TEMPORAL CHARACTERISTICS OF DYNAMIC CONTOUR PERCEPTION

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ABSTRACT

This study is presented in two parts, the first being an experimental study of the temporal characteristics of contour formation of a moving stimulus under several conditions of illumination and three stimulus sizes. Contour perception here is taken to mean the formation and subsequent maintenance of sharp edges during the entire movement phase of a small (a few degrees in visual angle) stimulus. Such contour is usually not maintained at speeds exceeding about 15 °/sec.; however, if the stimulus is first presented in a fixed position, contour may be maintained at speeds up to 30 °/sec. This study then investigated the relation between the velocity (V) of the moving stimulus and the duration of the exposure (T) of the stationary phase before movement under several conditions of illumination and stimulus size.

The criterion of maintaining contour was that the stimulus should be seen as sharp and clear during the entire extent of movement. Thus, an interesting feature of the data is that dynamic contour is never perceived under any condition, even at the slowest speed, unless there is at least a very short duration of T. It was found that, within the limits of this experiment, when contour formation is hampered by the stimulus speed, an increase in T facilitates contour formation of the subsequent moving phase. An increase in illumination level facilitates the perception of dynamic contour at speeds above 10 – 15 °/sec. The ease with which dynamic contour can be seen at slow speeds, and the fact that there seems to be a minimum excitation level to be overcome, combine to eliminate differences between the various conditions at speeds under 10 – 15 °/sec. For similar reasons, an increase of stimulus size

facilitates dynamic contour formation particularly at speeds above 10 – 15 ^{o}/sec. and at low illumination levels. A change in the contrast ratio (between screen background and stimulus brightness) has no consistent effect upon dynamic contour formation.

In the second part of this study is forwarded the hypothesis that the nervous system involves a central quantum field structuring process which is quantal in nature. This proposed theory of sensory processes is based upon the quantum field theory of physics and, while of necessity many ramifications are omitted, a brief background of both quantal theory in psychology and quantum field theory is given. A new position of the quantum field and particle concepts of physics is presented. It is postulated that the basic substratum of the universe is a structured quantum field whose intrinsic properties and formative tendencies are responsible for all processes and structural organizations. Reasons are given for the belief that a comprehensive and adequate explanation sensory processes, indeed all psychological phenomena, must be based upon a central nervous process and that the underlying parameter must be one (here held to be the quantum field structure) which runs throughout natural phenomena in whatever field.

This view leads to an expectation of step-wise functions in sensory discrimination. Individual plots of the data gathered in this study, although not at all conclusive, are used as an indication that dynamic contour discrimination is far from being continuous.

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Part I

An Experimental Study of Dynamic Contour Perception

Contour perception is the ability to perceive the sharp edges or borders of any object in the visual field; dynamic contour perception is hence the ability to perceive the sharp edges or borders of any moving object in the visual field. Contour perception is a form of brightness discrimination in which spatial, figural and intensity factors are the focus of investigation and which usually involves and abrupt gradient of color or brightness. It is the objective in studying contour perception to determine what role the intensity and spatial relations of all parts of the nearby visual field play in governing the discrimination of the sharp edges of objects. The study included not only the brightness and areas of the objects and their surrounds but also the structural configurations of the object and its surround. The stimuli used to study contour perception are usually simple lines or shapes (circles, triangles, etc.) which are presented to the observer at increasingly longer temporal intervals until the complete contour is perceived. In studying dynamic contour perception the stimuli are presented at increasingly greater velocities until the sharpness of the contour edge is lost.

It has been thought by some in the past that the resolving power of the retina is the main factor involved in contour perception.

Because of diffraction at the pupil and other imperfections of the optical system, the image of a line is not a sharp dark shadow subtending only part of the cone but a blurry shadow extending over several cones and thus the retinal images are never so sharp as the lines appear in perception. It has been found that the geometric image of a line subtending a visual angle of 0.5 seconds would cover only about 1/60 of the width of a single foveal cone. Consequently, this has led to the hypothesis that the retinal mosaic in some way acts as a resolving or a sharpening mechanism (38). According to this point of view, when a single line is to be sharpened or resolved, the blurred light is distributed so that a single line, although producing a statistical distribution of excitation over five or six cones, produces its maximum excitation within one standard deviation of the normal distribution of the intensity which amounts to one cone or one row of cones. Hecht and Mintz, two advocates of this point of view, then proceed to use the mass action principles of photochemistry to explain contour resolution (37). For example, it is known that visual acuity—a psychological function very much akin but not identical to contour perception—is a direct function of intensity and time variables. In fact, this is a statement of the Bunsen-Roscoe Law, $I \times T = K$. It is known that the Bunsen-Roscoe Law holds for only short durations of from 50 to 200 milliseconds. It is also known that the photochemical processes operate in temporal ranges similar to those which hold for the Bunsen-Roscoe Law. Thus, visual acuity is explained in terms of the mass action photochemical effects produced by photons entering the rod or cone structure and thereby causing the breakdown of the photochemical substance rhodopsin or idodopsin which, in turn initiates the nerve impulse

(72). Hecht and Mintz believed that a fine line is perceived at the small angle they found because even its blurred shadow reduces the light on one extended row of cones to a level which is just functionally less than the light on the row of cones to either side of it. They think the line appears sharp because it produces a recognizable shadow on one row of cones only. Thus, a sharp line is seen simply because the illumination of only the center row of cones is sufficiently different from the rest. From this, they conclude that no neural mechanism further up in the nervous system is necessary for compensating for the blur.

However, as Bartley has pointed out, "This explanation does not seem to cover the situation with low illumination where the minimal resolable angle is 10 minutes of arc, a spatial value 1200 times as great as the one we have just dealt with, and again we may have to resort to some neural process (higher up in the nervous system) to account for contour" (5).[1] Holway and Crozier then take the development from here. They state that intensity discriminations of any type in the various senses are all controlled alike by a statistical mechanism which is an expression of the central nervous system itself. This, of course, opposes the point of view that the photochemistry of the sense-cells is the primary determiner of the quantitative features of brightness vision. But Holway and Crozier utilize the basic statistical concept of Hecht, et al., for they assert that the properties of the various types of intensity discriminations can not be an

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[1] It appears that the period of mass action photochemical explanations have come to a close in retinal physiology (74). We should also note that the important contribution of Hecht and his students—that the action of light on the rod or cone is quantal—has been accepted. This will be an important point in the development in Part II.

expression of the receptors alone, but must be an expression of the whole nervous system which acts as a statistical mechanism (5).

In 1942, Marshall and Talbot took up where Holway and Crozier left off (49). They point out that there are only two logical alternatives in regards to explaining psychological functions such as visual acuity, one a field theory and the other an expression of a nervous system such that Holway and Crozier outlined which functions as a statistical mechanism and which employs gradients of nerve impulses in its operations. The established facts of neuro-physiology, Marshall and Talbot assert, support the latter view.

Since visual contour formation requires time, the study of temporal characteristics of contour formation is of prime importance. There is not much data available on this subject. Werner, in studying the time required for contour formation, found that in most cases when an enclosing figure with a common center follows certain geometric figures in 120-240 msec., the first figure is completely obliterated (73). In his study the first figure was presented stroboscopically for 12 – 25 msec., but no data are given on how much exposure time is required for this first figure to produce contour. Cheatham, in a study of temporal characteristics of contour perception, used the masking method to measure the development time for the perception of complete contours (20). He found it to be in the range of 30 – 100 msec. depending upon the brightness as well as the shape of the stimulus.

Before the work of Smith and Gulick in 1957 (67), the time required for contour formation of a moving stimulus had not been investigated. They found that, although sharp contour of a moving stimulus generally can not be observed at velocities greater than 10 –15 °/sec., such contour could be retained up to velocities of about 30 °/sec. if the stimulus were exposed in a fixed position before and after the movement. Under these conditions contour was maintained most effectively when the exposure times of the initial and final stationary phases were equal. When they were not equal, the initial stationary phase was found to be more effective than the final phase in the production of contour.

It is the objective in studying contour perception to determine the role intensity, temporal and figural factors, and spatial relations of the stimulus and all parts of the visual field play in governing the discrimination of the sharp edges of objects. In dynamic contour perception the same factors and relations are studied with the additional provision that the stimulus is moving, and thus the added factors of speed and extent of movement are involved. The present experiment is a study of the temporal characteristics of contour formation of a moving stimulus under several conditions of illumination and stimulus size. Contour perception here is taken to mean the formation and subsequent maintenance of sharp edges during the entire movement of a stimulus.

Method and Apparatus

Sharp contour of a small stimulus (of the order of a few degrees in visual angle) is usually not maintained at speeds exceeding about 15 ° sec. However, Michotte first observed that such contour can be maintained if there is an initial stationary interval at the beginning of the stimulus presentation. As quantitatively elaborated by Smith and Gulick (67), sharp contour may be maintained at speeds up to 30 –35 °/sec. if the stimulus is first presented in a fixed position. The present study investigated the relations between the velocity (V) of a moving stimulus and the duration of exposure (T) of the stationary phase before movement using several different illumination conditions and three stimulus sizes.

The essential features of the experimental situation, including details of the apparatus, are shown in Fig. 1. The stimulus was presented on a curved white screen nine feet in front of the cubicle in which the subject was seated. The image was projected from projector 1 to the rotating front surface mirror whose speed of rotation was controlled by a variable speed transmission. The drive shaft and belt activated the mount on which the mirror was fixed. The image of the stimulus projected onto the mirror then traveled from left to right across the screen at a speed determined by the adjustment of the transmission. The center of the screen coincided with the midpoint between the subject's line of sight and the mirror.

Immediately prior to the stimulus presentation, occluder 1 was positioned directly before the beam on which the image was carried from projector 1. Occluder 2 was in a position to the side of this beam. The initial stationary phase of stimulus presentation was controlled by an interval timer. The two occluders were controlled by two solenoids. Solenoid 1 was activated at the instant the interval timer was turned to the "on" position. This solenoid pulled back occluder 1 and exposed the stimulus for the duration registered on the interval timer. At the end of this interval, the release solenoid was energized and the mirror mount rotated until the brake pin came to rest against the brake block. This rotation of the mirror caused the stimulus to travel

across the screen at the determined speed. The contact of the brake pin and block completed a circuit which activated occluder 2. This occluder was pulled into the path of the projector light, thus terminating the stimulus. The extent of movement on the screen could be controlled by the adjustment of the position of the brake pin which was mounted in a slot in the mirror mount.

The stimulus was formed by mounted(-ing, sic) a fine wire in the middle of a square opening in heavy paper. This was inserted between two glass plates and placed in the slide holder of projector 1. The fine wire case a clearly defined vertical line shadow in the middle of a bright square surround. The intensity of the surround was varied by using filters and a variable diaphragm on projector 1. The intensity of the stimulus was determined by the brightness of the screen (surround) since the stimulus was, in fact, a shadow of an opaque wire. Projector 2 cast on the screen a rectangle large enough that the entire stimulus presentation occurred in this rectangular background. The appearance of the screen during a stimulus presentation is illustrated in Fig. 2. The brightness of this background was controlled by filters on projector 2. Different contrast ratios between the background area and the stimulus square were thus effected by adjusting the filters on projectors 2 and 1. Projector 3 cast a just perceptible pinpoint of light as a fixation point at the spot the line would first appear on the screen. A series of light bulbs above projector 2 enabled the experimenter to control the illumination of the entire screen during the adaptation period and between stimulus presentations. This illumination level was kept equal to that of the background area for a given stimulus condition.

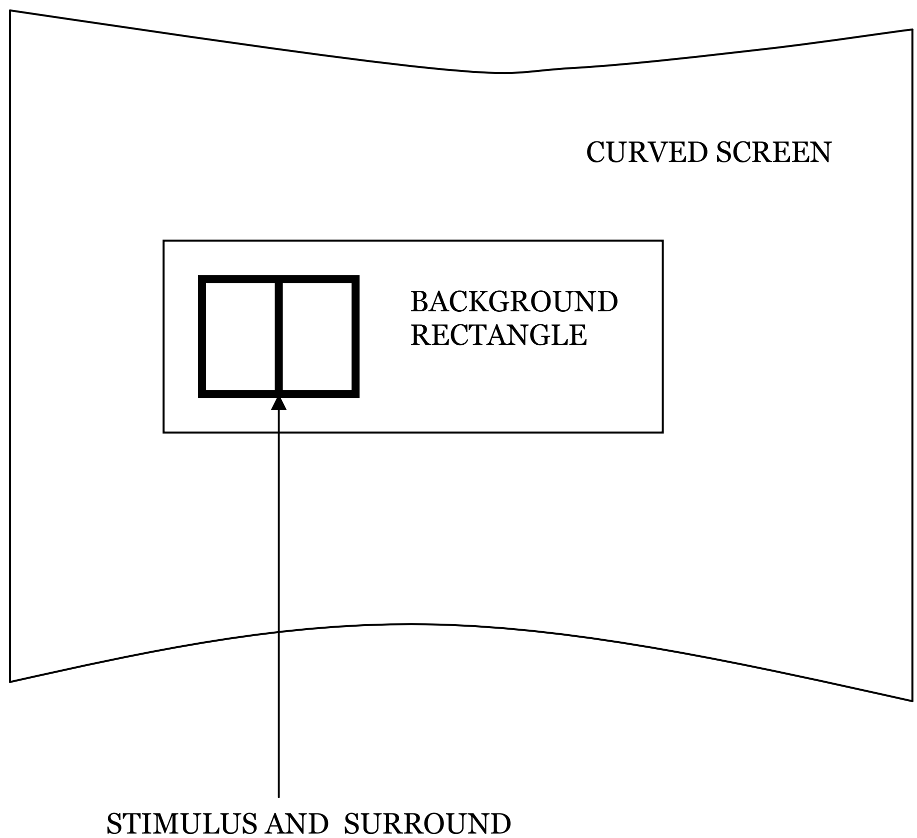

Fig. 2 Appearance of stimulus during a trial

The subject's head was held in position on a head rest placed directly behind the opening in the cubicle. Through this opening the subject could see only the screen. He viewed the fixation point on the screen and observed the entire stimulus presentation binocularly. The large (20° of visual angle), uniformly illuminated , curved screen was so situated that its center of curvature corresponded to the nodal points of the subject's eyes. This arrangement insured that stimulus was at all times equidistant from the subject's eyes. The stimulus appeared at the fixation point, traversed an extent of 5° of visual angle, and disappeared. Between trials the subject fixated on the screen.

At the beginning of each one-hour experimental session, the subject was exposed to the adapting screen for five minutes during which time the following instructions were read:

> You will see on the screen a white square stimulus divided by a vertical line. The center of this line falls upon a small fixation point. You are to fixate this point while waiting for the stimulus to appear. The stimulus sometimes will be moving to the right as it appears. At other times it will remain in a fixed position for a brief period of time centered on the fixation point before it moves to the right. The movement to the right on each trial will be at a constant rate. However, the velocity of movement may change from trial to trial. Your task on each trial is to report whether the vertical line appears sharp and clearly defined <u>throughout</u> <u>the</u> <u>extent</u> <u>of</u> <u>movement</u>. If you say "yes", this should mean that it appears sharp and clearly defined throughout the distance from the fixation point to the point where it disappears. You are to say "no" when the line does not appear sharp and clearly defined for all or any part of the movement. Thus, if the line appears unsharp or fuzzy throughout the movement or during any part of the movement you should say "no". On some trials your eyes may blink or for some reason you may feel that you are not properly prepared to make an observation. When this happens tell me and I will repeat the trial. Also on some trials you may find it very difficult to make a "yes" or "no" judgment. When you feel that a specific judgment is impossible say "yes questionable" or "no questionable". Between trials keep your eyes open and centered on the fixation point. While you are looking at this point I will say "ready",

> you will respond "yes" if you are ready, and some seconds after your response of "yes" the stimulus will appear. Remember you are to say "yes" if the vertical line appears sharply defined throughout the extent of movement. You are to say "no" if it does not so appear. Any questions? If you should become uncomfortable at any time during the experiment or have any questions to ask, let me know immediately.

Preliminary experimentation had shown that practice effects are an important variable to be controlled. Therefore each subject was given a practice session in which he became familiar with the stimulus representation and also became accustomed to making the required judgment.

After the adaptation period, during which the foregoing instructions were read, the subject was given a demonstration regarding contour criteria. He was given four stimulus presentations of V equal to 5^{o}/sec. and T equal to 1000 msec. which maximized conditions favorable for sharp contour.

The stimulus was presented to the subject in a random order and was presented each time 2 seconds after he was alerted. After each trial, the subject indicated the sharpness of contour by a "yes", "no", "yes questionable", or "no questionable". The "questionable" responses were allowed as alternatives chiefly to make the task of the subject less difficult.

Within a given experimental session the conditions of brightness, contrast ratio, and stimulus size remained constant with only the velocity of movement and duration of stationary phase varying. The velocities (in degrees per second) used were: 5, 10, 15, 20, 25, 30, 35, and 40; the exposure of duration (in milliseconds) of the stationary phase were: 0, 25, 50, 100, 200, 400, and 1000. A total of 11 conditions of brightness and contrast ratios were used which are listed in Table 1. The first 9 of these conditions were used only with a stimulus size of 3° of visual angle. Nine of the 11 subjects were each run at 3 of the conditions (besides their practice session). In the case where the same three conditions were presented to more than one subject, the order of those conditions was different. The two other subjects were run the entire gamut of nine conditions.

Conditions 1, 7, 10, and 11 of Table 1 were those used with the 3° and ½° of visual angle stimuli. Three subjects (including the two who were run on all nine other conditions) were run on each of these four conditions with both stimuli.

Each one hour experimental session consisted of 54 trials, not counting those which the subject asked to have repeated, with a rest period half-way through the session.

All 11 subjects, who were paid for their time, were considered "sophisticated" since they had had preliminary observations before they made those which are reported here. Each subject had 20/20 vision, either corrected or uncorrected.

Results

The data of each subject were recorded in a matrix, 8 V by 8 T, with N (no), Y (yes), N?, and Y?. Fig. 3 illustrates the manner of recording. The dotted line indicates the points which were taken as those where contour began. Judgments were made for each speed at each of the conditions by 5 subjects using the 3° stimulus. Three subjects made

Table 1

Summary of Conditions Used			
Condition	Contrast Ratio	Screen Brightness (ft. 1.)	Stimulus Brightness (ft. 1)
1	20:1	100	5
2	4:1	100	25
3	2:1	100	50
4	20:1	10	.5
5	4:1	10	2.5
6	2:1	10	5.0
7	20:1	1	.05
8	4:1	1	.25
9	2:1	1	.50
10	40:1	100	2.5
11	40:1	1	.025

DURATION OF T (MSEC.)

VELOCITY (DEGREES/SEC.)	0	25	50	100	200	400	800	1000
5	N	N	Y	Y	Y	Y	Y	Y
10	N	N	N	Y	Y	Y	Y	Y
15	N	N	N	Y	Y	Y	Y	Y
20	N	N	N	Y	Y	Y	Y	Y
25	N	N	N	N?	Y	Y	Y	Y
30	N	N	N	N	Y	Y	Y	Y
35	N	N	N	N	N?	Y?	Y?	Y
40	N	N	N	N	N	N	N	Y

Fig. 3. Illustrative data of a typical experimental session.
Dotted line indicates contour threshold.

judgments with the ½° and 6° stimuli. Composite graphs were made using an average of the 5 values for each T. Fig. 4, 5, 6, 7, and 8 present these graphs which are, in actuality, composite graphs summarizing all the data obtained in this experiment. A solid line is used wherever all 5 subjects being averaged continue to maintain contour within the limits of the experiment. When one (or more) of the subjects no longer sees contour, even with a T of 1000 msec., the remaining subjects are averaged and the average is weighted somewhat forward to account for the subjects who would require a T of at least a little more than 1000 msec. For this part of the graphs a dotted line is used.[2] Thus, while the dotted portion of the line may be difficult to place exactly at a particular point, it is felt that as a comparison of one line to another, it is quite reliable since each of the lines was determined in the same manner. Fig. 4 and 5 give a comparison of the illumination levels at the various conditions, Fig. 6 a comparison of stimulus size, and Fig. 7 and 8 a comparison of contrast ratios.

Of these data, those for the 3° stimulus were also analyzed using a double classification analysis of variance (52, pp. 283 ff.), the results of which are summarized in Table 2. For speeds of 5, 10, 15, and 20 °/sec., the analysis was performed on a table of 3 illumination levels by 3 contrast ratios, but at higher speeds, the size of the table was progressively reduced as the subjects began to have difficulty seeing contour at the lowest illumination and contrast ratio conditions.

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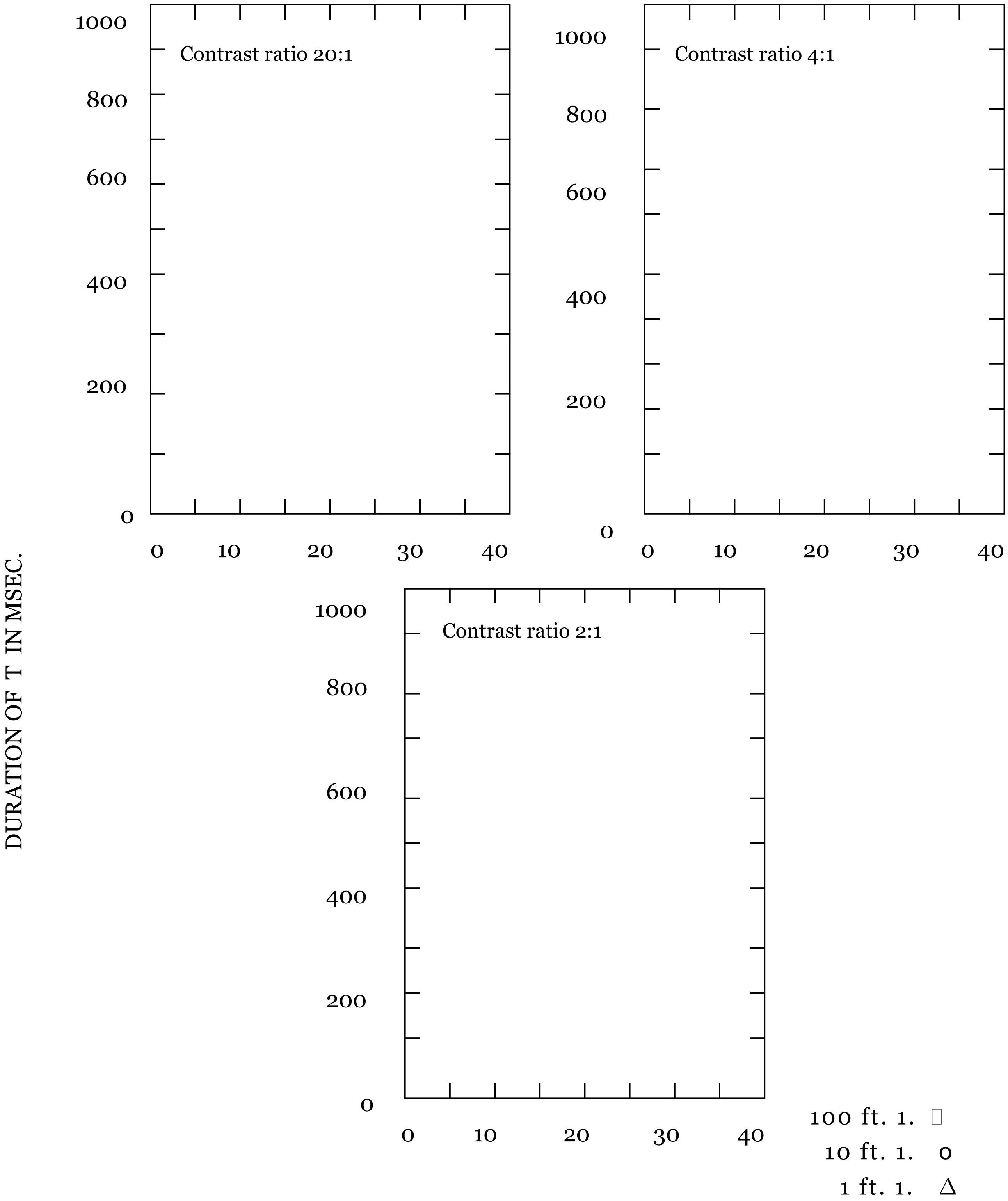
[2] It is logical to assume that at some velocity, it will no longer be possible to retain contour, no matter the duration of T used.



VELOCITY IN DEGREES/SEC.

Fig. 4. Composite curves comparing illumination level of 3° stimulus

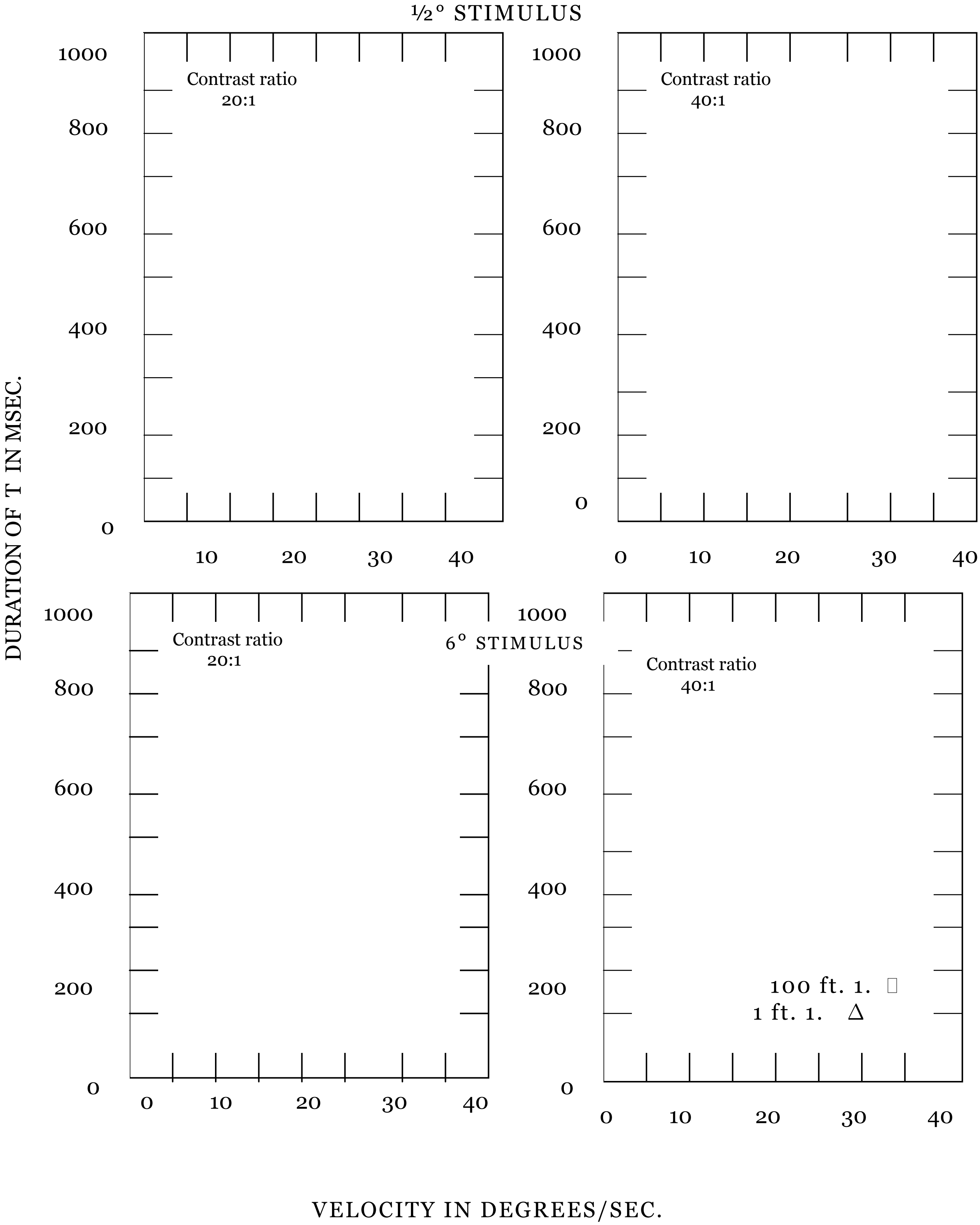


Fig. 5. Composite curves comparing illumination levels of both the ½° and 6° stimuli.

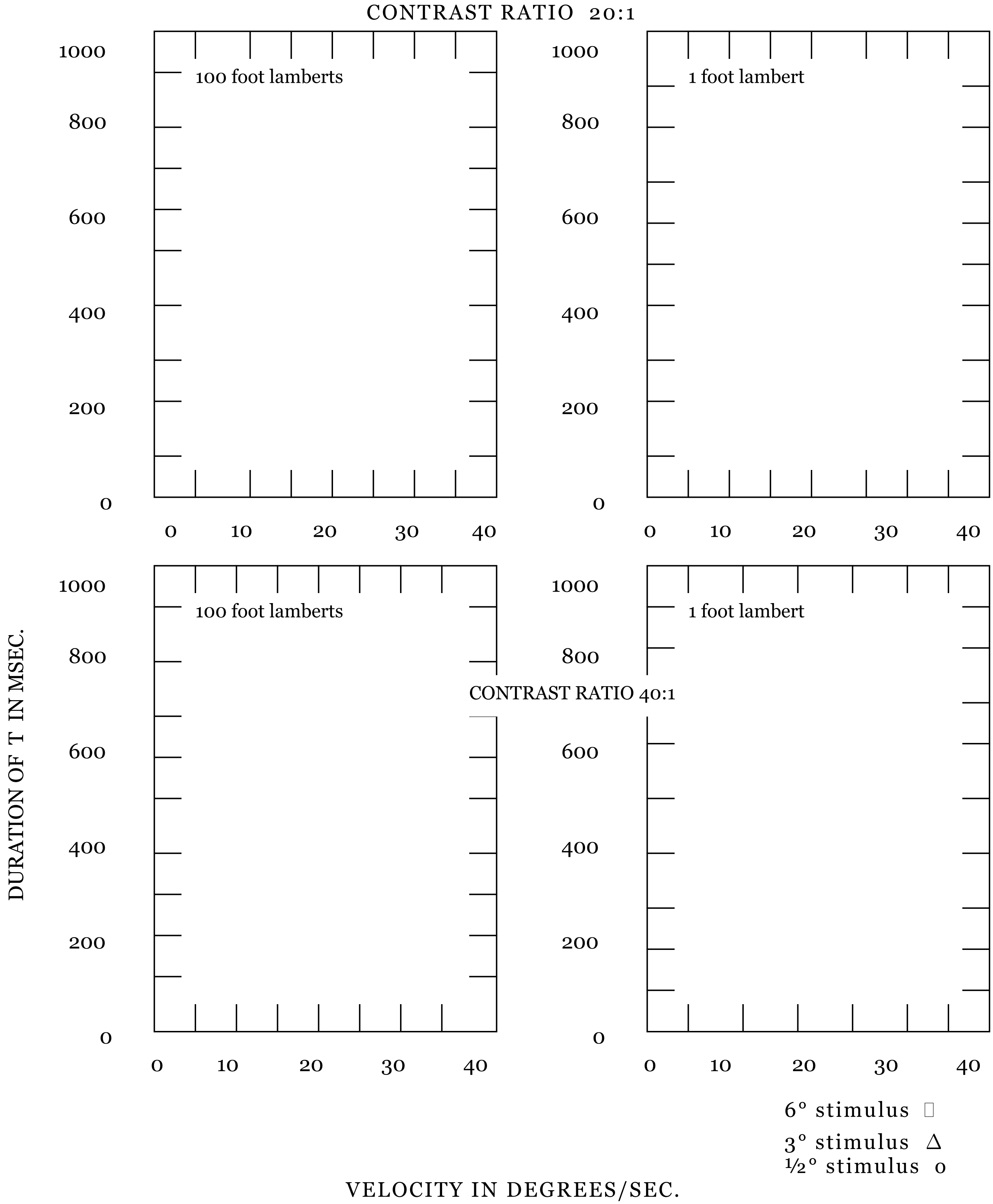


Fig. 6. Composite curves comparing stimulus size

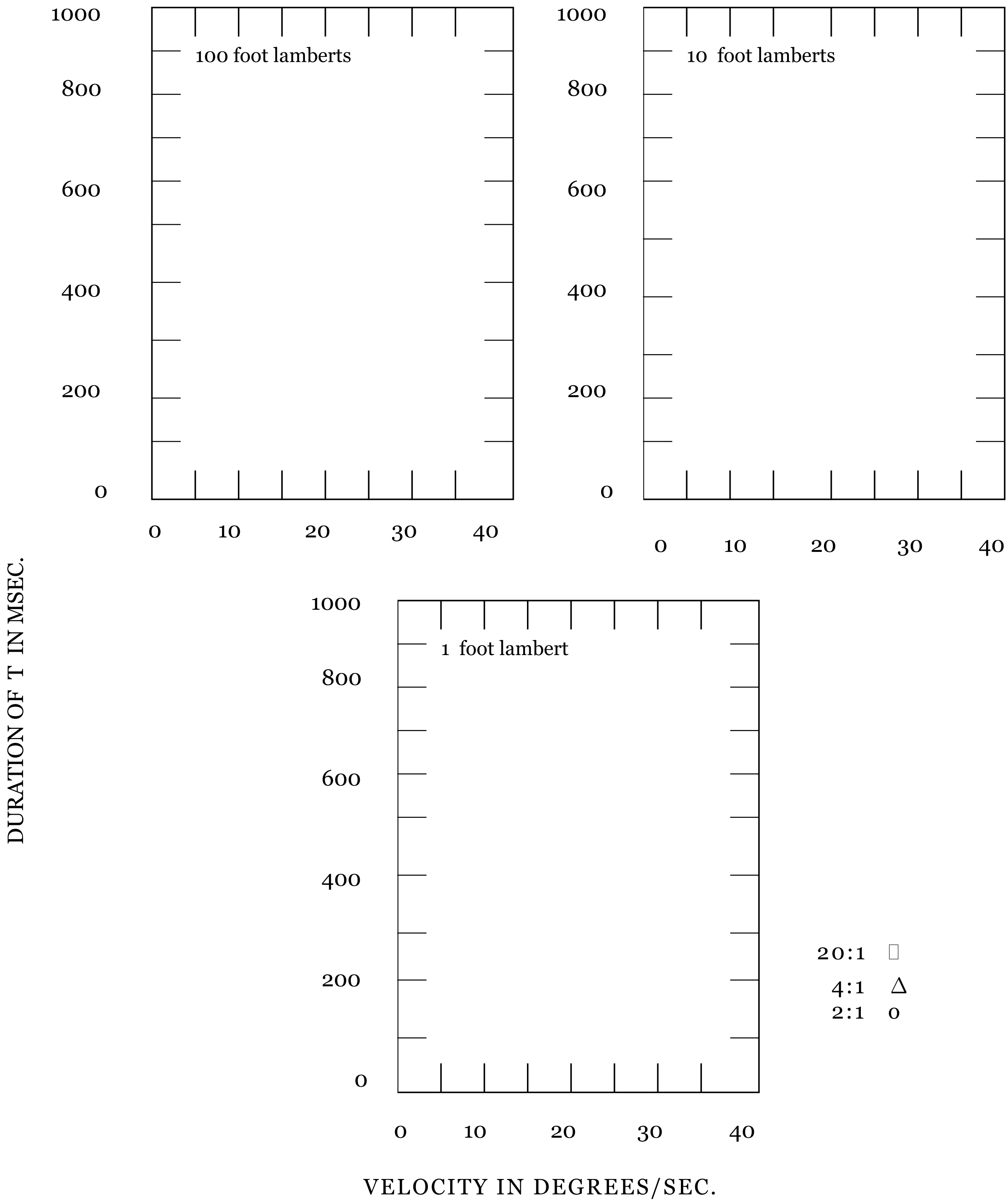


Fig. 7. Composite curves comparing contrast ratios using 3° stimulus

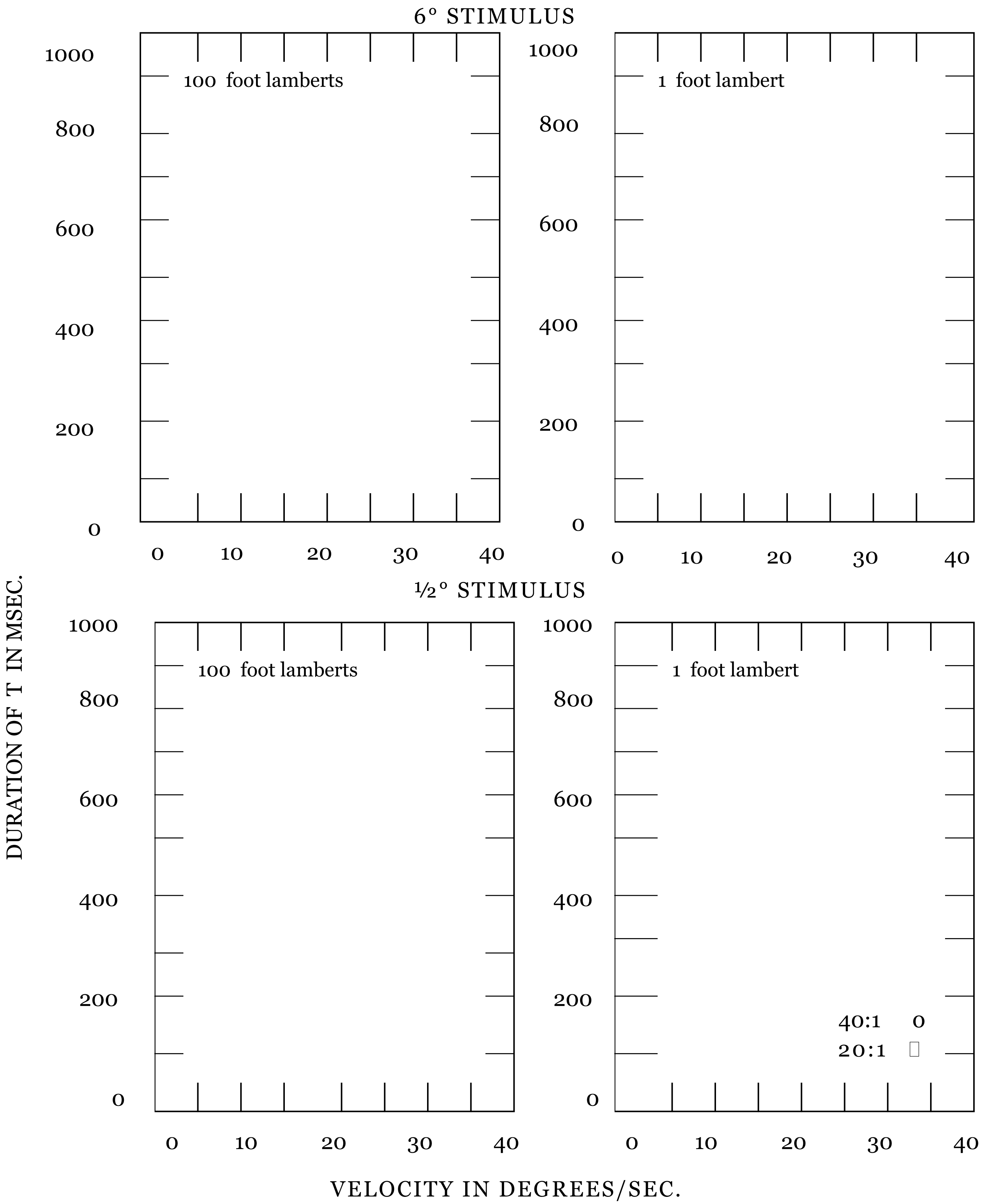


Fig. 8. Composite curves comparing contrast ratios at two illumination levels using both the 6° and the ½° stimuli.

Table 2

Summary: Analysis of Variance of Data Using 3° Stimulus

Speed of Stimulus (°/sec.)	Source	Sum of Squares	df	s^2	F
5	Illumination	861	2	431	.07
	Contrast	9,528	2	4, 764	.77
	Intersection	5,888	4	1, 472	.24
	Within Cells	221,500	36	6, 153	
	Total	237, 777	44	5,404	
10	Illumination	5,333	2	2,667	.49
	Contrast	9,333	2	2,667	.86
	Intersection	17, 334	4	4,334	.80
	Within Cells	196, 000	36	5,444	
	Total	228, 000	44	5, 182	
15	Illumination	44, 1 11	2	22,055	1.06
	Contrast	105,444	2	52, 722	2.53
	Intersection	61, 556	4	15, 389	.74
	Within Cells	750, 000	36	20, 833	
	Total	961, 1 1 1	44		
20	Illumination	65, 778	2	32, 889	.30
	Contrast	267,1 1 1	2	133, 556	1.23
	Intersection	75, 555	4	18, 889	.17
	Within Cells	3,904,000	36	108, 444	
	Total	4,312, 444	44		
25	Illumination	20, 417	1	20, 417	.30
	Contrast	5, 833	2	2, 916	.04
	Intersection	75, 833	2	37, 91 6	.56
	Within Cells	1, 217, 500	18	67, 639	
	Total	1, 319, 583	23		
30	Illumination	122, 500	1	122, 500	.11
	Contrast	62, 500	1	62, 500	.06
	Intersection	2, 500	1	2, 500	.002
	Within Cells	1, 290, 000	12	107, 500	
	Total	1, 477, 500	15		
35	Illumination	13, 333	1	13, 333	.10
	Contrast	53, 333	1	53, 333	.41
	Intersection	120, 000	1	120, 000	.92
	Within Cells	1, 040, 000	8	130, 000	
	Total	1, 226, 666	11		

Also at speeds of 25 °/sec. and above, the data of only 4 subjects is used (3 subjects at 35 °/sec.) because all subjects no longer saw contour at those speeds regardless of the duration of T. The F ratios resulting from this analysis did not reach significance as the individual differences obscured any real differences arising from the conditions used.

Table 3 lists, in msecs., the duration of T required at various illumination conditions for 50 per cent of the subjects to see contour of the 3° stimulus. To arrive at these values it was noted what per cent of the subjects saw contour at each combination of T and V. The 50 per cent point at each V was then calculated by interpolating between the two values which straddled 50 per cent. Fig. 9 and 10 present these results in graphic form. Each plot of Fig. 9 contains these 50 per cent points (of Table 3) at the three illumination levels for a given contrast ratio while each plot of Fig. 10 gives the same points at the three contrast ratios for a given illumination level. There are cases at speeds of 25 °/sec. and above where the largest duration of T used, 1000 msec., was no longer sufficient to maintain contour for at least 50 per cent of the subjects. On the graphs, these points are indicate by upward arrows.

A double classification analysis of variance (52, pp. 270 ff.) was performed on these data of 50 per cent points, and the results are summarized in Table 4. For speeds of 5, 10, 15, and 20 °/sec., the analysis was performed on a table of 3 illumination levels by 3 contrast ratios but at higher speeds the size of the table was reduced because some entries at the lowest contrast ratio and illumination levels were undetermined—i.e., greater than 1000 msec. None of the F ratios reaches a significant level in the analysis.

Table 3

Time of T Required (in msec.) to see Contour
in 50 per cent of the cases

Speed of Stimulus (°/sec.)	Condition 100 ft. 1. 20:1	4:1	2:1	10 ft. 1 20:1	4:1	2:1	1. ft. 1 20:1	4:1	2:1
5	91.65	91.65	137.50	150.00	91.65	137.50	75.00	116.70	45.80
10	116.70	91.65	125.00	150.00	81.25	137.50	91.65	91.65	91.65
15	137.50	91.65	116.70	175.00	116.70	150.00	175.00	137.50	175.00
20	162.50	250.00	125.00	250.00	183.30	183.30	600.00	233.40	600.00
25	183.30	500.00	150.00	325.00	250.00	300.00	1000	600.00	1000
30	300.00	350.00	250.00	850.00	500.00	900.00	1000	900.00	1000
35	600.00	900.00	500.00	900.00	1000	900.00	1000	966.60	1000

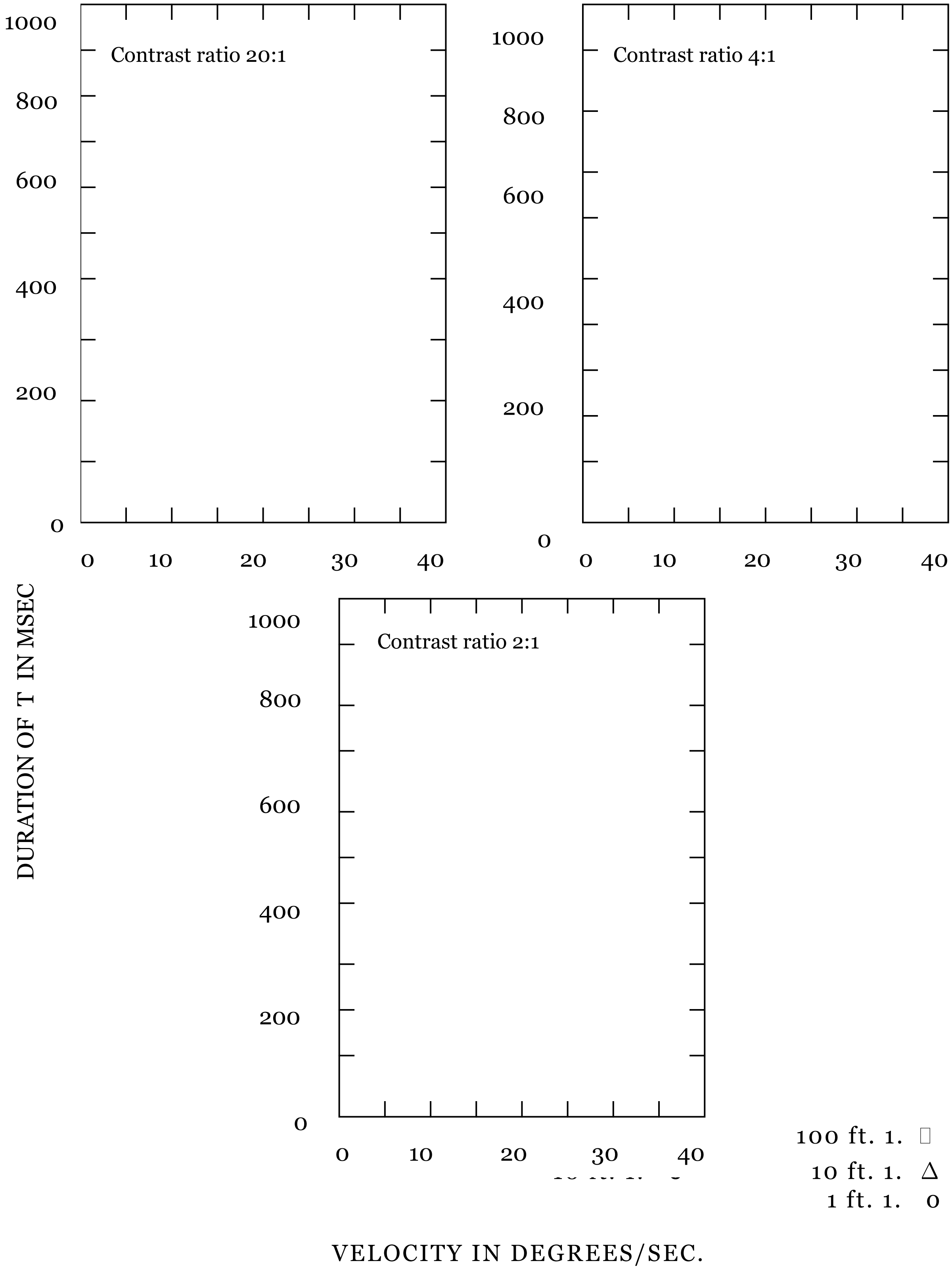


Fig. 9. Curves of 50 per cent points comparing illumination levels at various contrast ratios using 3° stimulus.

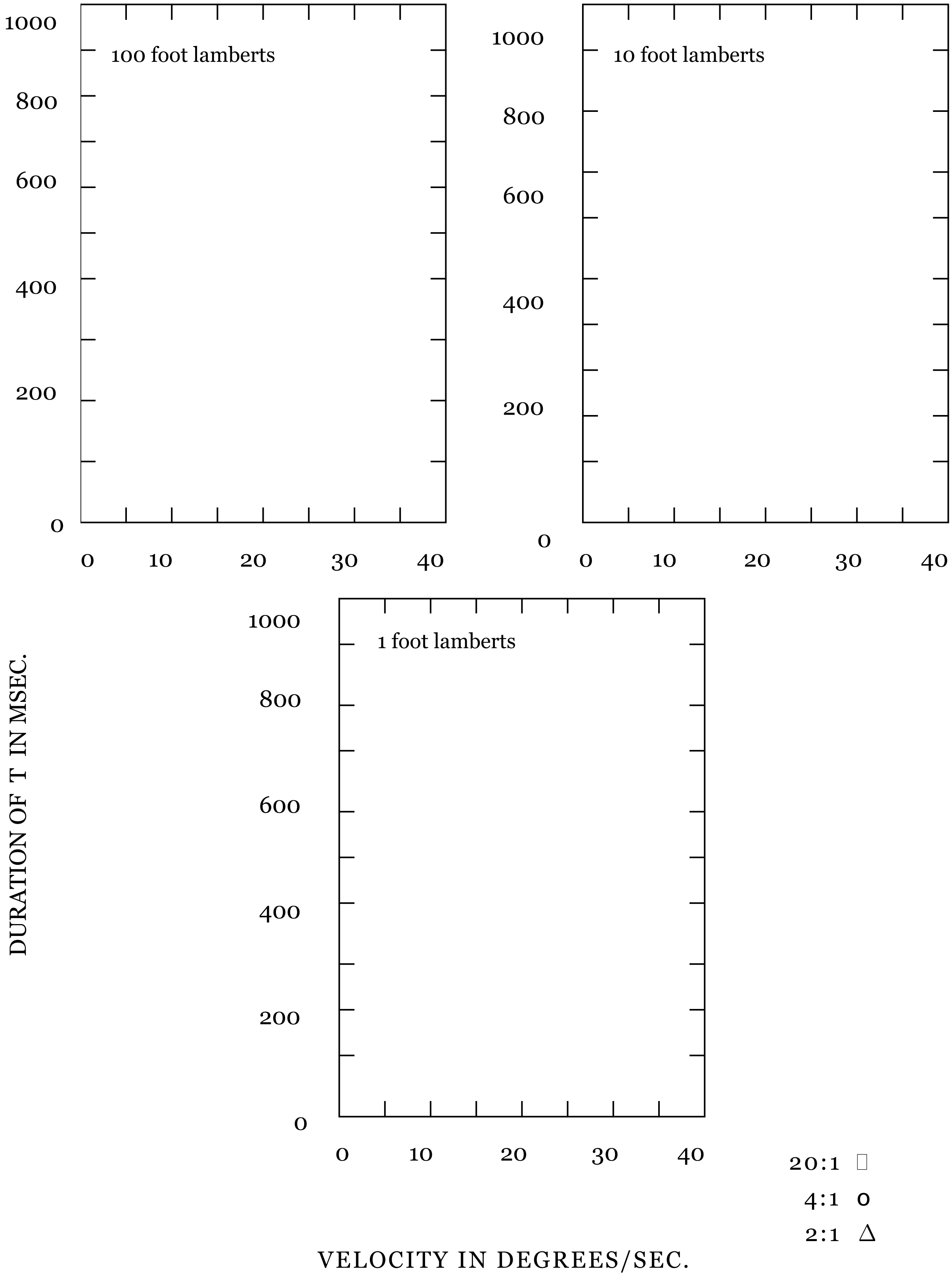


Fig. 10. Curves of 50 per cent points comparing contrast ratios at various illumination levels using 3° stimulus.

Table 4

Summary: Analysis of Variance of 50 per cent Points

Speed of Stimulus (°/sec.)	Source	Sum of Squares	df	s^2	F
5	Contrast	81	2	40	.028
	Illumination	3, 379	2	1, 689	1 .18
	Remainder	5, 747	4	1, 437	
	Total	9, 207	8		
10	Contrast	1, 872	2	936	2.65
	Illumination	1, 496	2	748	2.12
	Remainder	1, 413	4	353	
	Total	4, 781	8		
15	Contrast	1, 122	2	561	.95
	Illumination	2, 581	2	1, 291	2.18
	Remainder	2, 372	4	593	
	Total	6, 075	8		
20	Contrast	20, 978	2	10, 489	.53
	Illumination	164, 006	2	82, 003	4.11
	Remainder	79, 814	4	19, 954	
	Total	264, 798	8		
25	Contrast	14, 605	1	14, 605	2 .00
	Illumination	2, 932	1	2, 932	.40
	Remainder	7, 305	1	7, 305	
	Total	24, 842	3		
30	Contrast	22, 500	1	22, 500	.56
	Illumination	122, 500	1	122,500	3 .06
	Remainder	40,000	1	40, 000	
	Total	185, 000	3		

In Tables 5 and 6 is presented the summary of an analysis of variance utilizing the data obtained with the different sizes of stimuli. Three subjects made judgments for 3 sizes of stimuli at 2 illumination levels and 2 contrast ratios. These data were analyzed by a triple classification analysis of variance (52, pp. 299 ff.).

Discussion

One fact stands out as the results are studied. The consistency of the graphs indicates that there <u>are</u> definite differences due to the variables used, particularly illumination level and stimulus size. Yet none of the F ratios in the analysis—with the exception of a few in the "size" group—reaches a significant level. The individual differences in this study are great enough to obscure, statistically, most of the effects which the plots of data consistently point out.

The functions, as shown in Fig. 4 through 10, appear to be of a hyperbolic nature, with the duration of T necessary for the maintenance of contour increasing much more rapidly at higher speeds.[3] A noticeable feature of all plots is that dynamic contour is never perceived under any condition, even at the slowest speed, unless there is at least a very short duration of T. The criterion of maintaining contour was that the image should be seen as sharp and clear during the <u>entire</u> <u>extent</u> of movement. On those trials for which there was no T, the movement began immediately as the stimulus appeared. No subject ever was able to see

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[3] The averaging of individual data "smooths" the differences between individual plots resulting in a regular hyperbolic curve. Such individual plots, shown in Part II, are quite step-like in character and might argue for a quantal viewpoint which also will be considered in Part II.

Table 5

Summary: Analysis of Variance of Stimulus Size Using 20:1 Contrast

Speed of Stimulus (°/sec.)	Source	Sum of Squares	df	s^2	F	
5	Illumination	2, 222	1	2, 222	. 52	
	Size	1, 1 11	2	556	. 13	
	Individuals	18, 611	2	9, 306	2. 16	
	I x S	1, 1 11	2	556	.13	
	I x In	1, 944	2	972	.23	
	S x In	3, 889	4	972	.23	
	I x S x In	17, 222	4	4, 305		
	Total		17			
10	Illumination	2, 222	1	2, 222	.23	
	Size	21, 1 1 1	2	10, 556	1.09	
	Individuals	14, 444	2	7, 222	.74	
	I x S	14, 444	2	7, 222	.74	
	I x In	4, 444	2	2, 222	.23	
	S x In	22, 222	4	5, 556	.57	
	I x S x In	38, 889	4	9, 722		
	Total	117, 778	17			
15	Illumination	151, 250	1	151, 250	36 .30	.01
	Size	556, 944	2	283, 472	68. 03	.001
	Individuals	1 71, 944	2	85, 972	20.63	.01
	I x S	182, 500	2	91, 250	21. 90	.01
	I x In	40, 833	2	20, 417	4.90	
	S x In	148, 888	4	37, 222	8.933	.01
	I x S x In	16, 667	4	4, 167		
	Total	1 , 279, 028	17			
20	Illumination	108, 889	1	108, 889	2 .80	
	Size	374, 444	2	187, 222	4. 81	
	Individuals	2,1 74, 444	2	1, 087, 222	27.96	.01
	I x S	7, 778	2	3, 889	.10	
	I x In	47, 778	2	23, 889	.61	
	S x In	242, 222	4	60, 556	1.56	
	I x S x In	155, 556	4	38, 889		
	Total	3,1 11, 1 1 1	17			

Table 6

Summary: Analysis of Variance of Stimulus Size Using 40:1 Contrast

Speed of Stimulus (°/sec.)	Source	Sum of Squares	df	s^2	F
5	Illumination	833	1	833	1.00
	Size	833	1	833	1. 00
	Individuals	21, 667	2	10, 833	13. 01
	I x S	833	1	833	1. 00
	I x In	1, 677	2	833	1. 00
	S x In	1, 677	2	833	1. 00
	I x S x In	1, 677	2	833	
	Total	29, 167	1 1		
10	Illumination	53, 333	1	53,333	2. 56
	Size	30, 000	1	30,000	1. 44
	Individuals	111 , 667	2	55, 833	2. 68
	I x S	53, 333	1	53, 333	2. 56
	I x In	41, 667	2	20, 833	1. 00
	S x In	65, 000	2	3 1, 667	1. 52
	I x S x In	41, 667	2	20, 833	
	Total	396,667	1 1		
15	Illumination	440, 833	1	440, 833	13 . 25
	Size	520, 833	1	520, 833	15. 63
	Individuals	46, 667	2	23, 333	. 70
	I x S	520, 833	1	520,833	15. 63
	I x In	6, 667	2	3, 333	1. 00
	S x In	6, 667	2	3, 333	1. 00
	I x S x In	6, 667	2	3, 333	
	Total	1 , 549, 167	1 1		
20	Illumination	140, 833	1	140, 833	2 . 01
	Size	700, 833	1	700, 833	10. 01
	Individuals	620, 000	2	310, 000	4. 43
	I x S	7, 500	1	7, 500	. 1 1
	I x In	26, 667	2	13, 333	. 1 9
	S x In	186, 667	2	93, 333	1. 33
	I x S x In	140, 000	2	70, 000	
	Total	1,822, 500	1 1		
25	Illumination	53, 333	1	53, 333	1. 73
	Size	563, 333	1	563, 333	18. 27
	Individuals	501, 667	2	250, 833	8. 135
	I x S	3, 333	1	3, 333	. 1 1
	I x In	11, 667	2	5, 833	. 1 9
	S x In	251, 667	2	125, 833	4. 08
	I x S x In	61, 667	2	30, 833	
	Total	1, 446, 667	1 1		

contour during the beginning of movement on such a trial; the stimulus had always moved some distance from the fixation point before contour was established. With the appearance of a sufficiently long stationary phase, contour can be perceived from the beginning of the moving phase. The duration of T required was dependent upon the speed of the stimulus as well as upon the conditions of illumination.[4] The assumption has been made by others that the excitation gradient for a visual contour must reach or exceed some minimum level in order that a contour of any kind can be perceived. Smith and Gulick (66) add the provision that this gradient varies as some function of velocity in the case of a moving stimulus. This assumption would appear to be justified by the present data and the fact, just discussed, that even at the slowest speed, some duration of T is needed before dynamic contour is established. Just what the nature and significance of the minimum level of the excitation gradient might be is a theoretical problem dealt with in Part II.

In the sense that this study measured a threshold of contour formation, the results are not new, for other workers have also found a systematic increase in thresholds of visual phenomena with an increase in velocity. Pollock, using a spot of white light as a target,found a systematic increase of the luminance threshold with an increase in target speed (60). Smith and Gulick also found a systematic increase in the contour threshold with an increase in stimulus velocity (66).

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4 Since a stationary phase of the stimulus was used only at the beginning of movement, there is no danger of confusing the sharp appearance of the stimulus during real movement with that of apparent movement.

In Fig. 4 and 5, the composite plots comparing illumination levels, and in Fig. 9, a plot of the 50 per cent points, the curves consistently show that contour is more easily maintained at a higher illumination. This effect becomes clear and quite marked usually after speeds of 10 –15 °/sec. have been reached. At very low speeds, there seems to be little, if any, difference in ability to perceive dynamic contour at different illumination levels. It is not unexpected that the improvement of dynamic contour formation should increase with illumination noticeably only after speeds of 10 – 15 °/sec. are reached. There seems to be a minimum duration of T necessary, about 30 to 50 msec., to allow the excitation gradient to reach the minimum level for contour formation.[5] At very slow velocities the duration of the moving stimulus is quite long since the extent of movement of the stimulus is the same for all speeds. The judgment required of the subject at those speeds is so easily made that contour is readily seen with low illumination; but not even the most facilitating illumination condition can decrease T below the minimum duration which will allow contour formation. As the stimulus velocity increases, the task becomes more and more difficult and, since the T required for contour is now considerably above the minimum 30 to 50 msec., a difference in illumination conditions manifests itself as a difference in the duration of T required for contour. Fig. 9, a plot of the 50 per cent points for all subjects, summarizes what has been said of the 3° stimulus quite well. It shows a clear-cut and

[5] Again, the reader is referred to Part II for a more detailed discussion of the possible physical and physiological correlate of this perceptual phenomenon.

consistent difference in the illumination level at each of the 3 contrast ratios used at speeds above 10 to 15 °/sec.

The fact that dynamic contour formation is facilitated by increasing intensity (at those speeds where it can be manifested) can be compared to other studies in the psychophysics of vision. As long ago as 1897 Konig found that visual acuity increases with illumination, slowly at first, then rapidly, and finally levelling off. Shleer in 1937 found essentially the same function which has since become familiar in the psychophysics of vision. Cook and Graham determined the effect of intensity on visual acuity for seven exposure times and found that visual acuity increases with intensity at all exposure times (24). In one sense, this is similar to the finding in this study that contour perception increases with intensity at all stimulus speeds (above the minimum speed discussed above), for one component of stimulus speed is its duration of exposure. (That is, a slower stimulus is exposed for a longer period of time.) Thus, a higher speed results in a shorter exposure of the moving stimulus since the extent of movement is constant. Cook and Graham also note that the intensity of illumination necessary for the production of a given acuity is inversely related to the duration through which that intensity acts. A similar conclusion is reached by Brown (17). The parallel findings of the present study might be stated thus: The intensity of illumination necessary for the production of contour formation is inversely related to the duration through which that intensity acts—or directly related to the speed of stimulus—above stimulus speeds of 10 – 15 °/sec. (Of course, it is to be remembered that speed of stimulus involves <u>more</u> than just duration of exposure.)

Berger concluded, from his study of visual acuity and its relation to illumination, that the reason visual acuity improves with increasing illumination is that a smaller white space, or a smaller opening in a broken circle, etc., can be seen and thus details or visibility of form increase (7). As a result he notes that, in order to obtain a true measure of the dependence of visual acuity on illumination, the same size test object should be used at all illuminations rather than proceeding to a smaller test-object at a higher illumination. (In the present study, a 3° stimulus was used at all illuminations.)

A single dark hair line against a very evenly illuminated background (similar to that used in this study) is considered by some to be the simplest case of visual resolution. Hecht and Mintz, in studying the relation between visibility of single lines and illumination, found that acuity of such lines improved with increase of illumination varying between 10' and 0.5" of arc (minimum visible angle) (37). With but few exceptions, visual acuity was found in all cases to increase with an increase in stimulating intensity in the many studies done in this field. (In comparing these results, note must be taken of whether visual acuity or resolving power is meant. Both Senders (65) and Berger (7) make this distinction and have found that while acuity increases, resolving power decreases with increase in intensity.)

Of a somewhat different nature is the work of Liebowitz (46) who studied the variation of rate threshold for perception of movement with differing luminance. While the present study was primarily concerned with contour perception <u>during</u> the movement of the stimulus, it is noteworthy that Liebowitz found the threshold velocity to decrease as luminance increased. The rate of change was rapid at first, then slower, and finally reached a limiting value. That is, movement was more easily detected by higher illumination, and the shape of the function was comparable to those in other fields of visual psychophysics.

Still another somewhat related type of study was that of Krauskopf, Duryea, and Bitterman, who found that form perception of luminous figures briefly exposed in a dark room improved with increase in intensity, and that a short duration of exposure results in distortions similar to those produced by low intensity (46).

The work relating visual perception to the exposure time of the moving stimulus is related to this study and might be mentioned in view of the fact that one component of speed is the exposure time. Dimmick and Karl (30) in 1930 measured the lower limen for the perception of visible movement and found it to decrease as the exposure time increases. Brown and Conklin in 1954 found that such a decrease is large at first as the short exposure times are lengthened by equal steps and becomes progressively less as the exposure-times become longer (18). Although the present study was conducted at speeds always well above those of movement threshold, it is interesting to note that the general results are similar. That is, the “thresholds” for dynamic contour perception decrease rapidly (reading from right to left on the graphs) as the shorter exposure times are lengthened—or as the higher speeds are lowered. At the slower speeds (and thus longer exposure times) the change in contour perception threshold is less and often the function becomes quite flat. This is also in line with Liebowitz’s study, which found that an increase in exposure time shifts the whole curve of threshold velocity vs. luminance to progressively lower values on the threshold velocity axis (48).

It is clear from this sampling that the findings of the present study (as regards the dependence of dynamic contour formation on illumination) parallel those in other areas of the phsychophysics of vision. Form perception, visual acuity, and perception of movement all vary directly with both intensity and exposure time. The present study indicates that dynamic contour formation varies directly with intensity and directly with exposure time (or inversely with velocity).

The plots of Fig. 6 show that an increase in angular size of the stimulus facilitates the perception of dynamic contour. In plots 6C and 6D, which involve only the ½° and 6° stimuli, the 3° stimulus would presumably result in a curve falling between those for the ½° and 6° stimuli. There is in this Fig. 6 also the phenomenon which was noted in Fig. 4 and 5, namely, that the difference in stimulus size is definite and clear only above speeds of 10 to 15 °/sec. The explanation given above for this phenomenon is also applicable here.

Two further effects may be noticed in Fig. 6. The differences in stimulus size seem to have a stronger effect at a low illumination. This also follows the pattern noted above: under conditions which make a judgment more difficult, a facilitating change of the variable enhances dynamic contour formation more readily than under conditions more favorable to making easy judgments. Thus a higher illumination has more effect at higher speeds; a larger angular size of stimulus has more effect at low illumination and higher speeds. The other characteristics of Fig. 6 (as well as of Fig. 4 and 5 to some extent) is that the dotted line begins at a lower stimulus speed for more difficult condition—that is, small size and low illumination. This indicated that one or more of the subjects ceased to see contour at lower velocities for the more difficult conditions, as would be expected.

The results of this study parallel those of other workers in the field of vision who have found that visual acuity is enhanced by a larger stimulus (27, 31).

Fig. 7 and 8 show that this study failed to reveal any clear-cut differences between the contrast ratios used, although there is some indication from other studies that such a difference might be found (31). In the cases where the ½° and 6° stimuli were used, the 20:1 contrast ratio is consistently more facilitating for dynamic contour perception than is the ration of 40:1. With the 3° stimulus at both the 100 foot lambert and 10 foot lambert levels of illumination, there is no discrimionable difference in contrast ratio. At the 1 foot lambert level of illumination, there is some differentiation between a 4:1 contrast ratio and the other two. It might be pointed out that where there is any difference at all is again at the low illumination level where dynamic contour perception is most difficult. When the 50 per cent points for all subjects with the 3° stimulus are averaged and plotted to compare contrast ratios at each illumination level, as in Fig. 10, this is seen even more clearly. Here, even at 10 foot lamberts, there is some untangling of effects although still so slight as to prohibit any definite conclusions as to exact effect. The only conclusion which can be drawn as regards contrast ration is that a greater contrast ratio is not necessarily the better condition for dynamic contour perception.

The foregoing discussion and conclusions have been based on the graphs in Fig. 4 through 10. The judgment required of the subject in dynamic contour perception, as it was presented here, is one which varies from individual to individual, as can be seen from the results of the statistical analyses in Tables 2, 4, 5, and 6. The individual differences are so large that any differences which might be due to the variables are obscured. The differences due to size come the closest to being significant. Each of the subjects had a practice session during which he became familiar not only with the apparatus and stimulus presentation, but also with the appearance of the stimulus at all combinations of T and V. As the subject gave his judgment (during the practice session), the experimenter helped his by pointing out aids in perceiving contour and pursuing the stimulus. It is apparent that, even with such practice, individuals vary in their ability to follow <u>and</u> perceive a moving stimulus. Perhaps, in order to minimize individual differences, a large group of subjects ought to be divided—<u>after</u> making their judgments—into 2 or 3 smaller groups according to the range of speed at which they stopped seeing contour. Thus, within each of the smaller groups, there might not be such large individual differences and perhaps the variables would then also be statistically significant. Even though the statistical analyses in this study are negative, all of the plots --composite and 50 per cent points—were entirely consistent and also in a direction which parallels results in other areas of psychophysics of vision. From this more qualitative source, then, the conclusions are drawn.

It is appropriate to mention here the work of Blackwell who studied the measurement of visual thresholds with two different methods of responding in a psychophysical experiment (12). On the one hand he utilized a phenomenal "yes" or "no" response, on the other, a forced choice situation. In both cases the stimuli were ordered into groups of 20 in succession having the same magnitude (with the subject's knowledge). With a phenomenal response, "positive channelization" occurred; the subject increasing the frequency of "yes" responses toward the end of a group of 20 stimuli if the stimuli have been eliciting more than 50 per cent "yes" responses. He concludes that the procedure employed to measure visual thresholds can distort the data. Thresholds may differ by as much as 10 to 20 per cent as a result of presentation, suggestion, and pay incentive (11). Blackwell lists several aids to examine validity and reliability of results. Since the presentation in the present study was randomized rather than grouped, there would be no danger of "channelization" of phenomenal responses. Among the other suggestions he makes are that the subjects be taught cues for discrimination by notifying them of the correctness of their responses and that they be given reasonably extensive experience in threshold measurement. In the present study, the subject received experience in the practice session, and also was taught cues for the discrimination of contour. (There is, however, no "correctness" of a given response since the ability to perceive contour at a given speed varies from person to person.) Since the subjects were paid for their sessions, the motivation factor presumably was taken care of. With the additional aids of a "ready" signal and a fixation point, it is felt that the validity and reliability of the responses in this experiment were maximized.

Summary and Conclusions

This part of the study was concerned with the effects of several parameters—illumination level, stimulus size, and contrast ratio—on the perception of dynamic contour using a laterally moving stimulus at several speeds. It was found that, within the limits of this experiment (a) when contour formation is hampered by the stimulus speed, an initial stationary phase of the stimulus facilitates contour formation of the subsequent moving phase; (b) an increase in illumination level facilitates the perception of dynamic contour at speeds above 10 to 15 °/sec.; (c) an increase of stimulus size facilitates dynamic contour perception particularly at speeds above 10 to 15 °/sec. and at low illumination levels; (d) a change in contrast ratio has no consistent effect upon dynamic contour formation.

The ease with which dynamic contour can be seen at very slow speeds, together with the fact that there is a minimum excitation level to be overcome, combine to eliminate differences between the various conditions in dynamic contour perception at speeds under 10 to 15 °/sec. Only at speeds greater than this do improving conditions of illumination and size have facilitatory results.

Temporal Characteristics of Dynamic Contour Perception

Part II

Their Significance for a Quantum-Field Theory of Perception

> So long as there remains a distinction between mind and body, so long as a psychology is based, explicitly or implicitly, upon a dualistic view of the organism, just so long will an account of psychological performance remain a needlessly complicated and hypothetical affair (54).

In order to forward the hypothesis that the nervous system involves a central quantum-field structuring process which is quantal in nature, it is necessary to review briefly some background material. The individual plots of the data from this study will then be used as an indication that dynamic contour perception is an example of the quantal nature of all phenomena—physical and psychological.

Historical and Theoretical Rationale

The classical view in psychology assumes the position that continuity in sensory nerve action can be demonstrated to affirm the apparent continuity of experience. This view holds that a number of minute factors operate at random to influence discrimination according to chance and that an accurate description of observer responses may, therefore, be had by a psychometric function which is the integral of the normal probability curve. This has become known as the phi-gamma hypothesis (26, 68).

A number of recent workers, however, have become increasingly concerned with the apparent paradox presented by the classic view, in view of the physiological fact that sensory mechanisms are composed of discrete neural units which follow the all-or-none law. This group of workers feel that precise experimental technique must show sensory experience to be discrete, that the apparent continuum of experience is in reality a step-wise phenomenon (57).

As early as 1919 Titchener expressed the notion that the discontinuities observed at both absolute and differential thresholds could be accounted for by the “frictional resistance” which every sense organ presented to a stimulus, and which had to be overcome before the corresponding change in sensation resulted. Although this was not expressed in quantal terms, it was an attempt to explain discontinuities in sensation (26).

Boring in 1926 allowed that any theory based upon specific energies of nerves is then a theory of sensory quanta. In hearing, following this view, whenever the stimulus activates a different neural element (nerve fiber), a new pitch is produced. Thus the apparent sensory continuum would actually be made up of a finite number of small steps or quanta equal to the number of discrete responsive elements or nerve fibers in a given sense organ. However, in the face of a lack of experimental evidence for this view of pitch quanta, Boring supported instead a non-quantal frequency theory of pitch. Loudness was, however, found to be related to the number of nerve fibers actually activated and was therefore quantal in nature (26).

In 1930 Békésy presented the first real experimental evidence for a quantal hypothesis of sensory experience. He felt that, in order to measure precisely the intrinsic variability of that part of the sensory nervous system which is immediately involved in making a particular discrimination, all of the <u>extrinsic</u> factors which cause variability in response must be eliminated. These extrinsic factors, which include such things as the attention of the observer, functioning of laboratory equipment, and shifting criteria, because of their number and supposedly chance variation were felt to result in the chance variability found in psychophysical measurement (57). With much effort, Békésy was able to minimize to a great extent the extrinsic variability and obtained data which yielded rectilinear (rather than sigmoidal) functions. He presented a standard tone of 0.3 seconds duration which was followed immediately by a comparison tone of variable intensity also of 0.3 seconds duration. He interpreted this data as an indication that the differential sensitivity to intensity is quantal in nature (26).

Again in 1936 Békésy arrived at steplike discontinuities in the determination of the minimum audible pressures for pure tone (26). In his attempt to define the quantal unit, Békésy made the simplest assumption possible: that the quantal unit is equal to the smallest neural unit or the individual nerve fiber (57).

The theory of the neural quantum in audition was made explicit by Stevens, Morgan and Volkmann in 1941 and is derived from the assumption that the basic neural processes which mediate pitch and loudness discrimination operate on an all-or-none principle. They rejected Békésy's definition of the quantal unit for three basic reasons: (a) the quantum is of no fixed magnitude even for the individual subject (b) there are more neural units (auditory nerve fibers, for example) than there are quanta for any given sensory attributed, and (c) the quantum is regularly about two-thirds smaller when measured binaurally than when measured monaurally. Instead Stevens, Morgan and Volkmann suggest that the quantal function has its locus centrally, involves a number of fibers instead of just one, and is a functional rather than anatomical process (57).

These same three workers laid the basis of quantal theory in 1941 when they made three fundamental assumptions: (a) quantal processes involve neural structures which are divided into functionally distinct units or quanta (b) a stimulus increment will be discriminated whenever it excites one quantum more than the number of quanta excited by the standard stimulus at a given instant, and (c) the over-all sensitivity of the human organism fluctuates randomly and momentarily through magnitudes considerably larger than a single quantum (69).

The second assumption is based on the reasoning that when a stimulus excites a certain number of quanta, it will usually have not just exactly the amount of energy necessary to excite that number of quanta but will have some amount of surplus energy which is not, by itself, enough to excite an additional quantum. The amount of stimulus-increment (Δ I) needed, then, for discrimination will be greater or smaller depending upon the exact amount of momentary surplus energy "left over" by the original or standard stimulus. Thus, although this surplus energy of the stimulus is not enough to excite an additional quantum alone, when summated with some increment in energy supplied by a comparison stimulus it will acquire the magnitude needed to excite an additional quantum and discrimination occurs. The "law" of the quantal hypothesis would then read: "The probability of a given increment exciting an additional neural unit, and hence being perceived, will vary linearly with the size of the increment" (57). Mathematically, this can be expressed:

$$\Delta I + S_u = Q, \qquad \text{(I)}$$

where ΔI is the increment of energy added, S_u is the momentary surplus, and Q is the size of the quantal unit. From this equation it can be seen that ΔI varies inversely with S_u; the larger the momentary surplus of energy, the smaller the increment needed for discrimination.

The third assumption allows discriminatory responses to any increment smaller than one neural unit size. Without such an assumption, the expectation would be a perpendicular psychometric, from 0 per cent directly to 100 per cent, but this was found not to be the case. Therefore, by assuming that the over-all sensitivity of the organism fluctuates in random fashion, all values of surplus stimulation would occur equally often (69). The frequency of occurrence of surplus values will determine the rate at which the proportion of discriminatory responses increases with an increase in the size of the increment. Since one value of the surplus occurs as frequently as any other, the proportion of surpluses that can be raised to neural unit size (or greater) will be the same for any given increase in the size of the increment. The relationship between the size of the increment and the proportion of discriminatory responses is then linear (26). Or, the proportion of time that a given increment actually does succeed in exciting an additional neural unit will be given by:

$$p = \frac{\Delta I}{Q} . \qquad \text{(II)}$$

Thus far the discussion has assumed that the standard stimulus is constant and that the human organism can thus discriminate differences between the standard and comparison stimuli of 0 to 1 quantum jumps. This, however, does not hold true. The excitation of the standard stimulus of any duration is found itself to fluctuate up and down at random by single quantal jumps (69). If the standard itself fluctuates by a single quantal jump, then discriminations can be made only when the increment is between 2 and 3 quantal units. Equation (II) under these conditions becomes:

$$p = \frac{\Delta I}{Q} \; . \; - 1 \; . \qquad \text{(III)}$$

That is, not until the increment reaches a size equivalent to one quantum should the observer begin to perceive differences occasionally. By the time the increment is equal to two quanta, the difference should be observed all the time. Since the quanta are assumed to be equal in size for the same subject under constant conditions within a short period of time, the largest difference which is perceived 0 per cent of the time should be one-half as large as that which is perceived 100 per cent of the time.

There now have emerged two deductions which can be subjected to experimental verification. The first of these is that there is a linear relationship between the proportion of increments discriminated and the magnitude of stimulus increments presented, and the second is that a 2:1 ratio between the values of the function at the 100 per cent and 0 per cent points. A third prediction is based on the reasoning that a standard stimulus falling near the middle of a quantal unit should produce less variability in judgment than a stimulus which falls near the transition of quantal units. Therefore the variability of judgments should increase and decrease cyclically as the magnitude of the standard is changed.

There have been conflicting results from the attempts to verify these deductions. The expectation is, as stated above, that the proportions of comparison stimuli discriminated will be distributed linearly rather than sigmoidally (as expected from the classical point of view) between 0 per cent and 100 per cent. The procedure is to plot the data and then make a "goodness of fit" test for both types of curves.

Stevens, Morgan and Volkmann in 1941 found the rectilinear hypothesis to fit their data better, in both loudness and pitch discrimination studies. They also found that their data bore out the prediction of the slope of the function; i.e., a 2:1 ratio was found between the values of the functions at the 100 per cent and 0 per cent points (69). Flynn (1943) found a straight-line function in his work in pitch discrimination, but he failed to find the 2:1 ratio as predicted (26). Both Jerome in 1945 in measuring olfactory thresholds and DeCillis (1944) in measuring tactual movement thresholds found rectilinear relationships to hold better than the sigmoidal function but both also failed to find the predicted slope. It has been pointed out their failure to met this criterion may be due to the fact that they were measuring absolute, not difference, thresholds and that perhaps the 2:1 ratio does not hold for such cases (26).

One requirement of applying the "goodness of fit" criterion is that a number of data plots be available since it is only at the 20 per cent and 80 per cent levels that there is a difference of any magnitude between the two types of curves. Corso points out that in the study by DeCillis there were not many points at those portions of the curves where they differ most, and that on this basis his conclusion of rectilinearity might be questioned. Corso himself found only nine out of seventy functions to conform to the hypothesis of linearity in a study of both pitch and loudness discrimination in 1951 (25). Koester and Schoenfeld in 1947 also failed to obtain the predicted rectilinear functions (25).

Some criticism of the quantal hypothesis and its testing has been aimed at the number of stringent requirements held to be necessary if the extrinsic variables are to be controlled and hence permit the unobscured appearance of the quantal nature of the perception. Among the precautions to be taken in testing the quantal hypothesis are: (a) there must be no time interval between the standard and variable stimulus so over-all sensitivity will not change between the two stimuli; (b) the variable stimulus must be of short duration; (c) the task facing the observer must be made as easy as possible in order that he may establish and maintain a stable criterion (this includes practice sessions, insured attention, etc.); (d) the judgments should be rapid to eliminate the necessity of averaging results from different experimental sessions as the sensitivity of the observer might change and the size of the quantum does not remain invariant; (e) there should be a warning signal used to reduce the fatigue of sustained attention; (f) there must be no transient sounds between the standard and variable stimulus (in audition studies, that is). It has been noted by some workers that all these restrictions make the hypothesis exceedingly difficult to test, for any failure to meet the criteria may then be laid to failure to meet the proper conditions for testing the hypothesis (26).

One particular criticism has been leveled at the requirement to make the task as easy as possible for the observer. A random order of presenting stimuli, for example, may prevent the observer from adopting a stable criterion; but then again, the observer may set up a "subjective standard" for himself if he realizes that the stimuli in a given series are to be identical. Blackwell has found what he calls "positive channelization" or a tendency to increase the "yes" responses toward the end of a series of predominantly "yes" answers (12). He found also that a forced choice situation gave much more reliable results than a phenomenal "yes" or "no" type response (11, 13). His conclusion is that the specific procedure which the quantum theorists have advocated—phenomenal report with grouped stimuli—is not well suited for the purpose, and may actually distort the form of the threshold data to serve as evidence for the neural quantum theory. Miller and Garner, in an intensity discrimination study, used both a standard quantal procedure and a modified procedure with random alteration of the stimulus increment to prevent the establishing of a subjective standard. They found that the random presentation prevents even a well-trained subject from adopting a stable criterion, although the quantal hypothesis gave the better fit to the data in spite of this. These same workers also showed that combining data for the same subject at different sessions gave sigmoidal functions, while the data plotted separately gave rectilinear results (26).

Only one experimental test of a third prediction, cyclical increase and decrease of the variability of judgment, has been reported. Volkmann in 1946 reported such cyclical changes when he exposed tachistoscopically the same-sized black rectangle 26 times in succession, but changed the size of the stimulus from series to series (57).

One point which has been mentioned in favor of the quantal hypothesis is that it predicts another parameter besides the mere form of the function, that of the slope of the psychometric line. Also the phi function of gamma (or integral of the normal curve) emerges as a special case of the quantal hypothesis, for the sigmoidal function is often obtained when the experimental procedure leaves time for the observer to change his sensitivity between the presentations of the standard and comparison stimuli (69). Other advantages of the view are the clear distinction it makes between extrinsic and intrinsic sources of variability, and the fact that it offers a rational conception of the nature of sensory discrimination which is compatible with existing knowledge of the nervous system.

How Quantum Field Theory Differs from the Neural Quantal Hypothesis

A salient characteristic of the neural quantal hypothesis is that the unit or quantum is conceived to be a perceptual unit, a functional unit, as opposed to the physical quantum such as that utilized by Hecht in his theory of vision, where the quantum was contained in the stimulus energy.[6] From the point of view of the quantal hypothesis, the way to

[6] The neural quantal theorists are very explicit on this point as the following quotation indicates: "The term 'quantum' has a meaning entirely different from Planck's quantum in physical theory, Hecht, Shlaer and Pirenne's quantum in visual theory, and Gabor's quantum in auditory theory. In each of these instances, the quantum refers to a unit of physical energy; here it refers to a functionally distinct unit in the neural mechanism which mediates sensory experience. Hence, 'quantum in the present sense implies a perceptual rather than physical unit." (26)

resolve the seeming paradox of continuous environmental energy changes and the resulting seemingly continuous experiential phenomenon with the “all-or-none” physiological functioning of the nervous system is to postulate a perceptual unit or quantum which functions in the same “all-or-none” manner as the physiological nervous units which have been shown to exist. It has been shown by some workers that there does seem to be a step-wise nature to perception and that this quantal nature is easily masked by insufficient precautions to eliminate the relatively larger fluctuations present in both observer and experimental situation. Thus, perceptual processes—and presumably other psychological processes also—could be said to function on a basis different from that of many or or most physical processes.

This writer would agree that there is indeed a step-wise nature in perception and, in fact, in all psychological processes. However, the unit responsible for this step-wise characteristic is conceived to be a physical unit, the quantum field of modern physics. The quantum field is held by most physicists to be the basis of all matter and all energy. It is this worker’s fundamental conviction that all psychological processes as well rest upon an organization of quantum field structures. In other words, “matter”, “energy”, and “mind” are all different aspects of the same thing, an underlying organization of quantum field structures. Such a view would not only resolve the above-mentioned paradox; it would remove the paradox completely. The environmental energy <u>and</u> the functioning of the nervous system would have one basis: the quantum field. A basic property of quantum fields is that they are made up of discrete quantum-field structures. This view also serves to unite psychology with other sciences, both physical and biological, rather than set it apart.

This worker suggests that quantum field structures are involved in a dynamic structuring process which, in the higher living organisms, operates within the subcortical reticular formations. Quantum structural aggregates are formed within this structuring center and it is during the time involved in the structuring process that the psychological phenomena, such as perception and cognition, are experienced. We may now ask just what a quantum field and quantum field structures are and how quantum field theory differs from classical field theory? What, we may ask, is the rationale for the postulated structuring process and what are the reasons for placing it in the reticular formations? Is there experimental evidence for this viewpoint? Finally, we may ask, what are the generalizations emerging from modern biology, physics, chemistry, and astronomy that necessitate a search for a more basic parameter for psychological processes than either the neural quantal hypothesis discussed above of Eühler's field provide?

A Brief Background of Quantum Field Theory

Physics of the eighteenth century, based on Newton's system of motion and gravitation, led the systematizers of that age to hope that all phenomena could be reduced to cases of matter in motion and thus be treated in strict mathematical ways. The universe was a machine in the century of mechanical order. Out of this mechanical order, however, slowly grew a new foundation for physics: field physics.

First Michael Faraday explained the mysterious electromagnetic interactions by spatial states. His concept of field necessarily corresponded to a degree with the nineteenth century picture of the world; the field was a kind of tension or stress in space which revealed itself by the action of its forces on any material objects which happened to be in the same space. The electric and magnetic fields, which Faraday found also exerted effects on one another, lent themselves well to this conception of field. Maxwell formulated the exact mathematical time-space laws of these two fields and from these deduced that the electromagnetic fields traveled in the form of polarized waves with the speed of light. He guessed that light consists of traveling electromagnetic fields. This was a real step forward since in a true field theory, the changes of the field in space and time are more important than the particles and their motion. Planck in 1900 added the discovery that resonators (later called electrons) must emit and absorb energy in discrete packets of value hv, where h is Planck's universal and v the frequency of the resonator.

Since light is emitted or absorbed in units of hv, the next logical step was to postulate that light travels in packets or particles of energy of value hv. Planck never took this step; it was up to Einstein to do it. One of the papers he published in 1905 dealt with the action of ultra-violet light striking a negatively charged metal surface,being partially absorbed, and thus giving up its entire unit of hv to an electron which is in turn ejected from the metal and its energy measured. This had much to do with the revival of the corpuscular theory of light and is an important step in the development of the quantum theory.

Another of the papers Einstein published in 1905 was his Special Theory of Relativity in which he presented a new version of Maxwell's field theory but never mentioned the ether. With this abandonment of the ether-filled space to carry the electric and magnetic stresses went also the rejection of the idea of space as a fixed framework within which one can distinguish "true" from relative motion. The speed of light—or traveling packets of energy hv—was the governing constant of the universe. It will always be measured by 186,282 m.p.s. and no moving body can ever exceed this speed. This velocity is independent of the motion of either the source or receiver of the light and is constant with respect to any galaxy in the universe.

In the years 1915-1920, Einstein propounded his General Theory of Relativity.[7] This theory put forth a new concept of gravitation; abandoning Newton's concept of gravity as a force, Einstein conceived that the space around any celestial body is a gravitational field much like that around a magnet is a magnetic field. He then concluded that the presence of a gravitating body bends the particular region of space in which it lies. Light rays passing through this "bent space" would then travel, not in a straight line, but in curves. Four years later during an eclipse of the sun (1919), astronomers confirmed this conclusion and again in 1922. However, in 1929 the agreement was not satisfactory.

In the time since 1905 it had become more and more illogical to try to imagine everything in the universe as mechanical. It no longer corresponded with the facts as they were known to try to explain the fields in terms of mechanical models. Einstein's theory (a classical field theory) was a step in the right direction but, in general, the appeal of a theory of relativity was weakened in that many leading physicists, e.g., Max Born, Niels Bohr, Wolfgang Pauli, feel that it can not explain many

[7] This is a rigidly deterministic type of field theory which the majority of theoretical physicists now feel does not and can not suffice to explain micro-physical phenomena where they feel strict causality must be abandoned.

of the problems of quantum theory. In quantum theory, all objects of atomic size fluctuate continually, i.e., they can not maintain a precisely defined position for a finite length of time. These fluctuations are not predictable and the laws of quantum mechanics reveal only the statistical behavior over a period of time. These quantum fluctuations are regarded as not affecting the classical field at all; they become apparent only when the effects of an electromagnetic field on a single atom are measured. Thus, the theory of relativity breaks down when it is applied to microphysics, because it does not account for these fluctuations; in the classical field they were statistically obscured.

For a brief period in 1932 when James Chadwick discovered the neutron, it seemed that all physical matter could be explained in terms of three elementary particles: the proton, electron, and neutron. Nature was very simple. The 92 kinds of atoms consisted of various arrangements of these three particles. To be sure, since the quantum theory specified that energy as well as matter was made of discrete units, there actually were two other “elementary” particles—the photon, the unit of the electromagnetic field or light, and the graviton, the unit of the gravitational field (which has yet to be observed). But it was thought in 1932 that the former three could account for all physical phenomena.

However, it was not long—later in the same year, in fact—before a fourth particle, the positron, was discovered. By interaction with atomic nuclei, photons were converted into pairs of electrons and positrons thus demonstrating Einstein’s equivalence of mass and energy. Today there are known some 15-25 different (fundamental) particles and each is thought to be the manifestation of a qualitatively different quantum field. That is, the particle is to be explained in terms of the field rather than the field in terms of the particle. Each particle is representative of a qualitatively different quantum field and is generated by perturbations in that field. A less sophisticated way of putting it is to say that the particle is the result of a particularly heavy concentration of the field within a quantum field. Thus, everything would be regarded as both field and particle with the particle being formed where the field is very concentrated.

When "looked at" with large-scale apparatus, the quantum field is exactly like a classical field for on a large scale the quantum fluctuations average out to produce no effect. The quantum fields are short range fields less than the size of an atom and whose effect can only be felt for this distance. These fields fill the whole of space; in fact, the entire universe, including the classical fields, is believed to consist of such fields.

In a quantum field, energy can exist only in discrete units which are called quanta. When the theoretical details of these quanta are worked out mathematically, it is found that their properties correspond exactly to those of the elementary particles we find around us. Thus each field has its own characteristic energy; or, in other words, each field manifests itself as a type of elementary particle. Particles of a given type are all completely identical and indistinguishable. Also the number of these particles is not fixed, for they are continually being annihilated, created, or transmuted into one another. In this view of quantum field theory the individual particles is no longer a well-defined permanent entity. For one thing, Heisenberg's uncertainty principle implies that we could not ever be sure we have observed the same particle twice. There is no detectable identity or sameness; there is no way to mark a particle for identification. The particles then would be “more or less temporary entities within the wave field whose form and general behavior are nevertheless so clearly and sharply determined by the laws of waves that many processes take place as if these temporary entities were substantial permanent beings.” (68) The concept of particles can not easily be abandoned for it is needed to describe much of the structure of matter. In order to determine as precisely as we do the weights of nuclei or various elements and chemical compounds, the particles must be considered as concrete, real entities. This view that everything is at the same time both particle and field is, in general, accepted although there is some difference of opinion on details. Neither of the concepts (particle and field) is hypothetical; on the contrary, both are supported by innumerable experimental facts.

The problem of resolving the wave-field and particle concepts is a major effort of those who work toward a unitary theoretical concept to bring together the two major views in physics and in fact to unify all of scientific thinking. Until his death Einstein was numbered among those who strove continually for such a unitary theory. In order to be really unitary a theory should be based on only one of these concepts and the other of the two should be satisfactorily explained in terms of the one. Einstein’s aim was to create such a pure field theory and explain everything else in terms of it. This would not be denying the existence of matter but rather would be saying that the existence of matter should be deducible from field equations alone. Since a good field theory of necessity interprets matter—or particles—in terms of fields, the laws of the fields would have to be changed in order to admit solutions representing matter. Einstein believed that such a theory should explain not only the properties of elementary particles but also the motion of planets, stars, and galaxies. In the old theories, the existence of matter was an independent assumption.

The quantum field theory of today approaches this ideal although not exactly as Einstein had envisioned it. Everything is regarded as being both field and particle with each particle being representative of a field and being generated by perturbations in that field. The particle is to be explained in terms of the field rather than the field in terms of the particle; the fields together with their “resultant” particles are regarded as the basic sustrata of the universe. Our solid universe is thought of as a “balance” of these underlying quantum fields. The fields are regarded as being unstructured or continuous and are more or less permanent entities which can be treated as points in mathematical treatment. That is, the fields are assumed to undergo no internal change beyond the “perturbations” that produce the field particles. Interaction is the mode of process in the present conception of the field with the unstructured fields and their representative particles being the units of the interaction. This would seem to be the foundation of a pure field theory.

A Modification of Quantum Field Theory

In 1949, Lancelot Law Whyte put forth the criticism that, in the progressive development of physical theory, simplicity had been lost (75). The mathematics involved have become extremely complex, indeed, almost intractable. While Whyte holds many of the general aims of Einstein and others pursuing a unitary theory, he contends that the current theories are much too complicated and must instead be based upon a more simple principle. He points out that the physical systems processing a measure of stability—such as ultimate particles, or atoms, or crystals—are characterized by their properties of symmetry while physical forces and fields are distinguished by their asymmetry. Thus, the only reliable inference from the physical observation or measurement of a field is the absence of some element of symmetry. For example, the presence of polar asymmetry with certain quantitative properties may properly be inferred from the observation of an "electrical" phenomenon while any theories of "charges", etc. may or may not be correct. From this view, then, a physical field represents asymmetry. Any process resulting from the field is the decrease of asymmetry. The "forces" of the field result from the tendency of the field to approach its characteristic symmetry. In this view the particle concept is accepted as valid in so far as it represents spatially separated point-centers within extended spatial field patterns. The field concept is accepted for its extension of "observable spatial relationships over finite regions" (75). Both concepts, however, neglect the presence of any formative tendency and must, in fact, resort to complex interactions (mathematically derived) in order even to allow for the one-way character of process.

While current quantum mechanical theory is still based upon the assumption of a four-coordinate system, Whyte feels that the next advance in fundamental theory must have its basis on a simpler principle whose definition does not involve the necessity of a four-coordinate system and which will not neglect the fact of the one-way character of process. The reason, he feels, that recent physical theories have broken down—for instance, General Relativity when applied to quantum fields—is that each is only one aspect of some more basic principle. There is required a mathematical representation of the one-way development of a new type of structured field representing the history of a complex system. This new field would directly represent the process of the system.

Whyte makes yet another innovation in his unitary field theory. The field is considered to be structured rather than homogenous. It is a system of polarized parts displaying a tendency toward its characteristic symmetry. This tendency is present in all parts of the field as well as in the field as a whole. There can be two aspects of this tendency toward symmetry: a local tendency toward symmetry of the part, and an overall tendency to bring each part into conformity with the whole. The level of the whole with which other parts are brought into conformity is called the “norm” and the process is the “normalizing process”. On the surface these may appear to be two separate and different processes but are actually two aspect of the one tendency toward symmetry. The basic field principle as he states it is “Asymmetry tends to disappear and this tendency is realized in isolable processes.” (75)

With this brief background, this worker will now present his own position regarding the quantum field and particle concepts. It is postulated that there is but one quantum field, composed of a general type, three-dimensional quantum structure, and that this field fills the whole of the universe. It is this structured field, its intrinsic properties and formative tendencies that are responsible for all processes and structural organizations (including the elementary particles) in the universe.[8] This field is the basic substratum of the universe. The normalizing process, as part of a continuously operating structuring process, differentiated out of this unitary structured field the quantum field structures. Subsequently, the normalizing process structurally developed these quantum field structures into the twenty-five or so elementary particles (that are now found in atomic nuclei), each particle having its characteristic set of field properties. The normalizing process, its intrinsic activity continuing, subsequently structured the twenty-five elementary particles into tiny structural microcosms which marked the beginning of the next step in the organizational heirarchy with a new set of properties—the evolutionary origin of the chemical elements. Thus, this worker is postulating a cosmogonic-evolutionary point of view as to the origin of the various levels of the organizational heirarchy, a more recently developed example of which is the living organism and its various levels of psychological processes.

At the most basic level exists a general type field structure with "free energy" field properties. At the next level exist a number of quantum field structures which have yet to be discovered and of which the twenty-five thus far discovered "fundamental" particles are composes. It is these structures of the second level that should bear the designation "quantum field structures"; it is to these structures this worker is referring when he speaks of "quantum field structures", not to the "fundamental" particles thus far discovered. These latter particles are believed by current theorists to be quantum field structures and each is believed to represent a qualitatively different quantum field. On the other hand,

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8 The "intrinsic properties" of each general type field structure and the field as a whole are those properties ascribed to the thermodynamic entity "free energy".

following a cosmogonic point of view, this worker asserts that these particles are actually massive particles composed of still smaller ones, the quantum field structures. The proton, neutron, and electron were simply the first particles to be discovered. But prior entry into the theoretical ledger is no reason to accord them more fundamental theoretical significance than some yet more elementary structures which still remain to be discovered.

Thus, the quantum field theory concept utilized below is a combination of quantum field theory together with Whyte's innovations and the elaboration suggested by this worker. The view that all fields are quantum is accepted as a basic assumption. These quantum fields are considered to be highly structured entities. These structured fields are conceived to be composed of three-dimensional asymmetrical structures. These structures, moreover, are conceived to have dimensions smaller than the 10^{-13} cm. which is the general range of dimensions for the particles discovered thus far by nuclear physics. Each one of these quantum field structures is postulated to have a vibratory or frequency rate in the neighborhood of 10^{15} cycles per second. Each structured field is conceived to fill the whole of the universe.

The structured field is conceived as a delimited aggregate of dynamic quantum structures that are interconnected and interdependent and that continue to operate together according to the unitary principle to produce all structural aggregates and processes in the universe. The fields are distinct from other fields to which they may be dynamically related. Structural systems formed by the structured fields may be large such as the interdependent subsystems in the human body, each organ (or sub-system) of which is distinguishable in its operations. These structured quantum fields are conceived to undergo spontaneous tendencies toward change in shape, orientation, and position. These spontaneous changes result in the appearance of structural organizations throughout the universe. The spontaneous tendencies on the part of the structured field are the source of the unitary field process, the disappearance of asymmetry and the appearance of structural symmetry in parts of the field that are isolable at a particular moment.

The structured field process has two aspects, one toward a decrease of asymmetry in some isolable part of the structured field and the other toward a restoration of uniformity of asymmetry in the field as a whole. The former aspect of the field process manifests itself in the formation of local symmetry and the latter aspect is the source of all dispersing tendencies in nature. The two aspects in cooperation are the source of all organization and of one-way development. Both aspects of the structured field process, in acting together, form a structuring process wherein structural aggregates are formed and used by the normalizing process to promote the particular system's one-way development in accordance with its environment.

The structure of one type of structured filed may couple with the structures of another type of structured field (if their intrinsic properties permit) forming new types of structural organizations with new intrinsic formative tendencies. Since there are internal changes in the fields, the field process can not be reduced to an explanation of interaction between pairs of entities. When one structured filed encounters another such field both undergo internal structural symmetry formations. This continuous transactional activity between complex fields results in the one-way development of isolable structural organizations, the structural organization of the moment representing the history of the complex system or the structural transaction of the past. The properties of the structured field and its process provide for an intrinsic determinism (via its one-way character) but at the same time provide a tremendous potentiality for qualitative structural differentiation and individual differences as attestified by the four billion living species to have appeared on our planet.

It is beyond the scope of this work to mention the many areas and specific studies of scientific endeavor which seem to lend support to these concepts of the unitary principle and the formative process. Suffice it to say that the ramifications include such seemingly diverse fields as astronomy and biochemistry with especially the recent work in nerve and muscle thermodynamics providing new evidence pointing to a general-type process running through all biological processes and functions whatever their structural organization or whatever their phylogenetic level.

Application of Modified Quantum Field Theory to Psychological Processes

The events underlying neuro-psychological functioning are postulated to be quantum structure complexing, structuring of the field structures into quantum structural aggregates, and the formation of extended chains of quantum structural aggregates (memories). All psychological processes and all human behavior are postulated to be the resultant of underlying activities within these quantum structural aggregates and the quantum structuring process. The nucleoprotein (DNA) molecular organizations are conceived to furnish facilitatory properties for the underlying quantum structural organizations and the structuring process. The nucleoprotein organization per se is postulated to play no part in biological order. It is predicted that the laws of genetic and psychological processes, when fully known, will be fundamentally similar and described in full by unitary principles. Thus, the postulate is that a quantum structuring process, and quantum structural aggregates, are the basic parameters of psychological and genetic processes.

It might be noted here that this is a rejection of the nerve impulse doctrine as the basic neural parameter. This rejection is based on an extensive review and study of recent work not the least among which is the fact that the cell is no longer regarded as a basic functional unit in biology. A good many events have led a growing number of researchers and theorists to suspect that finer events than varying gradients of neural action potentials underlie neuro-psychological processes. Much of this research and theory is summarized in Katz and Ealstead (44).[9]

The synaptic junction surely offers no fundamental obstacle to the quantum field point of view when a reinterpretation of known events is made. When the quantum field structures arrive at the presynaptic nerve endings, acetylcholine intercepts them, reacts with ATP thereby undergoing depolarization, and uses the energy thus released to transmit the quantum field structures across the junction. (The acetylcholine acts as an ion by migrating across the junction over a distance up to one micron.) The acetlycholine then inducts the quantum field structures into energy-giving synaptic acetycholine. ("Synaptic acetycholine" is this worker's own postulate. Some experimentalists state that there is only pre-synaptic acetycholine; others hold that there is only post-synaptic acetylcholine. This postulate is an attempt to resolve the impasse and is based on evidence which will not be developed here.) This acetylcholine passes the quantum field structures to the atomic nuclei of a receptor protein in the postsynaptic membrane thereby causing its depolarization (53).

An experimental test of these quantum field theory views in relation to psychological processes might now be suggested, although such a direct test as this would need the cooperative effort of a team of expert specialists from many fields. As a beginning on experiments which would indicate that our psychological processes rest upon a quantum field organization, this worker suggests the repetition of all experiments in which there have been produced subjective visual effects by high-density a. c. magnetic fields in the human. Among these effects are subjective visual effects of high-intensity magnetic fields brought near the head as reported by Barlow; and Lissman demonstrated that some fish are quite sensitive to an ordinary hand magnet as it is brought near the aquarium in which they are swimming (52). Reynolds pointed out at the Nerve Impulse Symposium that the effects of magnetic fields of a. c. electro-magnets on visual function have been reported at least a dozen times

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[9] This reference holds that the nerve impulse doctrine is inadequate and attempts to substitute "nucleoprotein patterning" as the basic psychological parameter. This worker, however, rejects the nucleoprotein molecular hypothesis and asserts that a quantum field or a subnuclear hypothesis should take its place.

since the beginning of this century (52).

This worker suggests that the retinal cone-rod system disperses the individual photon into its electrical and magnetic components (quantum field structures) and that it is the quantum magnetic field structures which are transported from one atomic nucleus to another in the visual-neural pathways. This worker furthermore suggest that the subjective visual effects produced by the high intensity a.c. magnetic field are due to the effects that these external fields have on the visual-magnetic quantum field structures as they travel from one atomic nucleus to another. (In other words, the external field effects are inter-nuclear.) Therefore, if an a.c. magnetic field of proper strength and frequency (or perhaps an electrically charged a.c. electrode for modalities other than visual) can be put in the proper direction in relation to the traveling neural quantum field structures, two effects might be produced: (a) An external frequency and intensity of the a.c. magnetic field can be found which will "beat" with the quantum field structures traveling up the neural pathways. In this case, all subjective visual effects in the organism should be nullified or eliminated although most of the macro-neural electrical effects may go on unimpaired. (b) By changing the polarity or charge of the external field, the quantum field structures might be deflected out of the neural tracts so that the quantum field structures can be experimentally isolated and their properties studied in a Wilson cloud chamber much like the properties of the "fundamental" particles are now studied. It may well be that the tracks produced in the Wilson cloud chamber by the quantum field structures deflected from the

the visual neural pathway will be similar if not identical to those produced by the positron in the cloud chamber. Then as a corroborating experiment these quantum field structures, by proper arrangement of an intervening apparatus, should be transferable from one organism to another, with the latter organism experiencing the psychological phenomena that the former organism would have experienced had not the course of the internal stimulation been interrupted.

The only drawback to such an experiment might be the possible injury to the cellular apparatus and cell walls by the high energy magnetic or electrical fields or by fields induced by these external fields. However, with the insights provided in the nerve impulse symposiums, and with the demand for new information in rapidly expanding new fields such as space medicine, this worker has little doubt that the above or some analagous experiment will be performed, and performed successfully, within the next ten years. In fact, during the course of the nerve impulse symposiums, the passage of “fundamental particles” along the nerve fiber in lieu of the nerve impulse was mentioned several times. The “fundamental particle” suggested was the proton and this particle was chosen by analogy to the well-known proton transfer of acid-base reactions. The idea was suggested, moreover, without a rationale, at least not from a field theory. However, the chances are good that the visual quantum magnetic filed structures are not only magnetic particles but also carry a positive charge (which seems to be a paradox since magnetic particles are not supposed to have charges) so that experiments guided by the above reasoning could well demonstrate the presence of quantum field structures in the visual system. At any rate, the successful achievement of such an experiment could well close the dualistic-philosophical era in psychology and would open up vast new vistas in every field of biology which, of course, includes most of psychology.

Such an experiment will have to await more complete development of techniques in several of the specialized fields involved, however. For the present, experiments which indicate the discrete nature of psychological processes will have to suffice as indications of a quantum field structure parameter such as that being here postulated.

Nature of the stimulus process from this view. The environmental (distal) stimulus is viewed as a varying pattern of electromagnetic, mechanical, thermal or chemical energy. This pattern is transformed in the receptor into quantum structural (field) patterns of varying degrees of symmetry and asymmetry.[10] The transformed stimulus pattern is conceived to be composed of coupled three-dimensional quantul (field) structures each of which carries a part of the structural configuration of the environmental stimulus pattern. In some modalities there may be an actual input of environment structures into the receptor. (For example, it may well be that the magnetic quantum field structures of the incoming electromagnetic photon may be involved in the subsequent visual perceptual process.) In other modalities (such as tactual) the source of the transformed stimulus structure may lie in the receptor itself. That is, a pattern of physical contact is transformed into patterned quantum field

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[10] This transformation is the one and only transformation to be effected in the nervous system. That is, there are not two transformations—one at the receptor periphery and the other in the cortex where the psychological processes are believed to occur. All psychological processes, including the initiation of patterns of muscular contractions, take place at the level of quantum field structures.

structures which are furnished by the receptor itself.

The normalizing process operating at the receptor periphery keeps the receptors at a high asymmetry level by the induction of structural asymmetry (free energy). This process of repolarization or asymmetry induction induces a particular asymmetrical structural pattern in the receptor using structural asymmetry as the source of structure, and the specialized pattern intrinsic to the receptor to effect the patterned repolarization. This high level of patterned structural asymmetry induced in the receptor represents the symmetry tendency of the normalizing process manifesting itself at the periphery. By the process of receptor depolarization[11] which is postulated to involved the transformation process, environmental stimuli distort the symmetry tendency of the normalizing process appearing at the periphery. Thus, at the receptor periphery two factors are introduced: a moment to moment varying structural configuration (that is interceptible and differentiable by the specialized memories within the organism) and momentarily varying degrees of normalizing distortion. The incoming structural configuration is differentiated and then symmetrized in processes which temporarily become isolable in the reticular center, the symmetrization process being

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[11] A process of depolarization and repolarization of the molecular super-structure is simultaneously initiated. This provides the means for the quantum field structures to traverse the neural pathways. This is a nuclear action which involves a transport of fundamental particles, quantum field structures, from the atomic nuclei of one molecular structure to another by causing a grouping and regrouping of atoms which releases electrical energy in the process. This electrical energy or nerve impulse is the resultant of ionic changes taking place in the chemical reactions of the cellular steady states which maintain the ATP-ADP-PC system that directly sustains the depolarization-repolarization cycle. In the depolarization phase, ATP is split to ADP and the structural asymmetry or free energy is released to perform the function--transport of the fundamental particles—and in the repolarization phase, ADP is resynthesized to ATP by the PC metabolism and the molecular structure is again in an active state, ready for the next stimulus.

a structuring process in which structural aggregates are formed. These then become the basic source of the configurational properties of our psychological phenomena. The normalizing distortion, being simultaneously introduced at the receptor, appears as the dimensional aspects (intensity attributes) of our psychological experiences.

Since the incoming stimulus is complexed by memory structures, the entire sequence of operations—from the initiation of the environmental stimulation to the moment of structuring in the reticular centers—before the asymmetry level is restored, must be thought of as the process of stimulation or the decrease of asymmetry in an isolable process. The entire sequence of operations, from the restoration of the asymmetry level in the structural aggregate to its effect on the total environment via the excretory, locomotory, and manipulatory activities of the organism, must be thought of as the reaction of the organism or the restoration of the asymmetry level by the normalizing process. The complete operation is cyclic and one-way: the environment induces a configurational normalizing distortion in the organism which we call a stimulus. This stimulus eventually forms a unit of structural order in the human's reticular structuring system which unit of order this worker is calling a quantum structural aggregate. This unit of order is then used by the normalizing process in an immediate or delayed effect to exert an ordering influence on the environment. Thus, the normalizing distortion introduced from the distal environment is offset by the ordering activity of the normalizing process operating within the organism and on the distal environment. This cyclic sequence of operations is what is meant by the system organism-in-environment. The stimulus and the reactions of the organism are both links in this cyclic sequence of operations. The overall resultant of the sequence of operations initiated by the incoming stimuli is the progressive elimination of the normalizing distortion introduced into the organism by the environment (thereby bringing the organism and environment into mutual conformance) and the increase of differentiated organization of the memory areas. These memories, now part of a vast neural structural organization, provide the potentialities for the central semi-autonomous process (a term first used by Hebb) which we call the cognitive processes. (36)

Upon their exit from the receptor organization, the transformed stimulus patterns are conceived to be decoupled by quantum organizations lying within the molecular structures of the exteroceptive and interoceptive projection system. The decoupled structures then proceed to the geniculate structures or their functional equivalent where, it is conceived, spatial and temporal dispersal takes place. The decoupling idea and subsequent spatial and temporal dispersion of the transformed stimulus pattern into individual discrete structures is based on an interpretation of the work of Marshall and Talbot (49). Moreover, since Hecht, Shlaer, and Pirenne (38) made it reasonably clear that the absorption by a rod or cone of one photon of light is sufficient to excite it, it seems reasonable to conclude that it is this one photon or its transformed equivalent that must be spatially and temporally dispersed into discrete quantum field structures and each structure multiplied many times before it reaches area 17. Thus, by the operation of the projection system structures, each discrete quantum structure of the transformed stimulus acquires at the same instant the same velocity and the same direction of movement along neuro-anatomically prescribed paths. The dispersed incoming structural stimuli then pass through memory areas where they (the incoming structures) are structurally differentiated or made more complex by the memories in the organism. Their reappearance in the form of equivalent quantum structural aggregates is due to the spatial (cortical) convergence properties of the descending projection fibers and due to the nature of the structuring process going on in the reticular formations. [12]

The Reticular Formations

The recent symposium Brain Mechanisms and Consciousness was devoted entirely to discussing various aspects of the reticular formations. These neuro-physiological complexes have come under close neuro-physiological investigation only within the past decade. The term “reticular formations” refers to neurological arrangements of closely interconnected neurons which appear, as far as current knowledge goes, mainly in concentrated areas in the brain-stem but which are also known to appear throughout the cortical areas. From the nature of their external relations, it is deduced that the reticular formations perform three types of operations whereas other neural areas are almost invariably restricted to one operation. These operations, from the viewpoint of the neuro-physiologists participating in the above symposium, are nerve impulse-volley collecting, integrating, and redispatching.

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[12] It is known that every cell in the receptive layer of the projection cortex has two collaterals—one coming from the specific projection system (from the receptor periphery) and one going to the non-specific projection system (via areas 18 and 19?) in the reticular formations. It is also a known fact that the stimulus reaches its maximum magnification (or dispersal) when it reaches this receptive level and that then a progressive neuronic convergence of nerve fibers takes place upon the reticular formations (59).

The reticular formations have numerous collaterals over which they receive "messages" from, among other sources, the various projection areas in the cortex. After they receive these heterogeneous messages, the reticular formations work them over as integrators. That is, at this stage it is observed that there is input into the reticular formations without corresponding output (1). After the reticular formations integrate the heterogeneous volleys and transmit these to certain neural areas over "well defined afferent and efferent pathways". Thus at this stage there is output without corresponding input, the reticular formations serving as "autogenic generators". The selective and restraining aspect of the many competing neural messages that are brought to these centers is regarded as a salient functional property of the reticular formations and is conceived as being due to the "limited neural space" occupied by the reticular complex.

It is an experimentally established neuro-physiological fact that the respiratory process operates within or feeds into the reticular formations. The exact significance of the role of the respiratory process in the activities of the reticular formations is unknown. However, it has been noted that the electrical activity emanating from the reticular complexes is that of a continuous rhythmical sort and that this activity apparently acts as a pacemaker for both the processes taking place in the reticular formations themselves and for those taking place in the cortical areas (59). Kubie and others have suggested that this continuous rhythmic activity and pacemaking action is due to the respiratory process, and that the respiratory process activates the reticular formations and serves as a pacemaker rather than the other way around (1). It has been further suggested that the activating and pacemaking activities of the respiratory process rest on a biochemical basis (1).

For each receiving cell in the receptive layer in the cortex there are two fibers, one of which comes from the receptor(the specific projections) and the other from the reticular formations in the mid-brain (the non-specific projections). The writer has postulated that the specific projection fibers play a dispersal role, in addition to a projective role, which insures that each part of the stimulus structure traverses past quantum structural organizations (memories) in the cortex. Thus, maximum dispersal of the stimulus structure is conceived to be reached when the parts of the stimulus reach the receptive levels in the cortex via the specific projection fibers. The non-specific projections then come into action playing a role as a means of synchronization and convergence on the parts of the stimulus structure.

Without going into detail which is beyond the scope of this paper, let it suffice to say that from this view the structuring process consists of the two aspects of the unitary process acting in close cooperation forming quantum structural aggregates at a high asymmetry (free energy) level. The normalizing process, however, has a continued organizational control over the structural aggregates formed in the reticular formations. It interrelates the structural aggregates thereby providing the properties of psychological meaning, temporal order (and temporal continuity of processes taking place in each individual aggregate), and the properties of one-way development (e.g., learning) and also prevents the aggregates from reaching their static symmetry forms by maintaining them as viable forms as long as a sustaining asymmetry supply is always kept available.

The spatial arranging and relating of the structural aggregates on the asymmetry chain so that one structural aggregate follows the other, it is postulated, provides the temporal property that is called serial order within each specific modality. These structural aggregates are being arranged and spatially related on the asymmetry chain (of the normalizing process) as structural changes are going on in these aggregates. The structural changes yield our psychological experiences and the spatial arrangement [of] their temporal characteristics. Moreover, since the structural aggregates of each specific modality couple with the same asymmetry chain in parallel, this action provides inter-sensory relationships and interactive effects between the various modalities.[13] This sequential and lateral-parallel interlocking of these structural aggregates on a common asymmetry chain provides the contiguous temporal relationships between the sequential events taking place external to the organism (exteroceptive) and sequential events taking place in the organism(cognitive, interoceptive, proprioceptive, and tonic). This spatially contiguous structural interrelation between chains of these

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[13] When the structural aggregates from the various modalities feed onto the asymmetry chains they apparently interact to produce the well-known intersensory interactive effects between modalities. The structural aggregates that feed onto the common asymmetry chain are exteroceptive, interoceptive, proprioceptive, and tonic. It is via this spatial contiguity that internal affects (the primary drives, emotions, feelings, etc.) become related with exteroceptive (perceptual) and cognitive (conceptual-symbolic) processes in the human. Thus, the empirical referent of a concept contains congnitive, interoceptive, exteroceptive, proprioceptive and tonic components at one and the same time.

structural aggregates has been previously called “association” and was believed to occur in the cortex.

Dynamic Contour Formation

Underlying quantum field processes. We will now go into more detail concerning the aspects of the structuring process in which we are immediately interested—visual contour formation. Each discrete quantum field structure of the stimulus which has a different intensity level falls through different asymmetry gradients. The normalizing process then inducts structural asymmetry in the degree necessary to restore the structural aggregate to the asymmetry level of the normalizing process. Thus, if a particular structure has fallen through a larger asymmetry to symmetry gradient in comparison with another structure in the same aggregate, the normalizing process inducts more structural asymmetry into the former in comparison with the latter. If the asymmetry level inducted into a particular part of the stimulus configuration is high, we experience the intensity attribute "“right"” in this part of the stimulus configuration. The greater the drop in the asymmetry level in some part of the aggregate, the greater the normalizing distortion and, hence, the higher the asymmetry level is raised in that particular part. Thus, normalizing distortion in various degrees in the structuring centers yields our intensity attributes. Intensity attributes are thus measures of current normalizing distortion being produced by the stimulations of the moment. The intensity attributes are almost always, however, a part of some configurational quality phenomena but the two are not the same thing. Configurational qualities such as hues, objects, pitch, words, etc.

are due to the configurational-structural nature of the structural aggregates while intensity attributes are due to the normalizing process restoring its asymmetry norm by inducting structural asymmetry into the aggregate during the structuring process.

The stimulus variable determines how fast the individual aggregate is formed. The higher the asymmetry, or energy, the faster the individual aggregate is formed and the faster the structural aggregate is displaced from the reticular center. All forms of energy within the stimulus configuration act as a driving force which increases the rate at which structural aggregates are formed. But this also raises the energy level that is inducted into subsequent structural aggregates. That is, for example, if an initial intense stimulus depresses the asymmetry level, and thus induces normalizing distortion, the normalizing process overshoots its mark in restoring its asymmetry level and thereby inducts a higher level of asymmetry into subsequent structural aggregates.

It has been widely noted in the literature that the Bunsen-Roscoe law holds only within the range of 50 to 200 msec. for visual processes. The reason for the existence of this law and its temporal limits have been ascribed to "temporal summation within the retina" and the fact that it takes from 50 to 200 msec. in the human eye for the photochemical [ba]ck-reaction to get going (76). When the duration is larger than this critical duration, intensity is the only determiner of the effectiveness.

Yet the experiments of Smith and Gulick (66) and the experiment reported in Part I have firmly established that durations as high as 1000 msec. are effective determiners of contour perception. The Bunsen-Roscoe Law, in the opinion of this worker, is too well established to be questioned. Therefore, it is here suggested that he Bunsen-Roscoe Law, which holds within the limits of 50 to 200 msec., is one dealing with energetic summation within only one quantum structural aggregate. This would mean that the Law refers to a central and not a peripheral process. Thus, as long as the duration is kept below the time it takes to form one quantum structural aggregate, the simple product of intensity and duration determines the effectiveness of the stimulus. But when the duration is longer than the time it takes to form one aggregate—as in the case of dynamic contour perception—the increased duration does two things. It increases the subsequent speed of structuring and raises the asymmetry level in each subsequent structural aggregate. The increased duration simply increases the degree of normalizing distortion. (An increased intensity, a larger stimulus, or any factor that would increase the total quantity of energy involved in the process of stimulation would do the same thing.) Therefore, the normalizing process, in restoring the asymmetry level, swings back at a higher level and faster vibratory rate, thereby completing the structural aggregates at a faster rate and inducting a higher energy level in the subsequent structural aggregates than would be the case if the increased duration were not present in the initial stimulation.