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SUPRATHRESHOLD CONTRAST SENSITIVITY VISION TEST CHART

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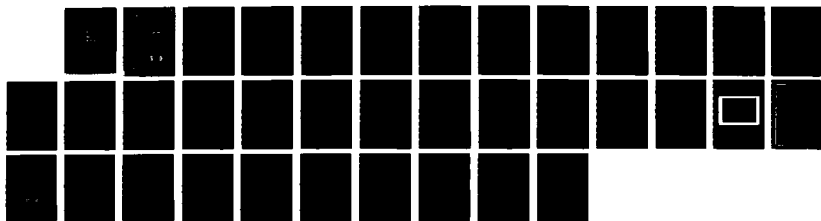
(U) VISTECH CONSULTANTS INC DAYTON OH A GINSBURG

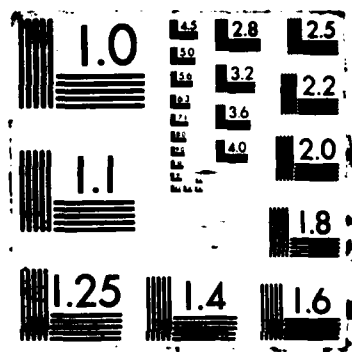
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Defense Small Business Innovation Research (SBIR) Program

Final Report

Suprathreshold Contrast Sensitivity Vision Test Chart

Vistech Consultants, Inc.

1372 N. Fairfield Road

Dayton, Ohio 45432



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Introduction

Although visual acuity has been the main measure of visual capability for over 125 years for both the military and civilians, it has been shown not to relate well to visual performance. A new measure of visual capability, contrast sensitivity, has been shown to relate to individual differences in visual capability such as target detection in the laboratory ~~(Ginsburg, 1980)~~ in flight simulators ~~(Ginsburg et al, 1982)~~ and in field studies. ~~(Ginsburg, et al, 1983)~~ Contrast sensitivity testing with sine-wave gratings provides a very accurate measure of target detection threshold. However, although threshold measurements are very important in evaluating pilot visual performance, there are many other critical visual tasks performed at suprathreshold contrast levels. Routine measurement of suprathreshold contrast sensitivity has been difficult to accomplish until now, however, due to the expensive, time-consuming, and complex computer-video systems required for testing. To answer this need, Vistech Consultants, Inc. proposed to develop a new suprathreshold contrast sensitivity vision test chart. This chart was to be designed to measure individual differences in suprathreshold contrast perception and to show how these individual differences relate to visual performance. The psychophysical procedure of contrast matching was used to measure an individual's suprathreshold contrast perception of sine-wave gratings for appropriate ranges of spatial frequency and contrast. As expected, the resulting data from trials run with this new chart provided an array of

curves, similar to the loudness sensitivity curves found in audition, from just-above threshold to high suprathreshold. A range of individual suprathreshold visual capabilities were then compiled.

Contrast Sensitivity

The visual system is made up of independently-operating cells called channels, which are tuned to different ranges of size or spatial frequency. This is similar to the auditory system, which also has independently-operating cells tuned to different ranges of sound. Audiological advances have resulted in testing of the hearing system at threshold for a more comprehensive evaluation of a range of sound. Similar advances are being made in vision. Of primary importance and interest among these emergent techniques for vision assessment is contrast sensitivity testing.

Contrast sensitivity tests the visual system with a range of sizes or spatial frequencies of sine-wave gratings. From these measurements, a curve, rather than a single number, e.g., 20/20, is assembled that describes visual function. This contrast sensitivity curve has been shown to relate to pilot performance in target detection in the laboratory (Ginsburg, 1980), in flight simulators (Ginsburg et al, 1982), and under field conditions (Ginsburg et al, 1983). Established techniques for measuring threshold levels of contrast in a quick, simple, and inexpensive

manner with a vision test chart have been proven for over three years in clinical and performance trials (Ginsburg, 1984; Ginsburg and Evans, 1985). However, because much of visual perception occurs at suprathreshold levels of contrast, techniques such as magnitude estimation and contrast matching have been developed for measuring suprathreshold contrast. To reduce the need for the time-consuming, complex, and expensive computer-video systems, Vistech Consultants, Inc. proposed to develop a quick, simple, and inexpensive vision test chart to measure suprathreshold contrast perception.

Having experienced considerable success in the development of a threshold contrast sensitivity test chart system, a system used extensively in the clinical and Human Factors areas, Vistech Consultants, Inc. was confident of developing a suprathreshold contrast sensitivity chart with the same attributes. To develop this new suprathreshold vision test chart, Vistech Consultants utilized the same exacting and difficult procedure for producing the precise contrast levels of the sine-wave gratings on printed media as with the Vision Contrast Test System (VCTS) (Figure 1). Their unique expertise and scientific excellence allowed Vistech Consultants to provide precisely-controlled contrast values to the suprathreshold vision contrast test system. Providing both Human Factors engineers and clinicians with a tool for the measurement of visual capability from threshold to suprathreshold in a simple, quick, and inexpensive manner, this suprathreshold contrast sensitivity test system is an important

adjunct to the threshold contrast sensitivity test chart developed by Vistech Consultants. With this new suprathreshold chart, visual performance and capability can be measured in a practical manner at high levels of contrast.

Sine-Wave Gratings as Targets

Sine-wave gratings, shown in Figure 2, are used as the targets for this new suprathreshold chart due to their sensitivity (Ginsburg, 1984; Guth and McNelis, 1969), their ability to provide the most complete information about an object, and their ability to relate to visual channels. As the most general stimuli that can be used to represent the visibility of more complex objects (Ginsburg, 1978), sine-wave gratings are the most sensitive patterns with which to test spatial vision (Guth and McNelis, 1969; Ginsburg, 1984). Using the same experimental conditions and subjects, Ginsburg showed that sine-wave gratings of different spatial frequencies are much more sensitive than letters and disks of different sizes (Ginsburg, 1984).

Using sine-wave gratings also allows information about complex objects to be described in terms of spatial frequency bandwidth and related to individual differences in the relevant range of spatial frequencies of contrast sensitivity functions. A direct relationship can then be found between the visibility of sine-wave gratings and the visibility of complex objects such as letters and geometric form (Ginsburg, 1978, 1981, 1985).

The human visual system is a collection of "channels" which are quasi-independent, narrow-band mechanisms tuned to a bandwidth of approximately one to two octaves of spatial frequency and ± 15 degrees in orientation (Ginsburg, 1978, 1981). Shown in Figure 3 are these channels and the inverted U-shaped contrast sensitivity function they form. Information from these channels is combined to form images. These channels must be tested separately using specific, simple stimuli to determine full visual function. By presenting sine-wave gratings of various spatial frequencies and different contrasts, the sensitivity of each channel is tested, and a contrast sensitivity function (CSF) results. This CSF represents visual ability measured across the wide range of object sizes and contrast conditions encountered in normal human visual experience. Therefore, threshold contrast sensitivity measurements offer a more complete visual function assessment than acuity tests, as well as relating visual capability to performance. Similarly, by measuring a larger part of the visual system, evaluating suprathreshold contrast sensitivity may reveal much additional information about both visual capability and performance.

Suprathreshold Contrast Perception

Four major Air Force needs can be addressed using suprathreshold contrast perception, including the relationship between a pilot's suprathreshold contrast perception and that pilot's visual performance, the development

of a suprathreshold model of perception, the behavior of visual channels at suprathreshold levels of contrast, and ocular pathology detection.

First, suprathreshold contrast perception may have far-reaching implications for pilots in general and military pilots in particular. While contrast sensitivity, not visual acuity, has been shown to relate to target acquisition in flight simulators (Ginsburg et al, 1982) and in field trials (Ginsburg et al, 1983), this testing was done at threshold levels of contrast. And although threshold contrast sensitivity testing accounts for much of the variance in predicting visual capability and pilot performance, suprathreshold contrast perception may help explain the variance not accounted for by threshold measurements. This new suprathreshold contrast test chart is an ideal tool with which to easily, quickly, and inexpensively obtain large population data of pilots' suprathreshold contrast perceptual capabilities.

Understanding the behavior of visual channels at suprathreshold levels of contrast can also be accomplished using the new suprathreshold contrast sensitivity chart. For example, the gain mechanisms of channels of normal observers show marked nonlinear behavior above threshold (Franzen and Berkley, 1975; Cannon, 1979; Gottesman, 1981; Legge, 1981), in opposition to earlier suggestions (Georgeson and Sullivan, 1975). Because the ability to perceive high contrast square-waves at different spatial frequencies of up to 55% contrast is highly linear (Ginsburg, Cannon, and

Nelson, 1980), many questions exist regarding the linearity of suprathreshold contrast perception and how the gain mechanisms behave at these levels. With the advent of this new suprathreshold vision test chart, these questions can be answered.

An understanding of suprathreshold contrast perception is also needed for the development of a suprathreshold model of perception, necessary not only for computer simulation models of vision but also for improved comprehension of the process of matching the observer's characteristic visual processing capability to displayed and simulated imagery. For example, just as contrast sensitivity functions are important in understanding certain aspects of displayed imagery, such as target bandwidth requirements (Ginsburg, 1980) and evaluation of heads-up displays (Ginsburg et al, 1983), suprathreshold contrast perception aids in the evaluation of other aspects of displayed imagery such as the number of contrast levels required for effective target imaging.

This new suprathreshold contrast sensitivity vision test chart can also be used effectively for the detection of ocular pathologies, including cataracts and glaucoma. Research in contrast matching has shown that the gain sensitivity of visual channels can differ for individuals having amblyopia by as much as 10-15 decibels between eyes (Ginsburg, 1978; Levi and Harwerth, 1977). It is likely that other pathologies may be found using this new suprathreshold contrast sensitivity chart in suprathreshold

contrast matching. By providing an even more comprehensive evaluation of vision than testing just threshold contrast sensitivity and a more relevant measure of vision than Snellen acuity, this new suprathreshold contrast test chart may aid in the detection of visual dysfunctions that have not been detected previously.

Development of the Suprathreshold Chart

The development of this new suprathreshold contrast sensitivity vision test chart concentrated on providing effective measurement of individual suprathreshold vision capability. Based on current accepted knowledge of vision science and testing and the large contrast sensitivity testing data base of the threshold vision testing system, this new suprathreshold chart was specifically designed to be fast, easy, and inexpensive as well as to accurately test the suprathreshold visual ability of individuals in both civilian and military capacities.

The main goals established and accomplished in this research were to:

- 1) Design a suprathreshold contrast sensitivity test embodied in a chart system.
- 2) Develop a specific format for the suprathreshold chart system.

- 3) Produce a prototype suprathreshold chart system.
- 4) Produce initial test data showing individual differences in suprathreshold contrast perception.
- 5) Investigate suprathreshold contrast printing techniques from previous knowledge of threshold contrast sensitivity testing in order to produce multiple high-quality chart systems.

Suprathreshold Chart Development

The initial research period concentrated on the design and development of the suprathreshold contrast sensitivity test chart system. Several chart designs were configured to determine their individual suitabilities from psychophysical and production perspectives. Based on configurations of the previously-developed threshold contrast sensitivity test chart, two specific formats were the most promising. The first configuration consisted of seven 6 cycles per degree (cpd) circular sine-wave test grating patches arranged vertically on the left side of a chart. The contrast levels increased from low to high, proceeding from the top to the bottom of the chart. Immediately to the right of these seven test gratings were five rows of sine-wave grating patches, whose spatial frequencies ranged from 1.5 to 18 cpd, from top to bottom of the chart. The contrasts of the test patches ranged from approximately .0026 to .0192

in octave steps. The observer's task was to match each test grating frequency to the corresponding matching grating for each contrast level. It was found in pilot trials that this configuration inhibited the observer's ability to perform contrast matching. From the initial results, it was found that only a single stimulus should be presented as the matching grating. Using this method, subjects would not have to visually scan across various spatial frequencies and contrast levels to match the patches that were geographically distant from each other on the chart. Thus, a second configuration was developed to include this design factor. The second configuration had a strip with one 6 cpd test grating patch mounted on the left side of the chart. Seven different strips were used, each having a patch with a different contrast level. The strip could be moved down the side of the chart so that the grating patch aligned with the different rows of spatial frequency. The observer's task was to match the single grating patch on the strip to one of the seven grating presented in each row of spatial frequencies.

Data consisting of the suprathreshold contrast sensitivity curves obtained was then assembled. Using a 6 cpd test target as a contrast match, the suprathreshold contrast sensitivity curves showed a predicted decline in contrast sensitivity at the higher spatial frequencies using both chart configurations. Data from the second chart configuration were much like that obtained previously from computer-video systems.

Methods

Four suprathreshold chart configurations were used in the study. Each chart was comprised of a contrast matching patch and five rows of test patches. The frequency of the gratings in the contrast matching patches was 6 cpd with contrast levels of .0192, .0143, .0108, .0081, .0046, .0034, and .0026. The five rows of test patches had frequencies of 1.5, 3, 6, 12, and 18 cpd. Each row of test patches consisted of seven contrast levels arranged in random order with the four charts differing in the random order of the contrast levels within each row of test patches. At a distance of 18 inches, every subject was shown one of the four chart configurations. The subject was then given a contrast matching patch and was instructed to find the patch from each of the 5 test rows that was most similar to its contrast level. This procedure was repeated for each of the seven contrast levels from the contrast matching frequency. The resultant data from each subject was then compared with the other subjects' results.

Standard photometric and contrast matching techniques were used to determine the contrast levels used. The contrast levels of each grating were determined by a specially-designed photometer which scanned the luminance distribution of the gratings and gave an average of that scan. The test charts were also compared to published data on contrast matching.

Seven subjects with corrected 20/20 acuity and no indications of visual disorders participated in the preliminary testing of this suprathreshold contrast sensitivity test chart. Subjects were adults of various ages and ethnic backgrounds with an average age of 29 years. All subjects were informed of the purpose and nature of the testing procedures, that there were no known risks, and that they could stop any test if it caused discomfort. The subjects were also advised that they could withdraw from the testing at any time, and that data would not be released or published in any form that would directly identify the subjects.

Recorded data included the subject's contrast sensitivity suprathresholds for various conditions, Snellen acuity, age, gender, and notations of any visual problems experienced prior to testing. Subjects' names were not entered on data sheets containing this information.

Results

Analysis of Individual Data

Seven emmetropic subjects were used for the final experiment in this preliminary study. As before, the subject's task was to compare a standard spatial frequency of 6 cpd to that of test spatial frequencies of 1.5, 3, 6, 12, and 18 cycles per degree. The suprathreshold contrast perception of the seven subjects is shown in Figures 4-10. In general,

these results are in agreement with similar suprathreshold data from other researchers using more complex computer-video systems, e.g., Watanabe et al, 1968, Georgeson and Sullivan, 1975, and Ginsburg, 1978, 1981.

As seen from these data, individual differences exist in making contrast matches. An ANOVA was conducted to determine if the differences in making the contrast matches were statistically significant between subjects. The data was analyzed using a three-way repeated measures paradigm. Significant effects ($p < .05$) for spatial frequency, contrast level, and subjects were found. All of the interactions involving spatial frequency, contrast level, and subjects were also significant. These results are summarized in Table 1.

Post-hoc analyses for individual subject differences were performed using the Student-Newman-Keuls procedure. Significant differences were found between subjects at $p < .05$. The results of these subject comparisons are shown in Table 2.

It is possible that these significant differences between subjects in contrast matching may be a function of criterion as well as a function of actual sensitivity. There were, however, several subjects who had contrast matches greater than ± 1 patch different from the average. For example, subject 4 deviated from the average score by more than one contrast level for three spatial frequencies, 1.5, 3, and 18 cpd.

Subjects 1 and 5 deviated from the average score by more than one contrast level at two spatial frequencies, and subject 7 deviated by more than one contrast level from the average at one spatial frequency. Since a difference of one contrast level is larger than .1 log unit, these types of deviations described above are larger than differences that could be caused by criterion. Consequently, these data suggest that these deviations are due to individual differences in making contrast matches. An important point will be to determine if these differences in contrast matching capability represent differences in perceived suprathreshold contrast that will affect functional vision.

Further experimentation will have to be undertaken to determine if the differences are due to any criterion and/or represent actual differences in suprathreshold sensitivity due to, for example, different gains in different channels in different observers' visual systems.

The average of these seven subjects' contrast sensitivity functions is shown in Figure 11. Here we see that this family of contrast matching curves, from threshold to suprathreshold, is also in agreement with previously referenced data. Thus, these data support the notion that one can obtain meaningful suprathreshold contrast sensitivity data with this particular chart configuration.

Discussion

These data show that it is possible to obtain suprathreshold contrast matching curves using a quick, simple, and relatively inexpensive suprathreshold contrast sensitivity chart. The characteristics found in much more complex, expensive, and time-consuming computer-video systems are exhibited by these data. Furthermore, these data show that significant individual differences exist for the subjects' abilities to match contrasts within ± 1 contrast increment (± 0.1 log unit) on the contrast test chart. That data suggests either a criterion difference between subjects and/or real differences in suprathreshold gain mechanisms. Since some subjects showed contrast matches which deviated by more than one contrast level from the average, these results indicate that these individual differences are not due to criterion. Consequently, individual differences in contrast perception can be accurately measured by this new quick and simple suprathreshold vision test chart.

During this same period, suprathreshold contrast printing techniques were investigated to determine if one could produce multiple high-quality chart systems for suprathreshold tests. It appears from this research that there will be no problem providing the high-quality control achieved previously with the threshold contrast sensitivity chart systems. The same techniques used to produce and control the quality of the threshold

contrast sensitivity charts appear suitable for use with the suprathreshold contrast sensitivity charts.

Conclusions

These data show the suitability of using suprathreshold contrast chart systems to contain suprathreshold contrast curves. Also shown by these data are significant individual differences that warrant further investigation. Further research should center on the repeatability and sensitivity of these data as to their representation of real functional differences in contrast perception of observers from a both clinical and performance point of view.

As stated previously, the specific objectives of this Phase I work were to:

- a) design a suprathreshold contrast sensitivity chart that could be embodied in a chart system
- b) develop a specific format for suprathreshold chart system
- c) produce a prototype suprathreshold contrast sensitivity chart system
- d) produce initial data showing initial differences in suprathreshold contrast perception

- e) investigate suprathreshold contrast printing techniques from previous knowledge of threshold contrast sensitivity testing in order to produce multiple high-quality contrast charts.

These specific Phase I objectives were met during this research period. Additional objectives furthering this research are outlined in a Phase II proposal, which is submitted under separate cover.

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TABLE 1

Spatial Frequency (SF) x Contrast Level (CL) x Subjects (S) ANOVA

Source	df	SS	MS	F
SF	4	1,976,518.06	494,129.52	925.94*
CL	6	3,046,509.89	507,751.65	688.21*
S	6	34,675.92	5,779.32	9.27*
SF x CL	24	1,124,180.41	46,840.85	246.66*
SF x S	24	19,014.17	729.26	3.56*
CL x S	36	74,899.75	2,080.55	4.47*
SF x CL x S	144	78,184.16	542.95	2.16*

* $p < .0001$

TABLE 2

Post - Hoc Analysis for Individual Subject Differences

Student - Newman - Keuls Procedure

S = significant at $\alpha = .05$
S = subject

							<u>S1</u>
<u>S1</u>							
<u>S2</u>							<u>S2</u>
<u>S3</u>							<u>S3</u>
<u>S4</u>	S	S	S				<u>S4</u>
<u>S5</u>				S			<u>S5</u>
<u>S6</u>	S			S			<u>S6</u>
<u>S7</u>	S	S	S	S	S	S	<u>S7</u>

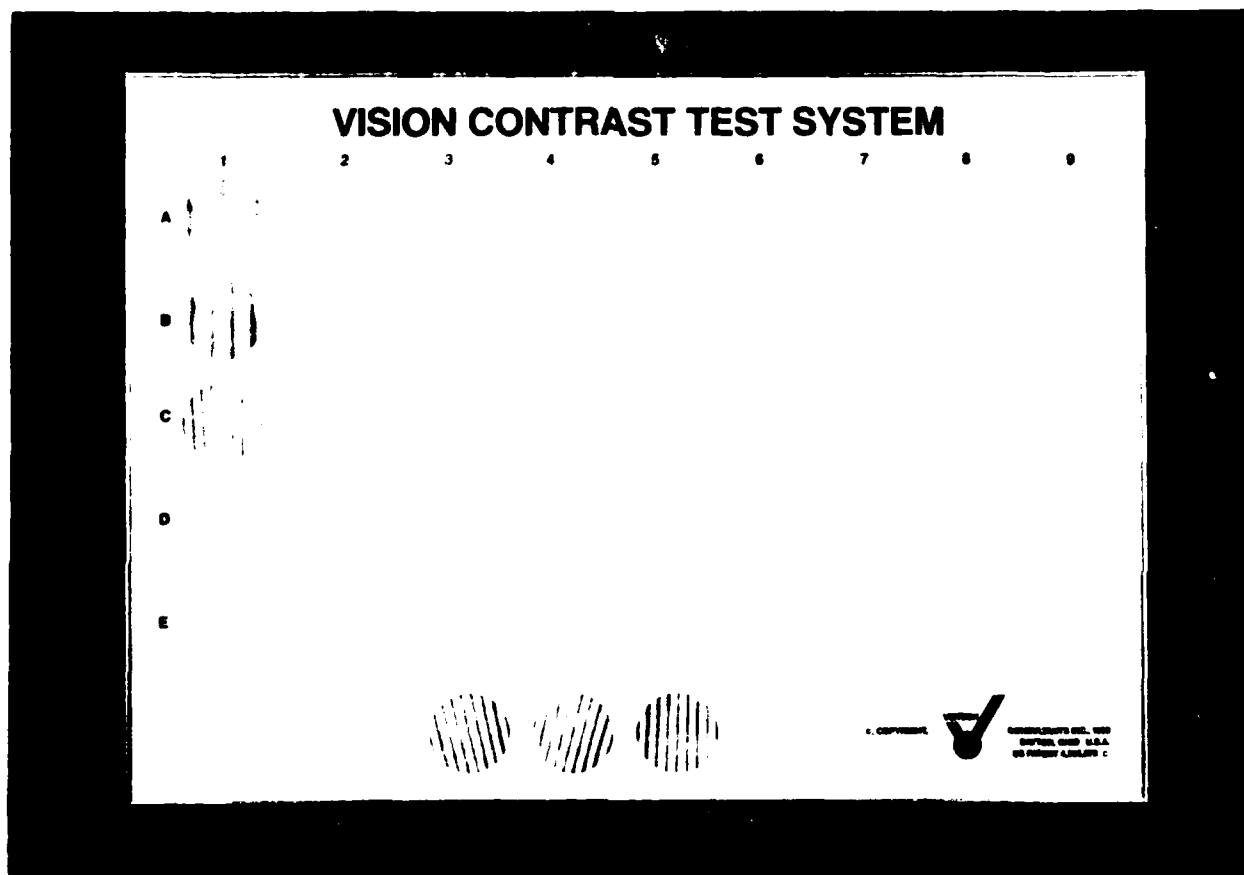


FIGURE 1

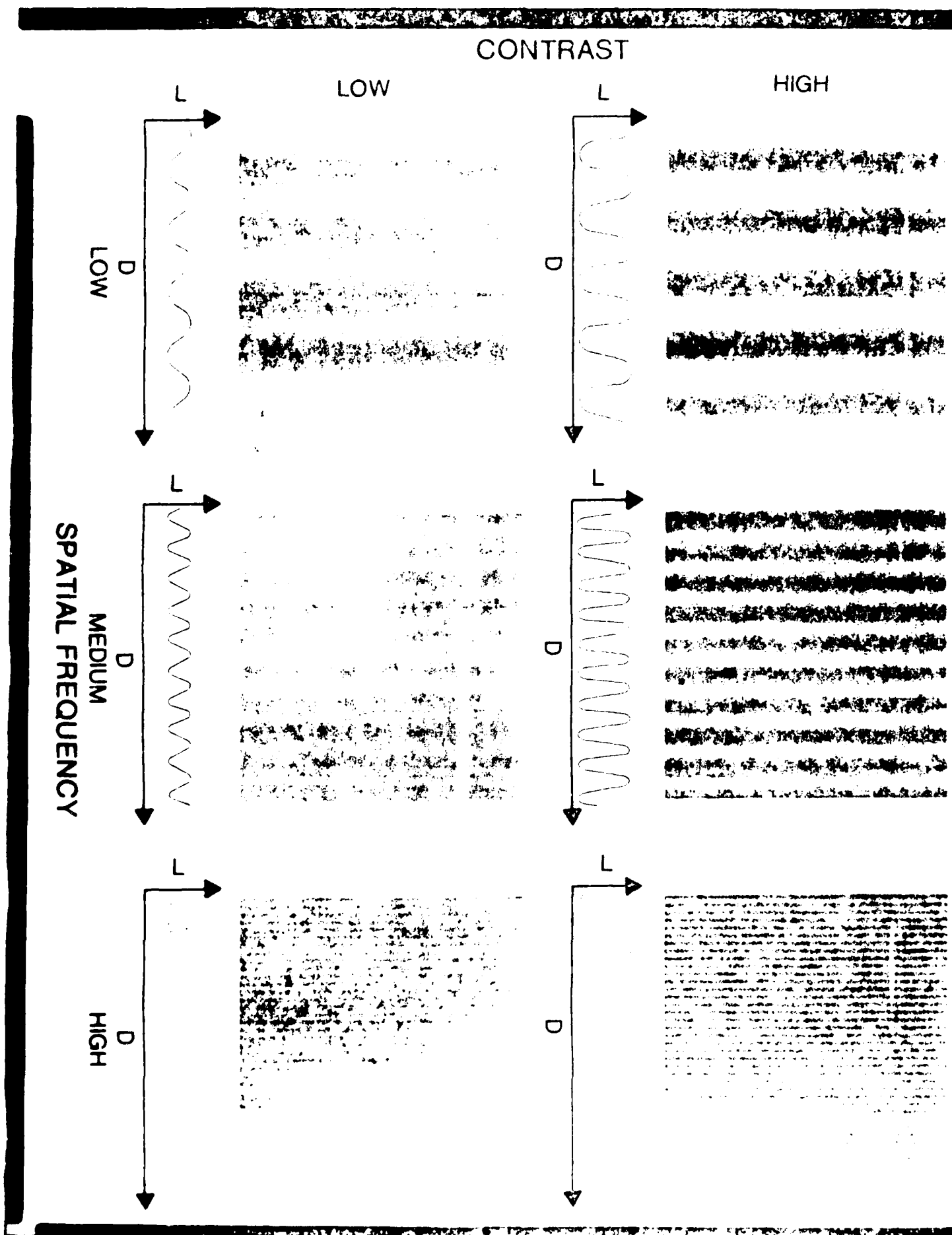


FIGURE 2

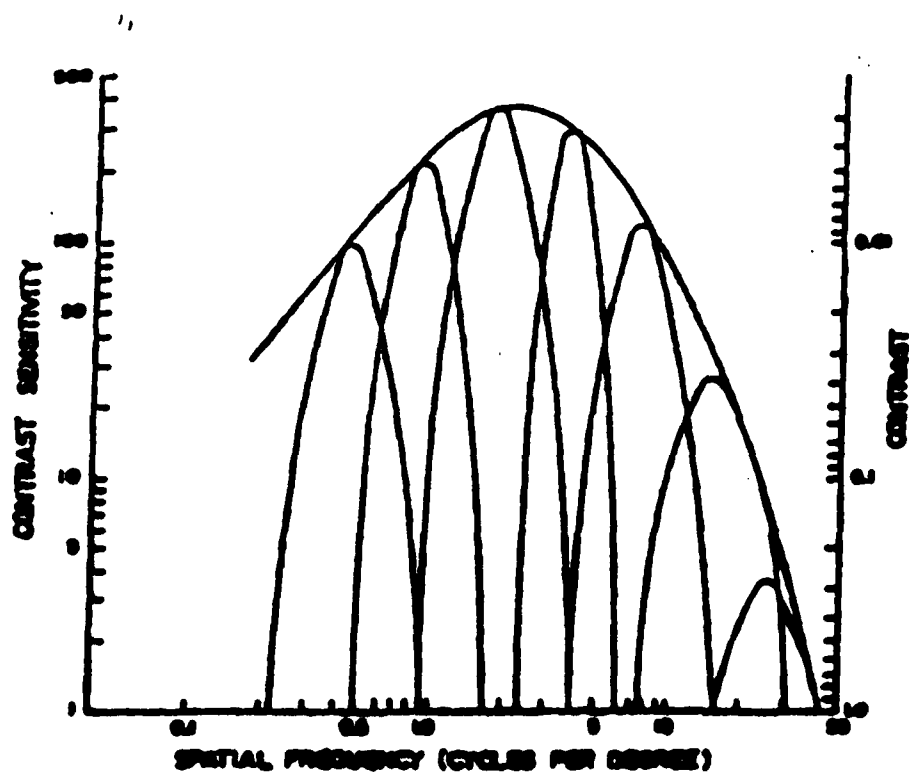


FIGURE 3

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY

SUBJECT 1

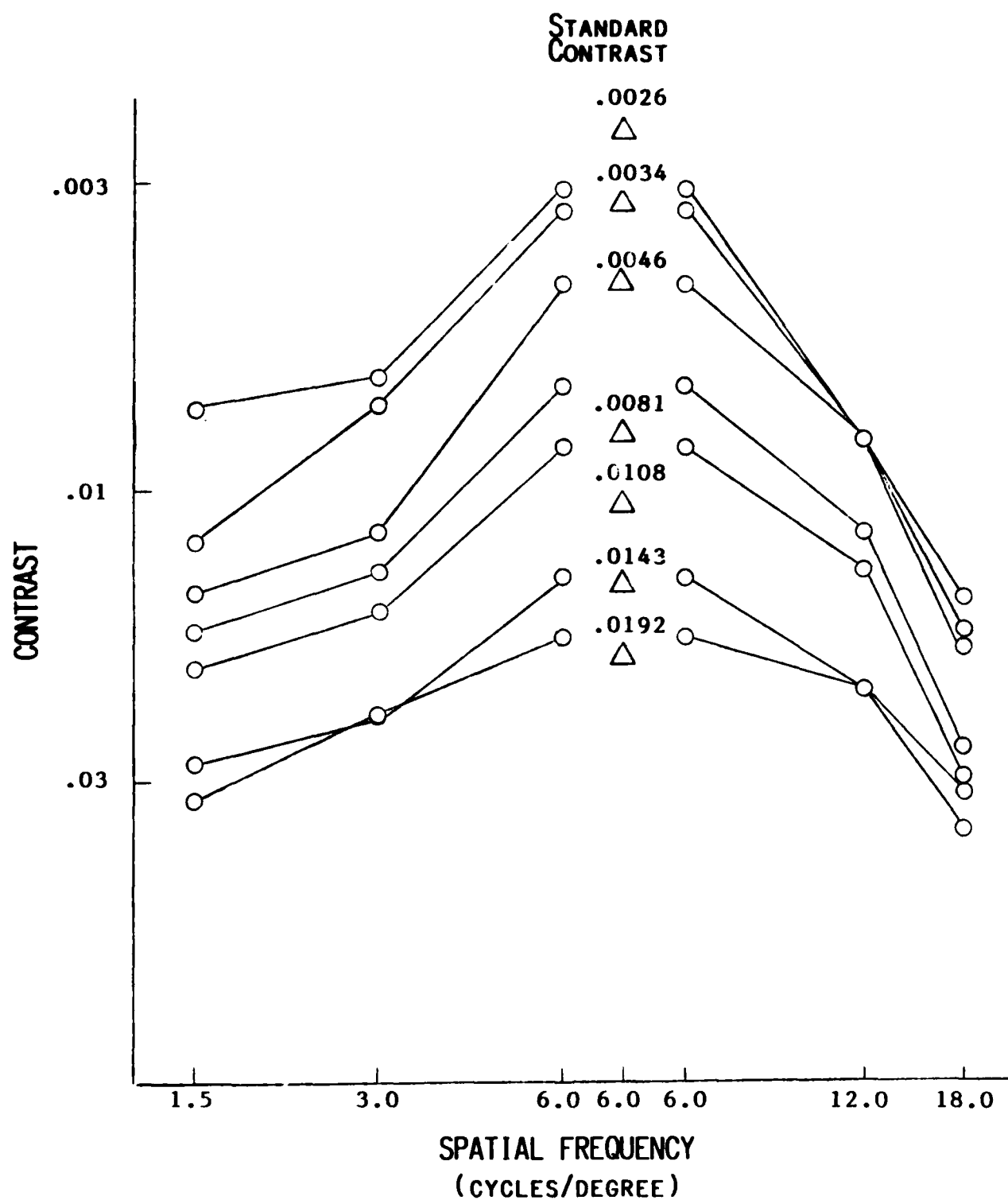


Figure 4. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY
SUBJECT 2

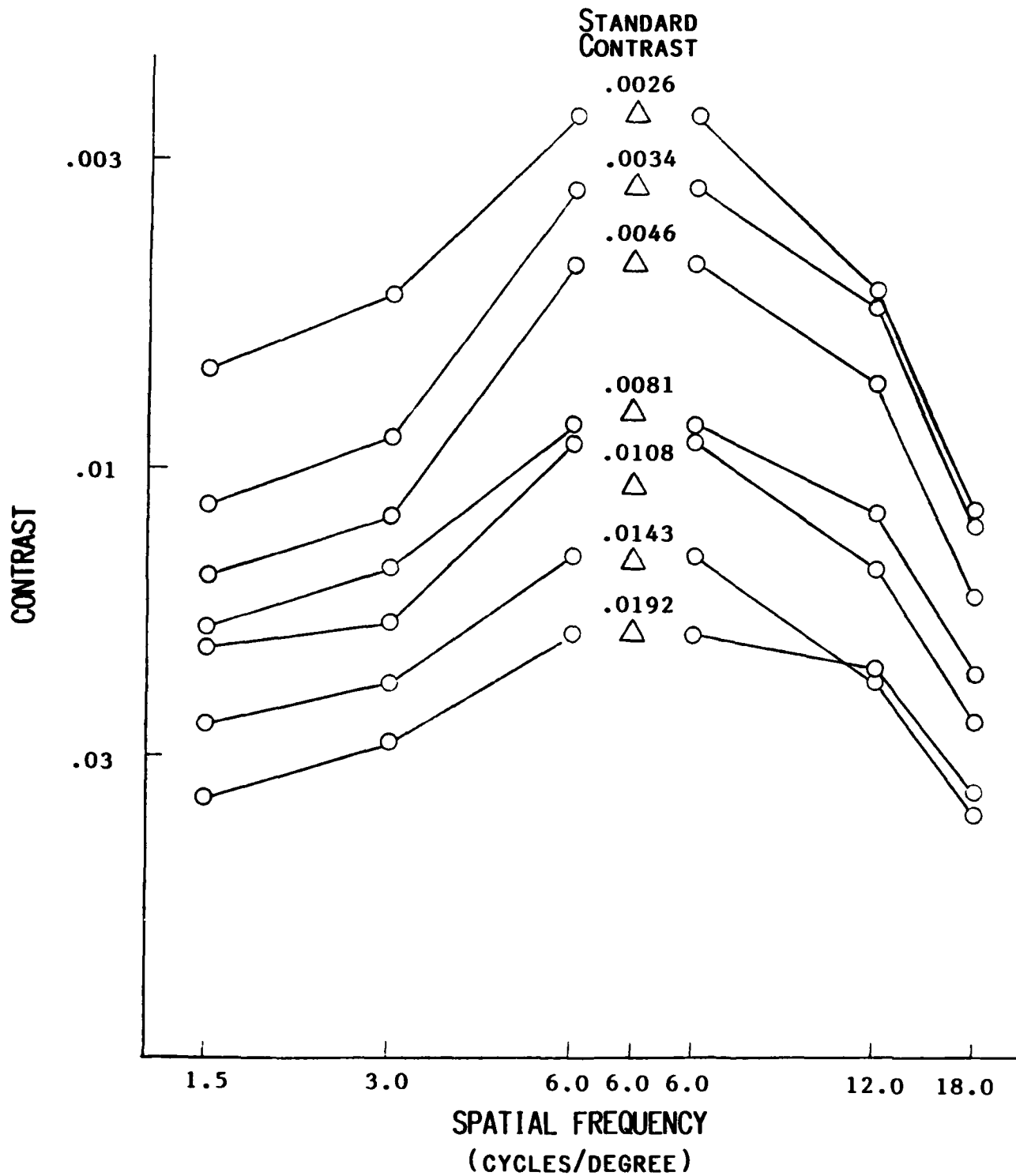


Figure 5. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY

SUBJECT 3

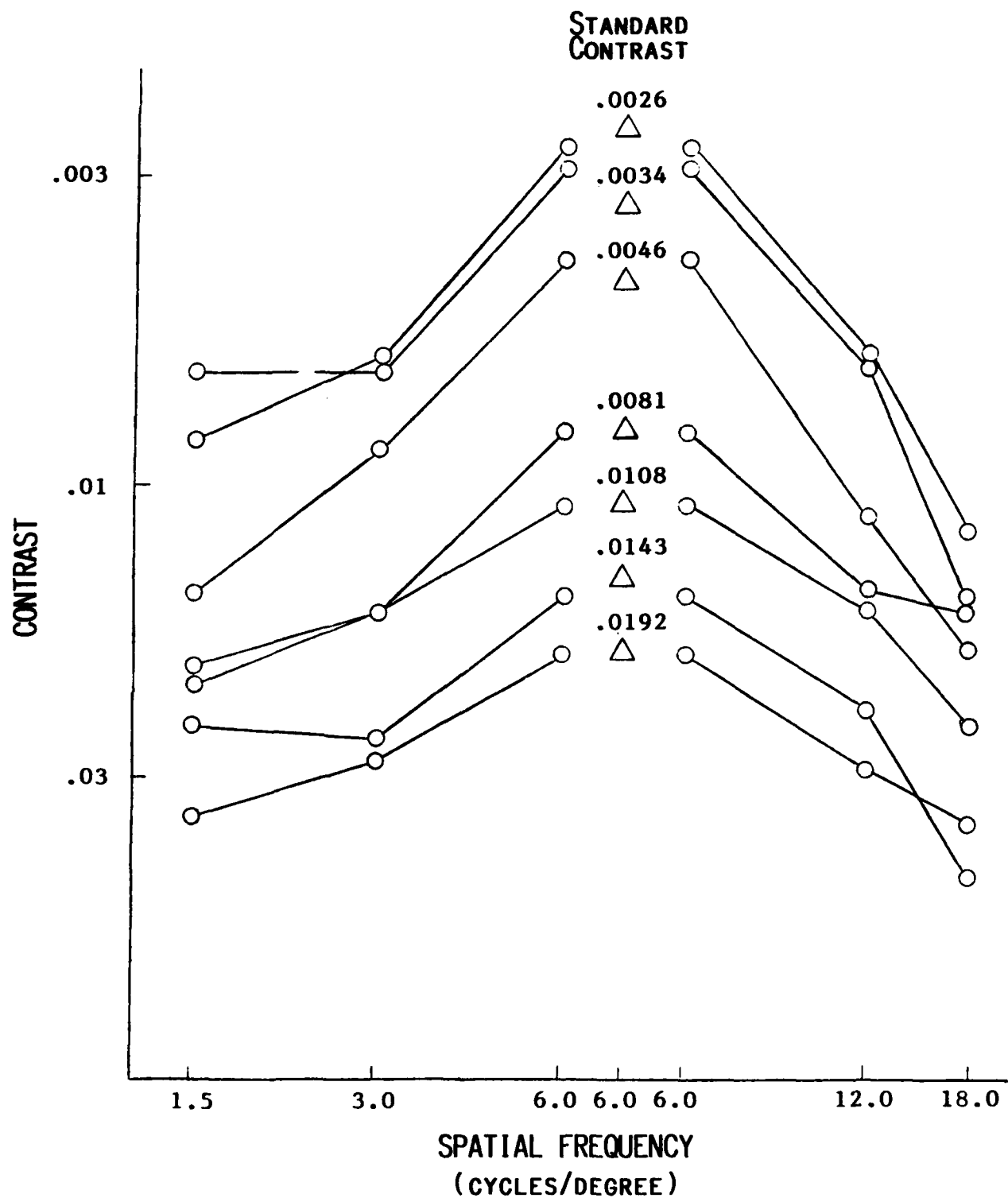


Figure 6. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY
SUBJECT 4

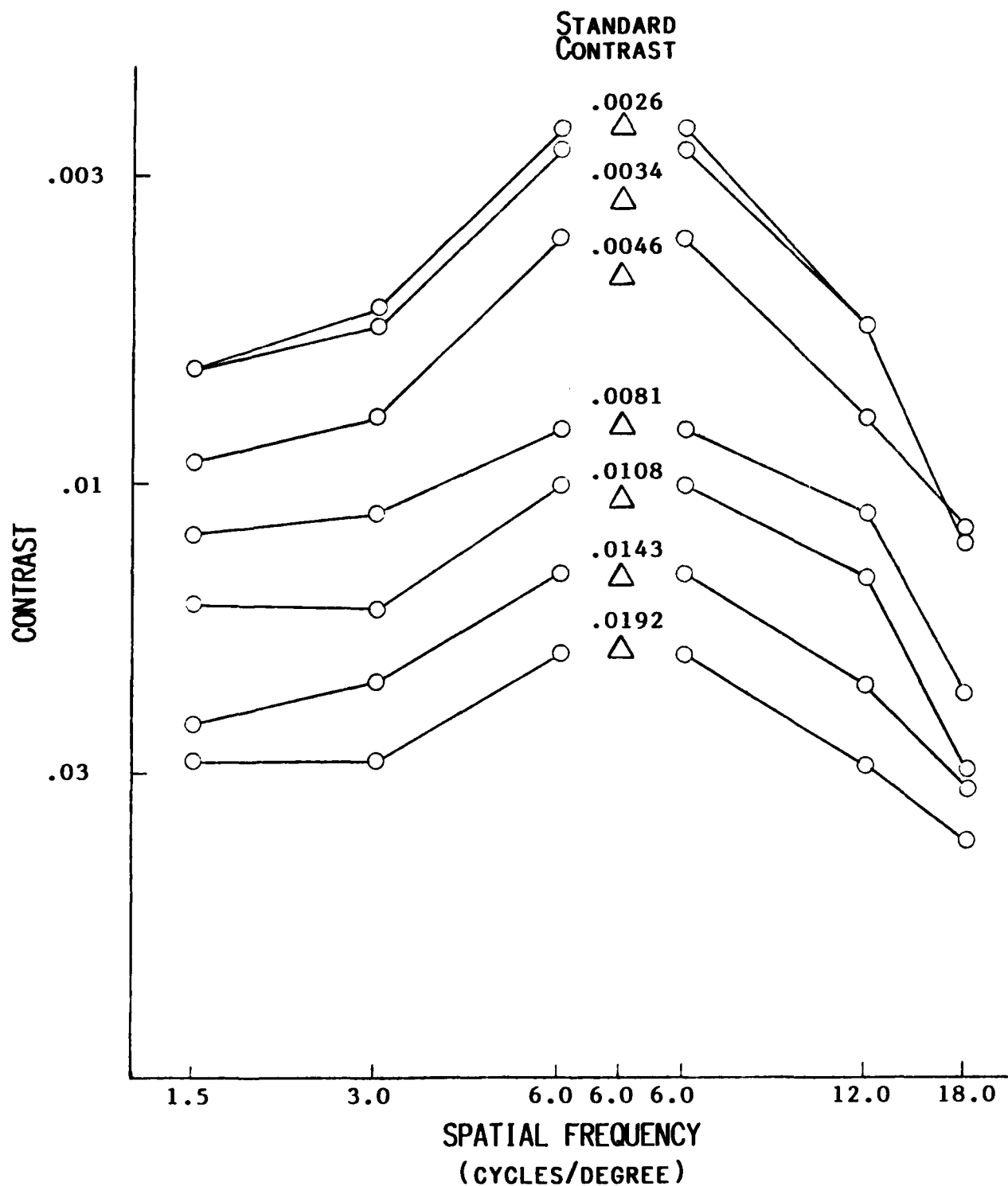


Figure 7. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY
SUBJECT 5

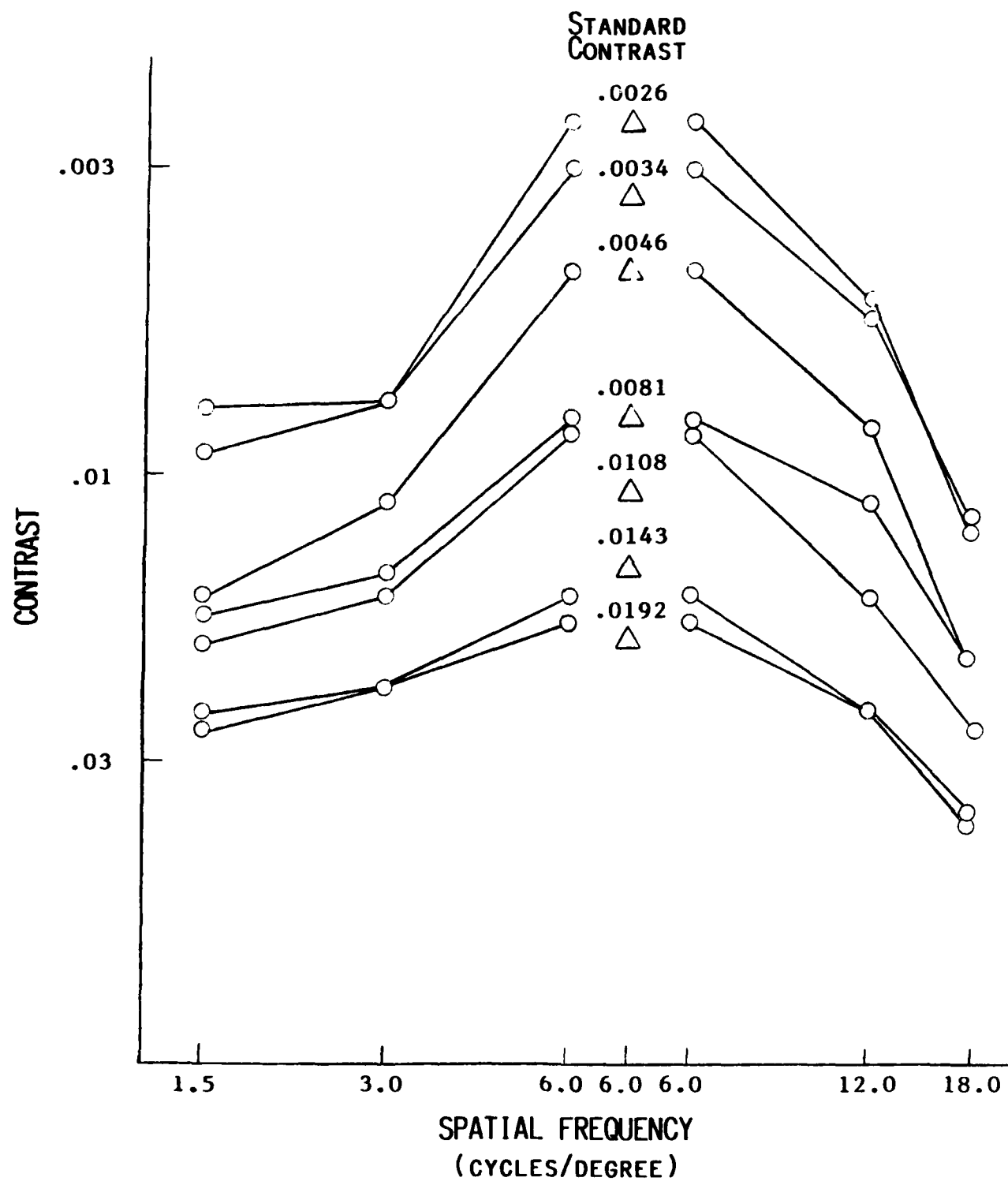


Figure 8. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY

SUBJECT 6

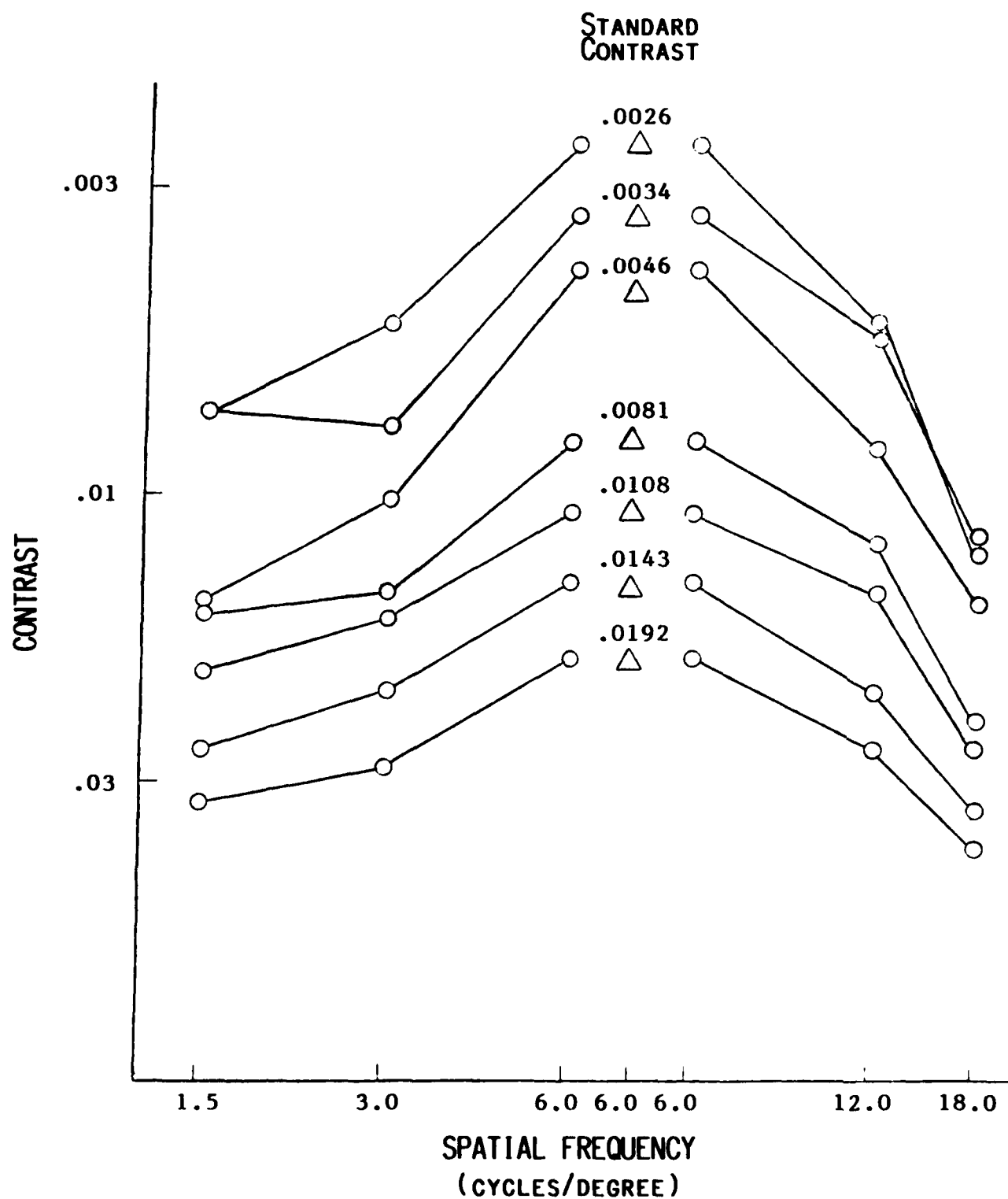


Figure 9. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY

SUBJECT 7

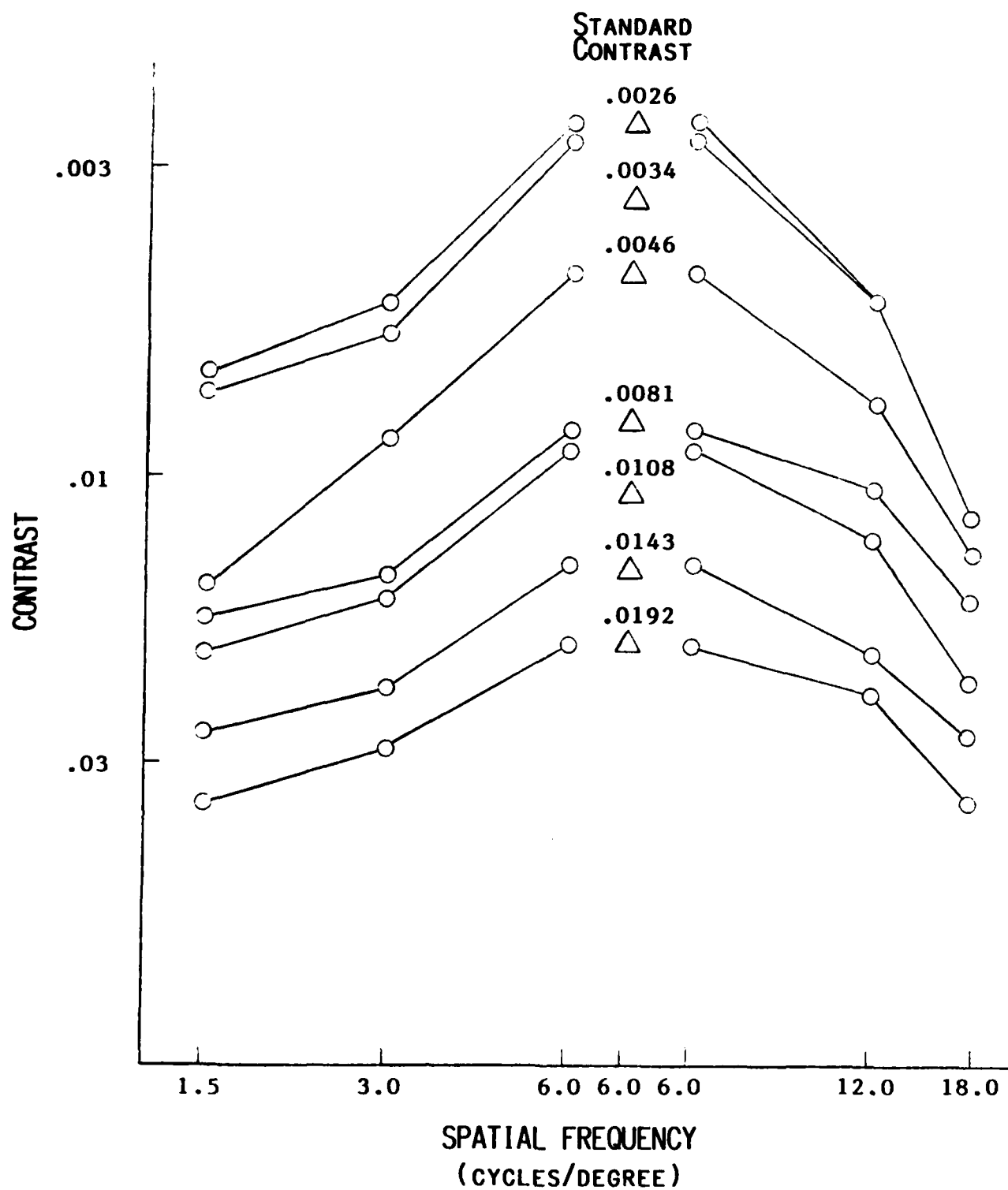


Figure 10. Average of Four Contrast Matching Functions

SUPRATHRESHOLD CONTRAST PERCEPTION vs. SPATIAL FREQUENCY SUBJECT MEANS

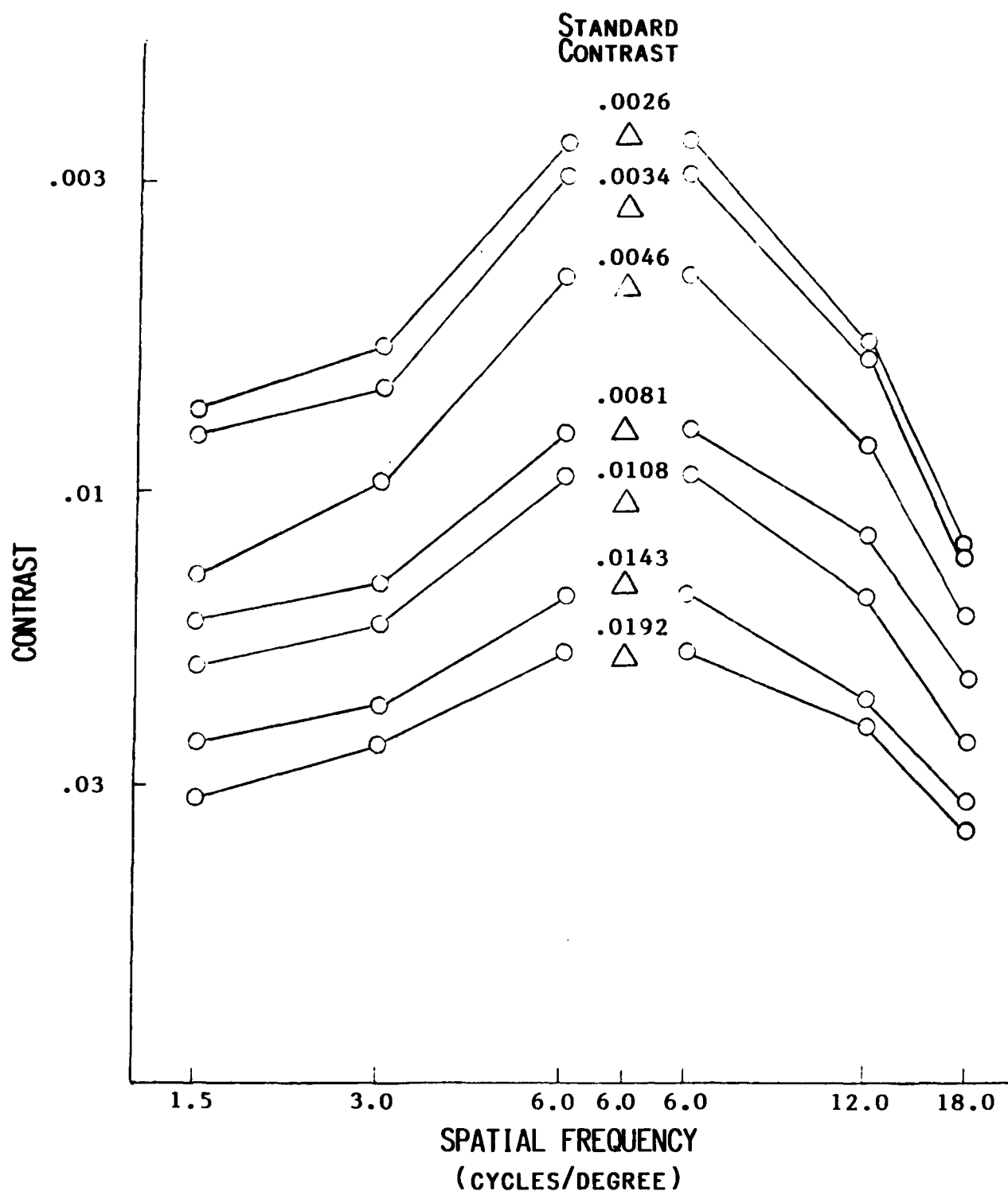


Figure 11. Average Contrast Matching Function Across Seven Subjects

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