SOME PARAMETERS OF VISUAL APPARENT ABIENT MOVEMENT

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SOME PARAMETERS OF VISUAL APPARENT ABIENT MOVEMENT

By

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ABSTRACT

This investigation was conducted with the purpose of exploring the parameters of stimulation necessary for the perception of optimal abient movement. Two simple luminous targets were exposed in succession, each being located at the same optical distance and with their centers on the principal visual axis. The first target was of constant area and intensity; for different exposure sequences the second was made to vary in area or intensity. The temporal relation between termination of the first exposure and initiation of the second exposure was serially varied, thereby producing varying degrees of unstimulated interval between exposures and varying degrees of temporal overlap of exposures. Monocular viewing was employed, and stimulation was localized in the fovea.

Threshold measures for the magnitudes of both the unstimulated interval between exposures and the interval of temporal overlap indicate that there is a range of relative differences in both stimulus area and intensity within which movement is perceptible. Within these ranges, the absolute values of the threshold measures of the temporal relation between exposures were found to lawfully increase as direct functions of both relative difference in area and intensity. An important provision was the exposure of both targets above minimal durations.

Collateral observations revealed an orderly variety of related phenomena. These were: continuity of light (fusion), discontinuity of light (flicker), intrusion of the smaller second square within the first, contour obliteration resulting in either of two forms of pure movement, and the total obliteration of the effect of the first stimulus. Each of these phenomena was semiquantitatively discussed in relation to the parameters of stimulation.

The interpretation of all phenomena reported is made in terms of a tentative, primitive conceptual scheme, which not only embraces these phenomena, but applies in part to aspects of flicker fusion and contrast phenomena. It is believed that this scheme is capable of generating testable predictions.

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INTRODUCTION

The perception of motion has been a topic of no mean significance in the history of psychology. As a psychological event in need of explanation, it comprised the spearhead of the attack by the Gestalt school on nineteenth century content psychology. It was then that Wertheimer (31) convincingly argued that phenomenal movement was a basic datum of perception; immediately given, nonanalyzable, and noninferential. Wertheimer's polemic was based largely upon the visual perception of apparent movement in which the stimulation was spatially and temporally discontinuous, and the special case of objectless movement. Prior to the demonstration of stroboscopic movement, the psychology of motion perception constituted no source of puzzlement; when there is a relative displacement between an object and the body of the perceiver, there is a corresponding displacement of the pattern of stimulation on the receptor surface. Continuity in the space-time field of the surrounds has its correlated continuity in sense organ excitation; hence, the perception of moving objects. With the demonstration of stroboscopic movement in the nineteenth century, and the almost simultaneous demonstrations of negative aftersensations of movement, the topic of motion perception assumed an enigmatic status. These demonstrations achieved the ignoble distinction of being classified with numerous other phenomena under the rubric of "illusions"; the designation referring to the lack of correspondence between perception and the surrounds. Traditionally, as with all of the so-called illusions, the perception of movement of the stroboscopic and aftersensation varieties was rationalized in terms of cognitive or oculo-motor processes. Numerous researches were conducted, especially at the beginning of this century, in the attempt to elucidate the matter. Wertheimer's publication emerged as the most outstanding among those of others which marshalled against the interpretations of seen movement in terms of cognitive or oculo-motor processes. Historical reviews of the research and theoretical issues involved are presented by Boring (6) and Neff (22). The latter has especially well elucidated the early issues; hence, no attempt at review will be presented here.

Once it was established that movement is immediate in perception, the task became that of describing it, specifying the conditions necessary for its phenomenal occurrence, and establishing the underlying physiological correlates. A taxonomy of movement is hardly recognized in the literature; although much research has been performed on the subject of movement, a systematic effort is sorely lacking; and, unfortunately, little is known of the physiology of perceived movement.

Let it be recognized at the outset that the proper study of perception consists first of all in the description and organization of the facts of perception. This is not intended to mean that experimentation and theorization are to await a complete phenomenology, but rather that the object of study should be conceptualized as clearly as is currently possible. The facts of perception are phenomenal, and as the objects of inquiry, they should not be confounded with abstractive constructions. Secondly, let it be attested that the task which is set in the study of perception consists in discovering and lawfully relating those conditions--energistic, physiological, and psychological--which are causal for particular perceptions. Emphasis is particularly directed against the frequently overlooked logical fallacy which is committed by attempts to explain one perceptual event in terms of another (and the literature is replete with examples of this error). Consistent with these tenets, a tentative conceptual scheme will be proposed for the study of movement. Included within this format will be a taxonomy of phenomenal movement. Conceptual movement is not the immediate concern of this discourse. As additional information becomes available, the scheme will undoubtedly be modified.

I. Conceptual movement

II. Phenomenal movement

  A. Taxonomy

    1. Pure

      a. Phi

      b. Gamma

    2. Object

      a. Two dimensional

      b. Rotary

      c. Three dimensional

      d. Perspective

      e. Deformative

      f. Disjunctive

    3. Self

      a. Two dimensional

      b. Rotary

      c. Three dimensional

      d. Perspective

  B. Programme

    1. Verifiable

      a. Consonant

2. Nonverifiable
    a. Consonant
    b. Dissonant

It is well to distinguish between conceptual movement and phenomenal movement. As has already been asserted, the latter is an immediate event of direct experience. On the other hand, conceptual movement is an abstraction, constructed from a history of phenomenal events. Accordingly, conceptual movement is not to be confused with direct experience. An example of conceptual movement which is pertinent to the study of sensory processes is the linear transformation of a rigid distribution of radiant energy in the space-time field. One might say that this is a *physical* construct of movement. The taxonomy of movement will merit little discussion here. Let it suffice to make two remarks. The identifications correspond in part with the recent treatment by Gibson of the perception of movement in the visual world (11). In addition, inasmuch as the perception of objects or the self is of concern, there will be various combinations and multiples of these types of movement.

We can subsequently programme consideration of phenomenal movement as consisting of two main modes. (Neglect should not be made of the fact that schematization of the phenomenal is itself a conceptual act; taxonomy and programme should be recognized as such.) We may consider those instances of phenomenal movement which are capable of verification, and those which are not. By "verification" we shall mean established constancy of movement in experience via various receptor orientations. This includes the general gamut of movements which are present in the ordinary perceptual world of the individual. The class of phenomenal movement thus considered might generally be referred to as "verifiable movement." In contrast, we can consider the class of phenomenal movements not subject to verification by varied receptor orientations. It should be obvious that herein are included the varieties of apparent movement alluded to earlier, as well as other forms of "subjective movement," to be described below.

One more conceptual distinction of heuristic value might be made. There is an abundance of evidence for the fact that phenomenal movement which is nonverifiable by varied adjustments of the receptors can be a consequent of either of two stimulus conditions; viz., that in which the conceptual distribution of energy is continuously transformed spatially and temporally on the receptor surface, and that in which it is not. In the former case, we may simply say that the stimulus moves or is kinetic; in the latter case we may say it is stationary or static. Henceforth, phenomenal movement that is a consequent of kinetic stimulation can be referred to as "consonant movement," insofar as there is continuous flux in both; and, accordingly, phenomenal movement which is a consequent of static stimulation can be signified as "dissonant movement," insofar as there is continuity only in the phenomenal. It is to be noted that consonant movement includes all perceived movement that is verifiable via immediate experience as well as a class of those perceived movements which are not verifiable.

If justification of this schematization of a programme for phenomenal movement be needed, then it might be found in at least two sources; viz., the research programs which have been conducted by various investigators and the theoretical implications arising herein. Allport has contributed an extensive systematic treatment of the significance of phenomenal verification in his general consideration of perception (1, pp. 14-46).. Nonverifiable (traditionally labelled nonveridical) perception illustrates the important fact that the organism contributes to the sensory input. Historically, this fact was of especial theoretical import with regard to what is here called dissonant movement, as discussed earlier. Although the theoretical furor may have dwindled, experimentalists are still disposed to treat dissonant movement as unique. Those investigators who are particularly attendant to the psychophysiology of sensory processes aspire to reveal some of the characteristics of the mechanisms underlying these events. Dissonant movement (and its attendant phenomena) is useful for the study of the spatial and temporal properties of the sensory apparatus. Furthermore, in his research program dealing with the psychophysics of the visual world, Gibson has recently (11) made an analysis of the stimuli for what is here called consonant movement. However, Gibson is avowedly concerned mainly with verifiable phenomena. In recent years, the events which are here designated as nonverifiable consonant movements have been highlighted, along with other comparable perceptual events, by a relatively new theoretical trend in the psychology of perception (16; 30). Here again, emphasis is made of the organism's constructions from the phenomenal. Actually, in the terms of this discourse, it is largely the process and results of phenomenal verification which is underscored by these investigators. Surely, phenomenal movement which is nonverifiable by varied receptor adjustments has filled and still occupies a distinctive position in theoretical and experimental psychology.

Having made this somewhat tedious excursion in the interest of systematization, we can now devote the remainder of this discussion to the findings of research. Particular attention will be devoted to phenomenal movement dissonantly produced, for the main intent of this discourse is the presentation of some experimental findings of that sort. First, however, a brief resume of some of the previously obtained information will be offered.

After Wertheimer's classical publication, the problem of apparent movement (referring specifically to movement perceived subsequent to the presentation of dissonant stimulation) was broadened to include movement in the cutaneous modalities as well as the visual domain. Interestingly, the interaction of the sense modalities in the occurrence of phenomenal movement has also been demonstrated (see Neff, 22), as well as a special case of intrasensory effects (see Gibson, 11). It is generally recognized that the perception of movement subsequent to dissonant stimulation is governed by certain contributions by the organism to the stimulus imput; i.e., attitudinal and cognitive processes (11; 22) are variously cited as determinants. The likelihood of movement being perceived is said to be facilitated when the observer adopts a set to perceive it, and when the targets employed produce phenomenal objects which are mobile in the experiential context of the observer. Aside from the demonstration of these facts, precise relationships have yet to be determined.

Experimentation has yielded descriptions of several "types" of apparent movement, dissonantly produced. The types are distinguished on the basis of the approximate stimulus conditions for their production. Some of these have been investigated more frequently than others, and typically in the visual modality. As a further concession to programme, we shall make two broad identifications here; we shall separately consider movement perceived utilizing steady dissonant stimulation, and movement perceived as a function of the onset and offset of discrete stimuli.

By steady dissonant stimulation, reference is made to an assortment of movement experiences including: the familiar expansion and contraction of Plateau's spiral; the negative aftereffects of this and the oft-described waterfall illusion (6), whereby subsequently inspected objects are seen to move in an opposite direction; the seen movement induced relative to a concurrent figure in the same sensory field; the erratic autokinetic movement of a visual object in an undifferentiated sensory field; and the total movement of phenomenal space characteristic of the vertigo. A systematic treatment of these examples of apparent movement is not available. It is worth adding that in some cases of induced movement as well as in the case of vertigo observer himself may have the experience of motion. Effects such as vertigo, autokinetic movement, and induced relative movement are special instances of the influence of concomitant stimulation on movement in phenomenal space. The negative aftereffects of Plateau's spiral and the waterfall illusion exemplify the operation of temporal processes in perceived movement.

Attention is now directed to apparent movement as a consequent of the onset and offset of discrete stationary stimuli. Originally, objectless movement was of the greatest theoretical interest. This has been described as motion without phenomenal reference to that which is moving. Wertheimer called this pure phenomenal movement, or "phi movement." Descriptions of "phi" tend to be somewhat weak in communicative value, and not very numerous in count. The stimulus conditions are the appropriate spatial, temporal, and intensive combinations of at least two discrete luminance distributions. "Gamma movement" is analogous to phi inasmuch as it may be described as the centrifugal or centripetal movement of light (or darkness) occurring during abrupt brightness changes in the visual modality. Some movement in depth is reported to sometimes accompany the production of gamma movement (23). The independence of gamma from a contoured figure (3, pp. 156-165) places it in the class of pure movement. The stimulus for gamma is a relatively abrupt temporal transition of luminance of an appropriate magnitude. Gamma movement is the only one of these presently under consideration in which the perceived movement is a consequent of a temporal transition of a single distribution of impinging energy.

Every other type is crucially dependent upon a spatial dimension between at least two stimulus distributions. "Part movement" is the general case in which an object appears to jump partially toward a successively appearing and spatially distinct object; the number of objects may vary with the number of stimuli. A complex form of part movement between the sense modalities of vision, audition, and touch has been described (see 22, p. 28). A visual, an auditory, and a tactual object appear to move toward one another in various orders dependent upon the order of modal stimulation. The type of dissonantly produced apparent movement which has perhaps received the greatest experimental attention is referred to as "optimal" or "beta movement." This type of movement is equivalent with the common experience of an object moving across the visual field. Complications of beta have been described in which more than one object are seen in motion, traveling in different directions and crossing paths. A special case of beta has been demonstrated in which an object is seen to move in a circular path, the diameter of which alters with the phenomenal velocity of movement. The next type, "delta movement," is phenomenally akin to beta insofar as an object is seen to move across the visual field, though decreasing in brightness; however, an important distinction exists between the two concerning the energistic antecedants. The distinctive stimulus condition for delta is that the weaker of two spatially and intensively different stimuli has temporal priority. The curved path of movement taken by an object around the locus of a currently or previously perceived object has been called ''bow movement.'' This too is akin to beta; the distinction is in terms of the particular operations of stimulation necessary for induction of a curvilinear path. In addition, there are the two general cases in which an object appears to divide into (or emit) other objects which move laterally (one may remain in the original locus); and the converse phenomena in which a plurality of objects move into a unitary merger. Of these, only the case of ''split movement'' has been labelled. Then, we have the type of dissonantly produced movement known as ''alpha movement.'' This designates the continuous change in size of a phenomenally moving object under the unique condition in which the discrete stimulus distributions are of equal size. The targets in this case are of the complex type known as size ''illusions.'' The Muller-Lyer figure is frequently employed. The dissonant production of movement in the third dimension is least well known. This is achieved primarily by the successive exposure of targets differing in area, but not necessarily at different viewing distances. Under appropriate conditions, one may see in depth: part movement, pure phi movement, and optimal movement (7). The path of movement may be unidirectional or to and fro, depending upon the stimulating conditions.

The main point of interest concerning these modes of apparent movement is the fact of phenomenal flux as a consequent of discrete static stimulation. Excepting for the case of gamma, two separate distributions of energy, effectively impinging upon the receptor surface (and under certain conditions), are sufficient for the experience of movement in phenomenal space. Two receptor processes, spatially and temporally distinct, can be the physiological initiators of a phenomenal movement in space. The psychophysical and psychophysiological problems are salient; what are the parameters of stimulation which are causal, and what are the physiological mechanisms which are operative in the dissonant production of apparent movement?

Unfortunately, the writer has been able to find only partial attempts to deal with the first of these problems, and these exclusively in the visual modality. A clarification of the stimulus conditions for gamma movement has been presented by Bartley (3, pp. 156-165). His considerations emphasize the necessity of a proper temporal course taken by a gradient of illumination on the retina. He further asserts that the discretion of the gradient is of no consequence; this is implied to be true also with respect to the other forms of movement to be considered. Using two stationary visible radiant energy sources, exposed simultaneously or separated by a variable interval, Wertheimer produced part movement, beta movement, and phi movement. He concluded that the interspace and temporal interval between exposures are of critical significance. Wertheimer's study set the style for subsequent investigations: the exposure of luminous targets in a dark field, varying mainly their intensity, size, exposure duration, interspace, and interperiod (hue and shape have also been manipulated). The experiment of Korte yielded his classical generalizations of the interrelationships of intensity, exposure time, interspace, and interperiod which proposedly delimit the stimulus conditions for beta. However, his procedure has been criticized and his conclusions have been partly contradicted on the grounds that the ranges of his variables were too narrow, and he confused absolute intensity with total luminous flux. Neuhaus repeated the study, correcting these limitations, and similarly presented his findings in the form of generalizations about the interrelationships of exposure time, interperiod, and interspace. He reported no influence of intensity and hue on these relationships. (An English summary of the generalizations of both Korte and Neuhaus is presented by Graham [12].) A survey of the numerous researches of this problem (see 12 and 22) indicates that a coherent set of principles is still wanting. The perception of movement under these conditions of stimulation is with certainty related to the duration of stimulations, the time gap between stimulations, the distance between stimulations, and the form of stimulus distributions; intensity and size of stimulus distributions remain as probable variables, as well as retinal locus, similarity, and complexity. No attempt will be made to reiterate the detailed findings inasmuch as systematic quantitative results are unavailable. The misleading incomparability of experimental conditions and parameters of stimulation do not lend themselves for precise quantitative statements. Too frequently the investigator's limited concern with the general abstract concepts of intensity, time, space, and form has caused an inadequate specification and limited application of the energy distributions impinging upon the receptor surface. There is obvious neglect concerning the comparability of seen movement in various regions of the sensory fields.

There have been too few and meager attempts to relate phenomenal movement to physiological processes. Bartley (3) has considered the role of neuroretinal function in his interpretation of gamma movement. The latency of differential neural response is implicated. Numerous considerations enter into the neural basis of apparent movement as response to multiple static stimulation.

Insofar as there is, within limits, an interrelationship of the stimulus parameters of intensity, area, and time for threshold response and the varieties of interactions in the optic system (see 3, pp. 19-30 and Chapter IX), and visual processes are organized in accordance with successive stimulation (4; 32; 33), it is to be expected that the various concepts of nerve discharge and interaction are applicable here. Concerning the apparent movement of objects having distinct borders, current neurophysiological concepts have proved resistance to a satisfactory understanding of contour processes and their relation to visual movement (3, Chapter X). One author (24, pp. 245-248) has recently conjectured about the role of shifting peaks of summating excitation distributions in the primary visual cortex; this discussion is admittedly not applicable to objectless movement. Furthermore, this conjecture is derived from an assumption of strict isomorphism which presupposes a space-time copy of perceptual events in the neural substrate. This bias was set by Wertheimer and his Gestalt school in their approach to the problem (17; 18). A physiological field theory was proposed to offset the inadequacy of existing neurophysiological concepts for the solution of the space and time gaps. These theorists asserted the need for postulating a continuous dynamic brain field operating in accordance with electrochemical principles, such that phenomenal continuity initiated by physical discontinuity would have its correlated spatial-temporal continuity in the hypothetical substrate. Although the reasoning may seem to have some plausibility, it rests upon the questionable assumption of rigid isomorphism, and its proponents are typically not deeply steeped in neurophysiology. Saucer has recently proposed a revision of this principle (25; 26).

The question of the critical anatomical loci for the physiological integration of movement processes has been the object of a few inquiries. Bartley (3) stresses the properties of the neuroretina. Some new techniques employed by Motokawa have provided results which allow him to also deduce the involvement of retinal processes (20; 21). On the other hand, Shipley *et al.* (27) obtained evidence that interaction in the neuroretina was not an essential factor for the production of apparent movement. These investigators obtained positive results using interocular stimulation. They also found that binocular stimulation was more effective than monocular. Interocular stimulation was similarly employed by Smith (28) with the derivation of positive results. This investigator alternately stimulated both nasal retinas, and on the basis of the fact that the cortical projections are so widely separated, he rejected cortical field theory.

The available information does little to clarify the psychophysiology of apparent movement. We can hardly expect much more at present. The nervous system as a whole represents a vast and insufficiently explored territory. It is likely that an understanding of the optic mechanisms involved in apparent movement will be greatly enhanced when further insight is gained with regard to the processes underlying spatial and temporal brightness discriminations, contour formations, contour effects, and sensory aftereffects--to name a few basic visual phenomena. Notwithstanding the old argument for the uniqueness of perceived movement (see Neff, 22), it is assumed that the visual response is organized and therefore each of these processes are functionally interrelated.

With the intent of substantiating this contention as well as reporting some newly acquired information bearing upon apparent movement, some experimental results will be presented concerning the parameters of stimulation essential for abient movement in the line of visual regard.

Bartley and Miller (5) have recently reported some experimental observations in which they cursorily relate some variables of stimulation to the occurrence of visual movement, oscillating in the line of regard. They label this form of movement ''adab movement''; signifying the adient and abient directions of motion. The procedure consisted in the fixation of three square luminous targets exposed briefly in immediate succession on a dark field. The first and third target were identical in all respects; the second was varied in duration, decreasing intensity and area. Three facts of especial pertinence are revealed by the findings of these authors: Apparent movement can be produced by the abrupt shifts in area and intensity of a retinal stimulus distribution produced by targets equally distant from the viewer; contour processes are intimately involved in the occurrence of this form of movement; and the stimulus parameters of duration, intensity, and area are critical variables.

A significant observation here is the necessity for the contour process, which is correlated with the smaller square, to be initiated in order for movement to be visible. As the exposure time of the second target was lengthened, starting from zero, a duration was reached at which the border of the second, smaller square first emerged. It was only when the second target was presented for periods above this duration threshold that "adab movement" was seen. The indications were that the duration threshold for border emergence is inversely related to the intensity of the second target, within limits; the authors hypothesize an absolute intensity threshold. The inference to be made is that the initiation of contour processes and border emergence is dependent upon the total flux of the smaller distribution being above threshold, and the occurrence of adab movement is dependent upon exposure durations above threshold.

Movement was difficult to observe when the areal decrement was greatest and intensity decrement least. A complex relationship was suggested for varying degrees of areal decrement.

In an earlier and little known study, Calavrezo explored the relation between apparent movement in depth and successive stimulation by patterns differing in area (7). Besides varying the area difference between successive targets, he simultaneously varied the exposure durations of the targets, varied the period between exposures, and varied the configuration of the targets as well as degree of lateral displacement. Judgments were made of the quality and extent of movement. Calavrezo reports that optimal movement in depth occurs when the exposure durations are relatively long and the interperiod is relatively short. When the exposure durations were relatively brief, pure phi movement was observed; with still briefer exposures, part movement was seen. Above an exposure duration threshold for optimal movement, further increases in duration had no effect upon movement in depth. The extent of movement is reported to rapidly increase with increasing differences between the areas of successive stimuli; however, very large differences did not produce movement.

The present study is intended to further elucidate the circumstances relevant to apparent movement in the line of regard. The plan of experimentation was comprised of two parts. In the first group of observations, the attempt was made to approximate for the second of two stimulus distributions, the lower limits of duration, intensity, and area, under present conditions, for the visual appearance of movement in the line of regard. In the interest of simplicity, only two targets entered into a given sequence throughout the experiment. When optimal movement was perceived, it was only of abient character. Previous evidence indicates that under certain conditions successive stimulations have a complex interactive effect on the visual result (4; 8; 10; 29; 32; 33); hence, a third stimulus pulse would probably obscure the relations of the stimulus parameters for the two-pulse sequence. Consequently, the general problem was limited to the case of the apparent visually receding movement of a luminous object in a dark field. With the aim of more fully exploring the parameters of stimulation pertinent to the interaction of the two successive pulses and the emergence of apparent movement, two additional stimulus variables were systematically manipulated; viz., the duration of the first of the two pulses, and the temporal relations between the termination of the first pulse and the onset of the second pulse. The area and intensity of the first stimulus distribution were held constant throughout the entire experiment. These initial observations were largely exploratory in character, serving a twofold purpose. They provided approximations of the relevance and ranges of the above variables in various combinations within which optimal abient movement occurred, thereby facilitating more precise psychophysical measurement in the second portion of the investigation. Secondly, they revealed in a semiquantitative manner the various phenomena which occur, under these general conditions of stimulation, just beyond the thresholds for movement. Inasmuch as all of these phenomena are related to the extent that they occur as gradual emergences which are consequences of systematic variation of basically the same parameters of stimulation, they will all be reported. It is most likely that there is some commonality of processes underlying these phenomena, such that an understanding of any one or more of these phenomena may contribute to the explanation of them all.

The second portion of the investigation was designed with the intent of quantitatively determining the relationship of the magnitude of the temporal interval between the two stimuli, within which optimal abient movement is seen, with the relative area and intensity difference of the two patterns of stimulation. In the classical investigations of apparent movement, particular emphasis has been traditionally directed toward this interval. The preliminary observations from the first part of this general investigation indicated that this temporal interval and the relative area and intensity decrement between the two stimulus patterns are lawfully interrelated for the occurrence of optimal abient movement.

METHOD

Stated in terms of direct experimental manipulations, the preliminary observations were monocularly obtained by using targets of the following character. Two luminous squares (presented in the orientation of a diamond), equally distant from the observer and in the line of regard, were exposed in succession. The temporal relation between the two was varied so as to produce: an interval of varied length between exposures, the immediate succession of exposures, and varying degrees of temporal overlap. The observer was set fo fixate the center of the targets, maintaining steady fixation throughout a sequence. The first target, of fixed area and intensity, was made to vary in duration of exposure. The second target was made to vary in area, intensity, and duration of exposure. Each of these variables was independently manipulated, the temporal relation between exposures being the main experimental variable, utilizing a modified method of serial exploration. Notations were made of the perceptual event which occurred for each of the many combinations of stimulus parameters employed. Because this portion of the inquiry was exploratory, a rigorous method of observation was bypassed. The number of exposures to each combination of parameters was free to vary at the discretion of the observer, permitting response definition. The lack of prior expectations precluded a fully systematic exploration of all conditions.

The viewing distance between cornea and target was set at 70 cm. The constant area of the first target was given by a 1.22 cm. side, or a retinal subtense of approximately 60 minutes of visual angle; the fixed intensity of the first target was 76.1 c/ft^2. In these preliminary observations, the area of the second target was varied twice, 1.04 cm. and .61 cm. side dimensions, corresponding to retinal subtenses of 51 and 30 minutes respectively. Two intensity levels were employed for the second target, 46.4 and 12.1 c/ft^2. Durations of exposure for each of the two targets varied stepwise over a range of from 10 to 600 msec. The varied interval of time between the termination of the exposure of Target I and the initiation of the exposure of Target II ranged from 100 msec. through zero and to negative values as large as 200 msec. (A negative value designates temporal overlap of exposures; i.e., exposure of Target II before Target I is withdrawn.)

The second major portion of the experiment was addressed toward the assessment of optimal abient movement thresholds, with the temporal relation between the termination of the exposure of Target I and the initiation of Target II as the primary experimental variable and relative area and intensity decrement of Target II as secondary independent variables. Insofar as this temporal relation was varied between positive values and negative values, a positive and a negative threshold are not inconceivable. These thresholds were assessed employing six intensity levels and six areal magnitudes for the second target. The area and intensity of the first target remained fixed throughout all measurements. The exposure durations for both targets were held constant and equal at 280 msec. The intensity of the first target was 76.1 c/ft^2; its area was that of a 1.22 cm. square, giving a subtense of 60 angular minutes. Intensity levels for the second target were 46.4, 28.2, 18.2, 12.1, 7.6, and 4.9 c/ft^2. The six areal magnitudes utilized for the second target were given by 1.10, 1.04, .92, .61, .49, and .31 cm. squares, subtending 54, 51, 45, 30, 24, and 15 minutes of angle respectively. Both targets remained equally distant from the cornea, 70 cm. The temporal interval, OFF-ON, was varied as before, through positive and negative ranges in 10 msec. steps.

The two arms of a Harvard tachistoscope had been extended. Light sources were stationed at the far end of each arm. These were each two four-watt fluorescent tubes. Opal glass filters were placed in front of these light sources to diffuse the energy and control the intensity levels. An opaque screen with a square aperture was placed in each arm of the tachistoscope between viewing aperature and filters at a transmitting distance of 70 cm. from the cornea of the right eye. The aperture in Arm II was continuously variable; the other was fixed. These constituted the targets.

The tachistoscope was activated by an electrical timer which provided the control of the three temporal parameters, independently variable. Each of the three scales on the timing mechanism was graduated in 10 msec. units. When the three scales were set, the depression of one button closed a circuit and initiated the desired stimuli sequence. A very low level of illumination was continually transmitted through the aperture in Arm I. When observed through the viewing aperture of the tachistoscope with a dark adapted eye, this continual low energy level, after passing through the opal glass filters and the target aperture, was just barely noticeable as a vague amorphous glow. In effect, a threshold stimulus for the dark adapted eye served as a fixation point in the locus of the to be presented target. This proved to be an invaluable operational aid. An eyeshield around the viewing apertures of the tachistoscope provided head stability.

All observations were made monocularly, and in a dark room. A 40 watt shielded red lamp was positioned over the timing mechanism to permit the necessary manipulations and readings. The eyes were dark adapted for about fifteen minutes before observation began. An observational session lasted from one to two hours, and all were staggered throughout a period of months. Although this was not controlled, each pair of threshold measurements usually occupied a full observational session.

The OFF-ON thresholds were measured by the method of limits; ten series were run using alternating series for every determination in the second portion of the study. Three general categories of response were employed, yielding estimates of two thresholds. For example, the targets were presented in succession separated by a noticeable time gap. The physical time gap was then decreased by 10 msec. decrements for each subsequent presentation of the two targets, until the visual response changed to abient movement. A reading was then taken from the scale on the timing mechanism which designated, in milliseconds, an estimate of the largest separation between the two exposures with which optimal abient movement could be seen. Subsequent presentations of the two targets were made with the temporal relation between termination of the first exposure and initiation of the second exposure decreased 10 msec. each time. This was continued until the visual response changed to one other than movement; a reading was again taken. It generally occurred that this reading was negative, signifying that the onset of the second target took place before the offset of the first; the two overlapped in physical time. Hence, this threshold estimate indicated the largest temporal overlap with which movement was just not noticeable. This description pertains to one series with the parameter varied in a given direction; i.e., decreasing time gaps through zero and into the overlap range. The next series was run with the parameter varied in the other direction. In other words, the targets were successively presented with an amount of temporal overlap which was calculated to produce a nonmovement percept. For each subsequent presentation, the temporal relation between offset of Target I and onset of Target II was varied by 10 msec. increments effecting a physical transition from temporal overlap, through immediate succession, and into the range of delayed succession. This series similarly yielded estimates of two thresholds. To repeat, ten series were run in alternation. The ten estimates for each of the two thresholds were averaged, thereby giving two empirical thresholds for apparent abient movement under a given set of conditions.

Such pairs of thresholds were determined for each of the conditions described earlier. All of the intensity levels for a given area of Target II were explored, in random order, before the area was altered.

Because this study was largely exploratory in character and the innumerable observations in addition to the threshold determinations occupied a countless number of total hours, the findings reported hereunder are based upon the observations of one observer; viz., the author. Although this procedure leaves much to be desired, it is a mode for obtaining data which would otherwise remain in want. The writer is aware of no preconceptions which may have influenced the relationships revealed by the results; therefore, if the data comply in some way with relevant information gleaned from other sources, their value can be accordingly assessed.

It may be pertinent to declare that these data were obtained from an experimentally sophisticated observer, much practiced and operating with strict, relatively constant criteria. After innumerable pilot observations, two important observational stances developed; viz., the stability of fixation and the definition of the response categories. The naive observer found it difficult to maintain steady fixation on a threshold point; and when the luminous target suddenly and briefly emerged in a dark field, the gaze almost invariably wandered in an indeterminable manner. For purposes of this sort, at the moment of onset and during stimulation a steady fixation is a significant factor. Furthermore, with the very brief exposures employed in this investigation, it was found that an event which to the uninitiated looked generally like a brief flash of light having more or less definite form, became a variety of rather definite and fairly well articulated visual events of some complexity to the experienced observer. This last fact is especially of some theoretical import. Very brief perceptual events may become articulated with repetition. However, further consideration of this point is tempered by recognition of the need to clarify whether or not this increased definition of perceptual categories is independent of the acquired stability of fixation. The fact remains--the observational data of the experienced observer are richer than those of the inexperienced observer.

It is also of consequence at this point to speak of the criterion employed in recording data. Although the observations were made with complete cognizance of the stimulating conditions, a very deliberate attempt was constantly exercised to avoid making a stimulus error; i.e., attention was focused conscientiously upon the phenomenal event as such. The various perceptual response categories, when finally defined in experience, were each capable of complete verbal description, independent of the stimulating conditions. During the determination of thresholds for optimal abient movement, a rigid criterion was maintained; movement was recorded only when an object was seen to recede into the distance. As is usually the case in psychophysical measurements, thresholds were not phenomenally discrete and the brevity of phenomena incurred difficulty in the response categorizations here. This difficulty was mainly existent at the negative threshold (temporally overlapping exposures) under certain stimulus conditions; i.e., when the intensity of Target II was rather low.

RESULTS

Figure 1 is presented as a schematic representation of the approximate relations of the various observed phenomena with the temporal parameters of stimulation. The relationships depicted in this diagram can be understood as generally true for those combinations of stimulus area and intensity revealed adequate for the perception of optimal abient movement (as discussed below). An important qualification for this illustration is that the phenomena pertain only to the circumstances in which Target II is exposed for durations which are at least approximately 100 msec.

The zone bounded by the two curves on the left is intended to represent variations in the exposure duration of Target I, t_1, ranging from 10 msec. durations at the bottom to 600 msec. at the top. The zone bounded by the two verticals at the far right represents exposure durations of Target II, t_2, over approximately 100 msec. Between these two zones lies a zone representing the maximum durations of the unstimulated interval between exposures, OFF-ON, over which Target II has a perceptual influence on the effect of Target I. This interval will henceforth be referred to as the "critical interval." For clarity of illustration, this latter zone has

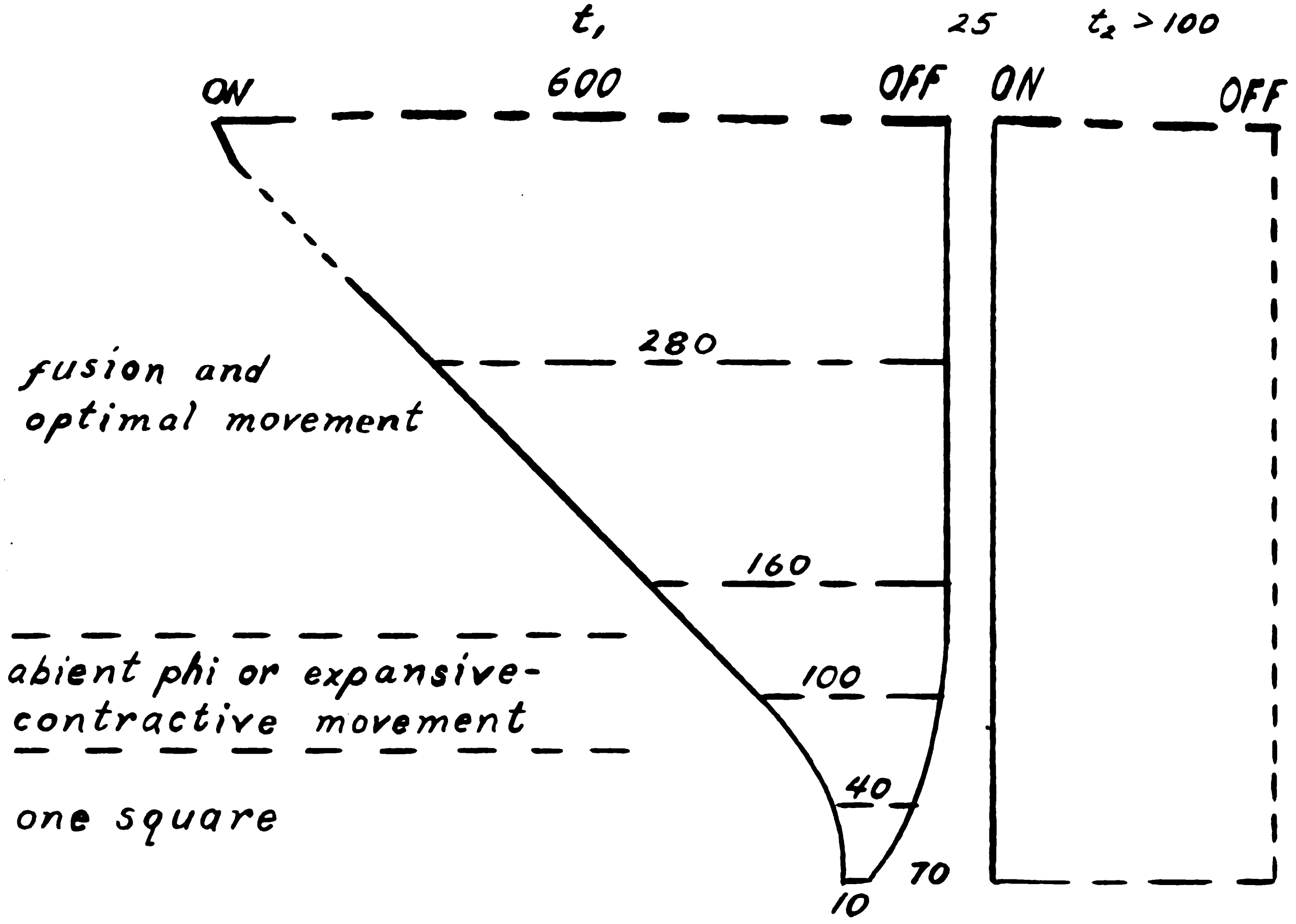

Fig. 1. Perceptual effects of varying the temporal relations of two photic pulses.

been given values applicable to the situations in which the second target was a 1.04 cm. square with an intensity of 12.1 c/ft^2. This latter zone is seen to vary from approximately 70 msec. for very brief durations of Target I to 25 msec. for exposure durations greater than approximately 100 msec. For very long exposures of Target I, the critical interval remains constant. The evidence suggests that the precise magnitude of this parameter varies with the particular set of relative area and intensity differences employed for the two targets. This will be considered below.

Optimal abient movement is seen only when Target I is exposed at durations greater than approximately 100 msec. and is separated in time from Target II no more than a particular constant critical interval. There need be no temporal separation between the exposures of the two targets for optimal abient movement to occur; in fact it will occur with some degree of temporal overlap (to be considered later).

As the duration of Target I is decreased below that necessary for optimal movement, different phenomena occur and the critical interval during which they occur increases. The first to appear as the exposure duration, t_1, of Target I is decreased is what shall be called "adab phi movement." This phenomenon appears as a flash of light which first sometimes looms slightly forward and then suddenly recedes to a greater distance, taking contoured form only at its distant terminus. Movement in the abient direction is the more predominant as a perceptual characteristic and was somewhat more frequent in occurrence. Occasionally, with these temporal parameters, a form of movement similar to gamma was perceived; i.e., an inarticulate flash of light would expand on sudden appearance; then it would quickly contract--finally taking contoured form. This is not precisely the same as the more familiar gamma movement which is produced by the sudden presentation and withdrawal of a single target. The expansive-contractive phenomenon reported herein is very much more compelling than is usually the case when one target is employed. In any case, utilizing these particular temporal parameters, the initial phases of these phenomena--during movement--were without definitive contours.

When the duration of exposure of Target I, t_1, was very brief, less than about 40 msec., the observation was that of a unitary, stationary object; vis., the second lighted square. It was during these circumstances that the critical interval was the greatest for a set of targets of given intensity and area; for the case illustrated it was 70 msec. There is no doubt that the seen square was exclusively the perceptual effect of the second stimulus and not the first. By starting with the long exposures of Target I and continually shortening its duration, it was possible to trace the gradual transitions of the phenomena--in the order described--whereby first the contour effect, and then the complete perceptual effect of Target I was obliterated by the processes initiated as a consequence of the second stimulus. Further clarification is offered by the fact that when Target I was presented alone for durations at least as brief as 10 msec., it was readily visible as a luminous square object.

The phenomena described above were observed under the special conditions in which the two targets of appropriate intensity and area difference were separated in time by some value less than the limit of the respective critical intervals, and when the exposure durations, t_2, of Target II were greater than approximately 100 msec. When t_2 was less than this value, the second square was seen to intrude within the first square, providing the two target exposures were separated in time by no more than the limit of the appropriate critical interval. For a given pair of targets the magnitude of the critical interval was found to vary with the magnitude of t_1 in a manner similar to the situation described above and illustrated in Figure 1. The primary difference in result is that movements were not seen. The phenomenon of intrusion takes the form of a lighted square which is surrounded by a black frame, which in turn is surrounded by a lighted frame. When t_1 is long, the first square appears, then to be intruded by the second smaller square. As t_1 decreases, the relative latency of intrusion decreased until the phenomenon appears immediately as the smaller square surrounded by the two frames. The two frames may vary in width, depending upon the area difference between the two targets. With a large difference, the black frame and the lighted frame were broader, and were segregated by a gradual brightness gradient. When the areas of the two targets differed to a lesser degree, both frames appeared narrower and possessed a sharper separating edge. Another factor which influenced the width of these frames was the exposure duration of Target I. Intrusion appeared to get stronger when t_1 was decreased to small values; i.e., the black frame became wider and more pronounced while the lighted frame became narrower. Also, similar to the preceding conditions, as t_1 was made brief the outer bounds of the lighted frame lost its sharp edgelike character; and when t_1 was decreased below approximately 40 msec., the frames vanished and only the second square was visible, providing t_2 was not smaller than t_1. If both t_1 and t_2 were made very small, the frames persisted around the small square although they were somewhat less salient. Unfortunately, the observations were insufficient for a reasonable assessment of the influence which stimulus intensity and area may exert on the fates of these phenomena. A precise statement of the relationships of relative differences in area as well as intensity with the target exposure durations, insofar as these phenomena are concerned, would require different experimental conditions. The exposure durations would have to be varied over more and smaller steps than those employed here.

These phenomena of intrusion and obliteration could be duplicated under conditions. If t_1 was not too small and t_2 was greater, the orderly occurrence of intrusion and obliteration could be produced by causing the exposures of the two targets to overlap sufficiently in time; on I--on II--off I--off II. A critical factor concerning obliteration seems to be the time between onsets. Although the observations of these events were not systematically precise enough to permit an exact statement, there were indications that the threshold magnitudes of the ON-ON intervals would be comparable whether the exposure duration of Target I were decreased without temporal overlap of a stimuli, or whether the stimuli overlapped in increasing amount. In the latter case, it was noted that if the intensity difference between the two targets was too great, intrusion never took place; two squares of different brightness were seen in immediate succession. Obliteration took place when the relative intensity difference was as great as .96.

Two additional facts may be mentioned. All of the phenomena described above were observed when the critical intervals had negative values; i.e., when the onset of the second stimulus just preceded the offset of the first stimulus by some appropriate magnitude, thereby effecting a temporal overlap of stimuli. This may not be surprising in the cases of perceptual intrusion and obliteration; however, it is to be noted that the varieties of movement were observed without the existence of an unstimulated interval between exposures. Some quantitative data are presented below.

Almost needless to say, in every case when the positive limit of the critical interval was exceeded, all phenomena gave way to the perception of successive duality. When the area difference was not great, this took the form of flicker; the dark phase was predominantly in the center, and became more general as the unstimulated interval was increased. With larger area differences, exceeding the limit of the critical interval gave rise initially to the immediate succession of two different squares with no noticeable dark phase as in flicker. This phenomenon existed throughout a measurable range before flicker became apparent.

Inasmuch as the primary phenomenon intended for investigation was movement, rigorous measurement was attempted only of the limits within which optimal abient movement was seen. The preliminary observations discussed above indicated that above minimum exposure durations for the two targets, which were thresholds for movement, further increases had no effect on optimal abient movement and the magnitudes of its critical interval. Hence, all subsequent measures were made with t_1 and t_2 each constant at 280 msec. The relative decrements in area and intensity, as well as the temporal relation between offset of Target I and onset of Target II, were found to be determining parameters above the exposure thresholds for the two targets.

Figure 2 is designed as a three-dimensional graph which yields an optimal abient movement solid depicting the interrelationships between the three independent variables, for these conditions of experimentation. The two horizontal axes represent continua for relative differences of area, $(A_1 - A_2)/A_1$, and intensity, $(I_1 - I_2)/I_1$. These data are plotted in terms of relative difference because it is likely that the obtained relationships have some generality to absolute magnitudes other than those employed. The temporal relation between termination of Target I and initiation of Target II, OFF-ON, is represented on the vertical axis. Negative values on this axis indicate the extent to which the onset of Target II precedes the offset of Target I. Positive values specify the magnitude of the

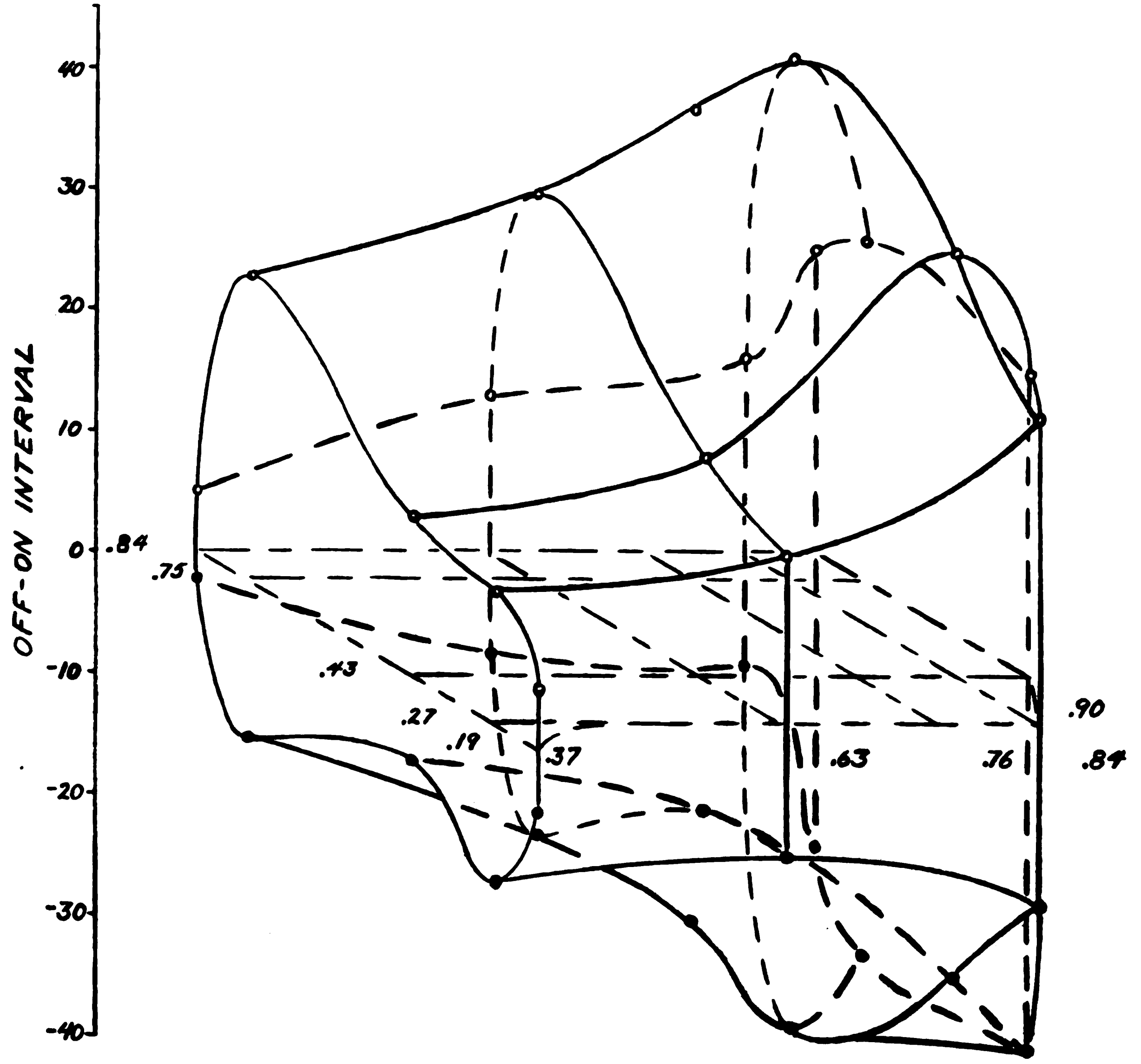

Fig. 2. Relationships between OFF-ON threshold for optimal-abient-movement and relative intensity and area differences between two targets. Frontal and perspective axes represent relative differences in intensity and area.

unstimulated interval between the two exposures. The plotted data are also contained in Table 1.

Within the volume bounded by the curves, any set of coordinates comprise parameters of stimulation adequate for the perception of optimal abient movement. A bright square is seen to briefly appear in a dark field, and quickly and smoothly recede to a distant position--then suddenly it disappears. No attempt was made to assess the extent or velocity of phenomenal movement. Beyond the bounds of the solid, movement is not seen. When the relative differences of area or intensity are too great, movement is replaced by the perception of the immediate succession of two squares--differing in area, brightness, or both. These transitions are relatively abrupt. A very slight difference in area gives rise to one square which may decrease in brightness. Experimental conditions did not permit observations with a very small difference in relative intensity. Beyond the positive OFF-ON threshold, movement is replaced by either the immediate succession or the flickering succession of two squares differing in area, brightness, or both. When the area difference is small, flicker is seen. As the area difference increases, the category of immediate succession becomes interpolated between flicker and movement. The range of this category increases progressively with increasing relative area difference. In every case,

TABLE 1

OFF-ON THRESHOLDS FOR OPTIMAL ABIENT MOVEMENT FOR VARIOUS RELATIVE DIFFERENCES IN STIMULUS AREA AND INTENSITY[a]

$\frac{A_1-A_2}{A_1}$						
.93 (15')				- -	- -	
.84 (24')	5 (1.8) 2 (0.6)	13 (1.7) 8 (2.6)		16 (2.1) 9 (1.6)	25 (2.1) 24 (2.4)	- -
.75 (30')	25 (1.5) 13 (1.3)	32 (1.5) 21 (2.2)	39 (1.6) 28 (2.1)	43 (3.3) 37 (3.3)	28 (2.1) 31 (2.2)	- -
.43 (45')	13 (2.3) 7 (2.0)	18 (1.5) 11 (2.2)		35 (2.6) 25 (1.5)	25 (2.1) 31 (2.2)	- -
.27 (51')	11 (2.1) 13 (2.0)	14 (1.8) 11 (2.2)		25 (2.6) 15 (2.1)	- -	
.19 (54')	5 (0.5) 5 (0.5)	- -	- -			
$\frac{I_1-I_2}{I_1}$	.39 (46.4 c/ft^2)	.63 (28.2 c/ft^2)	.76 (18.2 c/ft^2)	.84 (12.1 c/ft^2)	.90 (7.6 c/ft^2)	.94 (4.9 c/ft^2)

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[a] Data from one subject. Upper and lower numbers in each cell designate positive and negative thresholds, respectively. Standard errors in parentheses. Marginal parenthetical values represent absolute dimensions of second stimulus. First stimulus was a 60' square at 76.1 c/ft^2.

when the negative OFF-ON threshold is crossed, the second square is seen to intrude within the first.

The movement solid indicates that the temporal interval between termination of Target I and initiation of Target II, within which optimal abient movement is seen, lawfully varies in magnitude--both positively and negatively--with manipulations of both the relative area difference and the relative intensity difference. Positive and negative OFF-ON thresholds tend to vary together in the same manner (although their values differ), so that the negative portion of the solid resembles a reflection of the positive portion. Qualitatively, it might be said that movement is more impressive under the conditions in which the absolute values of the critical intervals on the OFF-ON dimension are largest; e.g., when the relative differences in areas and intensities are .75 and .84, respectively. This is not necessarily intended to imply that movement is more compelling than at other combinations of parameters, but rather that it appears to be more extensive in space or time.

DISCUSSION

The varied facts of apparent movement, dissonantly produced, have invariably prompted the invocation of hypothetical physiological processes to account for the continuity of perception which may result from such stimulation In this respect, the problem is analogous to that of flicker fusion. The necessity of postulating continuity of physiological events remains a moot point if one seeks a correlation between perception and neural action, in view of the fundamentally discrete character of the nerve discharge. Nonetheless, the facts indicate that the processes associated with these perceptual events, whatever their true nature may be, must continue to be active for a brief time after stimulation has ceased--in order to give rise to the perceptual after-effect of stimulation. Evidence for both neural and perceptual after-effects of stimulation is not lacking in a variety of sources. The problem concerning spatial continuity (movement) as well as temporal continuity (fusion) in perception vastly increases the challenge of the task. Spatial interaction at both the perceptual and neural levels is varied in form, and continues to hold a somewhat enigmatic status in both areas of inquiry. The following discourse will attempt to interpret the obtained experimental findings in terms of hypothetical neural correlates. Speculation will not be offered for the precise character or locus of these processes.

Almost needless to say, temporal continuity or fusion in perception is an essential condition for apparent movement. When movement was seen, the brightness of the object was steady. This was true throughout the range of an unstimulated critical interval. The range for fusion was usually somewhat greater than that for movement. In any event, the percept lingered at least as long as a period measured by the critical interval. The maximum of this interval, 43 msec., was obtained when the relative differences in area and intensity were .75 and .84 respectively. Manipulations of these latter two variables systematically altered the magnitude of the critical interval for movement; they similarly appeared to alter the interval for fusion. Furthermore, fusion of the effect of this type of stimulation was found to obtain only when the first pulse was delivered for durations as long as approximately 40 msec.; shorter durations resulted only in the visual effect of the second pulse. Examination of Figure 1 suggests that a minimum interval between pulse onsets is a necessary determinant for fusion to result from two successive pulses. It should be noted that above this ON-ON threshold for fusion, increasing the ratio of the stimulated to the unstimulated interval is of no apparent consequence. Providing the interval between pulse onsets is not decreased, the exposure duration of Target I may be increased and the unstimulated interval may be decreased--fusion always obtains. This finding is consistent with that of Bartley (2). He similarly reported that within the limits of the ON-ON threshold for fusion of intermittent stimulation the ratio of the stimulated to the unstimulated intervals may vary considerably. Bartley also notes that when the pulse duration is made too brief, flicker may result. The results of this investigation imply that when the pulse duration is decreased while stimulating at a frequency rate equal to the ON-ON threshold for fusion, flashes are seen in succession and hence, flicker would result

The time course of obliteration can be traced by varying the length of the ON-ON interval. This was effected in the preliminary observations by independently manipulating the magnitudes of the exposure duration for Target I and the duration of the unstimulated interval. (Similar observations were noted when targets overlapped in time.) The perceptual result of shortening the ON-ON interval below approximately 143 msec. was: first the contour of the first square failed to appear; and as the interval was further abbreviated, the total effect of the first pulse failed to appear. This perceptual obliteration took place continuously, from periphery to center, as the ON-ON interval was shortened. In perceptual terms, this is as though the dark surrounds of the second square began to emerge before the square itself appeared. One may hypothesize that the neural process correlated with the emergence of a figure has associated with it in its surrounds a neural process of opposite character which antedates the figural process in the form of a temporal-spatial gradient of activity. The activity of this surround process is initiated first in the periphery and then spreads toward the bounds of the figure process during the course of time. The time course of this centripetally spreading surround activity is given by the course of obliteration of contour and flash as the ON-ON interval is diminished (see Fig. 1). The surround activity is characterized as inhibitive of ongoing activity differing in strength. When the intensity difference between Target II and its field is very large, the antecedent inhibitory activity is strong; this cuts short the persisting after-effect of the first exposure--resulting in flicker at short OFF-ON intervals. As the intensity difference between Target II and its field is lowered, the preceding inhibitory effect becomes weaker and, accordingly, the figural process of the first exposure persists longer; this yields a larger OFF-ON interval for fusion. Within the limits of the critical interval for movement, the centripetal spread of inhibition is terminated by the figural processes and movement is seen. If the inhibitory effect is thereby weakened to a large extent, it ceases to antedate its figural process and the first figural process therefore persists throughout its unimpeded limit--resulting in the immediate succession of two squares within the limits of a critical unstimulated interval for fusion. A similar interpretation is applicable to the effects of variations of the area of Target II. Large areas are preceded by strong inhibitory activity, and give rise to brief critical intervals. Reduction in the area of the target is accompanied by a corresponding reduction in the strength of the inhibitory activity and a subsequent increase in the critical intervals. If the inhibitory activity is weakened too much by area reduction, the centripetal spread of inhibition fails to occur and two different sized squares are seen in immediate succession. The combined effects of area and intensity difference are maximal.

The foregoing interpretation of the interaction of successive figural processes conforms with all observations made in this investigation. Although thresholds for fusion were not measured, a trend was noticeable suggesting an increased OFF-ON interval for fusion as both relative difference in area and intensity were increased. In conjunction with this, the measured, OFF-ON thresholds for movement were found to similarly vary. The fact that the negative OFF-ON thresholds varied in the same manner as did the positive is further support for the thesis that the inhibitory activity of the surround process associated with a figural process is weakened as area and intensity are decreased. Furthermore, it is additionally significant that whenever intrusion was noted, the salience of the dark frame (representing the immediate surround of the second square) was a function of both the intensity and area of Target II. At large intensity and area, the frame was very dark and sharply contoured. The opposite was true in the reverse case.

Numerous observations of the course of obliteration as the OFF-ON interval was decreased convincingly illustrate the centripetal spread of the dark surround. In conjunction with the facts of fusion, and the fact that the phenomena of obliteration are dependent upon successive stimulation, it is highly likely that the surround activity is attributable to the later pulse.

The behavior of the second process when exposures are very brief is perhaps of secondary interest. Under these conditions, movements were never seen. If the exposures of Target I and Target II were, respectively, over and under approximately 100 msec., the first square was seen to be intruded by the second throughout a measurable critical unstimulated interval. When the exposure duration of Target I was made shorter than that of Target II, the first square was no longer seen. The intrusion by the brief second square suggests that very brief figural processes are accompanied by very weak antedating surround processes and very weak contemporary surround processes. Therefore, the persistence of the processes initiated by the first exposure would be prolonged to its near maximum limit, only to be slightly impeded by the contemporary immediate surround process associated with the second figural process. Only when the first exposure was itself very brief did evidence for the inhibitory activity of antedating surround processes emerge. If the exposure duration of Target I was made less than that of the second, the first square did not appear even though the second exposure was less than approximately 100 msec. Seemingly, the weak antedating surround process of the second figural process could inhibit the first figural process (within the limits of the critical interval) only if the latter was itself much weakened by a very brief exposure. It is worth noting that the fact that the critical interval for the total obliteration of the first square is greater than that for movement is evidence for the greater magnitude of the critical OFF-ON interval for fusion.

In the experiment of Bartley and Miller (5) the presentation of targets was of the order I-II-I; Target II was varied in duration, decreasing intensity and area. All exposures were in immediate succession. These authors reported adab movement, the recession and approach in the line of regard of a bright square in a dark field. Their findings indicate that an essential determinant for the occurrence of adab movement was exposure of the second target at durations somewhat greater than that necessary for the emergence of the contour of the second square. They assert that the duration increment necessary for movement is a function of the total energy level of the second target employed to elicit the perception of the second square; weak second targets required long exposures for their contours to emerge in perception. A subsequent increase in exposure produced movement (providing other parameters were adjusted accordingly). The present conclusions concerning the effect of a later stimulus on the processes initiated by a previous one are consistent with the observations reported by these authors. It may well have been the case that their second and third exposures were interacting in a manner like that of the first and second exposures described herein. They report that the total emergence of the former is a function of an inverse relationship between intensity and duration; the occurrence of movement resulted from a further increase of duration. The intensity of the first exposure was not varied in this experiment, but minimal durations were observed above which first the figure and then movement emerged. Had the intensity of the first exposure been manipulated in this investigation, the rationale presented above would predict the function reported by

Bartley and Miller; i.e., the duration threshold below which total obliteration occurs would be inversely related to intensity. This is precisely the result obtained independently by Cheatham (8) who investigated only the phenomena of obliteration, under similar conditions of stimulation.

Bartley and Miller also suggested a complex role played by the area of their second target. Large targets are said to involve two opposing effects; viz., increased total energy and the closer proximity of contours. Although the former would tend to lower the duration threshold, the latter would presumably raise it The authors reported that small targets required briefer durations for their contours to emerge. Here again, although the area of the first target was not manipulated in this study, the principles derived would make similar predictions. Inasmuch as the antedating inhibitory activity of surround processes spread centripetally, it is to be expected that contour processes representing a small area would be affected later than those representing a large area; hence, a lower duration threshold would exist for the obliteration of contours.

At this point it is necessary to direct consideration to the phenomena arising when the target exposures overlap in time, ON-ON-OFF-OFF. The contemporary surround process associated with a figure process is characterized by inhibitory activity, the strength of which is maximal at the boundary between the two processes--decreasing toward the periphery. This applies to the phenomena of intrusion, when a graded black frame was seen to separate the contour of the smaller square from that of the larger. It is also consistent with the more familiar manifestations of "simultaneous contrast" (24, pp. 229-236). The strength of this activity is directly related to the steepness of the intensity gradient at the border of the stimulus; and, accordingly, to the duration of exposure. When the intensity of Target II was relatively high, intrusion was observed to occur with minimal temporal overlap of stimulation and the black frame was very dark. The fact that movement was observed with small amounts of temporal overlap suggests that the centripetal spread of inhibitory activity can be contemporaneous with the onset of stimulation, and an appreciable amount of time is required for the strength gradient of inhibition to develop. If the intensity gradient at the border of the stimulus was made too shallow, the strength gradient of inhibitory activity never developed sufficiently for intrusion to take place--despite very large temporal overlap of stimulation As before, similar interpretations apply to the effects of area. Small areas have weak surround processes associated with them; hence, more time is required for the strength gradient of inhibitory activity to develop, and accordingly, a greater amount of temporal overlap is necessary for intrusion to occur. Although very small areas were not employed, it would be predicted that intrusion would never occur if the relative differences in area as well as intensity were made too large.

As mentioned earlier, no attempt will be made here to ground these concepts in principles of neurophysiology. The facts of neurophysiology which can be successfully applied to these findings are not presently available. The various familiar forms of spatial and temporal interaction in perception have not as yet been adequately related to concepts of neural organization. It is believed that the results of this study pose a particular problem for neurophysiology which has not yet received its due recognition; viz., the fact that a pulse of stimulation may have considerable influence upon the effect of a preceding pulse. Traditionally, attention has been directed toward the reverse relation. Psychologically, this fact was first recognized by Werner (29) and has since been explored by Cheatham (8).

Concerning the phenomenal fact of movement in three dimensional space, conclusions are to be made with caution. It is to be emphasized that observations were made with a definite set to see one object moving into the distance. The appropriate relative differences in area and intensity between two successive exposures, under proper temporal conditions, were found to favor this set. However, this does not preclude the possibility that another observer (assuming sophistication in observational technique) might perceive one stationary object continuously decreasing in size and brightness, were he operating with a different set. This is an empirical matter. There have been numerous demonstrations of the effect which observational sets have on the perceptual outcome (13; 16). The likelihood remains that the centripetal spread of the dark surround closing in on a figure which decreases in brightness (and this is a *post hoc* construct) may be a sufficient condition for the respective sets to result in either outcome. The relationships between perceived distance and both size and brightness have been amply demonstrated (9; 14; 15; 19).

SUMMARY

This investigation was conducted with the purpose of exploring the parameters of stimulation necessary for the perception of optimal abient movement. Two simple luminous targets were exposed in succession, each being located at the same optical distance and with their centers on the principle visual axis. The first target was of constant area and intensity; for different exposure sequences the second was made to vary in area or intensity. The temporal relation between termination of the first exposure and initiation of the second exposure was serially varied, thereby producing varying degrees of unstimulated interval between exposures and varying degrees of temporal overlap of exposures. Monocular viewing was employed, and stimulation was localized in the fovea. Data reported are from one trained observer.

Threshold measures for the magnitudes of both the unstimulated interval between exposures and the interval of temporal overlap indicate that there is a range of relative differences in both stimulus area and intensity within which movement is perceptible. Within these ranges, the absolute values of the threshold measures of the temporal relation between exposures were found to lawfully increase as direct functions of both relative difference in area and intensity. An important provision was the exposure of both targets above minimal durations.

Collateral observations revealed an orderly variety of related phenomena. These were: continuity of light (fusion), discontinuity of light (flicker), intrusion of the smaller second square within the first, contour obliteration resulting in either of two forms of pure movement, and the total obliteration of the effect of the first stimulus. Each of these phenomena were semiquantitatively discussed in relation to the parameters of stimulation.

The interpretation of all phenomena reported is made in terms of a tentative, primitive conceptual scheme, which not only embraces these phenomena, but applies in part to aspects of flicker fusion and contrast phenomena. It is believed that this scheme is capable of generating testable predictions.

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