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SPATIAL FREQUENCY MASKING AND VISIBILITY.(U)
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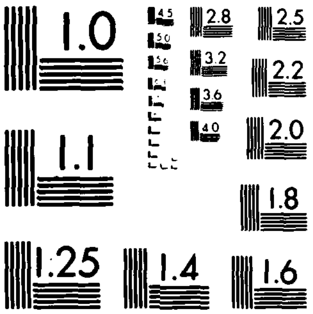

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Visibility, Spatial Frequency

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In the past year, work has progressed in four interrelated areas.

1) Substantial evidence supports the hypothesis that visual detection in the presence of masking noise occurs at a constant signal/noise ratio only if the subject is unfamiliar with the mask. —> cont

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cont.

(2) The computerized model of visual masking now incorporates enhancement by sub-threshold masks and spatial frequency tuning, in addition to 1), above.

(3) Spatial adaptation studies provide a better estimate of channel bandwidth than was previously available. This appears, however, to represent an altogether different mechanism from that involved in masking.

(4) Attempts to confirm studies showing the existence of two separate visual systems for the processing of spatial and temporal information have failed even to replicate published effects. The reason for this is still under investigation.

AFOSR-TR- 82 -0223

SPATIAL FREQUENCY MASKING AND VISIBILITY

Prepared by

Robert A. Smith

For: Air Force Office of Scientific Research
AFOSR- 80-0015

Second Annual Report
1 October 1981

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82 [illegible] 18

B. Objectives

Overall -- verify our model of masking in CRT images.

1. Continue to explore the unexpected discrepancy between Weber's Law and power law masking, determining which of these is most relevant to practical studies of visibility.

2. [illegible] our new much more ambitious [illegible] [illegible].

C. Status of the Research

1. Introduction

We are now studying the hypothesis that the detection or acquisition of a [illegible] contours are not immediately adjacent to the target. This is a pattern-[illegible] and should not be confused with [illegible] [illegible] method to study this problem was [illegible] in [illegible]. [illegible] that sensitivity to [illegible] reduced if the target was presented on a uniform CRT [illegible] (this is the usual condition for viewing a [illegible], the CRT is [illegible] with the [illegible] [illegible] enough to be practical (as much as a log unit), and applies [illegible] high contrast [illegible].

[illegible] "[illegible]-field" masking is a [illegible] [illegible].

A dark surround [illegible], to be sure, not a harmonically pure stimulus; its Fourier spectrum contains energy over a broad band, principally at low frequencies. Nevertheless, by treating this energy as "noise", it is reasonably straightforward to do a signal/noise calculation from the Fourier transform of the [illegible] stimulus, and to predict thresholds from this. These predictions show a power-law fall-off in masking as a function of target frequency, with [illegible] depending upon the shape of the field: square fields show a fall-off of f^{-1}, circular fields show $f^{-3/2}$, and diamond-shaped fields show f^{-2}. Our pilot data (Fig. 1), taken with a circular field, do indeed show this dependence, as do those of McCann et al (Fig. 2), which were taken with a square field. This gave us a great deal of confidence that our signal/noise model could make [illegible] predictions [illegible] from the Fourier [illegible] of the mask. In an effort to [illegible] this [illegible], we abandoned adjustment [illegible] methods for thresholds. [illegible] this was a mistake since it now appears that our signal/noise [illegible] to [illegible]. However, the understanding we have gained in the process has certainly been worthwhile.

2. [illegible] Year

Our first year's research produced some unexpected results. We found [illegible] basic (and almost universally [illegible]) assumption in our model of masking was not generally true. Specifically, if the mask stimulus is considered as noise, then it is found that detection does not always occur at a constant [illegible] ratio ([illegible] Law). Much of the first year was devoted to [illegible] Weber's Law. We [illegible] that temporal factors were responsible, and studied the [illegible] of detection in some depth. Although these studies did not [illegible] about Weber's Law, they led to [illegible] the critical

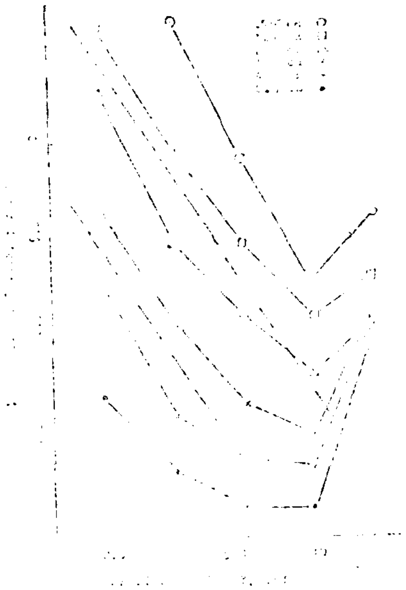


Fig. 1. Threshold as a function of spatial frequency for various [illegible] field sizes. The dotted lines show the predicted slope of -3/2.

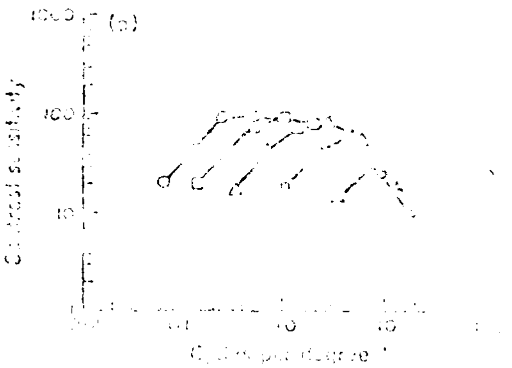


Fig. 2. Data from McCann et al. (1978), similar to Fig. 1 for various square fields. Here the low frequency slope has the predicted value of unity.

[illegible] (presented below) and to some potentially practical applications to [illegible] which form the basis of our current studies of image-enhancement ([illegible] in our [illegible] Proposal).

[illegible] end of the first year, [illegible] a dual [illegible] for detection which we continue to believe is correct. We [illegible] computer model of the masking process -- incorporating our dual mechanism -- which, [illegible] detection, in agreement with our experimental results.

5. Status of our Research in the Current Year

[illegible]

[illegible] of the year was [illegible] taking additional data to support our hypothesis [illegible] Weber's law masking occurs when the subject is sufficiently unfamiliar [illegible] stimulus to discount its presence. Under a variety of conditions, [illegible] a particular masking task, [illegible] (but not to zero) and a power-law replaces Weber's law. We [illegible] (Legge and [illegible]), [illegible] that any monotonic nonlinear system will display Weber's law [illegible] if external noise is the limiting factor. Conversely, the theorem also implies that when the discrimination is well-learned, and the mask can be discounted, [illegible] the resulting power-law behavior represents a true picture [illegible] nonlinearity. These studies led to a paper which is currently in [illegible]

[illegible] first year, our computer model of spatial masking was [illegible] Weber's law or power law detection, depending upon the [illegible]. [illegible] year it has been expanded to [illegible] experiments, in which stimulation to the test channel is [illegible] is not based on [illegible] a particular [illegible] in the [illegible] by [illegible] slight [illegible] predicting [illegible] that this assumption will also explain the results of [illegible] experiments. A major problem has been predicting the shape of the [illegible] bandwidth function (threshold change versus mask frequency). The fact [illegible] frequencies more effectively than vice-versa [illegible] to predictions from any reasonably smooth assumed receptive field. [illegible] discrepancy can be resolved by assuming that [illegible] are not smooth, but contain a [illegible] of noise. [illegible].

[illegible] information [illegible] channel bandwidth for [illegible] we have [illegible] earlier, completing our [illegible]

[illegible] threshold adaptation as a function of adapting frequency [illegible] under relatively weak assumptions, to represent [illegible].

[illegible] hypotheses [illegible] the sustained, but not the transient, channels of the visual [illegible] interest in these two temporal systems led us to try to replicate [illegible] could [illegible] evidence for or against the strict sustained/transient dichotomy [illegible] proposed. To our surprise, we were not able to verify the [illegible] differences between pattern and flicker detection which have been [illegible] the building [illegible] Differences were found, but [illegible]

[illegible]

5b. Weber's Law and Masking

[illegible] which [illegible] upon the observation of Weber's Law and the underlying [illegible] signal-to-noise detection threshold. It is, therefore, disconcerting [illegible] number of other investigators do not find that Weber's law applies [illegible] masking. Because it is important [illegible] our study, and because Weber's Law is [illegible] applicable generalization in all of experimental psychology, it [illegible]

[illegible] present experimental [illegible] either equal [illegible] the omission of several well-known studies). [illegible] generalizations become clear. It is apparent [illegible] of the method of adjustment also found Weber's Law [illegible] the converse is not necessarily true. Exceptions include [illegible] find Weber's Law. [illegible] presentation [illegible] becomes most plausible [illegible]

[illegible] 1

[illegible]	Mask [illegible]	T[illegible] Temporal	Spatial Freq.	Paradigm
		[illegible] Weber's Law		
[illegible]	C[illegible]	Cont.	2-5 cpd	Adjustment
[illegible]	C[illegible]	Cont.	4-12	Adjustment; mask was visual noise
[illegible]	--	2 sec	12	Forced Choice
[illegible] (19[illegible])	Cont.	Cont.	10	Adjustment
[illegible] (1973)	2[illegible]0 ms	200 ms	many	Forced choice, Dichoptic masking
[illegible] (1973)	Steady	0.5 Hz on-off	>7.5	Adjustment
	8 Hz Reversal	8 Hz Reversal + 8 Hz on-off	0.6	Adjustment
[illegible]-Willner et al (1973)	Steady	8 Hz on-off	12	Yes-No

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	Forced Orifice, [illegible]
[illegible] ([illegible] 7[illegible])	[illegible]nt.	[illegible]	2-1[illegible]	Forced Orifice
[illegible]	[illegible] ms.	[illegible]	2	Forced Orifice
[illegible] ([illegible])	150 [illegible]	2[illegible]	3	Forced Orifice
[illegible]	Steady	0.3 [illegible]	<7.5	Adjust[illegible]
[illegible]	Steady	[illegible]	1.5	[illegible]
[illegible] ([illegible] 78)	1 sec	1 [illegible]	4.25	Forced Orifice

[illegible]

[illegible]

[illegible] point, that [illegible]

[illegible]

[illegible] edition. [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

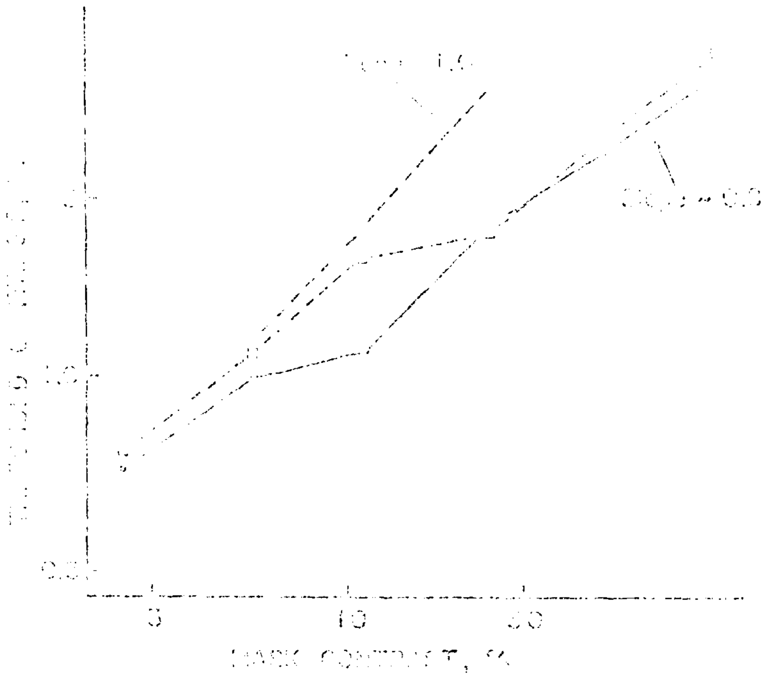
[illegible] hypothesis II above.

[illegible]

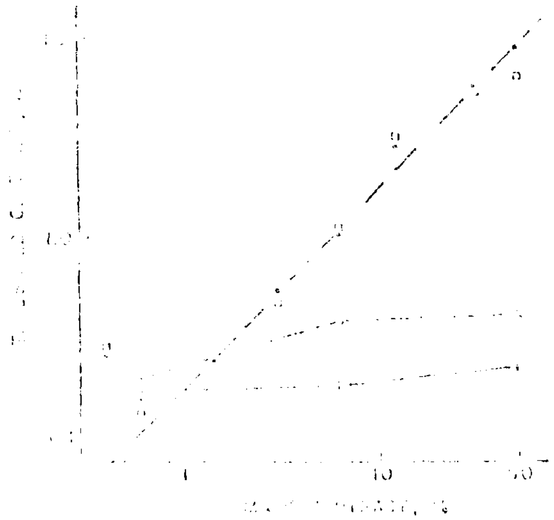
[illegible] conditions. [illegible] the duty cycle of [illegible]

[illegible] and [illegible] in the [illegible] conditions, [illegible]

[illegible]



[illegible] mask (- - -) [illegible]; [illegible] mask (—) [illegible]



[illegible] and Gorea's [illegible]

[illegible] shown in Figure [illegible] a variation in [illegible] In fact, the results are quite [illegible] when the mask stimulus [illegible]

[illegible] of 2. A [illegible] compared with [illegible] Weber's Law [illegible] in the [illegible]

[illegible]

cycle, so that complete spatial frequency separation would be expected to occur, and Kulikowski would predict that Weber's Law should apply. Although the details will be discussed later, the general conclusion is quite clear: using a 4 cycle test, we could find no condition whatever in which an spatially pure mask produced Weber's Law. This result demonstrates two important points. 1. It is a further counterexample to Kulikowski's hypothesis [illegible] that physical [illegible] methods alone may determine whether Weber's Law is observed, since (as noted above) Weber's Law is observed with the method of adjustment psychophysics under these conditions.

Our fourth hypothesis was that different, but seemingly equivalent, masking conditions may actually represent different tasks which only [illegible] [illegible]. The final conclusion of the previous paragraph is a clear statement that this is so. This leads us to ask how the subject actually [illegible] grating in [illegible] [illegible] location [illegible] of the [illegible] alone.

[illegible] a form of this criterion in [illegible] compensation experiment shown [illegible]. The principle of this experiment is that in each [illegible] of the mask by an amount proportional to the [illegible] of the test. If the constant of proportionality is selected correctly, the effect of this [illegible] will be to maintain the energy in the test [illegible] modulation. Under these conditions the subject would be able to set a threshold. The proportionality [illegible] unfortunately not known; it would be [illegible] sensitivity of the test channel to the mask frequency. [illegible]

[illegible] the [illegible] paradigm for a [illegible] [illegible] which produced a sharp rise in threshold. In fact, as shown in Figure 5, threshold is altogether flat with respect to [illegible]. Figure 5 also shows the very [illegible] prediction [illegible] [illegible]. It thus appears that [illegible] in the test channel is an inadequate criterion for [illegible] threshold differences.

[illegible] further insight. There are two related paradigms in the masking literature which are sometimes confused, probably inappropriately. We shall call these true masking and contrast discrimination (Legge, 1981). In true masking, [illegible] and test frequencies are different, while in contrast discrimination [illegible] are the same. While it is [illegible] true masking [illegible] can [illegible] be [illegible] a special case of masking, it is quite possible [illegible] that [illegible] detection in the contrast discrimination situation must be [illegible]

[illegible] the stimulation of a variety of channels in true masking [illegible] however, makes it quite possible that [illegible] discrimination is [illegible] a [illegible] pattern analysis. We hypothesize that this is the case and [illegible] hypothesize that the true masking discrimination is of a qualitative nature; either a particular pattern configuration is detected by the subject or it is not. This hypothesis may be tested. The subject is asked to [illegible] discrimination and true masking [illegible] a [illegible]. As the interstimulus interval is made progressively longer, [illegible] that a qualitative discrimination based on [illegible] will be degraded to a greater extent than will a [illegible] discrimination. The results of such an experiment are [illegible] in

Figure 3, where the prediction is verified. This reinforces our assertion that a simple incremental channel energy criterion cannot be responsible for all masking results. It also makes the point that the contrast discrimination situation should probably be considered separately from true masking and that results obtained with the two paradigms may differ in fundamental ways. With a few explicitly noted exceptions, we have previously avoided the contrast discrimination paradigm, and shall continue to do so for the remainder of this study. In fact, Legge (1981) has performed an experimental analysis of this paradigm, asking many of the same questions which we ask here; significantly, not all of the answers are the same for the two paradigms. For example, contrast discrimination does not obey Weber's Law, even when background is [illegible] ies.

At about this point in our studies, we became concerned that we had never [illegible] Weber's Law to hold with forced-choice masking [illegible] (one of [illegible] presentation [illegible]). We therefore tried to [illegible] Weber's Law w[illegible] that the failure of Weber's Law might be some artifact of our presentation order; we had typically measured masking slopes by starting with the lowest mask modulation and proceeding through to the highest, in order. In [illegible], we reversed the presentation order; we also tried a random presentation order. Finally we interspersed trials randomly for different mask levels. The results of all of these experiments were uniform; after each [illegible] that [illegible]. Contrary to other observers, we also found a 0.7 power law for this [illegible]. Finally, however, we discovered conditions under which [illegible] held. To achieve this, we masked with a different [illegible]

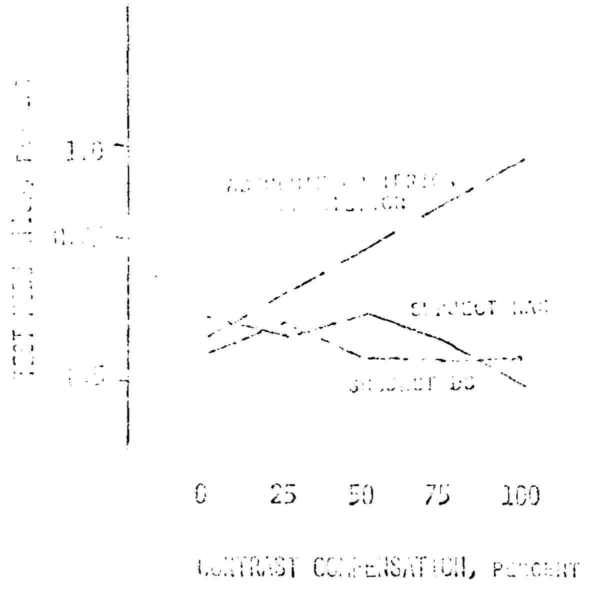


Fig. 5. The effect of contrast compensation (see text) on test threshold. Mask frequency 5 c/deg, contrast [illegible]; test frequency 4 c/deg. The dotted line shows the prediction of [illegible] and Foley's absolute channel energy model.

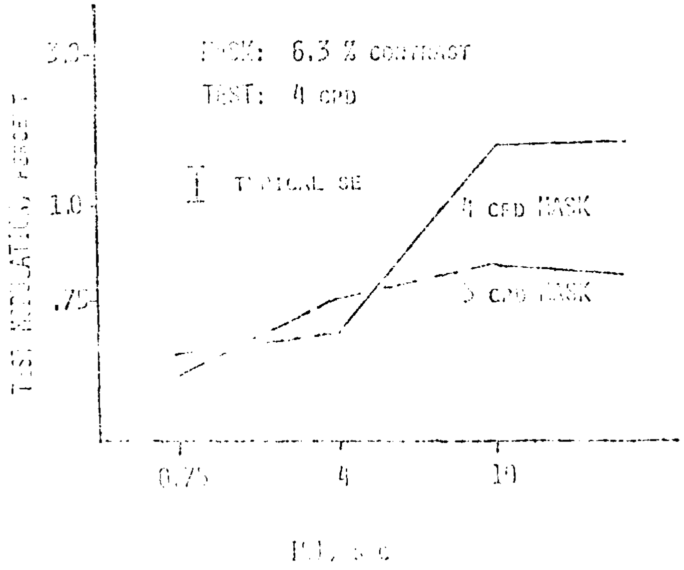


Fig. 6. The differential effect of ISI on contrast discrimination (test 4 c/deg) and on masking (mask 5 c/deg).

[illegible] in each [illegible] trial (Fig. 7). Thus the subject [illegible] given mask pattern only once, for the time necessary to make a single decision. We believe that this result can be interpreted in terms of the information content of the mask. If a mask is familiar to the subject then it effectively contains no information. Such a mask can be discounted if the subject looks for small deviations from the expected appearance of the mask. It was sub- [illegible] course of many trials, the subject would learn to use a particular local criterion for making any given discrimination. This criterion would vary with different masks, and had to be discovered by the subject for each new mask. A typical criterion might have been to compare the relative brightnesses of two [illegible] bars in the masking noise pattern, and seeing if this differed from what was expected for the mask alone. (See Nachmias and Weber, 1975). The [illegible] decrease in threshold towards a final asymptote. This discovery (discussed in [illegible]

[illegible] these experiments is the universality of the 0.7 power law. The fact that so very many different masking situations all yield [illegible] this is a basic and [illegible] property of the visual system. If it were the case that the [illegible] to totally discount the mask, then we would expect no masking at all to occur. [illegible] this is not so, it [illegible] which [illegible] the test signal when the mask is present.

[illegible] consider the following results which [illegible] in these [illegible] with practice, but [illegible] of the [illegible] typically decreases from about 1 to about 0.7. This phenomenon --

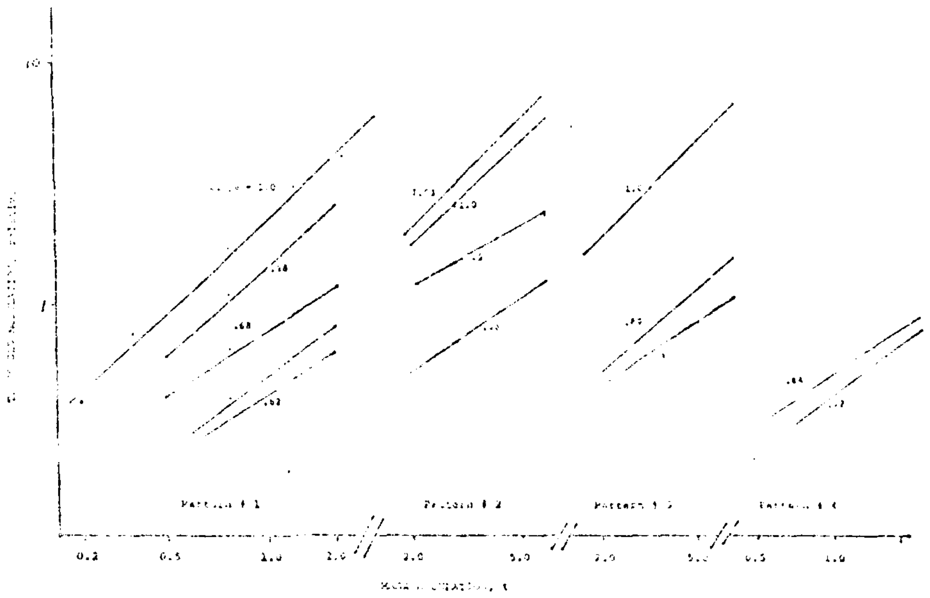
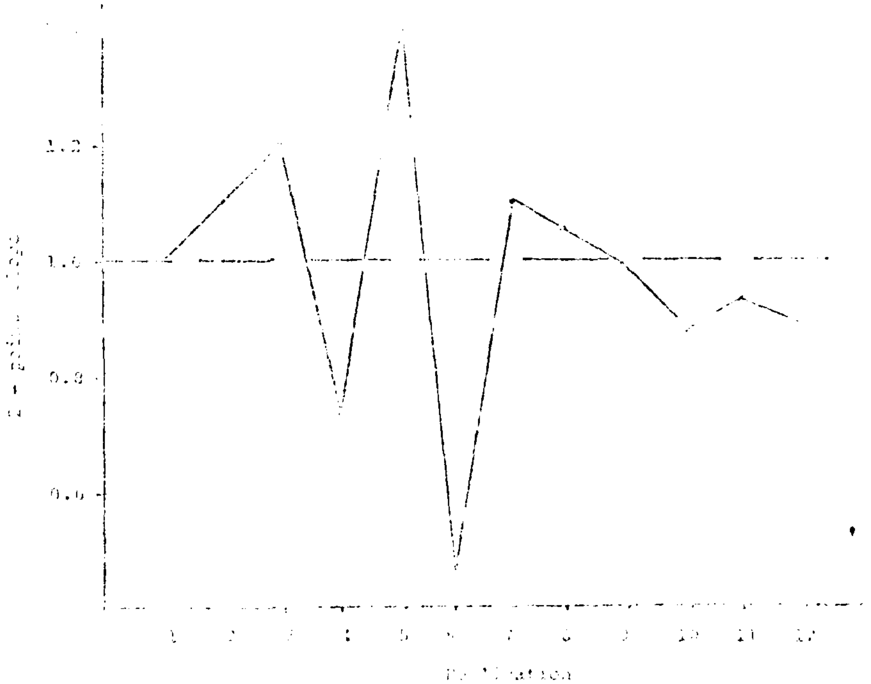


Fig. 8 Forced-choice masking data with four different 3-component (2 - 8 cpd) mask patterns, each with a single 4 cpd test grating. Lower lines represent increasing practice with each pattern. Numbers represent slope [illegible] [illegible]. [illegible] in slope with increased practice for each pattern.



[illegible] slope computed from [illegible] with a single [illegible] [illegible] of psychometric variation [illegible] fixation.

[illegible], [illegible] [illegible] -- caused [illegible] confusion in our search for conditions which produced Weber's Law. As we tried each new condition, it at first appeared that we had finally succeeded, only to have our results slowly degenerate to the familiar 0.7 power law. Since this learning is a one-time phenomenon, not easily replicated and averaged, we present data in detail for subject RS, learning to detect the 4 c/deg test in the [illegible] [illegible] noise stimuli (Fig. [illegible]). The session started with [illegible] [illegible] subject's masking function (5 points) which displays a slope of 1. From this, two convenient points were selected for repeated settings. As RS continued to set his threshold for these two points, settings decreased systematically as did the slope of the line joining the two points. Eventually this slope reached a value of 0.7. At this point [illegible] and the slope again rose to 1.0, falling off as before with repeated settings. RS [illegible] [illegible] trials to reach asymptote, and eventually is able to do so on the first trial. [illegible]

[illegible] shows the data for two additional observers. [illegible] [illegible] each point represents the mean of [illegible]. The overall decrease in threshold is much less pronounced, here [illegible] it occurs in the first few trials. Despite these differences, [illegible] the decrease in slope is still observed. Thus we conclude that there is a general learning phenomenon involved in masking and that as learning [illegible] [illegible] to change from Weber's Law to a power law. The substantial individual differences [illegible] a detailed study of this learning process. In particular [illegible] the [illegible] of [illegible] [illegible].

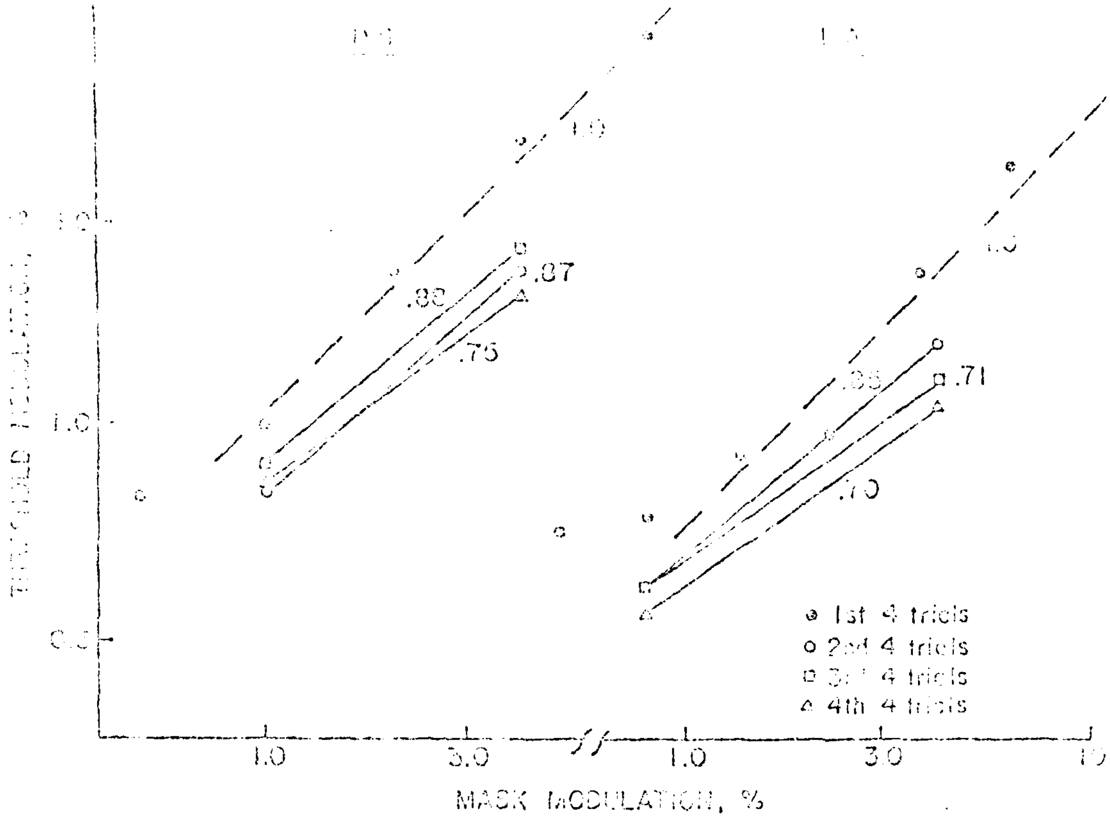


Fig. 9. Similar to Fig 8 for subjects DS and LA. Here each [illegible]

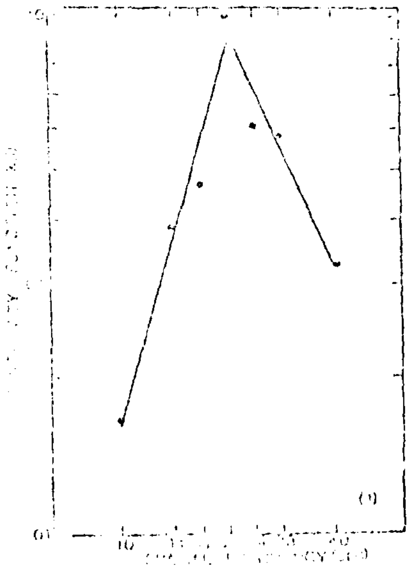


Fig. 10. Channel shape derived [illegible] the anomalously high center point, and the fact that higher mask frequencies are more effective than lower mask frequencies.

[illegible] results [illegible] ificant detection mechanism. When an observer is familiar with the [illegible] this [illegible] the amount of [illegible] The observer [illegible] fully discount [illegible] possibility, making [illegible] familiar with the mask, however, he clearly cannot use this strategy. Under these conditions the observer must look for the actual appearance of the test itself, rather than merely finding a deviation in the mask pattern. This [illegible] is most easily understood for [illegible] other frequencies, rather in the manner of the [illegible] frequency is [illegible] ation in the noise pattern purely from chance, then the test is [illegible]

[illegible] to maintain [illegible] tern. This constitutes Weber's Law. Even in the case of [illegible] it appears that the mask -- when initially seen -- [illegible] as noise. With practice, of course, the [illegible] perhaps even more rapid [illegible] detection in the [illegible] and Cohn ([illegible]) present [illegible] factor in the [illegible] that when detection is limited by [illegible]

[illegible]

[illegible] channel [illegible] of all the [illegible]

The results of the simulation are clear. The [illegible] threshold [illegible]

[illegible] relation between the [illegible] function (Eq. 4) and the shape of the underlying channel [illegible] Generally the underlying channel [illegible] as observed by [illegible] only in the [illegible] of underlying [illegible]

[illegible] experimental [illegible]

[illegible] channels, rather than absolutely. In practice, the only [illegible]

[illegible]

[illegible] For this purpose, [illegible]

[illegible]

[illegible]

[illegible]

[illegible] a channel [illegible] which present difficulti[illegible] [illegible] that this [illegible] [illegible] ones, are equal) [illegible] represents a totally different [illegible] to deal with in a modeling model. The second p[illegible] of [illegible] is the fact that [illegible] activity is [illegible] the exact opposite of the behavior of any single [illegible] fied. We propose to deal with this in a novel manner. [illegible] individual [illegible]

[illegible] them from being averaged [illegible] of the frequency [illegible] of such receptive fields [illegible] they have the desired properties. Actually [illegible] in the model is [illegible], the solution of the other problem discussed above.

B. [illegible] Systems for [illegible]

[illegible] positive [illegible] in the [illegible] response for the [illegible]

[illegible]

[illegible], they [illegible] that the shape of the [illegible] frequency represented a [illegible] shape. [illegible] highly nonlinear function of [illegible] -- it displays a threshold followed by [illegible]. This [illegible] usually obscure the underlying channel shape. It seemed to us [illegible] well controlled [illegible] of adaptation as a function of [illegible] adaptation. The [illegible] (Fig. [illegible]) [illegible] and [illegible] adapting frequency [illegible] shape in [illegible] [illegible] channel.

[illegible] particularly puzzled [illegible] the data shown in Fig. 11 [illegible] of other investigators [illegible] very [illegible]. In [illegible] (1971) [illegible] our results [illegible] a more [illegible] with forced choice [illegible]. The results [illegible]

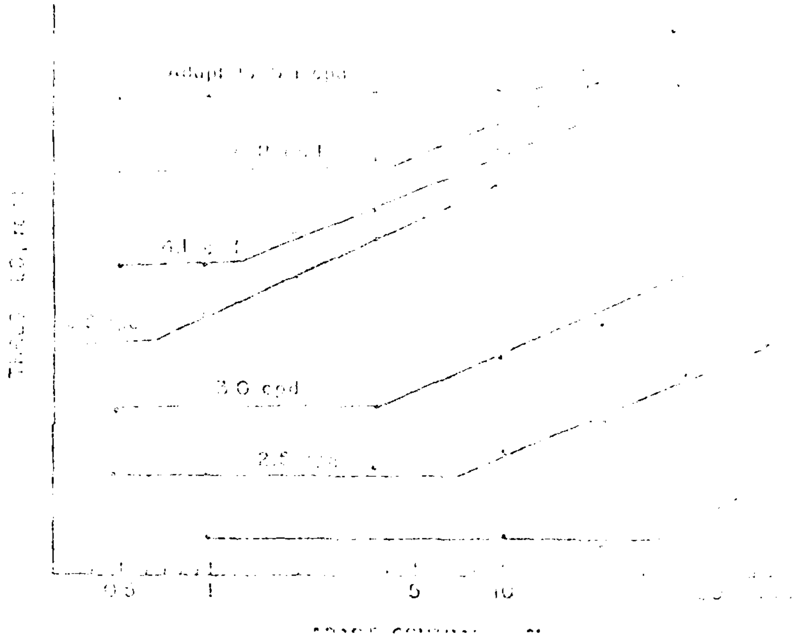


Fig. 11. [illegible] method adapting [illegible] [illegible] [illegible] method of [illegible].

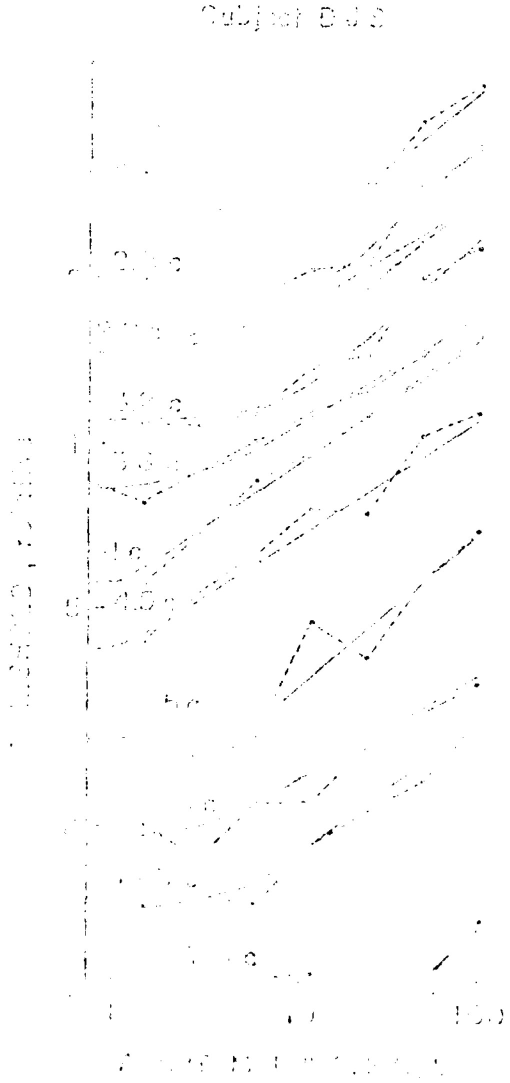


Fig. 12. Similar to Fig. 11 using Forced Choice.

[illegible]

[illegible] the [illegible] in good agreement with our [illegible] of [illegible] yet [illegible] form of [illegible], we [illegible] [illegible] of [illegible] [illegible] [illegible] technique is valid and replicable.

[illegible] which [illegible] other [illegible]. In [illegible] are not readily comp[illegible] with our [illegible] [illegible] to [illegible] [illegible] have not found [illegible]

[illegible] adjustment [illegible]

[illegible] adjustment [illegible]

[illegible] of our [illegible] [illegible]

[illegible]

[illegible] investigated [illegible] experiment [illegible] The initial experiment used the [illegible] detection [illegible]

[illegible] Both [illegible] reduction.

[illegible] (5 [illegible]

[illegible] (1) [illegible] differ by [illegible] (2) [illegible]

[illegible] of the curves, [illegible]

[illegible]

[illegible]

[illegible] The [illegible]

[illegible]

[illegible] A [illegible]

[illegible] Our initial data [illegible]

[illegible]

[illegible] These data would [illegible]

[illegible] forced choice [illegible]

[illegible] experiment [illegible]

[illegible] and test grating [illegible] chosen [illegible] represented a continuum between the hypothetical [illegible] and [illegible] a "Leaky [illegible]" [illegible]

[illegible] gratings were presented for 60 seconds [illegible]

[illegible] fixed [illegible]

[illegible]

[illegible] all the [illegible]

[illegible] spatial [illegible]

[illegible]

[illegible] Smith, Robert [illegible] Spatial [illegible]

[illegible] and Smith, Robert A. [illegible]

[illegible]

[illegible]

[illegible] -- Don J. Swift, Ph.D. ([illegible] Hochman, [illegible]
[illegible]).

[illegible] -- [illegible] Reed, Ph.D. ([illegible]).

[illegible]

Swift, Don J. and Smith, Robert A. Stimulus and [illegible] of Cheat[illegible]
[illegible]

Smith, Robert A. and Swift, Don J. [illegible]
[illegible] AACC, Spring [illegible].

[illegible]

[illegible] and Kaliske [illegible] (19[illegible]). [illegible]

[illegible]

[illegible] (19[illegible]). [illegible]

[illegible]. Invol[illegible]

[illegible] (19[illegible]). Visual detection of aperiodic stimuli [illegible] channels. Vis. Res., 17, [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible], 7, [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible] (19[illegible]). [illegible]

[illegible] S. (19[illegible]). [illegible]

[illegible] (19[illegible]). A [illegible]

[illegible]

[illegible] (19[illegible]). A [illegible] mechanism [illegible]

DATE
ILME