatial frequency, a factor that is also known to affect contrast sensitivity.[6,7] In fact, data collected on the same subject with both a conventional method and that suggested by Dobson and Davison do not agree over the full curve, differing significantly in the low and middle spatial frequency range. Although the inability to precisely compare data across techniques is not always a fatal flaw, it does present a problem for the experimenter or clinician who may want to compare his or her results with those obtained by a colleague who used a different technique. That is, discrepant conclusions about a patient's condition may be reached artifactually due to the use of different procedures for assessing contrast sensitivity.

Sekuler and Tynan[8] have proposed a technique making use of a conventional grating stimulus that uses a computer-implemented algorithm to assess the CSF. The algorithm is based upon a procedure suggested by Békésy[9] for use in audition, but that has been adapted and optimized for the rapid assessment of contrast sensitivity.

This method entails the presentation of a suprathreshold grating whose contrast is decreased in fixed steps. The observer's task is to press a button as long as the grating is visible. When the button is released, the contrast of the grating increases in fixed steps until the button is again pressed. This continues for about 1 min at which time the spatial frequency of the grating is doubled and the task begins again.

The procedure is rapid, easy, and does not suffer from the problems associated with the presentation of an unconventional display. Furthermore, by allowing an observer to see the grating at the beginning of a block of trials, a degree of spatial certainty is introduced which should serve to maximize sensitivity.[10] Yet, this very exposure and the fact that the grating is above threshold during half of the testing period may result in a small but systematic decrease in sensitivity over time. This is because threshold elevation can be induced by low contrast gratings,[11] even as low as 1%.[12] The severity of this problem will, in part, depend upon the average reaction time of the observer.

The method that we are proposing is also implemented on a computer, is rapid, and presents an observer with an easy task. Unlike the Sekuler and Tynan[8] technique, the algorithm to be described: (1) exposes an observer to only threshold level gratings, (2) allows the observer to become familiar with the grating on two practice trials per spatial frequency, (3) introduces a degree of temporal certainty by allowing a threshold level of contrast to be reached at approximately the same time within each trial, and (4) passes through the threshold region as slowly as possible.

The algorithm achieves these ends by maintaining a weighted average of the thresholds assessed on previous trials, or with respect to an initial estimate on the first trial. Beginning at a contrast of zero, the computer increases the contrast of the grating toward the estimated value in two stages (Fig. 1). During the first half of a trial the contrast rises rapidly to a point just below the expected threshold, and in the latter half of the trial it rises more gradually. On each successive trial, the difference between the rate of contrast increase during the two phases becomes greater, with the rate of change through the threshold region slowing down.

A disadvantage that this method shares with most others is that expectancies associated with spatial and/or temporal cues can influence responding. It is conceivable that with our technique an observer could base a response upon knowledge about when the grating should appear, rather than upon detection of the grating per se. This could result in artificially low standard errors. However, there are precautions that can be taken. They include the introduction of catch trials (i.e., trials on which no grating is displayed) that will allow the assessment of a false alarm rate, and presenting a variable interval between a warning tone and the beginning of a trial. The use of these practices will increase the length of a testing session, but with proper control over the parameters of the algorithm it

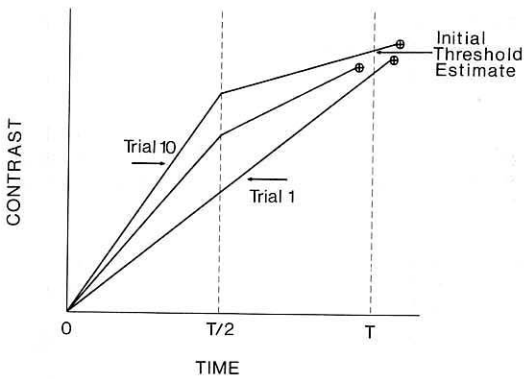

FIG. 1. Examples of how contrast increases in time for a number of trials. T, the expected duration of the trial.

should still take no more than 6 or 7 min to assess a six-point CSF.

The following equations describe how the change in contrast for each half of a trial is calculated. The starting contrast value for the first phase, a_1, is always zero, and:

$$b_1 = s(n)\hat{t}(n)/(T/2) \quad (1)$$

where b_1 is the slope of the first phase, T is the expected duration of a trial (i.e., the time at which the anticipated threshold is reached), s(n) is the proportion of the anticipated threshold to be reached at T/2 (half the expected duration of the trial), and $\hat{t}(n)$ is the estimated threshold to be reached at time T on trial n. Calculation of s(n) and $\hat{t}(n)$ is accomplished with the use of equations 2 and 3, respectively:

$$s(n) = 0.4 + 0.1 \sum_{i=1}^{n} p^{i-1} \quad (2)$$

where p is the factor by which b_1 increases on each trial and is usually set to 0.75 so that the midpoint contrast asymptotically approaches 80% of the anticipated threshold. On trial 1, s(1) is always 0.5 so that the contrast will reach half of its anticipated final value at the midpoint (T/2). For trial 1, therefore, and only for trial 1, the contrast will rise linearly throughout (Fig. 1). The anticipated contrast is given by:

$$\hat{t}(n) = (2\hat{t}(n-1) + t(n-1))/3 \quad (3)$$

where $t(n-1)$ is the actual contrast threshold on the previous trial, or equal to the estimate when n = 1. It should be noted that by giving greater weight to the running average threshold than to the actual threshold from the previous trial, the influence of an aberrant response is minimized. This serves to prevent the algorithm from locking an observer into a range of contrasts that is artifactually high or low.

The initial contrast value for the second phase, a_2, is necessarily the final contrast value of the first phase at T/2:

$$a_2 = s(n)\hat{t}(n) \quad (4)$$

and the slope of the second phase, b_2, is calculated as follows:

$$b_2 = (1 - s(n))\hat{t}(n)/(T/2) \quad (5)$$

We have implemented the algorithm on minicomputers (PDP11/10 and PDP11/34) that were interfaced, through digital to analog converters, to function generators in order to produce a stationary sine wave grating on a cathode ray tube.[13] Fig. 2 shows data collected from a multiple sclerosis patient, an inexperienced control observer, and an experienced control observer[14] with variability around each datum point expressed as ±1 standard error. Seven trials were run per spatial frequency with the first two considered practice trials. Hence, each datum point represents the geometric mean of the last five trials.

Table 1 presents SD's from a number of studies using various psychophysical techniques for assessing contrast sensitivity. No variability

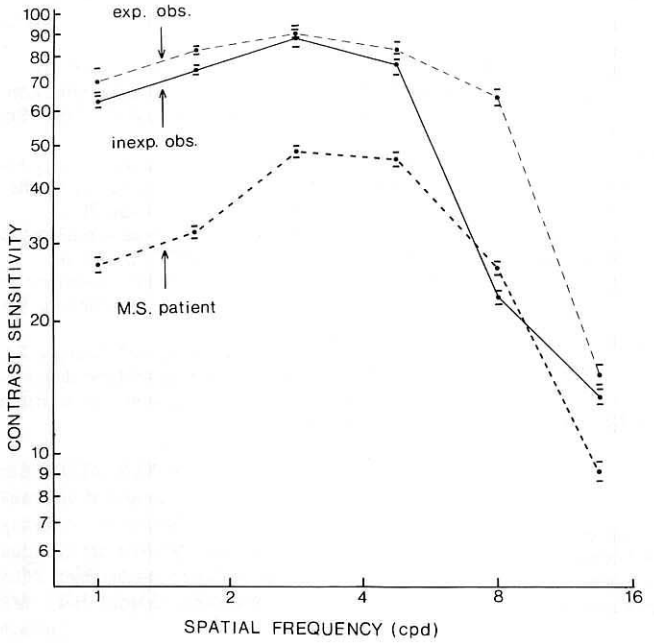

FIG. 2. Data generated by the anticipated threshold method for one experienced psychophysical observer, one inexperienced observer, and one multiple sclerosis patient. Bars around the data points represent ±1 standard error.

TABLE 1. A comparison of log SD's from a number of methods and a variety of studies.

Study	Method	Observers	Log SD
Blakemore and Campbell[11] (Fig. 5)	Adjustment	1 Experienced	0.08
Burton[16] (Fig. 3)	Adjustment	1 Experienced	0.06
Bradley and Freeman[17] (Fig. 1)	Adjustment	4 Naive	0.17
Regan et al.[18] (Fig. 3A)	Limits	1 MS[a] patient	0.19
Brussell et al.[14]	Ant. thresh.[b]	2 Experienced	0.04
	Ant. thresh.[b]	3 Naive	0.06
Brussell et al.[14]	Ant. thresh.[b]	5 MS[a] patients	0.04
Brussell et al.[14]			

[a] Multiple sclerosis.
[b] Anticipated threshold.

data is available for the newer procedures mentioned earlier,[2,3] but for the method of adjustment and methods of limits there is a distinct difference in variability between experienced and naive observers (about a factor of 2). The anticipated threshold method does not show any difference between experienced and naive observers and consistently gives more stable measures than the other two methods.

It should be noted that use of the anticipated threshold method is not always appropriate when the threshold for a flickering grating is to be measured. The reason is that a number of temporal cycles must be allowed to stimulate the eye before any change in contrast is implemented. For low temporal frequencies the rapidity of the technique, which is based upon a continuous change in contrast over time, would therefore be undermined. With the exception of this constraint, which applies to any flickering stimulus, the technique we have proposed is not restricted to the grating detection paradigm. It has been used when an observer's task was to discriminate whether a rectangular grating contained wide white or wide black bars,[15] and is applicable to any paradigm and stimulus configuration for which the classicial psychophysical techniques are considered appropriate.

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REFERENCES

1. Kelly DH, Savoie RE. A study of sine-wave sensitivity by two psychophysical methods. Percept Psychophys 1973;14:313–8.
2. Arden GB, Jacobson JJ. A simple grating test for contrast sensitivity: preliminary results indicate value in screening for glaucoma. Invest Ophthalmol Vis Sci 1978;17:23–32.
3. Dobson JS, Davison PA. A new rapid test of contrast sensitivity function utilizing spatial bandwidth equalization. Invest Ophthalmol Vis Sci 1980; 19:213–7.
4. Howell ER, Hess RF. The functional area for summation to threshold for sinusoidal gratings. Vision Res 1978;18:369–74.
5. Wright MJ. Contrast sensitivity and adaptation as a function of grating length. Vision Res 1982;22:139–49.
6. Savoy RL, McCann JJ. Visibility of low-spatial-frequency sine-wave tragets: dependence on number of cycles. J Opt Soc Am 1975;65:343–50.
7. Estévez O, Cavonius CR. Low frequency attenuation in the detection of gratings: sorting out the artefacts. Vision Res 1976;16:497–500.
8. Sekuler R, Tynan P. Rapid measurement of contrast sensitivity functions. Am J Optom Physiol Opt 1977;54:573–5.
9. Békésy GV. A new audiometer. Acta Otolaryngol (Stockh) 1947;35:411–22.
10. Cohen TE, Lasley DJ. Detectability of a luminance increment: effect of spatial uncertainty. J Opt Soc Am 1974;64:1715–9.
11. Blakemore C, Campbell FW. On the existence of neurones in the human visual system selectively sensitive to the orientation and size of retinal images. J Physiol (Lond) 1969;203:237–60.
12. Swift DJ, Smith RA. An action spectrum for spatial-frequency adaptation. Vision Res 1982;22:235–46.
13. Campbell FW, Green DG. Optical and retinal factors affecting visual resolution. J Physiol (Lond) 1965;181:576–93.
14. Brussell EM, White CW, Mustillo P, Overbury O. Multiple sclerosis only indirectly affects spatial contrast sensitivity. Invest Ophthalmol Vis Sci 1982;22:224.
15. Cavanagh P, Brussell EM, Coupland S. Spatial frequency characteristics of discrimination mechanisms. Invest Ophthalmol Vis Sci 1980;20:44.
16. Burton GJ. Visual detection of patterns periodic in two dimensions. Vision Res 1976;16:991–8.
17. Bradley A, Freeman RD. Contrast sensitivity in anisometropic amplyopia. Invest Ophthalmol Vis Sci 1981;21:467–76.
18. Regan D, Raymond J, Ginsburg AP, Murray TJ. Contrast sensitivity, visual acuity and the discrimination of Snellen letters in multiple sclerosis. Brain 1981;104:333–50.

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