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A new apparatus for central fixation training and a preliminary investigation of a new entoptic phenomenon

David B. Flemmons
Pacific University

Lance C. Lubach
Pacific University

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Abstract

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David B. Flemmons

Lance C. Lubach

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David B. Fleming
Lance C. Lubach

ABSTRACT

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---George Sperling---

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INTRODUCTION

Many devices are presently available for strabismus training. Each device is generally constructed to deal with one or two aspects of the strabismus training regiment ie. suppression, eccentric fixation, amblyopia and so forth. To this extent, each device has specific advantages over other techniques and similarly specific limitations. This project consists of the construction and initial testing of an apparatus designed to incorporate many of the individual training devices into one central fixation training apparatus. The objective in constructing such an apparatus would of course be to seek out and incorporate the best features of individual training devices into one more or less multipurpose training device. To this extent, this paper consists of a reasonably broad literature survey on those topics under consideration for the construction of such an apparatus, the capabilities of the device as constructed, and an initial report on a new entopic phenomenon to be used in fixation training, with the device.

LITERATURE SURVEY

Retinal Correspondence

The concept of retinal correspondence is traditionally presented in terms of visual directions. In monocular vision it is assumed that every retinal receptive field that is stimulated gives rise to a subjective visual direction along which that visual point is "seen". Each direction is differentiatable from all others and has a fixed relationship with the eye. In binocular vision, the principle visual direction of the left eye unites with the principle visual direction of the right eye to form a binocular principle visual direction. So every binocular visual direction has associated with it two monocular visual directions. Any object point that stimulates a pair of these "corresponding" monocular visual directions is seen in a single visual direction formed by the pair. The aggregate of all these points in object space is the horopter. Similarly, any object point whose image on each eye falls on noncorresponding retinal elements, causes noncorresponding monocular visual directions which do not unite to form one binocular visual direction. It follows that one of four things will happen in such a case:[1]

(a) Retinal rivalry may occur and if both elements are manifest, the object will be seen double.

(b) Both rivalrous elements will have apparent singleness and depth relative to the horopter.

(c) The object may be seen singly if one rivalrous element dominates.

(d) Both rivalrous elements are suppressed and not seen at all.

It is a well known fact that in certain cases of strabismus, none of the four alternatives occurs and the patient achieves some degree of single binocular vision despite the fact that the object of attention is imaged on highly disparate retinal points.[2] This phenomenon is anomalous retinal correspondence.

The exact mechanism underlying ARC has not been entirely understood. A number of theories have been proposed which are briefly summarized:

(a) Bagolini[3] states that ARC is caused by an insensitivity to disparity which in turn is caused by a large suppression zone (a very large Pannum's area).

(b) Hubel and Wiesel[4] have shown that an artificially induced strabismus in Siamese kittens results in an abnormal physiological linkage of retino-cortical fibers.

(c) Verhoeff[5] and Bruck postulate that ARC patients are ambiocular (both eyes act independently of one another) and there is no binocular correspondence.

(d) Boeder[6] states that ARC patients use normal correspondence but do so by means of a shift in visual directionality of the retina. The conditioned reflex that results is such that the fovea of the deviating eye no longer dictates principle visual direction.

The first theory related ARC and suppression. Although the precise relationship is still being investigated, certain facts regarding suppression and its relationship with ARC are known and make it amenable to treatment. Suppression is not a passive process, but is an active form of sensory inhibition. It is usually acquired to eliminate confusion (the two foveas each receive different images) and diplpia (the same object is seen in two different places in space). The suppression associated with strabismus:[7]

(a) is confined to specific retinal regions. Esotropes who have ARC for example, demonstrate binasal retinal suppression so that the field under binocular conditions appears similar to a bilateral hemianopsia.

(b) exists only under conditions of binocular vision.

(c) is present primarily when similar contours are seen.

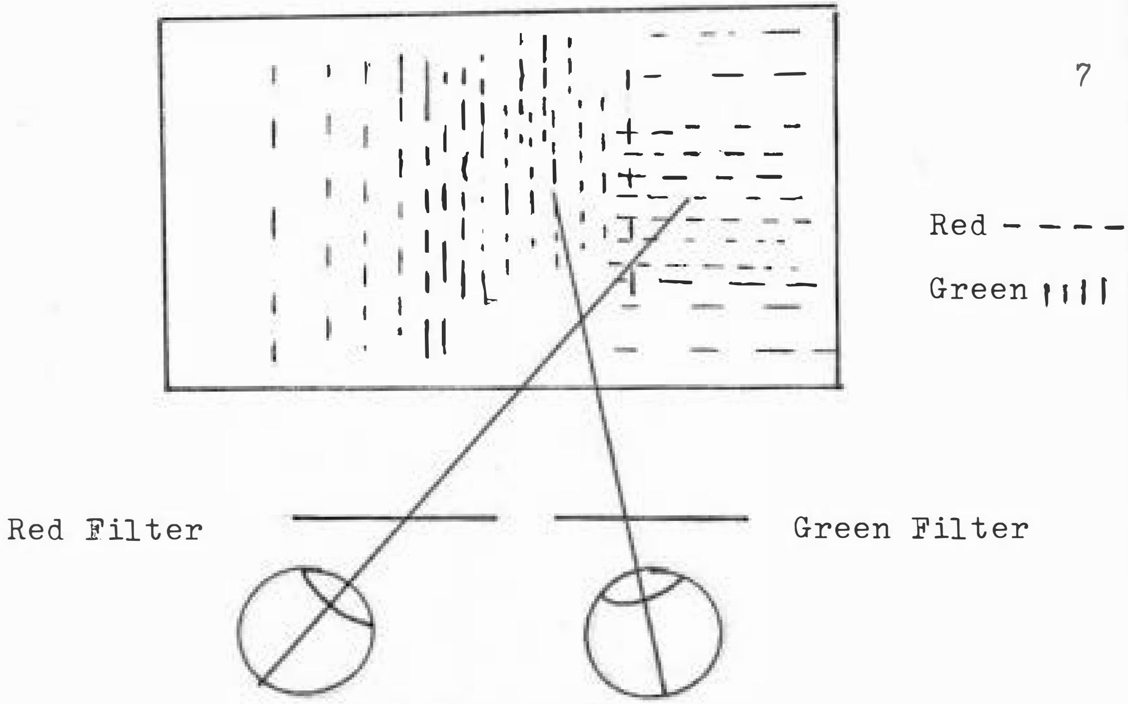
(d) requires a latency of 100 mSec or longer.

Suppression and ARC have been treated by taking advantage of the fact that a latency exists. Banes,[8] Stonebridge,[9] Gibson and Meakin[10] and Mallett[11] have used alternate stimulation in treating ARC. Mallett recommended an asynchronous stimulus of four to six Hz as an optimum frequency for the breakdown of ARC. Reading and Mallett[12] reported that anomalous correspondence was replaced by normal correspondence at certain critical frequencies of alternate stimulation in a synoptiscope ranging from 2.0 Hz to 6.3 Hz. With a contour free background the critical frequency for normal correspondence was between 2.0 Hz and 4.0 Hz. Using a similtaneous flash, normal correspondence was attained over a frequency of 4.0 Hz to 6.3 Hz. Schor[13] demonstrated that the visual aciuty of the nonpreferred eye of a number of amblyopic patients having harmonious ARC was increased significantly by alternate stimulation at frequencies of 2.0 Hz and 7.0 Hz. These facts suggest that a time relationship exists for ARC and that relationship is frustrated by alternate stimulation.

Anaglyphic Phenomena

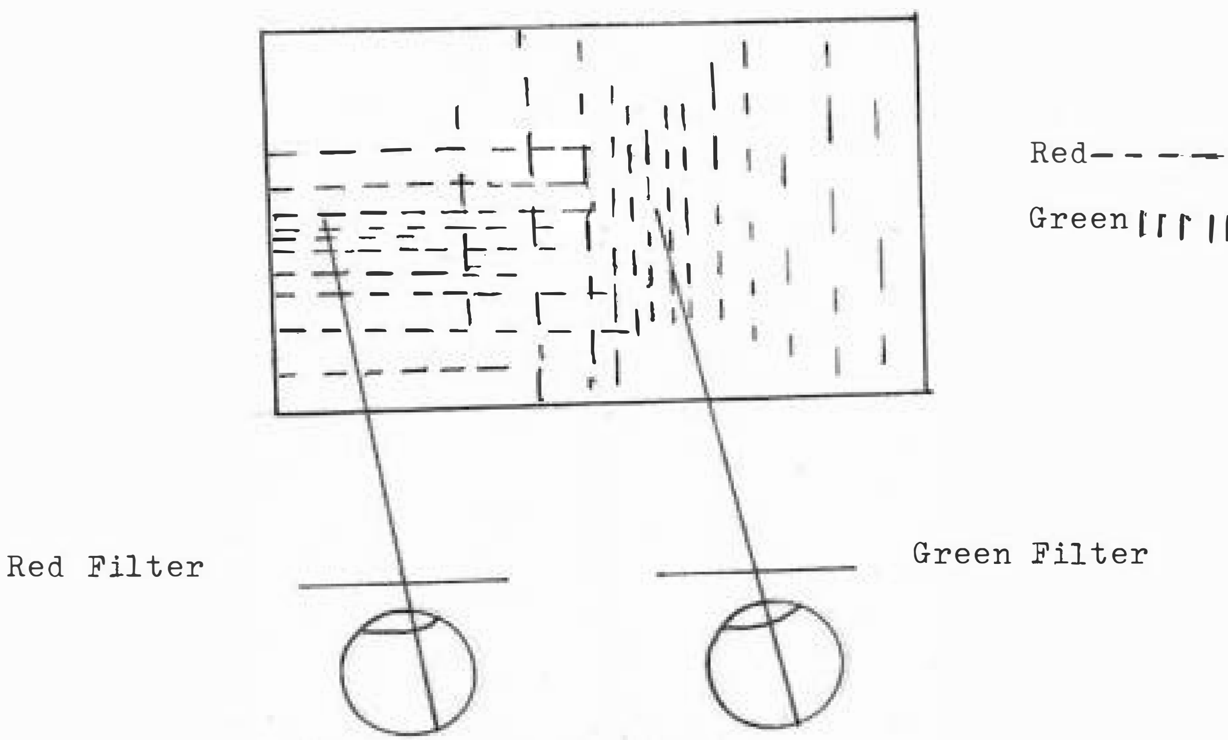
The best results in orthoptics training are thought to occur if the training transfers to the normal seeing environment and this occurs most readily if the training techniques simulate natural seeing conditions.

Free space viewing with red-green anaglyphs is desireable for orthoptics conditions with strabismus patients for this reason. When a normal adult views a blank screen with anaglyphic glasses he will describe a mixture of red and green or an alternate predominance of red and green in the case of color rivalry, which may be complete or patchy. However, the screen is rarely if ever seen as just red or green as in monocular vision.[14] Patients have esotropia or exotropia with normal correspondence and no amblyopia demonstrate a similar pattern modified only by the magnitude of the deviation. Parts of the screen are seen double with pure colors on either side where the two images of the screen do not overlap. The areas of pure color appear uncrossed in esotropia and crossed in exotropia, in short, the same as that which would be expected in induced diplopia in a normal person. In long standing untreated strabismus with anomalous correspondence, a different pattern occurs. For example, an esotrope standing a short distance from a blank screen with a red filter over the deviating left eye and a green filter over the right has the left third (approximate) of the screen imaged on the retina just temporal to the macula in the fixing eye. But in the deviation left eye it is imaged on the retina nasal to the optic disk (assuming an angle of 25°-30°). The right one third of the screen is imaged on the macular region of the deviating left eye. Most of the central area and the left side of the screen appears green while the right one third appears red.[15]



Left Esotropia

In exotropia with harmonious anomalous correspondence a similar division of the screen into fields can be observed except that the colors appear uncrossed.

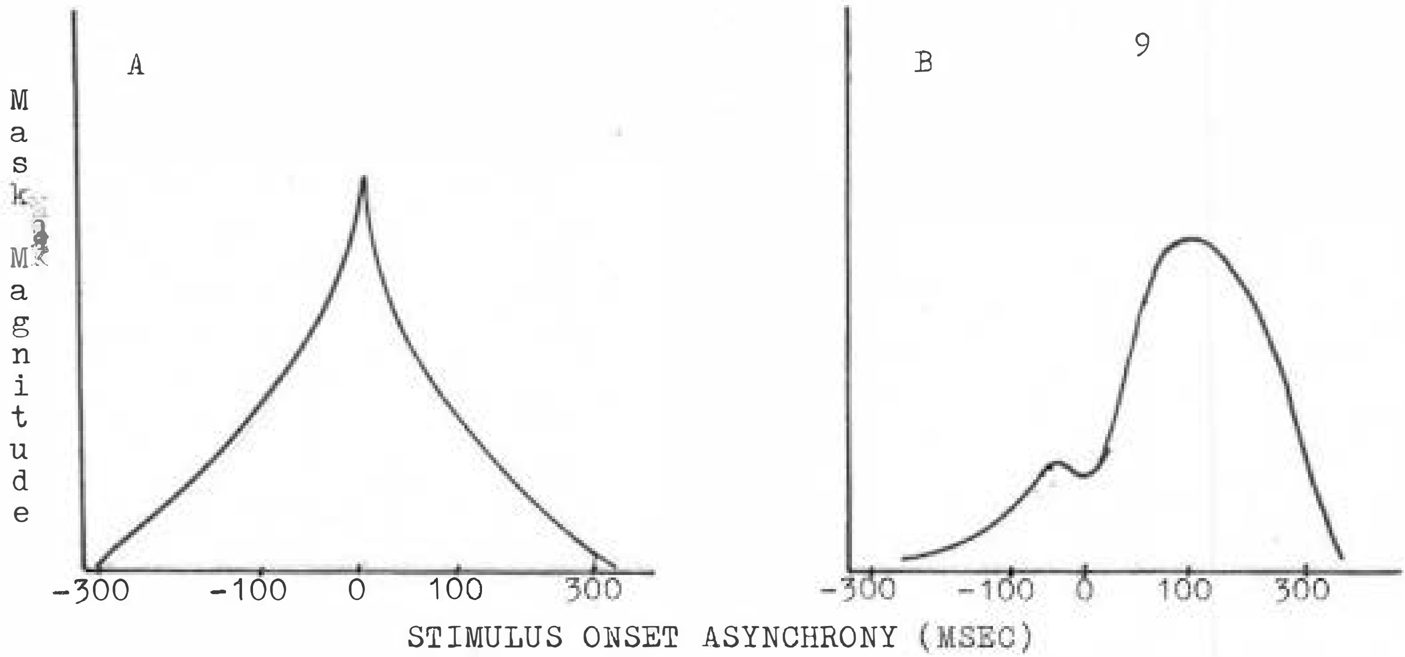


Left Exotropia

In both cases a predominance of the macular region of each eye exists over the abnormally corresponding peripheral retinal areas in the other eye where dissimilar stimuli of equal intensity are presented to these regions.

Visual Masking

The action of one visual stimulus on the visibility of another is called masking. George Sperling in regard to this subject has stated: "All visual stimuli may be studied as masking stimuli; the observed complexities of masking indicate that it involves much or all of the visual system. Therefore, an understanding of visual masking may generate a profound understanding of vision."[16] The temporal interval separating the onset of the target and the mask is the stimulus onset asynchrony (SOA). A positive SOA value implies that the mask follows the target in time. This is backward masking. A negative SOA value indicates that the mask precedes the target in time. This is forward masking. A masking technique in which the contours of the mask do not overlap but approximate the contours of the target is called paracontrast when forward masking is in effect and is called metacontrast when backward masking is involved. Masking by noise is yet another procedure in which the mask and target overlap but in which case the masking contour bears little resemblance to the target pattern. When the spacially overlapping mask is related structurally to the target it is called masking by structure. Both types of masking, forward and backward, yield two types of effects. A type A effect is said to occur if the masking magnitude decreases monotonically as the SOA value increases. Figure A.[17]



A type B effect occurs when the masking magnitude varies as a non-monotonic inverted V-shaped function Figure B. Masking by light occurs when a given light stimulus is masked by another overlapping light stimulus. Both type A and type B effects can be produced with this type of masking.

Retinal Physiology

One of the reasons for developing an apparatus that can provide asynchronous paired pulses of light is to take advantage of certain properties of groups of retinal ganglion cells whose functions differ. For example, in cats (and presumably humans) it has been established that the retinal ganglion cells can be classified into two types; those which respond to a stationary contour at the receptive field center with transient firing and those which respond with sustained firing.[18] The former are called transient or Y cells and the latter are sustained or X cells (Enroth-Cugell and Robson, 1966; Cleland, Dubin, and Levick 1971; Ikeda and Wright, 1972) and are not sensitive to refractive error or image blur

(Ikeda and Wright). However, they show selectivity for intermittent stimulation, such as high-frequency flicker or rapid motion (Fukuda and Saito, 1971). Sustained cells, on the other hand show opposite spatio-temporal response selectivities. They respond selectively to small or high spatial frequency patterns that are presented for prolonged periods or at low temporal rates (Cleland et al. 1971, 1973), and to sharply defocused images. The response latencies of transient cells is on the order of 50 msec while that of sustained cells is on the order of 100 msec or more. All other property that differentiates these two cell types are their respective receptive field sizes. Hoffman (1972) reports that the sizes of both types of receptive fields increase as receptive field location shifts from the fovea to the periphery.

As an example of how these two systems interact, consider how we inspect the visual world in general. There are roughly 250 msec periods of fixation alternating with saccades of 20-50 msec, depending on the length of the traverse. Saccadic suppression refers to the fact that sensitivity actually begins 50 msec or more before the saccade, it continues through the traverse, and terminates some 50 or so msec after the eyes have reached their destination (Volkman, 1962; Volkman, Schick and Riggs, 1968). It is appropriate at this point to discuss the role of metacontrast in this act since it is a type of masking similar to metacontrast which is responsible for the entopic phenomenon reported in this paper. Saccadic suppression has a number of casual components. Matin (1974) reported the most important of these as being

(a) blurring of the retinal image during the rapid movement,

(b) an afferent component attributed to backward masking and

(c) an efferent component, central inhibition, which is related to corollary discharges originating from the motor command (Holst and Mittelstadt, 1950).

Most significant here is the suppression of sustained channel activity generated in the 100 msec interval prior to the saccade. It was mentioned that sustained channels had a long integration time. This integration time increases with selectivity for higher spatial frequencies (Breitmeye and Ganz, 1976). It is easy to see how the last 100 msec or more of fixation in a prior fixation interval could interfere, via masking by integration, with the 100 msec of the following fixation interval. This problem would increase since higher spatial frequencies comprise fine contour detail. This forward masking by integration is prevented or attenuated by metacontrast suppression (Brietmeye and Ganz, 1976).

Rationale

The apparatus devised for this project is unique in a number of ways, it is designed to take advantage of known or accepted visual mechanisms for training fixation. Some troposcopes used an alternate flash with incandescent bulbs as the light source for breaking down suppression. Flashing lights are becoming increasingly common for use in the treatment of suppression as well as to prevent suppression during testing of patients who suppress. The technique uses pairs of lights or lighted targets alternating at 6 Hz to 8 Hz. This could be improved by using flourescent lamps. Incandescent bulbs are subject to thermal lag and only the smallest bulbs are capable of even mediochre responses at frequencies in this range. Consequently these techniques have been restricted to use in instruments or to trans-lid interaction devices. Flourescent lamps are capable of operating with reasonable fidelity well beyond this range. Neon lights, glow tubes and zenon flash tubes have also been used in this context but all suffer from a number of drawbacks, such as poor spectral content and low luminous efficiency. A neon glow tube has a luminous efficiency of only three watts per lumen and are usually only three watts or smaller in size. Zenon flash tubes provide high wattage pulses but have relatively short life spans at these frequencies and are rather expensive. The high intensity of the flash can also cause problems by bleaching the retina in prolonged exposures and creating annoying afterimages.

An improvement on the flashing light method of dealing with suppression would be to use sequentially paired pulses of light. This would allow more selective masking to take place and thereby facilitate a more rapid breakdown of an embedded strabismic posture. If done out of instrument there is a greater tendency toward transferance to the normal seeing environment. Anaglyphic glasses allow for anti-suppression training to occur either monoptically or binocularly. The entopic phenomenon created by certain SOA's can be used to train fixation at the same time suppression is being dealt with.

Most of the techniques relating to strabismus therapy require separate instrumentation for each stage of therapy. The apparatus devised for this project combines many of the advantages of the separate instruments into one, open field device which has the potential for shortening the total time period involved in training while increasing the efficiency of the training.

DESCRIPTION OF APPARATUS

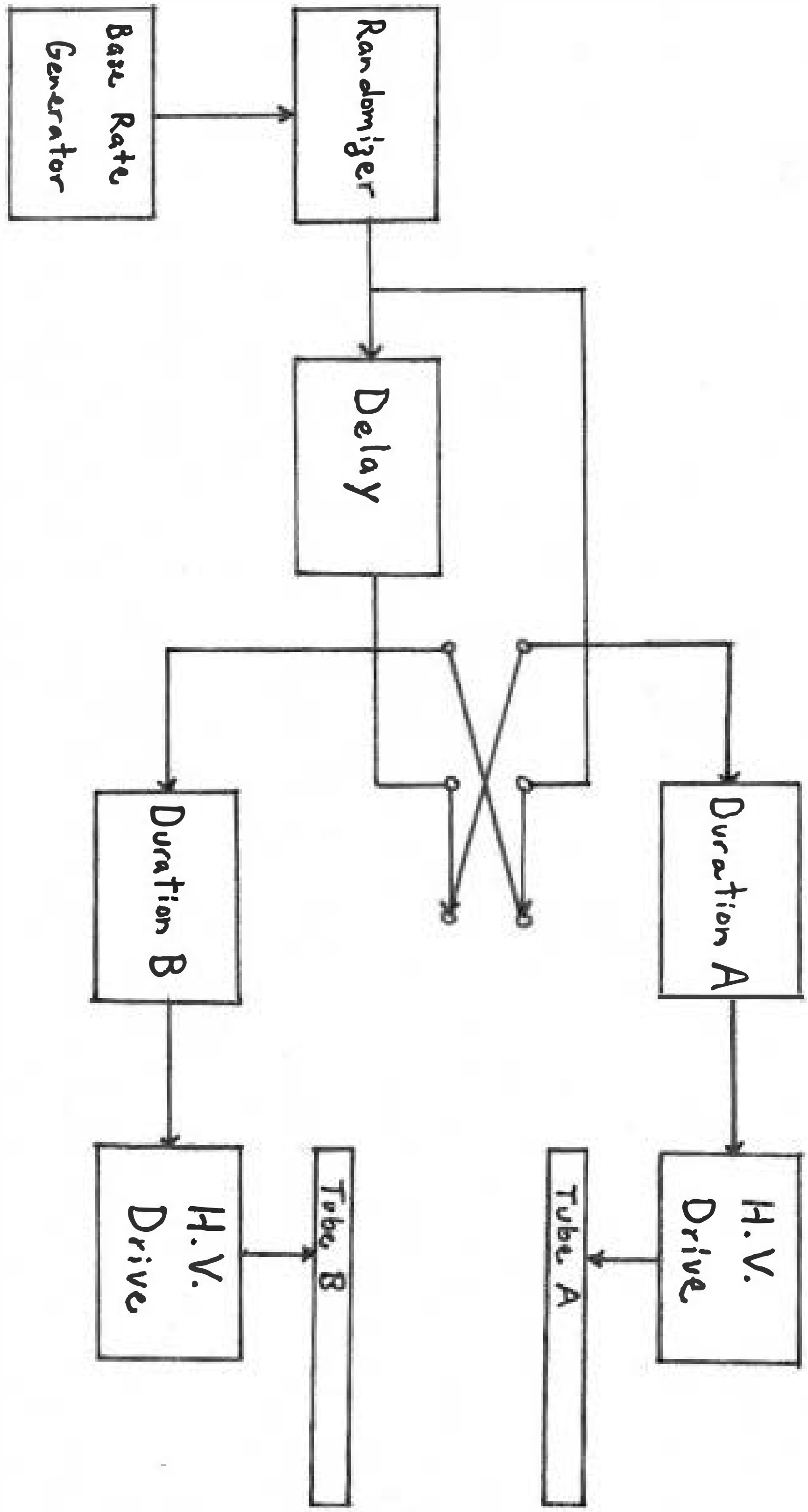
The flash apparatus devised for this project consists of two parts, a control panel and the housing for the flourescent tubes, one red and one blue or green. The temporal characteristics of the flash unit are as follows:

(a) SOA Range: 0 - 1000 msec (minimum Δ 10 msec)

(b) Flash Duration: 0 - 1000 msec (minimum Δ 10 msec)

(c) Randomization Capability: $\pm$ 0 - 100 msec deviation from the mean.

(d) Glide (gradual increase in "on cycle" duration while SOA is maintained over a given time interval): 10 msec - 1000 msec over 1.0 minutes to 10 minute intervals.


Base Rate Generator
Randomizer
Delay
Duration A
Duration B
H.V. Drive
H.V. Drive
Tube A
Tube B

PROCEDURE

Each subject was seated facing a blank white projection screen eight feet distant. The flash unit was mounted five feet above the floor, one foot in back of the subject. Each subject was allowed to dark adapt for seven minutes. Initially the apparatus was set for a 90 msec SOA to introduce the phenomenon to the subject. The SOA was then set at 10 msec, the duration of the on-cycle at 20 msec, the delay between on-cycles at 1500 msec, and the sequence of presentation with red before blue. The SOA was increased in 10 msec intervals until the subject first identified the spot as a black or dark pulsating spot at the point of fixation and the value recorded. The next point sought was that which produced the most obvious or maximally visible entopic effect. This was done by a bracketing procedure similar to that used in a #7a finding. The SOA was then increased until the spot became questionable or disappeared entirely. The sequence of presentation was then reversed with blue before red, and the same procedure repeated. Thus, six pieces of data were logged for each subject, a lower limit, a maximal SOA, and an upper limit for each of the two sequences of presentation.

DATA

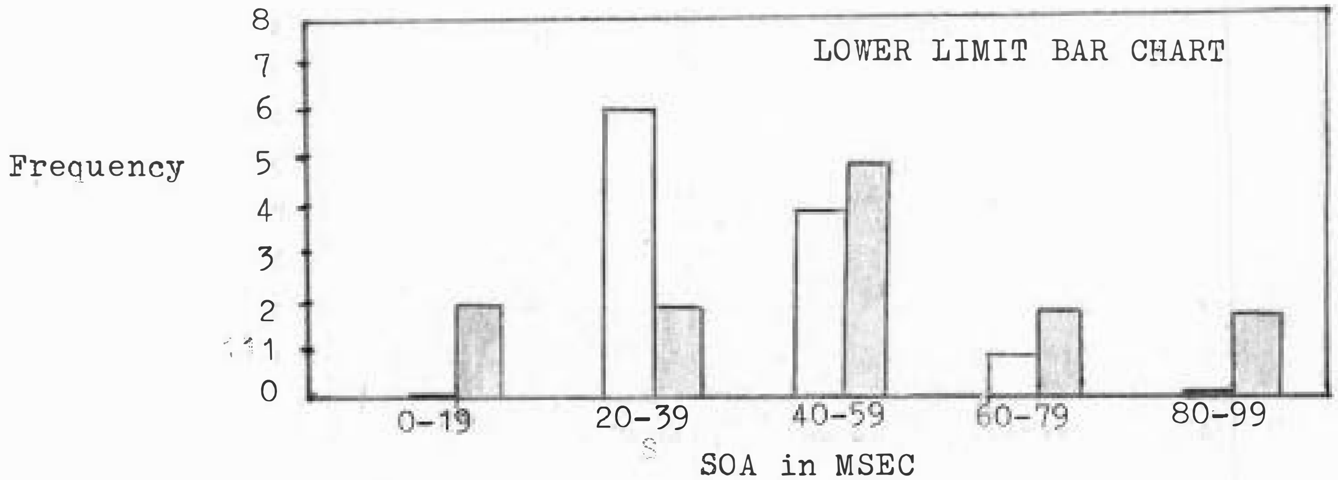
The data is presented in tabular form along with the mean, mode, and standard deviation. An X indicates that the response was questionable or that no response could be obtained. The second data page is simply a bar chart of the data broken down into the three main catagories. There are two bars in each subgroup, the first is for a red to blue sequence of presentation and the second for blue to red.

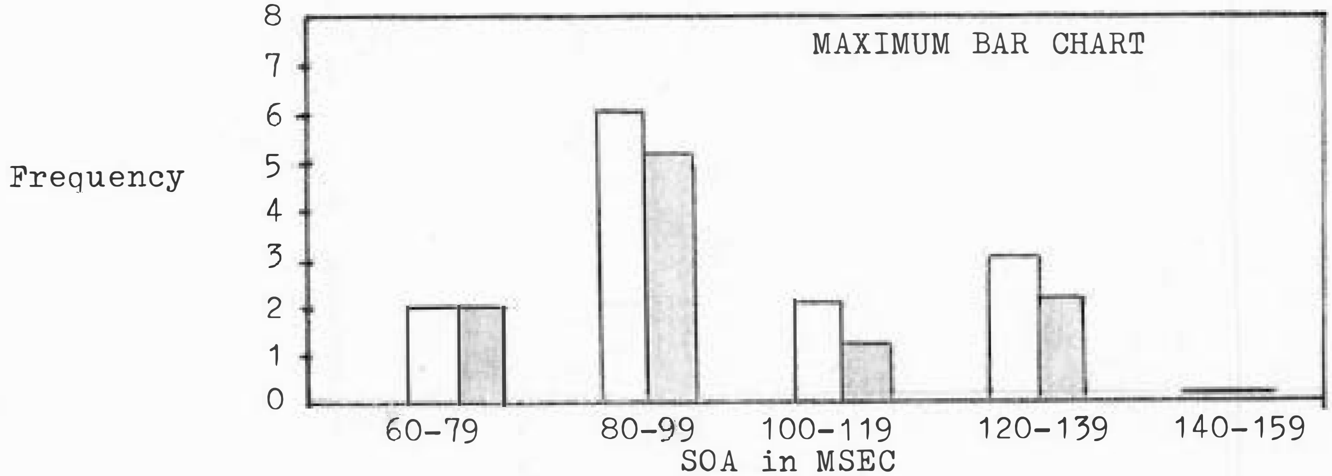
Subject	Lower Limit		Maximum		Upper Limit	
	R-B (msec)	B-R (msec)	R-B (msec)	B-R (msec)	R-B (msec)	B-R (msec)
1	45	70	110	90	200	140
2	50	65	125	90	450	180
3	25	45	110	100	600	200
4	35	45	90	90	200	200
5	25	50	70	60	200	125
6	70	80	125	125	150	170
7	30	80	70	70	400	190
8	45	45	125	X	190	X
9	30	30	90	95	250	200
10	40	30	90	120	225	250
11	0	55	90	X	160	X
12	30	X	90	X	180	X
13	0	X	90	90	X	190
MEAN	39	54	98	93	267	184
MODE	30	45	90	90	200	200
S.D.	13	18	19	20	140	35

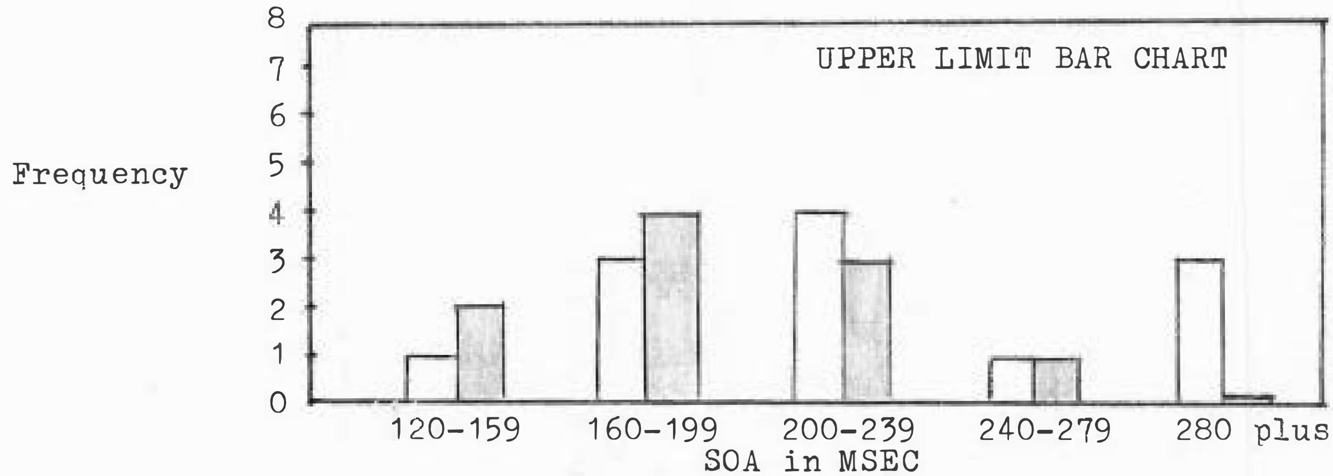
R-B = Red presented before blue

B-R = Blue presented before red

all numbers in msec units







White Bars = Red to Blue Sequence
Gray Bars = Blue to Red Sequence

CONCLUSION

An interesting, useful and to the authors' knowledge previously unknown entopic phenomena has been discovered with the device. When viewing in a free field in either total darkness or in mesoptic background illumination a definite pulsating spot which appears at the point of fixation can be seen. The exact appearance of the spot changes with both the order of and temporal delay between flashes and is maximized when red and blue tubes are used; although the phenomena was first noticed with red and green tubes and is present to a lesser degree with blue and green tubes. The temporal characteristics of the phenomena generate a U-shaped nonmonotonic backward masking function not unlike that obtained with masking by light in an overlapping disk-disk masking paradigm when necessary criteria are met.[19] Metacontrast, or masking using nonoverlapping figures yields an almost identical nonmonotonic U-shaped backward masking function. One of the most promising explanations of metacontrast is the theory proposed by Bruno C. Breitmeyer and Leo Ganz. This theory proposes that metacontrast is do to interchanel inhibition of the X or sustained cell system by the Y or transient system at the striate cortex.

> "Transient and sustained cells are found in the same cortical columns in the monkey cortex; transient cells are predominantly in the lower layers; sustained cells are in lower, middle, and upper layers (Bow, 1974). Moreover, neural inhibition among different columns also exists (Beneveto et al, 1972; Hess, Negishi Crevtzfeldt, 1975). Under such conditions the inhibition of sustained cells by transient cells in the same column or in neighboring columns that show similar orientation specifically would result in the high degree of spatial and structural specificity found in Type B metacontrast effects."[17]

Metacontrast effects can be obtained both monoptically and dichoptically while masking by light in an overlapping disk-disk masking paradigm yields masking effects under monoptic conditions only, in the absence of interacting contours.[20] This effect can be readily explained if one considers the neurophysiology of the visual pathways. There is a definite dichotomy between the x and y cell systems both at the retina (Ikeda and Wright, 1972) the LGN (Cleland et al; 1971), and visual cortex (Ikeda and Wright, 1974).[17] Also, both retinal on center and off center neurons are found distributed similarly in transient and sustained cell channels.[21] Simple on center and off center receptive fields are also present at the LGN; but have a much stronger surrounding inhibition that does not disappear with dark adaptation as it does at the retinal level.[17] It has been shown that transient cells inhibit the activity of sustained cells at the LGN.[22] This inhibition is presumably mediated by interneurons that are stimulated directly by retinal afferent ganglion cell axons.[23] The x cell system also has a much greater response latency than the y cell system as well as a longer conduction time.[17] Therefore the author proposes that interchannel inhibition between sustained and transient channels at the LGN is a possible mechanism for type B backward masking effects by light with overlapping discs and furthermore proposes this as the mechanism for the Flemmons entopic phenomena as will be discussed below.

Similarities between the Flemmons entopic phenomena and backward masking by light with overlapping disks.

Since the central fixation training apparatus was devised to use free field viewing conditions with red-green anaglyphic filters no contours are present in the field. (Except when specific training methods are being employed.) When viewing without anaglyphic glasses one is presented with a monoptic stimuli consisting of two superimposed flashes with an adjustable temporal relationship as is the case in masking by light with overlapping disks. The backward masking effects generated are visible monoptically but not dichoptically as is also true for masking by light with overlapping disks. In overlapping disk-disk masking, the mask energy (luminance x duration) should be no more than about 10 times that of the target and the mask must be larger than the target. The first condition is easily met by the design of the apparatus and the second by the neurophysiology of the visual system. It is well known that red has the smallest color field while blue has the largest. Also, there exists a blue-free zone within the central area of the fovea of approximately 7 to 8 minutes in size.[24] The distribution of sustained and transient receptive fields is such that the fovea contains almost exclusively sustained receptive fields whereas transient cells predominate as one moves into the periphery.[25] These dichotomies satisfy the conditions necessary for disk-disk masking. I.e. the blue light impulse provides the necessary stimulation for a large masking stimulus that is preferential to the receptive fields of the Y ganglion cells whereas the red flash provides a more central stimulus which is preferential to the receptive fields of the x ganglion cells. It is under exactly these conditions that the maximal entopic effect is generated. Also, the effect is more predominate when no background illumination is used which is as would be expected since the Y cells saturate at low light levels and this would cause a differential reduction in the inhibition of the x system by the y system.

Since the theory rests on the neurophysiological dichotomy between the X and Y cell systems one can predict from this circumstances that would lead to the presence of similar phenomena. The theory would even predict a weak effect with single flashes of mono- or polychromatic light due to the fact that the periphery with its' higher concentration of Y cells will give a quicker more transient response whereas the central region will give a slower responding, longer lasting effect due to its' longer latency and sustained response. This has been tried by the authors and the effect does exist. This can be tested by anyone with access to a light switch and a darkened room. The reader may try this by allowing himself to adapt for several minutes in a darkened room and then turning the light on and then off again as quickly as possible, while viewing a blank wall. The light should be turned on and then off again once every two seconds in order to maximize the effect. Since the effect relies on the fact that there are on center and off center receptive fields within both the X and Y cell systems, there should also be a similar effect with negative masking stimuli.

Subjective Responses

The most striking effect is obtained when the blue flash follows the red flash after a delay of 70 to 120 milliseconds. This results in the appearance of a black spot about one degree in size at the point of fixation in a blank field. The spot is surrounded by a red halo that shrinks into the center of the spot after a few hundred milliseconds. With simultaneous presentation a few subjects report a diffuse red spot at the point of fixation. When the red flash follows the blue flash the red spot becomes more noticable and subtends several degrees of angle.

Maximum effect is with delays on the order of 90 milliseconds. The effect appears to subside with delays greater than 120 milliseconds with either presentation and may reappear again with delays over 200 milliseconds as a red central spot. With extremely long delays a weak effect can be seen separately with both the blue and the red flashes. It would therefore seem that the dark spot and the light (red) spot are mediated by separate mechanisms. The dark spot occurs under those conditions which are maximal for type B backwards masking and is a function of inhibition of the X cell system by the Y cell system. The light (red) spot occurs as a function of the sustained response of the X cell system.

FURTHER CONSIDERATIONS

A number of items are ripe for investigation with regard to the apparatus used in this project. The glide circuit which allows for a gradual increase in duration of the on-cycle should prove useful for anaglyphic anti-suppression training. An investigation into targets to compliment this system is desireable. One idea would be to have a variable horizontal grating mounted on a fixed vertical grating such that the angle between the two is variable. The potential of different SOA values to elicit a normal correspondence response in squints with anomalous correspondence needs to be investigated. Further investigation of the entopic phenomenon is in order. Trained subjects are necessary for generating masking curves, quantifying spot size under different conditions and optimizing luminance for maximum effect.

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