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VOLUME IV

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Canadian Forces evaluation of contrast sensitivity for measuring visual capability DCIEM No. 90-53

Abstract DCIEM has carried out several studies to examine the suitability of contrast sensitivity for assessing the visual capability of military personnel. The studies include evaluations of different methods of assessing contrast sensitivity, the establishment of norms for aircrew candidates, and evaluations of the relationship between contrast sensitivity and performance on military tasks involving vision. This paper reviews briefly the results of these studies, most of which have been published elsewhere. The results are integrated into a cohesive statement on the measurement of contrast sensitivity in a military population and the minor role that contrast sensitivity tests, in their present state of development, might play in assessing visual ability.

Throughout the Canadian Forces (CF), there has been increasing pressure to use selection criteria that are relevant to the tasks undertaken by personnel. In many tasks, good vision is an essential requirement. Current visual tests used in the CF assess primarily the ability to recognize high-contrast letters and patterns. However, many of the visual tasks carried out by military personnel such as pilots, lookouts and radar and sonar operators involve the detection and recognition of different sizes of objects that are just visible. This discrepancy has resulted in considerable interest over the past few years in tests of contrast sensitivity that seem to provide a more comprehensive measure of visual capability.

Before a contrast sensitivity test can be used as a selection criterion, it is necessary to measure it reliably and efficiently and to determine its usefulness relative to existing measures. DCIEM has carried out several studies to examine the suitability of specific contrast sensitivity tests for assessing visual capability and visual performance. The primary emphasis has been on the assessment of different methods or tests of contrast sensitivity and the establishment of norms. In addition, some work has been carried out on the relationship between contrast sensitivity and performance on tasks carried out by military personnel in the CF.

Assessment of contrast sensitivity measures. Three different measures of contrast sensitivity were assessed. All of the assessments involved the collection of normative data and an evaluation of the suitability of the tests for the routine assessment of contrast sensitivity. The first assessment was carried out using a modified version of an Optronics CS2000, a microprocessor-controlled system with a CRT display, and the method of increasing contrast. The second study compared this system and method with the Vistech VCTS 6500 test charts. A third study compared the charts with the Optronics system using a two-interval forced choice (2IFC) methodology and an adaptive procedure. In addition, normative data were collected on a large sample of naval personnel using the Vistech VCTS 6500 charts.

In the first three studies, the subjects were aircrew candidates. Prior to final acceptance into aircrew training, all candidates undergo an extensive physical examination at DCIEM. The contrast sensitivity tests were given as a part of this test battery by the technicians carrying out the assessment. Thus, testing was carried out under conditions similar to those that would be used during routine testing. However, the candidates were informed that the results of the test were for research purposes only and would not be used in determining their acceptance for training. Since the candidates were only available for a short period of time, retesting was not possible. In compensation, a large number of subjects were tested. In addition, the population was relatively homogeneous, being composed primarily of males between the ages of 18 and 25 with normal visual acuity.

Evaluation of the CS2000 using the method of increasing contrast.

The initial assessment was carried out as a result of a Test Project Agreement (TPA 826-61) between the CF and the USAF under the auspices of Air Standardization Coordinating Committee Working Party 61. Under this agreement the USAF lent the CF a modified Optronics CS2000. The CS2000 allows the presentation of vertical sinewave gratings at prespecified spatial frequencies and contrasts. As delivered, contrast sensitivity was assessed using an increasing contrast methodology. It was similar to that available on the commercial version of the Optronics CS2000. However, some improvements such as randomizing the onset time of the stimuli had been added. At the beginning of a trial the grating was presented at 15% contrast for 3 seconds. The contrast was then reduced to zero and after a randomly determined period increased slowly until the subject pressed a button to indicate that a grating pattern was just visible on the screen.

Two hundred and ninety-seven aircrew candidates were tested binocularly at

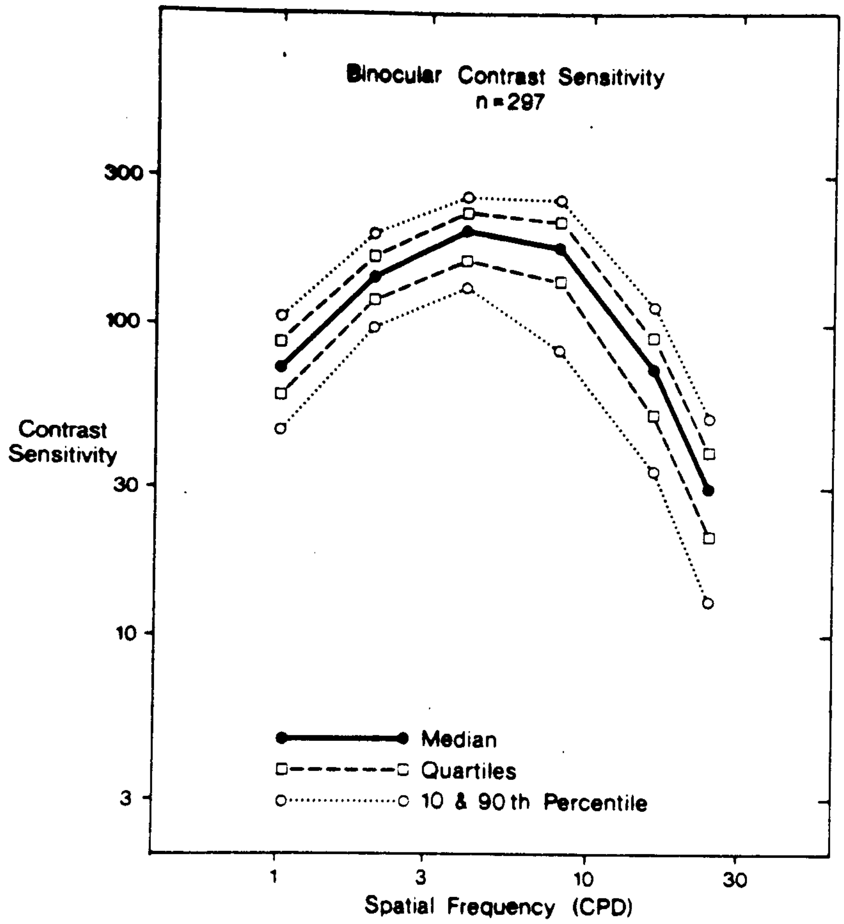

Figure 1: Binocular contrast sensitivity of 297 aircrew candidates. The curves show median, 75th, and 90th percentile points of the data.

six spatial frequencies of 1, 2, 4, 8, 16, and 24 cycles per degree (cpd). In addition, 56 of these subjects were tested monocularly. The sine wave grating pattern subtended 3 by 3.6 degrees of visual angle at the viewing distance of 265 centimetres. Further details of the the study can be found in DCIEM report 87-RR-04 (1).

The contrast sensitivity score of each subject at each spatial frequency was the mean of at least three estimates of the increasing contrast threshold. Figure 1 shows the median, 10th, 25th, 75th and 90th percentile points of the scores of all the subjects tested under the binocular condition. The medians have been reported to allow comparison with a previous study using the same system (2). In that study, the median contrast sensitivity was somewhat lower and the variability in the data was larger, especially at the lowest and highest spatial frequencies, than in the current study. This was not surprising given the characteristics of the population tested. More than 90% of the aircrew candidates had visual acuity of 6/6 or better and the average cycloplegic refraction was 0.4 diopters in each eye. The results of the monocular assessments were similar in form but thresholds were somewhat lower.

The main problem with the CS2000 test was the time that it took to carry it out. Ginsburg and his colleagues (2) reported that contrast sensitivity could be measured at six spatial frequencies in approximately twelve minutes. In our study, testing averaged thirty minutes. The test involved measuring three ascending thresholds at each frequency. If the variability amongst these three estimates was excessive, then further measures were taken. Typically, additional measurements were necessary because of the large variability in the original measures. It was felt that thirty minutes was too long for routine testing. In addition, there was some concern with subject bias. Despite the subjects' awareness that the test had no bearing on their acceptance, they appeared highly motivated. In some cases they responded before the contrast of the grating had started to increase.

<u>Comparison of the CS2000 using an increasing contrast method and the VCTS charts</u>

Based on the results of the first study, it was decided to examine an alternative test that would be potentially faster and simpler to administer and less susceptible to subject bias. The test chosen was the Vistech VCTS 6500 test charts. The charts consist of five rows of pictures of sinusoidal gratings. Each row is a different spatial frequency of 1.5, 3, 6, 12, and 18 cpd going from top to bottom. Contrast decreases

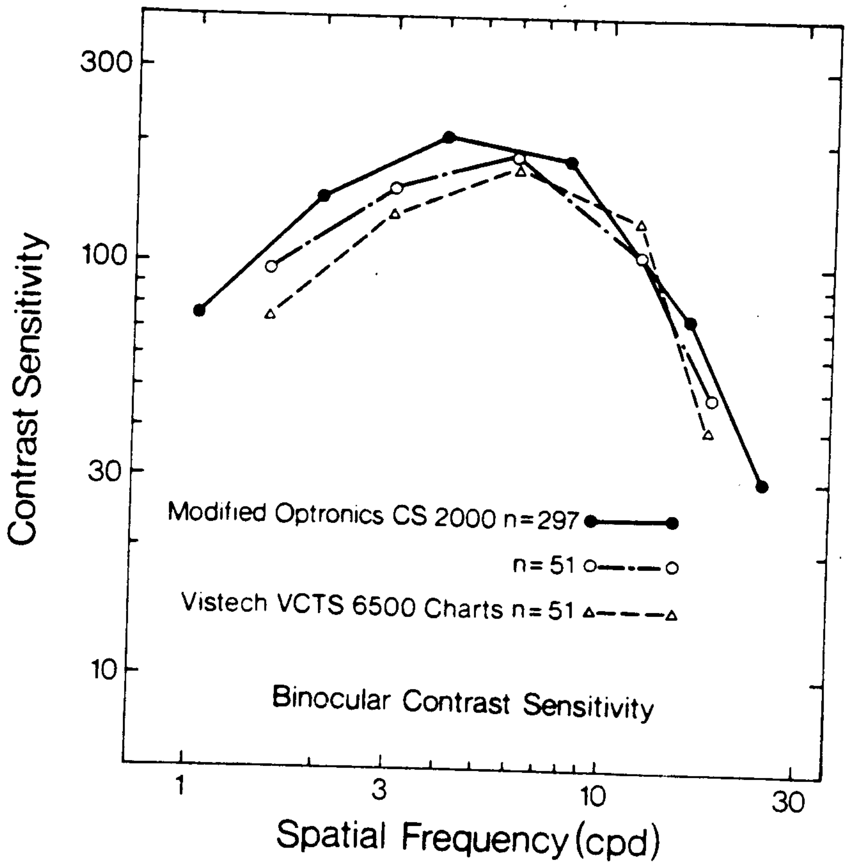

Figure 2: A comparison of the median binocular contrast sensitivity of a population of 297 aircrew candidates and a population of 51 aircrew candidates. The contrast sensitivity of the larger group was measured using the method of increasing contrast on a modified Optronics CS2000 and that of the smaller group with the CS2000 and with the Vistech VCTS 6500 charts.

across the first eight columns in approximately 0.28 $\log_e$ unit steps. The ninth column has zero contrast. The grating patterns are aligned -15, 0 or +15 degrees from vertical and subtend a visual angle of 1.4 degrees at a viewing distance of 305 centimetres.

Fifty-one subjects were tested binocularly and monocularly on the Vistech VCTS 6500 charts and on the Optronics CS2000 using the method of increasing contrast. The same method as in the previous study was used with the CS2000 except that the spatial frequencies were those available on the charts to simplify comparisons. The recommended procedure was followed with the charts. Subjects viewed the charts from a distance of 305 centimetres in a well-lit room and indicated the direction of tilt of each grating pattern. A different chart was used for the binocular and each of the monocular measures. The subject's score was the contrast of the grating to the left of the first grating for which either an incorrect or no response was given. Details of the method can be found in DCIEM Report 87-RR-51 (3).

The charts proved simple and quick to administer, making them reasonable for routine assessment. It typically took less than five minutes to explain the methodology and to assess contrast sensitivity on the charts as compared with twenty to thirty minutes with the CS2000 for binocular contrast sensitivity alone. As shown in Figure 2, the two systems appear to provide similar estimates of contrast sensitivity. Given the many differences in the methodologies and the stimuli for the two tests, larger differences between the results of the two tests might have been expected. For instance, fewer cycles are visible at each spatial frequency on the charts than on the CS2000. Previous studies have found that when less than ten cycles are presented, contrast sensitivity can vary with number of cycles shown (4). The small differences at 1.5 and 3 cpd could be due to this parameter.

The median contrast sensitivity of the aircrew candidates, as measured with the charts, was higher and less variable than the normative contrast sensitivity data provided with the charts. Median scores for the aircrew population were at the 90th percentile of the normative data provided with the system and the variance was typically smaller than the difference between two successive patterns (Table 1).

Given the high contrast sensitivity of the aircrew candidates, there was some concern that the range of contrasts on the charts was inadequate. If this were the case, we would have expected a significant proportion of the candidates to be able to correctly classify the lowest contrast pattern on the charts at all spatial frequencies.

Table 1. Log standard deviations of contrast sensitivity data for Vistech charts compared to the Optronics CS2000 using the methods of increasing contrast and 2IFC.

System	Spatial Frequencies				
	1.5	3.0	6.0	12.0	18.0
Vistech Charts (study 2)	0.25	0.15	0.16	0.26	0.22
CS2000 - Increasing contrast	0.26	0.21	0.35	0.44	0.49
Vistech Charts (study 3)	0.16	0.13	0.12	0.17	0.20
CS2000 - 2IFC	0.34	0.25	0.33	0.42	0.51

Figure 3 shows the percentage of aircrew candidates falling into each of the contrast sensitivity categories on the charts at each spatial frequency. Only at 12 cpd do a significant number of candidates correctly identify the lowest contrast level. Thus, for the majority of aircrew candidates, the charts should be adequate for at least an initial assessment of contrast sensitivity.

The small variability among the subjects on the other hand, could be of some importance. The aircrew candidates tested in this study met all the existing vision standards. To be useful, a contrast sensitivity test should differentiate amongst such people. Otherwise, it adds no new information. The current results suggest that contrast sensitivity, at least as measured by the Vistech charts, does not provide additional information. The reason could be the coarseness of the steps on the charts. However, repeated testing on the charts of a limited number of subjects has shown within-subject variability (5) of a similar magnitude to the between-subject variability found in this study.

One concern in the initial study using the method of increasing contrast was that an observer's performance might be affected by his or her criterion for visibility. The overall effect would be greater variance across observers than would be found with an objective test. The results for the charts provided a relatively objective estimate of contrast sensitivity against which to compare performance on the CS2000. As shown in Table 1, with the method of increasing contrast, the data at the upper three spatial frequencies were twice as variable as the data collected from the charts on the same subjects. However, an examination of individual results showed no evidence of systematic criterion effects among the observers. The contrast sensitivity of subjects was not consistently better or poorer on the one test than on the other. If there is a response bias operating with the increasing contrast method, it is not systematic within or across subjects.

<u>Comparison of the Optronics CS2000 with a 2IFC method and the Vistech charts</u>

While the charts appear adequate for an initial assessment of contrast sensitivity, their fixed format and small range of contrasts and spatial frequencies may limit their usefulness for detailed assessment of borderline cases and for studying the relationship between performance of aircrew on complex visual tasks and their contrast sensitivity scores. The Optronics system offers this flexibility. By using an

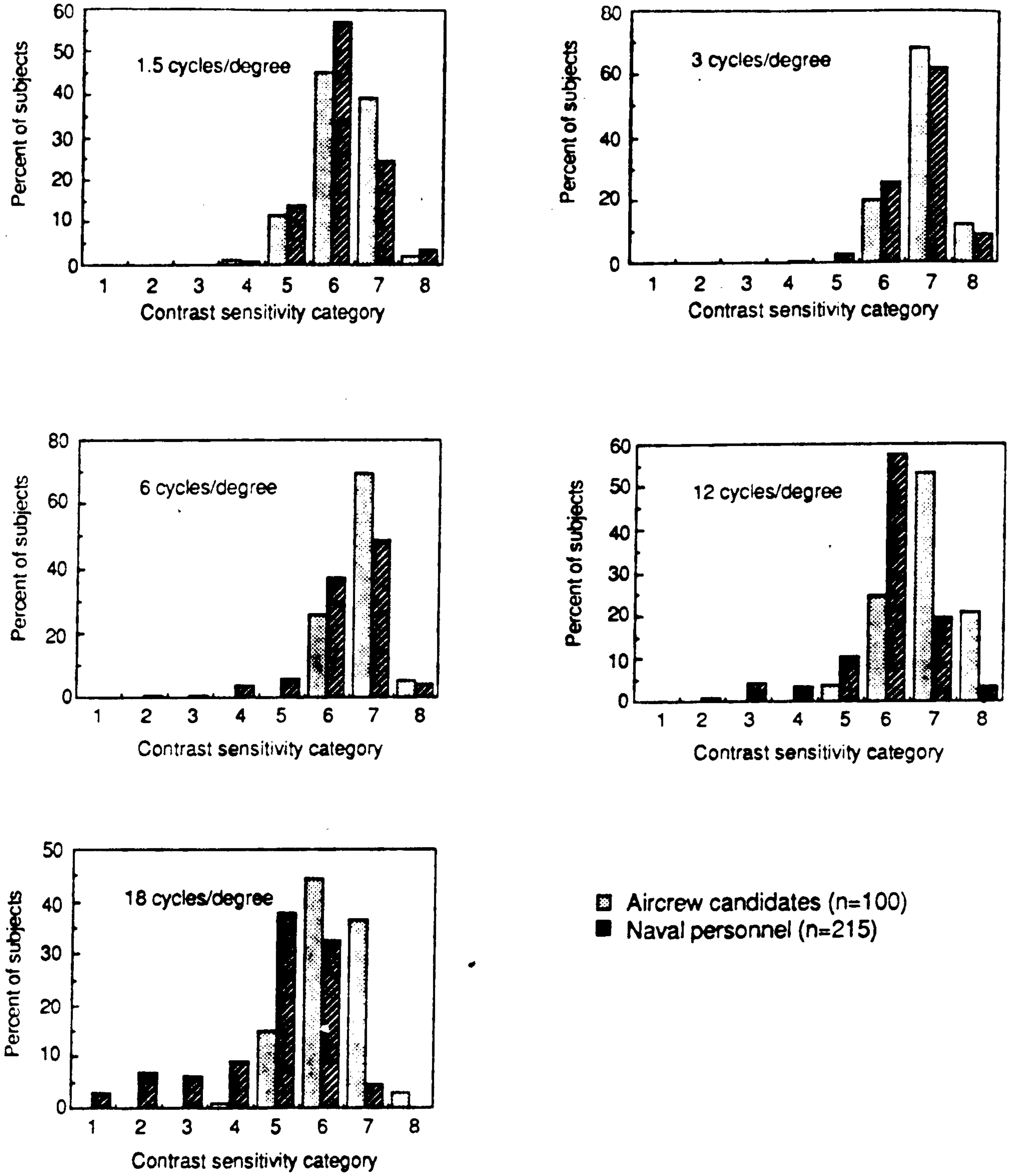

Figure 3: Summary of the binocular contrast sensitivity data at each spatial frequency collected on aircrew and naval personnel using the Vistech VCTS 6500 charts. The histograms show the percentage of observers falling into each category on the charts.

objective methodology on the CS2000, it is also possible to reduce the effects of observer bias.

The third study collected normative data on a two-interval forced choice test (2IFC) developed for the Optronics CS2000 at AAMRL (Armstrong Aerospace Medical Research Laboratory). The test presented a vertical grating pattern in one of two successive intervals at a specified spatial frequency. The duration and onset of the grating pattern, set by the experimenter, were 500 and 17 milliseconds, respectively. Threshold was determined by means of an adaptive procedure. Initially, the grating pattern was above threshold. Thereafter, contrast was lowered 2 dB (decibels) after 3 correct responses and increased 2 dB after each error. The run ended on completion of six reversals. Threshold was the average of the contrasts of the grating pattern at the six reversals.

In all other respects the method followed in this study was the same as that followed in the previous study. However, only binocular contrast sensitivity was measured. A total of 49 subjects were tested.

The results for the 2IFC test, shown in Figure 4 and Table 1, were unexpected. First, there were larger differences in the estimates of contrast sensitivity with the two tests at the 1.5, 3 and 6 cpd than in the previous study. Second, the variability with the 2IFC method was closer to that found with the method of increasing contrast than to that found with the charts. However, the results do appear to be consistent with existing knowledge of contrast sensitivity.

For different reasons, both the method of increasing contrast and the charts provide conservative estimates of contrast sensitivity. More cycles are visible on the CS2000 than on the charts. As discussed previously, this could result in lower thresholds on the CS2000 at the lower spatial frequencies. At the same time, a threshold based on detecting a stimulus that is increasing in visibility is usually higher than a threshold based on not being able to detect a stimulus decreasing in visibility. Since the adaptive procedure in the current study averaged across these two thresholds one might expect a threshold determined by this method to be lower than that found with the method of increasing contrast.

One problem with this second explanation is that the thresholds for all three tests were similar at the two highest spatial frequencies tested. This would suggest that other factors are affecting the results. One possibility is the use of discrete short

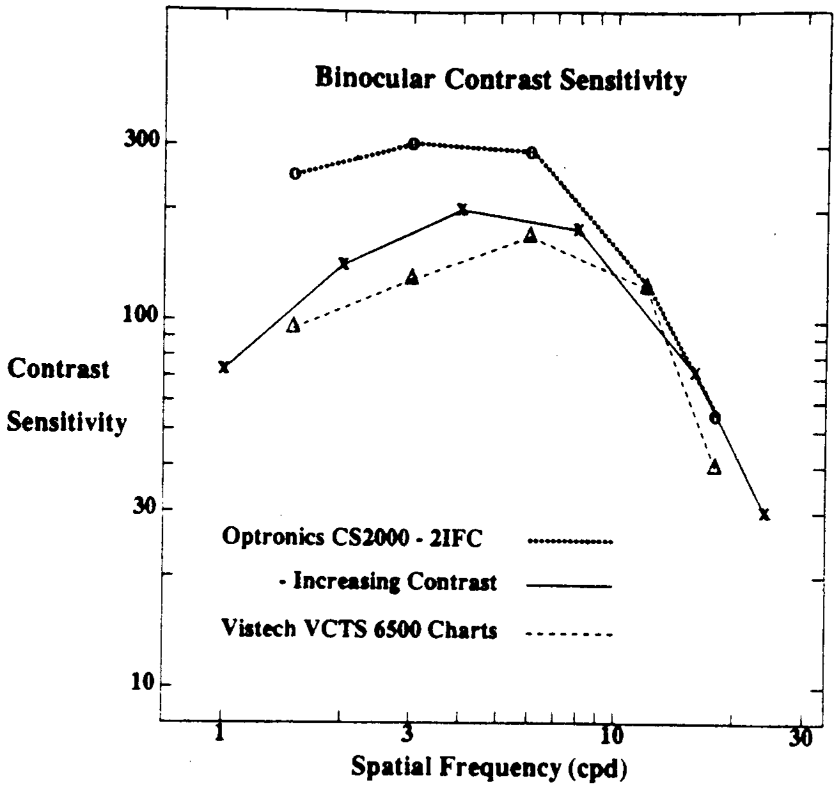

Figure 4: A comparison of the median binocular contrast sensitivity of a population of 297 aircrew candidates and a population of 49 aircrew candidates. The contrast sensitivity of the larger group was measured using the method of increasing contrast on a modified Optronics CS2000 and that of the smaller group with the CS2000 using a 2IFC method and with the Vistech VCTS 6500 charts.

duration stimuli in the 2IFC task. Previous studies (6,7) have found a flattening of the contrast sensitivity function at lower spatial frequencies when discrete rather than continuous stimuli are used.

The second unexpected result was the higher variance found with the 2IFC test than with the charts. In the previous study, it was suggested that the difference in the variance was due to variability in criterion across subjects with the method of increasing contrast. If this were the case, the variability for the two tests in the present study should have been similar, since they both used objective methodologies. These results suggest that the differences in variance were due to other factors. One possibility is that the increased variability was due to the fact that the stimuli were presented on a CRT. Alternatively, inexperience with the methodologies used on the Optronics system could have increased the variability in the scores. To date neither of these hypotheses has been evaluated.

The relatively large variability associated with the methods used on the Optronics system could have important implications for their use for clinical diagnosis and for predicting performance on more complex tasks. If the variance due to the test is greater or equal to the variance due to differences in contrast sensitivity, it may be difficult to compare scores on different tests or to compare estimates of contrast sensitivity with estimates of performance on more complex visual tasks.

Contrast sensitivity of naval personnel In addition to the data collected above, normative data have been collected on the Vistech charts on 215 naval personnel from a number of trades (8). The data were collected as part of a study investigating the usefulness of contrast sensitivity for predicting watchkeeping performance. Figure 3 compares these data with those of the aircrew candidates that participated in studies 2 and 3. Contrast sensitivity scores for the naval population were lower and covered a wider range of categories than the scores of the aircrew population at the high spatial frequencies (12 and 18 cpd). The increased sensitivity of aircrew candidates at the higher spatial frequencies may be a result of pre-selection based upon visual acuity measures and the smaller and younger age range tested in study 2. However, an age related change in contrast sensitivity was found only at 18 cpd. Similarly, there was only a weak correlation between contrast sensitivity at 18 cpd and the vision standards (based primarily on visual acuity) of the naval personnel.

In general, this last set of results suggests that the normative data for aircrew candidates may not be used for other trades and that the lack of variability in the data for that population may be an anomaly. Thus, any conclusions about the usefulness of contrast sensitivity for assessing the visual capability of aircrew cannot necessarily be applied to other trades or populations.

Usefulness of contrast sensitivity Most of the applied work on contrast sensitivity has concentrated on assessing its value for clinical diagnosis and for predicting performance on complex displays. The results of the clinical studies are reasonably consistent. Usually, individuals with visual disorders show abnormal contrast sensitivity functions with sensitivity reduced at one or more spatial frequencies. Abnormal functions have been found in individuals suffering from cerebral lesions (9), multiple sclerosis (10), retinitis pigmentosis and central serous retinopathy (11) for example.

The results of studies comparing performance on complex visual tasks and contrast sensitivity are less consistent. Some studies have found a relationship between contrast sensitivity and a pilot's ability to detect approaching aircraft (12,13), a driver's ability to detect road signs (14), and an observer's ability to classify tanks and human forms against complex backgrounds (15). Other studies investigating similar parameters have found no relationship between performance on these types of tasks and contrast sensitivity (16-19).

At DCIEM, research on the usefulness of contrast sensitivity has concentrated on its value in predicting performance on more complex tasks. For the most part, the results have been consistent with those studies that find little or no relationship. An exception was the study discussed in the previous paper that found that contrast sensitivity at higher spatial frequencies (12 and 18 cpd), as measured by the VISTECH charts, was related to the detection of crash sites in a simulated air to ground search task (20).

In contrast, a study with naval personnel found no correlation between contrast sensitivity and watchkeeping ability. The purpose of this study was to investigate possible changes in contrast sensitivity due to normal watchkeeping tasks and to evaluate contrast sensitivity as a potential predictor of visual watchkeeping ability. A bridge watchkeeper's primary task is to spot and maintain sight of contacts that appear on the waters or in the air surrounding the ship. The operations room watchkeeper's primary task is to spot and maintain sight of contacts that appear on radar screens. Visual target detection is an important aspect of both these tasks and accurate assessment of the visual capability of watchkeepers could help ensure good performance on these tasks.

A total of 37 bridge and operations room watchkeepers were tested with the Vistech charts before and after a normal four hour watch period. No significant changes in contrast sensitivity were found over watch periods indicating that workload under normal operating conditions does not influence contrast sensitivity. Supervisors completed questionnaires providing subjective evaluations of watchkeeper's performance. The questionnaires assessed performance on visual and radar contact detection as well as attributes of watchkeeping such as motivation, confidence and alertness. Their ratings of performance, in terms of speed and efficiency in detecting approaching contacts, were not correlated with contrast sensitivity measures. However, performance ratings of the supervisors were positively correlated to their ratings of alertness, motivation and confidence. This study concluded that numerous factors influence watchkeeping performance and that contrast sensitivity measures alone do not provide a good predictor of performance.

Implications Studies on the usefulness of contrast sensitivity do not offer much support for its inclusion as a selection criterion for CF personnel. However, this may be a hasty conclusion. The results may be due not to a lack of a relationship, but to inadequate experimental design and confounding factors. For example, in the study of naval personnel, a correlation was found between supervisor ranking of ability and motivation. In a complex task, factors such as motivation and experience may compensate for possible differences in performance due to underlying differences in visual capability

Second, in many studies, the actual range of visual ability in the population tested may have been relatively small, increasing the difficulty of finding a relationship between performance on a complex task which is influenced by many factors and performance on one of those factors. To adequately assess whether there is a correlation between contrast sensitivity and performance on complex visual tasks, it is necessary to include subjects whose scores cover the whole range of contrast sensitivity found in the normal population. One study that did this (15) found a strong correlation between the time required to recognize objects against a complex background and contrast sensitivity.

Unfortunately, it may not be easy to determine the source of the variation in the contrast sensitivity test scores for a given population. Based on our studies, contrast sensitivity is likely to vary as a function of the methodology and possibly the medium used, as well as the characteristics of the test population. In any given study, the variation in performance on a test due to non-visual factors may mask the true variation in contrast sensitivity of the population. Until the role of each of these factors is understood, it is not possible to accurately determine the extent to which contrast sensitivity varies across a population without measurable visual problems, nor to determine if contrast sensitivity can predict performance in more complex tasks. Thus, the value of contrast sensitivity as a measure of visual capability remains to be determined.

More persuasive evidence against the addition of contrast sensitivity tests to the visual tests currently used to assess the vision of aircrew candidates can be found in normative studies. If the purpose of the contrast sensitivity test is to select amongst candidates that have passed all other tests, the evidence suggests that it will not. With the Vistech charts, most of the subjects were clustered in two, or at the most three, categories. As stated previously, that variability is close to the test-retest variability found in another study (5).

However, contrast sensitivity may have a role to play in evaluating borderline candidates. If such a candidate has average or above average contrast sensitivity, he or she might be considered a better candidate than one with below average contrast sensitivity.

Conclusions Over a three year period, DCIEM evaluated the suitability of three different tests for assessing contrast sensitivity, and examined the possible relationship between contrast sensitivity scores and performance on complex visual tasks. Of the three tests, the Vistech VCTS 6500 test charts were most suitable for the routine testing of contrast sensitivity because they were simple and fast to administer. The CS2000 was more difficult and time consuming to use and the results were more variable, even when an objective methodology was used.

The results of the studies comparing contrast sensitivity scores and performance on complex visual tasks were consistent with previous results that found little or no relationship between the two. However, as indicated in the discussion of our results, it may be that the negative findings were due to inadequate experimental design. First, it is necessary that the population being tested exhibit real differences in contrast sensitivity. Second, contrast sensitivity is probably only one of several factors contributing to performance on a complex visual task and it is necessary to control for the other factors in some way.

Finally, it was felt that the small range in the contrast sensitivity scores of aircrew on the VCTS 6500 test charts indicated little benefit in adding that test to the existing test battery used for screening candidates. However, some form of contrast sensitivity test might be useful in deciding on the suitability of borderline cases.

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