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Determination of Reduction and Enhancement of the Apparent Contrast of Grid Patterns as a Function of Brief Adaptation Durations

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DETERMINATION OF REDUCTION AND ENHANCEMENT OF THE APPARENT CONTRAST OF GRID PATTERNS AS A FUNCTION OF BRIEF ADAPTATION DURATIONS

BY

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

The purpose of this study was to measure the reduction and enhancement of the apparent contrast of grid patterns as a function of brief varying masking intervals, various spatial frequencies, and periodicity or aperiodicity of stimuli. If enhancement and reduction follow a characteristic pattern (whose time scale may vary for individual subjects) then this may indicate something about the firing characteristics of populations of property specific neurons in the human visual system. If property-specificity is part of a frequency-transformation mechanism, then, in addition, one ought to be able to obtain evidence of this kind of transformation in visual system responses.

Extensive neurophysiological evidence has been obtained establishing single units in sensory systems which fire only in response to certain features of stimuli and not to others. One of these units which has been classified as an "on" unit can be shown to increase in firing with the presentation of a stimulus, generally drop off firing somewhat after prolonged presentation, and drop below its level of spontaneous firing after the stimulus is removed (Kuffler, 1953).

The neurophysiological measuring of an "on" unit to a stationary stimulus in a species of animal close to man, was accomplished by Wurtz (1969). Using slits of light and recording from the striate cortex of an awake monkey, he discovered nonadapting units which responded with a bursting pattern of discharge for as long as a stimulus was on, with a depression of recovery of seconds after removal of the stimulus. The general characteristics of this unit can be found in Figure 1.

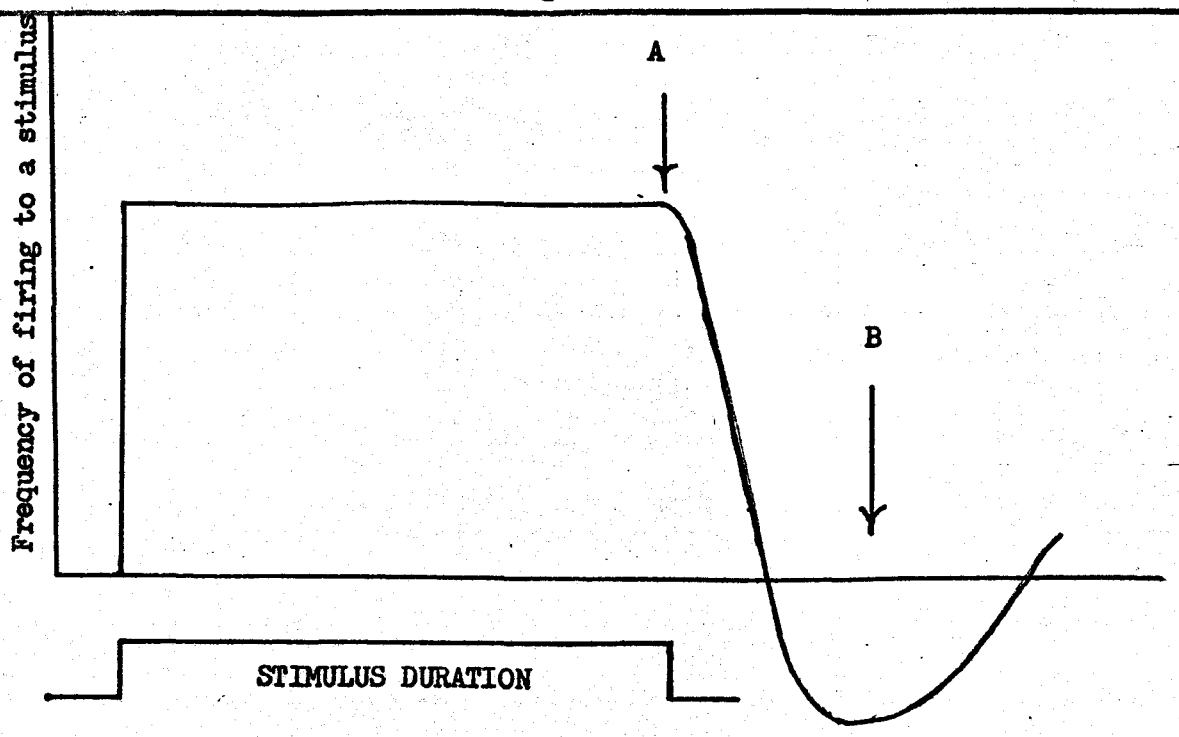

FIGURE 1. The basic characteristics of nonadapting units to a stationary stimulus in the visual system.

Psychophysical studies of populations of neurons in the human visual system have shown that they fire only in response to certain features of stimuli and not to others. Many properties of the functions obtained psychophysically seem analogous to the recordings of the single unit responses obtained neurophysiologically in lower animals. For example, Gilinsky and Doherty (1969) and Blakemore and Campbell (1969) have shown that after prolonged viewing of a square or sine wave grating of a given spatial frequency and orientation, the sensitivity to, or the apparent contrast of the same or closely similar spatial frequencies and orientations will be lowered while the sensitivity to, or the apparent contrast of gratings of different frequencies will remain unchanged. Both studies have also found this effect to be central in part (it can be obtained under dichoptic viewing conditions although in reduced amplitude). For monoptic

conditions, Blakemore and Campbell determined the rise of threshold over a range of spatial frequencies. For spatial frequencies in the low range (1.3, 1.5, 1.8, 2.5, and 3.0 cycles per degree) there was a maximum adaptation effect at 3 c/deg. The middle range of spatial frequencies (3.5, 5.0, 7.1, 10.0, and 14.2 c/deg.) were found to adapt the best. At higher spatial frequencies (20.0 and 28.3 c/deg.) the adaptation characteristics were narrower while the maximum effect was greater than at lower spatial frequencies. Blakemore and Campbell suggested that the visual system may possess neurones selectively sensitive to spatial frequency.

These neurons may directly code for size (i.e. a half-cycle of a particular frequency) or they may code for frequency. A number of investigators (Pollen, Lee, and Taylor, 1971; Julesz and Stromeyer, 1971) have suggested that the visual system performs a frequency analysis of the object amplitude of a visual pattern. Previous investigations have, in general, been concerned with periodic stimuli and have shown, for example, that adaptation to a square wave grating can be obtained both to the fundamental frequency and to the third harmonic (Blakemore and Campbell, 1969). But if the visual system does perform some kind of frequency transformation, then one should be able to find evidence of this for aperiodic as well as periodic stimuli.

Every aperiodic stimulus has a unique Fourier transform. In particular, a half-cycle of a square wave grating of frequency f can be considered a gate function of width $\tau = \frac{1}{2f}$, and its Fourier transform is a $\sqrt{\frac{\text{Sin } X}{X}}$ with $X = \frac{w\tau}{2}$. This is also known as the sampling function of amplitude τ, and zero crossings at 2f, 4f.....2nf. If the visual system transforms a gate into its Fourier components, then visual masking techniques ought to be able to detect this transformation.

The previous studies above (Blakemore and Campbell, 1969; and Gilinsky

and Doherty (1969)) used what is called a forward masking paradigm: prolonged viewing of a suprathreshold stimulus (mask) after which a threshold stimulus was presented (target). Visual masking, in general, refers to events which occur when two or more stimuli are presented close to each other in time and space. The threshold of one of the stimuli (target) is raised, or, if the target presentation is suprathreshold, its appearance changed, by the presence of another stimulus (the mask). The masking stimulus can occur prior, to, during, or subsequent to the presentation of the target. The first is called forward masking, the third backward masking. The stimulus called the mask is presented in such a way that its effect will be greater on the target than conversly, usually because of larger size, longer duration, or more intense illumination. The masking effect varies systematically with the interval between the offset of the mask and the onset of the target (ISI or interstimulus interval). Visual masking permits one to make inferences about underlying neural circuitry in the human visual system.

Thus spatially, the masking functions found by Blakemore and Campbell resemble the neurophysiological evidence obtained (see e.g. Campbell, Cooper and Enroth-Cugell, 1968, 1969). Temporally this may also be true. Looking at Figure 1, we could assume that Blakemore and Campbell and Gilinsky and Doherty obtained results in time at B. If this function is correct, then enhancement should be obtained psychophysically at A. This initial enhancement of stimuli of like frequencies would be due to the high burst of firing of units upon the presentation of a stimulus, assuming that the temporal inhibitory influences (that is, the reduction in firing below spontaneous level after removal of a stimulus) on a unit are not instantaneous but that there is a characteristic rate of decay towards suppression of firing. Then, while the frequency of firing is above the spontaneous level, presentation of a

stimulus of like frequency should raise the level of firing above what it would be had there been no prior activity.

Gilinsky (1967) had in fact obtained this enhancement. Using an open-choice procedure with no fixation point, she had four subjects inspect patterns of horizontal, vertical, or oblique line gratings of black and white lines one mm. wide for adapting durations from .1 to 8 seconds. After, they had to discriminate other identical striated test patterns in the same or opposite orientation. The results showed that brief exposures facilitated the identification of the same orientation, while long exposures inhibited or masked lines with the same orientation. However, Gilinsky's facilitative results were unclear, since enhancement or facilitation occurred only for one subject.

It is not clear why facilitation was only obtained for one subject. If the facilitation effect is due to the temporal characteristics of single units then one ought to be able to obtain it with all subjects. One possibility is that there are individual differences in burst and decay rate, and therefore, facilitation varies for each subject with the duration of the stimulus. This would be reasonable since individuals differ widely in many psychophysical paradigms (see Weisstein, 1971; Teller and Lindsay, 1970). If so, testing subjects at a variety of durations ought to produce facilitation effects for some of the durations tested. If this facilitative effect were confirmed this would support the interpretation that visual masking can specify in detail the activity of populations of feature-specific units in the human visual system.

The neural circuitry which is presumably involved in these facilitation and adaptation effects could also perform the frequency analysis referred to above (see Pollen, et. al., 1971 for a model). One of the simplest hypothesis

as to how this transformation would work is this: if a subject views a gate (line) for a varying duration, adaptation would occur to the frequencies in the Fourier transform of that gate. This adaptation would be expected to be proportional to the viewing duration.

Both the facilitative effect found by Gilinsky (1967) and the frequency transformation hypothesis were investigated in the following study. This study took the three values of spatial frequencies (low, medium, and high) to which the human visual system is sensitive (Blakemore and Campbell, 1969) and tested masking of grating-gate(line), grating-grating, gate(line)-grating, and gate(line)-gate(line) at various durations and ISIs. The first major prediction of this study was that enhancement would be present for every subject if enough mask durations are tested at sufficently early ISIs. The second major prediction of this study was that if a line mask is presented of width $\tau = \frac{1}{2}f$ masking will occur to a target of frequency f (recall the zero crossings are at 2f,.....2nf). In addition, a grating mask should not mask a gate(line) the width of one bar of the grating as much as a gate(line) whould mask a line. This assumed from frequency analysis: square wave gratings (together with the attenuation characteristics of the eye) contain many less frequencies that a single line so their masking effect should be less.

CHAPTER II

METHOD

SUBJECTS: Five college students (VS, AC, TR, PW, and CT) with 20/20 vision were paid to serve as subjects. One subject (PW) was tested under two different masking situations.

APPARATUS: Stimuli were presented in a six-channel binocular tachistoscope (Scientific Prototype Manufacturing Corp., Model GB). The stimuli were rectangular slide negatives on Kodak Ortho Type III film consisting of a 7° horizontal by 5° vertical illuminated field. Luminance measurements were made with an SEI photometer and monitored by phototubes which were placed in each channel with the output displayed on a Tektronix Oscilloscope, Model 504. Luminance was varied by means of intensity controls on the tachistoscope and by neutral density filters.

There were seven adaptation stimuli (masks) and six test stimuli (targets) used. These are shown in Figure 2.

Three masking stimuli consisted of vertical square wave gratings with spatial frequencies of 3 cycles per degree, 10 c/deg., and 15 c/deg. Their contrast was about one (defined as $\frac{\text{Lmax - Lmin}}{\text{Lmax + L min}}$) presented at a mean spatial luminance of 16 ft. L's with the lighted portion of the grating illuminated at 32 ft. L's. Another three masking stimuli were single vertical lines corresponding to one bar of the square wave grating of 3, 10, and 15 c/deg. positioned in the center of the slide presented at a luminance of 16 ft. L's. The last masking stimulus was a blank white field presented at a luminance of 16 ft. L's.

The targets were three identical square wave gratings of the same spatial frequency as the masks (3 c/deg., 10 c/deg., and 15 c/deg.); and three

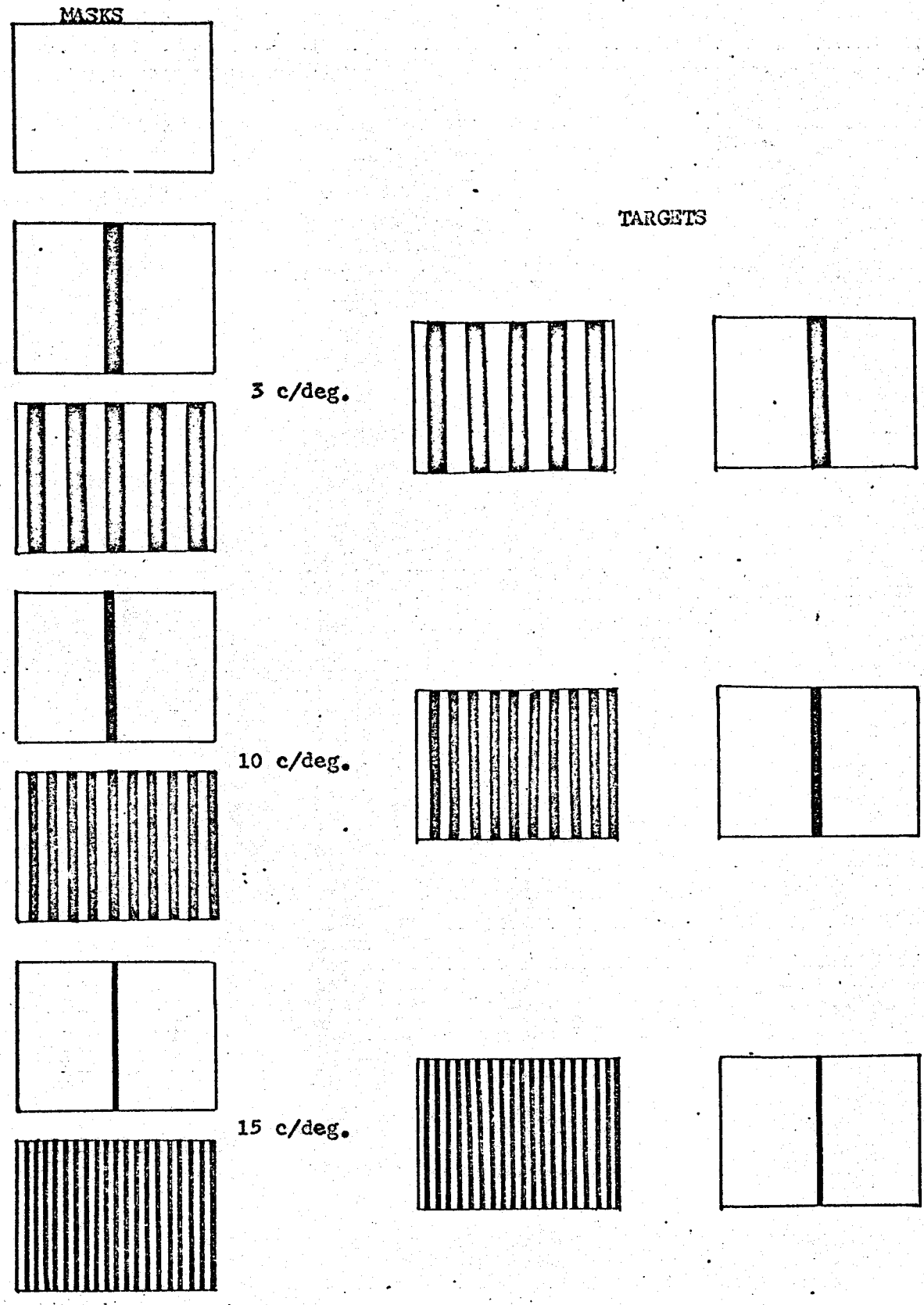

FIGURE 2. Adaptation (column 1) and test (columns 2 and 3) stimuli of 3, 10, and 15 c/deg. used in the study.

single vertical lines corresponding exactly to the masks, positioned in the center of the slide, behind one of the gratings or directly behind a masking line. The targets were presented at a luminance of 3.2 ft. L's, a contrast of one, and a duration of 16 msec.

The mask-target combinations used were: 1) blank-grating (BG), 2) line-grating (LG), 3) grating-line (GL), 4) grating-grating (GG), and 5) line-line (LL) for each spatial frequency for a total of 15 possible mask-target combinations.

A fixation dot positioned in the center of a lighted blank 2 ft.L's field was also used as a slide in one phase of the experiment.

PROCEDURE: There were two phases of the experiment each employing different masking situations. These are shown in Figure 3. Phase I consisted

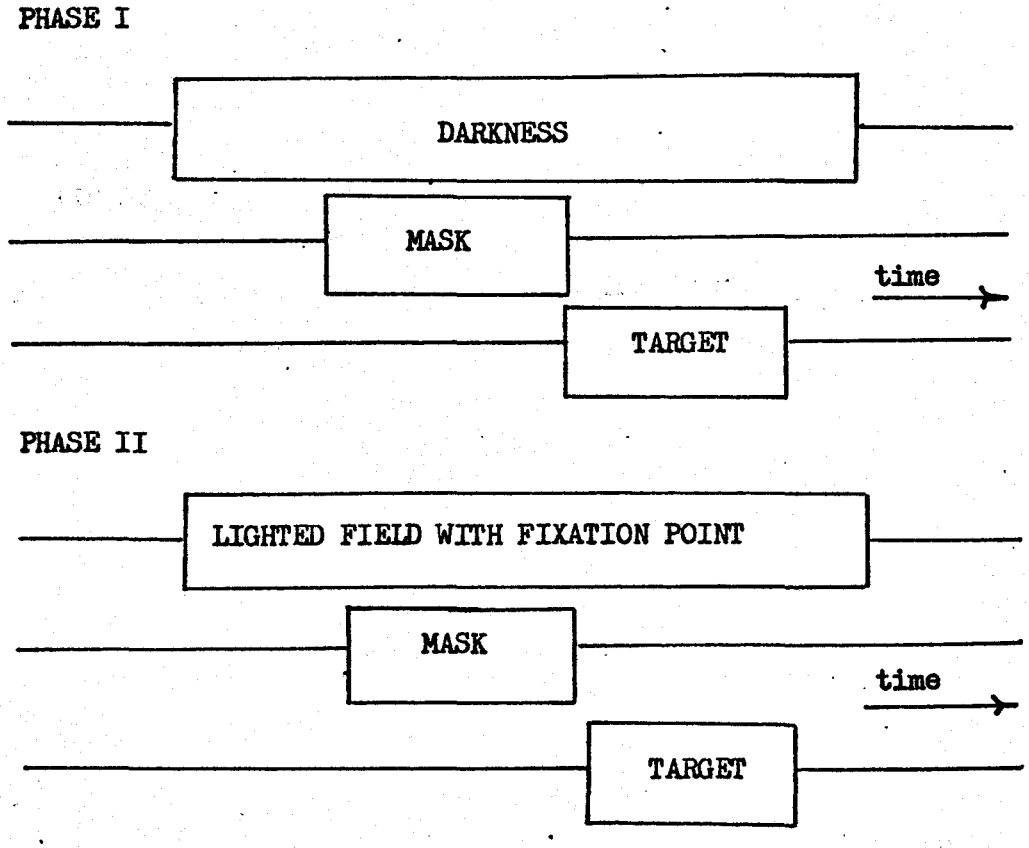

FIGURE 3. The two types of masking sequences used in the experiment (Phase I without a fixation point; Phase II with a fixation point).

of darkness, presentation of the masking stimulus for a specific duration, then presentation of the target. Four subjects were used (VS,AC,TR, and PW). The Ss were told to fixate on the center of the mask slide when it was flashed. Phase II consisted of a fixation dot in the center of a lighted two ft. L field always present during the masking sequence. The luminance levels of the target and mask were elevated two ft L's due to the continuous presence of the fixation dot. This elevated the mask to 18 ft. L's and target to 5.2 ft. L's; it also reduced the contrast to .78 for the masks and .23 for the targets.

Subjects were dark adapted for ten minutes prior to a experimental session. The target and mask was used with four ISI (interstimulus intervals measured from the offset of the adaptation field to the onset of the test stimulus). These were 0, 5, 10, and 30 msec. The masks were presented at seven different durations of 10, 25, 50, 75, 100, 150 msecs., and 10 secs.

Steven's magnitude estimation was used with a modulus of 10 assigned to the luminance of the target flash presented by itself. This standard was shown to the subject at the beginning of each trial and the subject estimated the apparent contrast of the target as a proportion of the standard. Subjects were instructed that they could have the standard whenever they wanted it during a trial, but no subject requested it.

One experimental trial consisted of one mask-target combination presented for each of the four ISI in random order which were then presented at random over each of the seven durations, for a total of 28 reaponses. There was a five second delay between each ISI presentation of a mask-target sequence.

A complete experimental session consisted of the fifteen mask-target combinations over each of the single trials. There were ten replications of each experimental session (a total of 4,200 responses per subject). Each subject had a practice experimental session of 420 responses before the experiment.

CHAPTER III

RESULTS

If magnitude extimations are transformed into logarithms, they will give a normal distribution of data (Stevens, 1966). A five way analysis of variance was thus performed on the logarithmic transformation of the data for Phase I (subjects, frequency, conditions(mask-target combinations), durations, and ISI). The error terms in this analysis are the next order interaction involving Ss. The results of this analysis showed three main significant effects: conditions $(4,12) = 6.4$ $p<.01$; durations $(6,18) = 4.0$ $p<.05$; and ISI $(3,9) = 6.5$ $p<.05$. Two significant second order interaction effects occurred: frequency and conditions (different mask-target combinations act differently at different frequencies) and conditions and durations (different mask-target combination act differently at different durations) at $p<.01$. And also two significant third order interaction effects at $p<.01$ for frequency, conditions, and ISI; and for frequency, conditions, and durations (different mask-target combinations were differentially effected by frequency and ISI).

The apparent contrast of the target for each masking combination were graphed for each subject individually for each duration over ISI to determine any characteristic enhancement of any subjects. Enhancement was defined as the mean apparent contrast for a grating (target) after viewing a grating (mask) at a particular ISI and duration which is higher than the corresponding mean apparent contrast for a grating (target) after viewing a uniformly illuminated field (mask).

The results showed that one subject (VS) enhanced for the GG condition for various durations and spatial frequencies as predicted, but three subjects (FW, AC, and TR) did not enhance at any duration. VS enhanced at durations

of 50 and 75 msec. at a frequency of 3 c/deg, at durations of 100 msec., 150 msec., and 10 sec. for a frequency of 10 c/deg., and at duration of 150 msecs. and 10 secs. for a duration of 15 c/deg. The enhancement of VS was shown in Figures 4, 5, 6, and 7. There is evidence of a functional relationship. As frequency increases, enhancement occurs at greater and greater durations.

The ISIs were averaged together over each duration for the BG and GG conditions. The BG condition was then subtracted from the GG condition and drawn for each dubject for each frequency in Figure 8. The extreme variability of subjects can easily be noted with VS above all other subjects at all durations.

Most individual masking functions did not vary appreciably with ISI, so an analysis of masking conditions for each spatial frequency for each mask-target combination was performed averaged across ISI. These t-tests across conditions collapsed across durations, summed across subjects and ISI are shown in Table 1. (1 = BG, 2 = LG, 3 = GL, 4 = GG, and 5 = LL).

Two features of the data emerge clearly. First as frequency increases, the number of conditions that vary from each other decreases. This was no doubt due to the attenuation characteristics of the visual system. It is increasingly difficult to see gratings as the frequency increases. Thus, masking is greater for every condition for 15 c/deg, and since there is a floor for this data (zero as a magnitude estimation) the differences between conditions are, in effect, compressed.

Secondly, a line masks a grating (1-2); and a grating does not mask a line as much as a line masks a line (3-5). (Masking, as enhancement, was defined as the difference from the blank condition, but unlike enhancement, the difference is in a negative direction).

Finally, it was of interest to determine at what duration for each grating

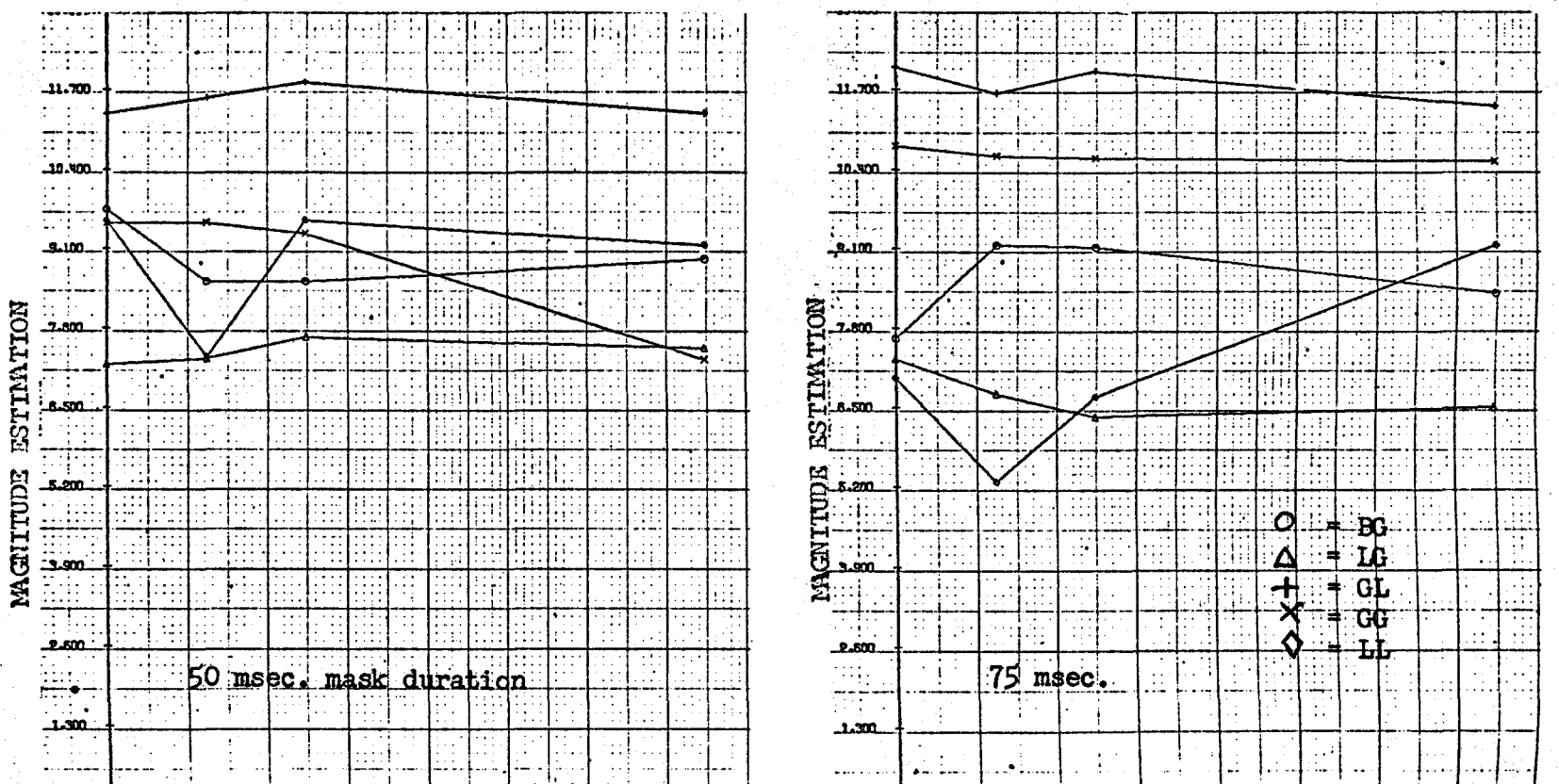

FIGURE 4. The apparent contrast of the targets for all conditions over ISI of subject VS, showing enhancement of the GG condition at durations of 50 and 75 msecs. for a frequency of 3 c/deg.

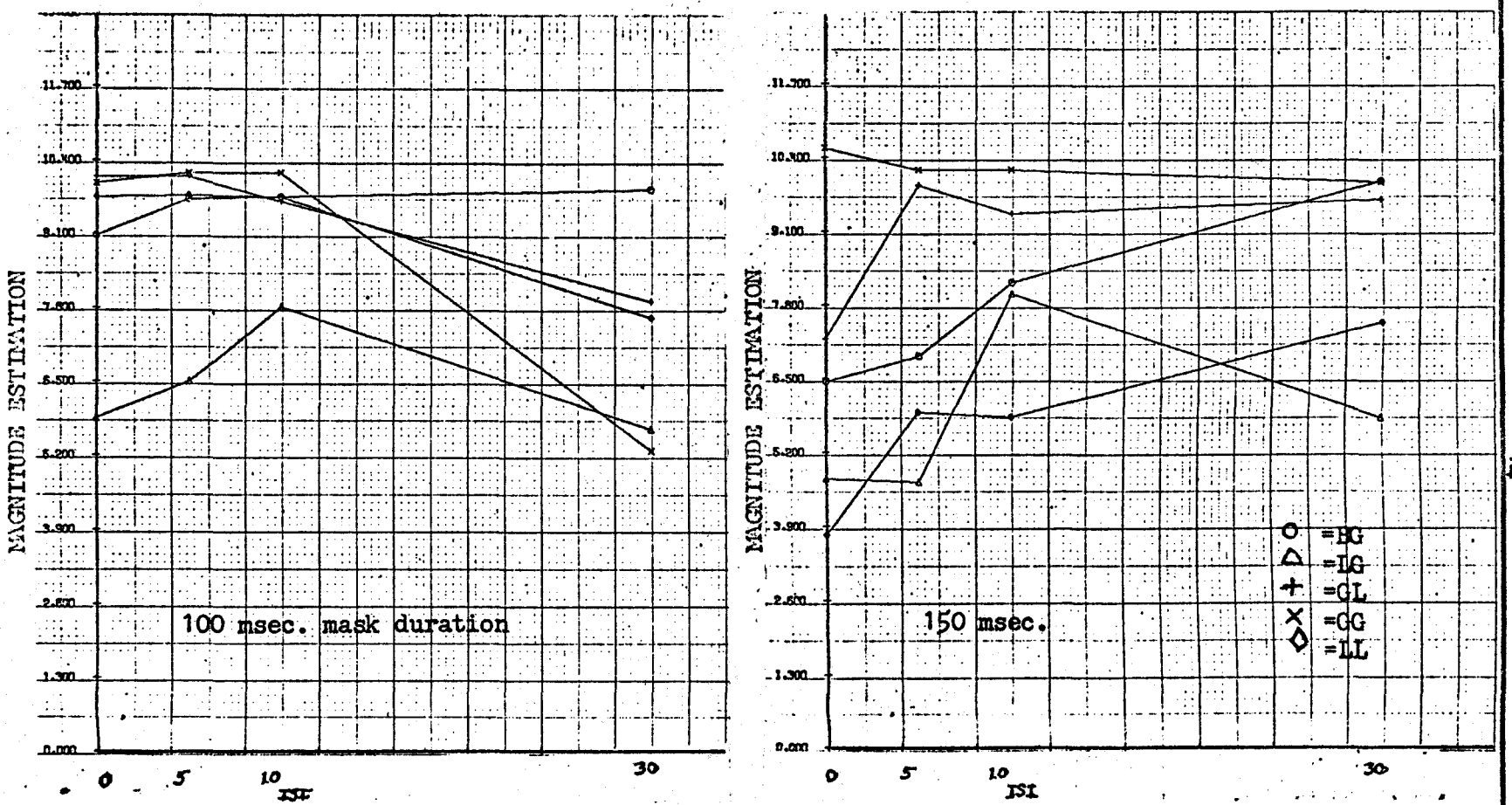

FIGURE 5. The apparent contrast of the targets for all conditions over ISI of subject VS, showing enhancement of the GG condition at durations of 100 and 150 msecs. for a frequency of 10 c/deg.

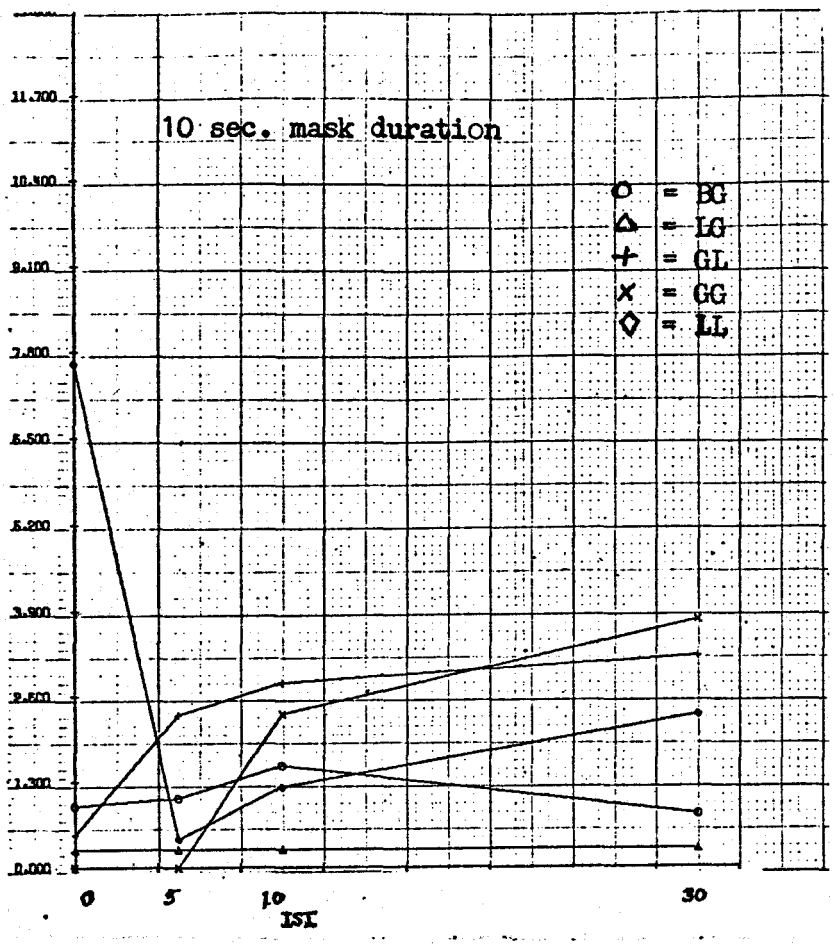

FIGURE 6. The apparent contrast of the targets for all conditions over ISI of subject VS, showing enhancement of the GG condition at duration 10 seconds for a frequency of 10 c/deg.

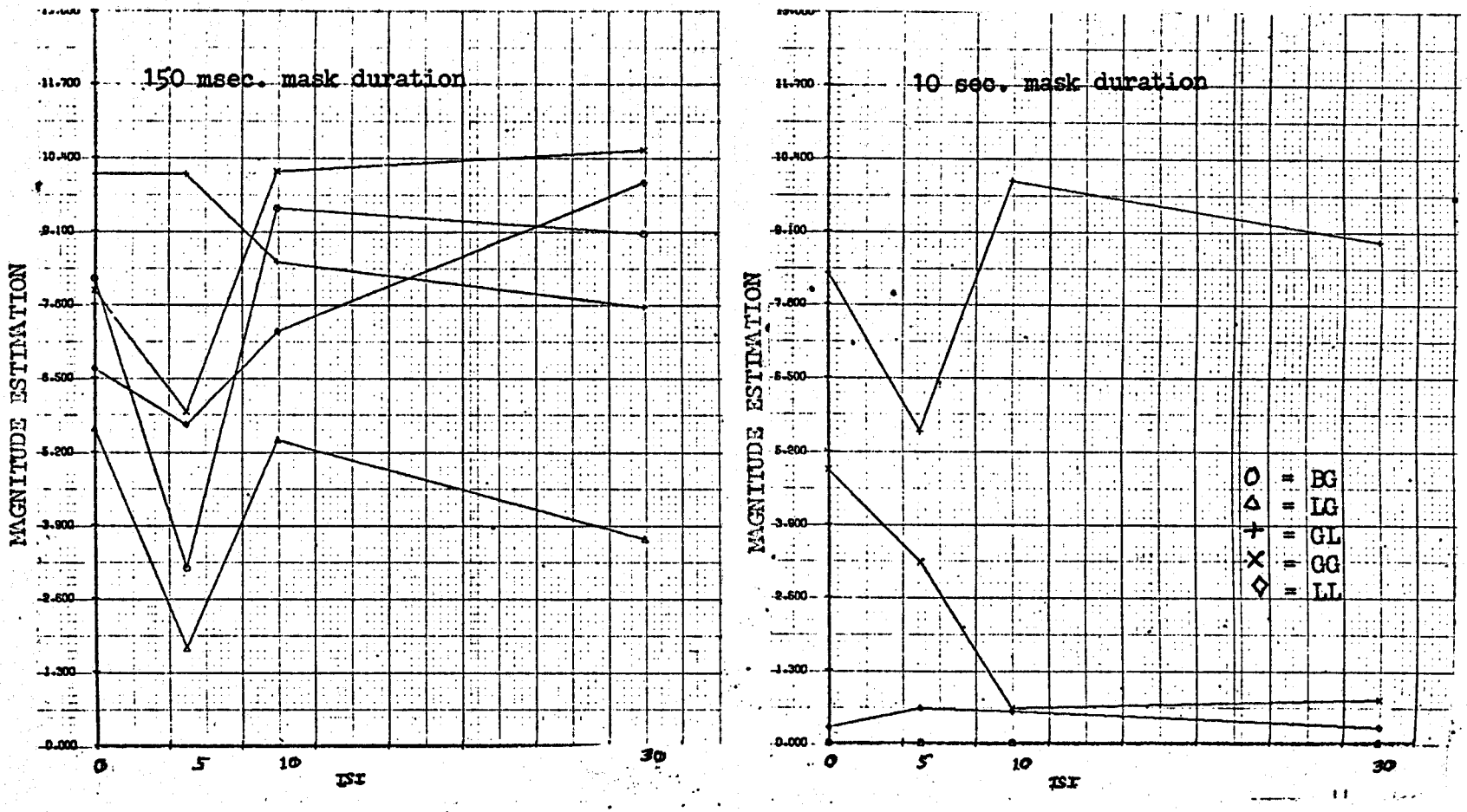

FIGURE 7. The apparent contrast of the targets for all conditions over ISI of subject VS, showing enhancement of the GG condition at durations of 150 msec. and 10 secs. for a frequency of 15 c/deg.

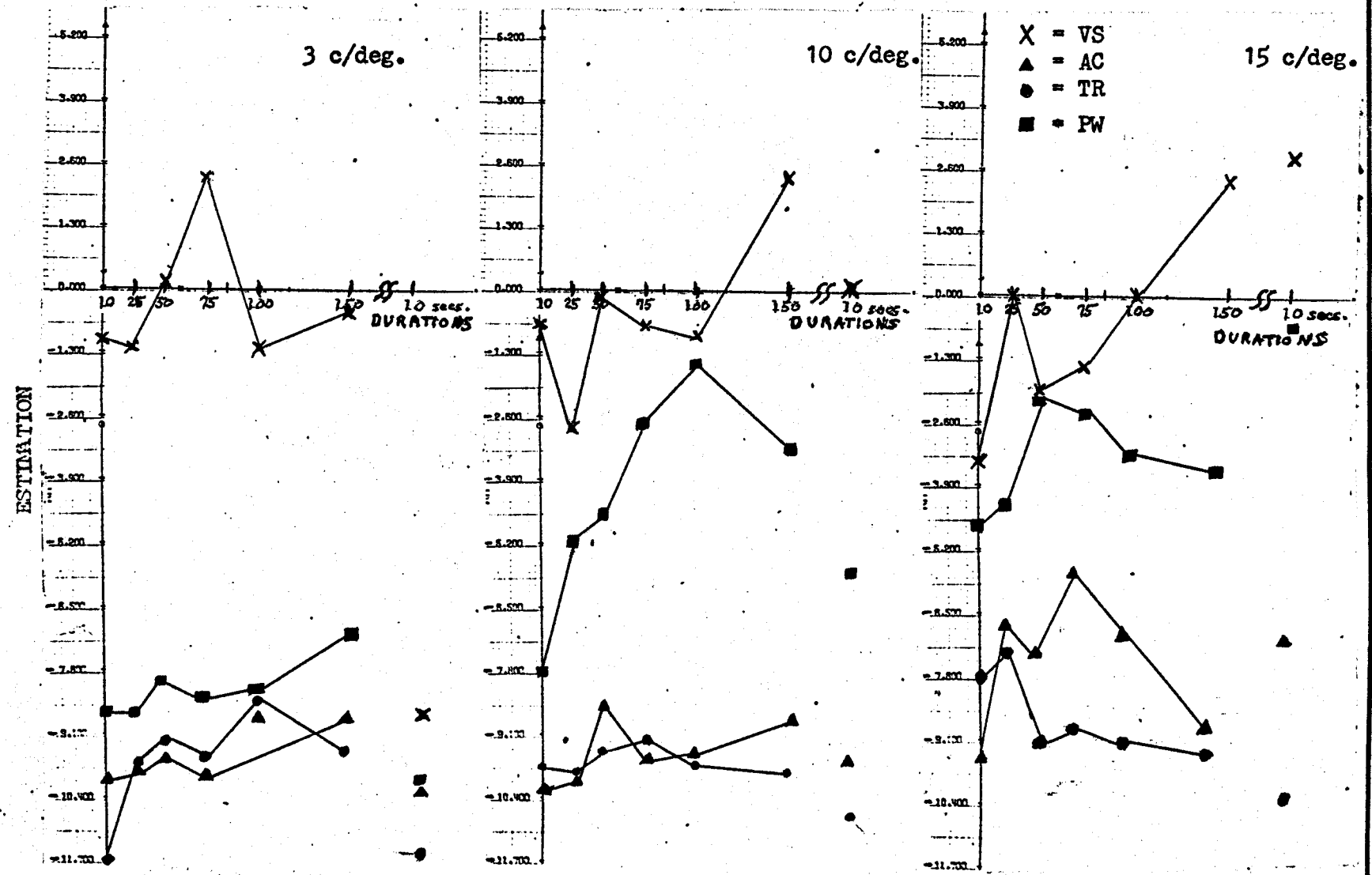

FIGURE 8. The mean contrast of the target of the GG condition subtracted from the BG (control) condition for each subject over duration for 3, 10, and 15 c/deg.

TABLE 1

Pairwise comparison: mean amount of masking for each condition compared with each other condition over composite scores for frequencies, 3, 10, and 15 c/deg.

a. 3 c/deg.

	Mean differences				
	1	2	3	4	5
1 BG		-8.33****	-3.63**	-16.82****	-22.69****
2 LG			-2.71*	-13.35****	-17.86****
3 GL				-6.61****	-7.00****
4 GG					-5.81***
5 LL					

b. 10 c/deg.

	Mean differences				
	1	2	3	4	5
1 BG		-12.09****	-4.47**	-21.07****	-27.81****
2 LG			-2.71*	-16.63****	-22.09****
3 GL				-4.33**	-5.05***
4 GG					0.95NS
5 LL					

c. 15 c/deg.

	Mean differences				
	1	2	3	4	5
1 BG		-6.09****	-7.53****	-20.04****	-30.97****
2 LG			0.40NS	-23.36****	-16.36****
3 GL				-8.20****	0.03NS
4 GG					
5 LL					

(* = $p < .05$, ** = $p < .025$, *** = $p < .01$, **** = $p < .005$)

the conditions differed from each other. This is shown in Table 2a, b, and c and in Table 3a, b, and c. Table 2 showed the mean amount of masking for each condition compared with each condition by a t-test for each duration (a = 3 c/deg., b = 10 c/deg., and c= 15 c/deg.). Table 3 showed the same compairison but without subject VS. Since VS's results were so much different than those of the other three subjects, this test between conditions was performed.

Data from the tables are not easily interpreted without reference to corresponding graphs. Composite graphs summed over ISI and over subjects were graphed over durations for each condition are shown in Figure 9 for each frequency. It can be seen that at 10 seconds (data points at a duration of 10 seconds were not connected with the other durations due to the extreme time difference) masks 1 and 2, in general converge. However, the graphs show that, even at 3 c/deg. masks 1 and 2 differ from each other by a smaller amount than at other durations. Meanwhile condition 3 at short durations does not differ from condition 2, but approaches condition 5 as duration increases. Conditions 4 and 5 can also be seen to be the most alike in amount of masking. The interaction effects of frequency and duration, and duration with conditions are easily seen with different conditions differentially effected by duration and frequency.

Data for phase II of the experiment were collected as an added control, since no fixation dot was used in Phase I there was a possibility that all Ss were not fixating on the center of the slide as instructed, producing an extraneous variable. The data was graphed across ISI and duration and a comparison of Phase I and II for apparent contrast of conditions was performed. Very little difference was found between Phase I and Phase II. The major difference was that apparent contrast of the target was reduced (more masking

TABLE 2a

Pairwise comparison: mean amount of masking for each condition compared with each other condition at each duration at a frequency of 3 c/deg.

Mean Differences
10 msec.

	1	2	3	4	5
1 BG		-3.21**	-1.07NS	-3.05*	-3.84**
2 LG			-0.30NS	-2.70*	-3.51**
3 GL				-3.13**	-4.43**
4 GG					-1.33NS
5 LL					

Mean Differences
25 msec.

	1	2	3	4	5
1 BG		-2.47*	-1.14NS	-3.15*	-4.32**
2 LG			0.52NS	-2.65*	-3.56**
3 GL				-2.10NS	-2.44*
4 GG					-1.04NS
5 LL					

Mean Differences
50 msec.

	1	2	3	4	5
1 BG		-2.12NS	-1.40NS	-2.80*	-2.99*
2 LG			-1.12NS	-2.35NS	-2.63*
3 GL				-1.85NS	-2.50*
4 GG					-1.10NS
5 LL					

Mean Differences
75 msec.

	1	2	3	4	5
1 BG		-1.80NS	-1.46NS	-2.57*	-3.34**
2 LG			-1.22NS	-2.12NS	-2.81*
3 GL				-1.56NS	-2.33NS
4 GG					-2.64NS
5 LL					

Mean Differences
100 msec.

	1	2	3	4	5
1 BG		-1.99NS	-1.60NS	-3.03*	-3.74**
2 LG			-1.16NS	-2.29NS	-2.87*
3 GL				-1.81NS	-2.22NS
4 GG					-1.95NS
5 LL					

Mean Differences
150 msec.

	1	2	3	4	5
1 BG		-1.42NS	-1.61NS	-2.85*	-3.15*
2 LG			-1.50NS	-2.56*	-2.94*
3 GL				-2.11NS	-2.98*
4 GG					-1.29NS
5 LL					

Mean Differences
10 sec.

	1	2	3	4	5
1 BG		-4.34**	-6.20****	-10.59****	-14.29****
2 LG			-6.23****	-10.66****	-14.56****
3 GL				-1.62NS	-1.71NS
4 GG					-1.22NS
5 LL					

(* = $p<.05$, ** = $p<.025$, *** = $p<.01$, **** = $p<.005$)

TABLE 2b

Pairwise comparison: mean amount of masking for each condition compared with each other condition at each duration at a frequency of 10 c/deg.

Mean Differences
10 msec.

	1	2	3	4	5
1 BG		-2.22NS	-0.81NS	-3.09*	-3.59**
2 LG			-0.08NS	-2.36*	-2.72*
3 GL				-2.75*	-3.17*
4 GG					-1.15NS
5 LL					

Mean Differences
25 msec.

	1	2	3	4	5
1 BG		-4.50**	-1.24NS	-3.53**	-3.01*
2 LG			-0.44NS	-2.76*	-2.33NS
3 GL				-2.49*	-2.13NS
4 GG					-2.30NS
5 LL					

Mean Differences
50 msec.

	1	2	3	4	5
1 BG		-1.55NS	-1.60NS	-2.73*	-3.18*
2 LG			-1.27NS	-1.89NS	-2.26NS
3 GL				-1.44NS	-1.80NS
4 GG					-1.55NS
5 LL					

Mean Differences
75 msec.

	1	2	3	4	5
1 BG		-2.88*	-2.22NS	-2.70*	-2.69*
2 LG			-0.78NS	-1.70NS	-1.72NS
3 GL				-1.63NS	-1.77NS
4 GG					-0.49NS
5 LL					

Mean Differences
100 msec.

	1	2	3	4	5
1 BG		-1.73NS	-1.94NS	-2.85*	-2.98*
2 LG			-1.10NS	-1.54NS	-1.80NS
3 GL				-1.36NS	-1.74NS
4 GG					-0.85NS
5 LL					

Mean Differences
150 msec.

	1	2	3	4	5
1 BG		-8.94****	-2.00NS	-2.25NS	-3.37**
2 LG			-1.29NS	-1.84NS	-2.77*
3 GL				-1.35NS	-2.20NS
4 GG					-0.95NS
5 LL					

Mean Differences
10 sec.

	1	2	3	4	5
1 BG		-1.70NS	-2.37*	-3.00*	-2.34NS
2 LG			-1.80NS	-2.28*	-1.77NS
3 GL				-1.97NS	0.20NS
4 GG					2.52*
5 LL					

(* = $p < .05$, ** = $p < .025$, *** = $p < .01$, **** = $p < .005$)

TABLE 2c

Pairwise comparison: mean amount of masking for each condition compared with each other condition at each duration at a frequency of 15 c/deg.

Mean Differences 10msec.

	1	2	3	4	5
1 BG		-2.23NS	-1.19NS	-3.56**	-3.48**
2 LG			1.07NS	-2.37*	-2.28NS
3 GL				-2.58*	-2.49*
4 GG					-1.41NS
5 LL					

Mean Differences 25 msec.

	1	2	3	4	5
1 BG		-2.89*	-1.15NS	-2.83*	-2.61*
2 LG			1.04NS	-1.41NS	-1.38NS
3 GL				-1.99NS	-2.00NS
4 GG					-0.12NS
5 LL					

Mean Differences 50 msec.

	1	2	3	4	5
1 BG		-5.49***	-1.26NS	-3.18**	-2.59*
2 LG			1.10NS	-1.65NS	-1.32NS
3 GL				-2.59*	-2.14NS
4 GG					1.23NS
5 LL					

Mean Differences 75 msec.

	1	2	3	4	5
1 BG		-3.93**	-3.02*	-3.10*	-2.89*
2 LG			0.13NS	-1.55NS	-1.41NS
3 GL				-2.33NS	-2.06NS
4 GG					1.52NS
5 LL					

Mean Differences 100 msec.

	1	2	3	4	5
1 BG		-3.99**	-2.10NS	-2.78*	-2.76*
2 LG			1.26NS	-1.51NS	-1.51NS
3 GL				-2.27NS	-2.26NS
4 GG					0.00NS
5 LL					

Mean Differences 150 msec.

	1	2	3	4	5
1 BG		-4.35**	-1.59NS	-2.54*	-2.65*
2 LG			0.26NS	-1.52NS	-1.54NS
3 GL				-2.09NS	-2.04NS
4 GG					0.21NS
5 LL					

Mean Differences 10 sec.

	1	2	3	4	5
1 BG		0.44NS	-0.66NS	-1.29NS	-1.85NS
2 LG			-0.66NS	-1.29NS	-1.89NS
3 GL				-1.32NS	-1.20NS
4 GG					-1.00NS
5 LL					

(* = $p<.05$, ** = $p<.025$, *** = $p<.01$, **** = $p<.005$)

TABLE 3a

Pairwise comparison: mean amount of masking for each condition compared with each other condition at each duration at 3 c/deg. without VS.

Mean Differences
10 msec.

	1	2	3	4	5
1 BG		-2.28NS	-1.87NS	-12.88****	-36.74****
2 LG			-1.16NS	-10.26****	-38.87****
3 GL				-4.90**	-8.54***
4 GG					-1.49NS
5 LL					

Mean Differences
25 msec.

	1	2	3	4	5
1 BG		-1.67NS	-1.43NS	-25.78****	-19.96****
2 LG			-1.36NS	-10.11****	-8.85***
3 GL				-2.08NS	-1.99NS
4 GG					-0.31NS
5 LL					

Mean Differences
50 msec.

	1	2	3	4	5
1 BG		-1.48NS	-1.98NS	-7.10***	-23.57****
2 LG			-2.10NS	-4.75***	-10.27****
3 GL				-1.85NS	-2.96*
4 GG					-1.11NS
5 LL					

Mean Differences
75 msec.

	1	2	3	4	5
1 BG		-1.20NS	-2.12NS	-10.36****	-22.65****
2 LG			-2.50NS	-5.65**	-8.65***
3 GL				-1.61NS	-2.13NS
4 GG					-1.21NS
5 LL					

Mean Differences
100 msec.

	1	2	3	4	5
1 BG		-1.48NS	-2.04NS	-9.40***	-19.42****
2 LG			-2.09NS	-7.74***	-11.57****
3 GL				-1175NS	-1.99NS
4 GG					-1.41NS
5 LL					

Mean Differences
150 msec.

	1	2	3	4	5
1 BG		-1.21NS	-3.06NS	-7.45***	-19.49****
2 LG			-3.76*	-4.91**	- 9.19***
3 GL				-1.99NS	-3.16*
4 GG					-1.10NS
5 LL					

Mean Differences
10 sec.

	1	2	3	4	5
1 BG		-4.50**	-13.63****	-74.64****	-97.87****
2 LG			-14.42****	-49.22****	-58.92****
3 GL				- 0.90NS	- 1.00NS
4 GG					- 1.00NS
5 LL					

(* = $p<.05$, ** = $p<.025$, *** = $p<.01$, **** = $p<.005$)

TABLE 3b

Pairwise comparison: mean amount of masking for each condition compared with each other condition at each duration at 10 c/deg. without VS.

Mean Differences
10 msec.

	1	2	3	4	5
1 BG		-1.43NS	-0.99NS	-27.75****	-31.25****
2 LG			-0.80NS	-10.74****	-11.31****
3 GL				-3.97*	-4.06*
4 GG					-1.00NS
5 LL					

Mean Differences
25 msec.

	1	2	3	4	5
1 BG		-3.13*	-1.49NS	-9.82***	-8.86***
2 LG			-1.01NS	-6.03**	-5.52**
3 GL				-2.53NS	-2.34NS
4 GG					-1.98NS
5 LL					

Mean Differences
50 msec.

	1	2	3	4	5
1 BG		-0.96NS	-1.49NS	-5.78**	-8.83***
2 LG			-1.80NS	-3.19*	-4.20*
3 GL				-1.72NS	-2.15NS
4 GG					-1.00NS
5 LL					

Mean Differences
75 msec.

	1	2	3	4	5
1 BG		-2.55NS	-2.84NS	-4.97**	-6.75**
2 LG			-2.83NS	-3.48*	-4.50**
3 GL				-1.79NS	-2.23NS
4 GG					-1.00NS
5 LL					

Mean Differences
100 msec.

	1	2	3	4	5
1 BG		-1.35NS	-2.34NS	-5.79**	-11.43****
2 LG			-2.41NS	-2.02NS	-2.84NS
3 GL				-1.37NS	-1.97NS
4 GG					-1.00NS
5 LL					

Mean Differences
150 msec.

	1	2	3	4	5
1 BG		-11.85****	-3.33*	-4.76**	-7.55***
2 LG			-2.71NS	-4.15*	-6.55***
3 GL				-1.55NS	-2.00NS
4 GG					-0.25NS
5 LL					

Mean Differences
10 sec.

	1	2	3	4	5
1 BG		-2.58NS	-15.55****	-14.49****	-25.97****
2 LG			-16.00****	-12.66****	-19.50****
3 GL				-1.21NS	-0.10NS
4 GG					1.99NS
5 LL					

(* = $p<.05$, ** = $p<.025$, *** = $p<.01$, **** = $p<.005$)

TABLE 3c

Pairwise comparison: mean amount of masking for each condition compared with each other condition at each duration at 15 c/deg. without VS.

Mean Differences
10 msec.

	1	2	3	4	5
1 BG		-1.73NS	-0.92NS	-11.68****	-10.27****
2 LG			-0.80NS	-4.11*	-3.86*
3 GL				-3.79*	-3.57*
4 GG					1.00NS
5 LL					

Mean Differences
25 msec.

	1	2	3	4	5
1 BG		-2.14NS	-1.43NS	-8.74***	-13.03****
2 LG			0.30NS	-2.51NS	-3.03*
3 GL				-2.19NS	-2.59NS
4 GG					-1.00NS
5 LL					

Mean Differences
50 msec.

	1	2	3	4	5
1 BG		-4.09*	-1.90NS	-5.55**	-5.22**
2 LG			0.35NS	-3.07*.	-2.9NS
3 GL				-2.58NS	-2.47NS
4 GG					1.00NS
5 LL					

Mean Differences
75 msec.

	1	2	3	4	5
1 BG		-2.69NS	-4.49**	-6.90**	-5.80**
2 LG			-2.78NS	-3.12*	-2.73NS
3 GL				-3.16*	-2.70NS
4 GG					-1.00NS
5 LL					

Mean Differences
100 msec.

	1	2	3	4	5
1 BG		-2.73NS	-2.63NS	-6.66**	-6.66**
2 LG			1.77NS	-3.11*	-3.11*
3 GL				-3.30*	-3.30*
4 GG					0.00NS
5 LL					

Mean Differences
150 msec.

	1	2	3	4	5
1 BG		-3.15*	-2.73NS	-7.50***	-5.87**
2 LG			-1.84NS	-3.41*	-2.85NS
3 GL				-4.57NS	-2.19NS
4 GG					-1.00NS
5 LL					

Mean Differences
10 sec.

	1	2	3	4	5
1 BG		-0.42NS	-3.27*	-3.11*	-3.11*
2 LG			-3.48*	-3.28*	-3.28*
3 GL				+1.00NS	-1.00NS
4 GG					0.00NS
5 LL					

(* = p<.05, ** = p<.025, *** = p<.01, **** = p<.005)

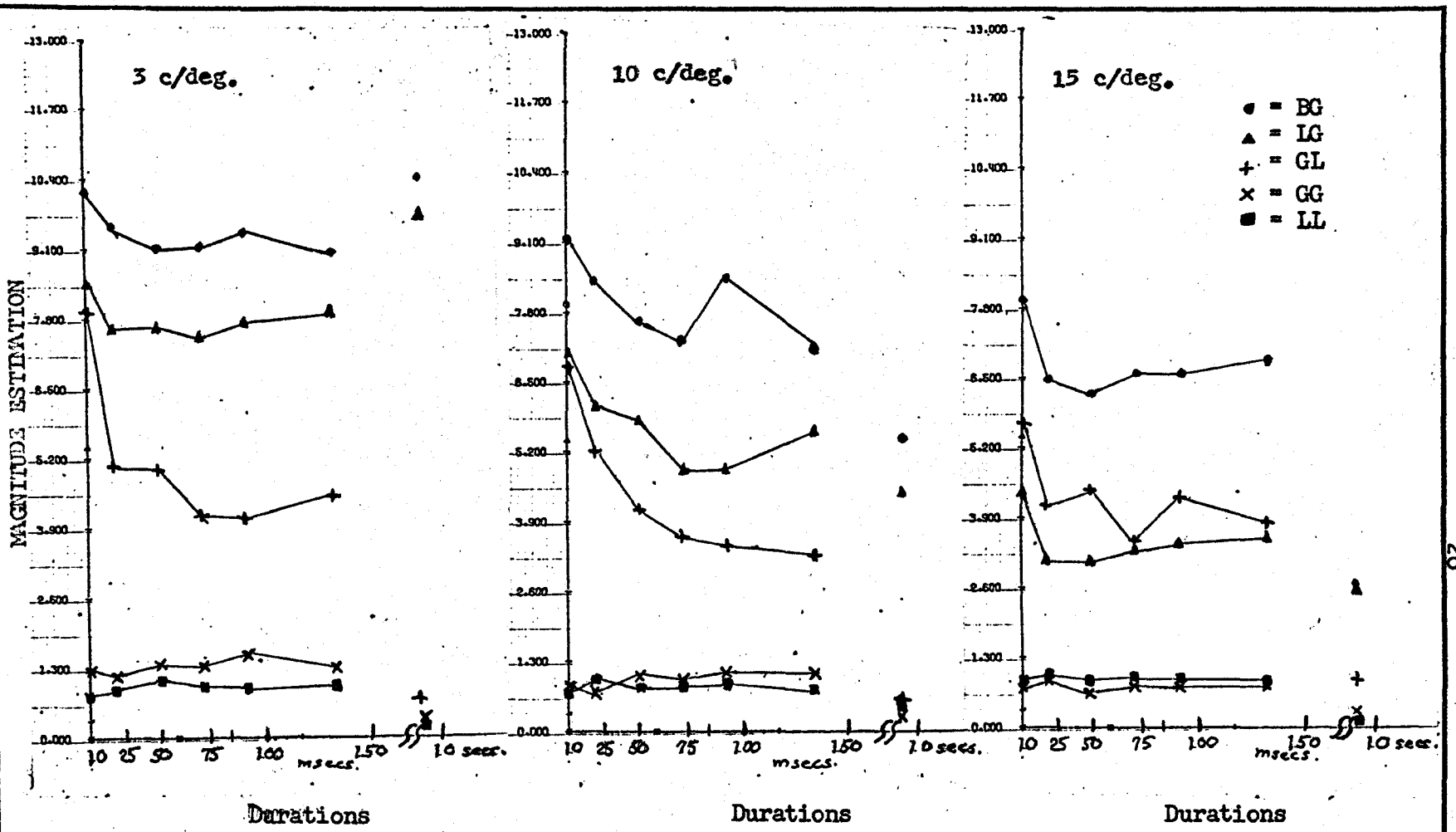

FIGURE 9. Apparent contrast of conditions for composite scores of Ss averaged over ISI over duration at frequencies of 3, 10, and 15 c/deg. (Phase I).

for all conditions) in Phase II as compared to Phase I. This is evident in Figure 10 which is the composite graphs summed across subjects and averaged over ISI and plotted across duration for frequencies of 3, 10, and 15 c/deg. for Phase II. This reduction was probably due to the lowering of contrast of the target by addition of the added luminance of the fixation field to all conditions.

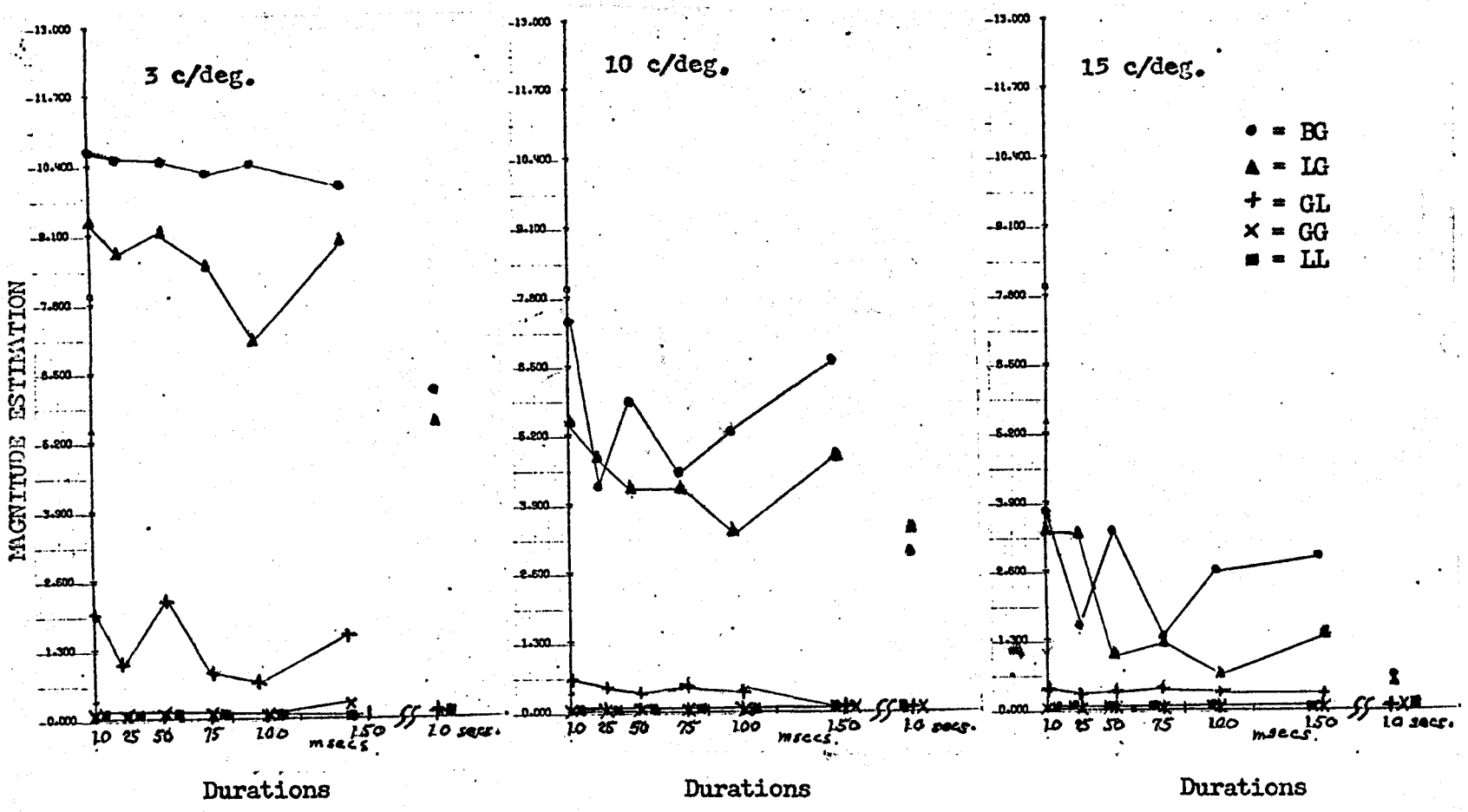

FIGURE 10. Apparent contrast of conditions for composite scores of Ss averaged over ISI over duration at frequencies of 3, 10, and 15 c/deg. for Phase II (fixation dot).

CHAPTER IV

DISCUSSION

Enhancement was found for one subject, but there seems to be a functional relationship in this enhancement. As frequency increased, so did the duration at which enhancement was found. It is possible that this relationship reflects differences in neural populations in the visual system. That is, different populations of neurons may respond to different frequencies and each population may have some different temporal characteristic.

Although not all durations and interstimulus intervals were tested, it would seem probable that the subjects who did not enhance would not enhance if other durations were used, and the subject who did enhance would enhance again at some other frequency, duration, or ISI combination. It is not clear why one subject enhanced and the others did not. It may have to do with individual differences in rise and decay rates in neural populations, but in order to test this hypothesis, data for enhancement should be collected at much larger ISIs since if the decay hypothesis is valid, enhancement should either decrease rapidly or change to masking at later ISIs. While enhancement was found in this study, the conditions under which it was found do not support our original hypothesis. But they do not necessarily disconfirm it either. More data at later ISIs are necessary to decide whether this hypothesis is tenable.

A line was found to mask a grating at short masking durations. A grating was found to mask a line less than a line masks a line at short durations. These effects more or less disappear at 10 seconds, that is, at an adaptation duration. What conclusion for frequency coding can be drawn from these features of the data?

All conclusions, of course, are at this stage very tenative. But it appears that units which code for frequency when a line (or gate) is presented do not fire over an entire duration of presentation if the presentation is lengthy. This suggests that perhaps an initial stage in visual processing involves frequency coding while later stages do not. The increase in masking with increase in duration for mask three (grating-line) would also support this hypothesis, since at short durations masking for three versus five (line-line) was as would be predicted from a frequency hypothesis. By ten seconds masking resembles more what would be expected from a simple untransformed feature detector system. If there are one or more gates in a visual field, this would simply mask a subsequent gate. The masking at long durations then, depend on the individual stimulus, not its frequency characteristics.

In summary: enhancement was found for one subject out of four in this study. (Gilinsky also found masking for one subject out of four in 1967). The enhancement appears to be characteristic of a subject rather than to depend on temporal parameters. Further experimentation is necessary in order to decide whether a neural burst and decay rate hypothesis can explain this enhancement.

This data also showed striking evidence for frequency coding in the human visual system at initial stages of processing. Again, more experimentation is needed. For instance, if a true Fourier transformation is performed, then there should be no masking at the zero crossings. Moreover, dark stimuli were used on a lighted background; lighted stimuli on a dark background should also be tested. But a tentative conclusion of early-stage frequency transformation is definitely warranted by this data.

This data provides the first direct experimental evidence of such processing, and as such, has extremely broad implications for an understanding of the role of frequency transformation in visual processing.

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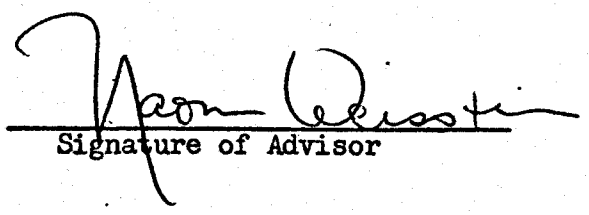
APPROVAL SHEET

This Thesis submitted by John Bisaha has been read and approved by members of the Department of Psychology.

The final copies have been examined by the director of the Thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the Thesis is now given final approval with reference to content and form.

The Thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Arts.

9/13/71
Date


Signature of Advisor