THE EFFECTS OF INTERMITTENT LIGHT
ON
VARIOUS PSYCHOLOGICAL PROCESSES

by

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STATEMENT BY AUTHOR

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INTRODUCTION

The psychological effects of intermittent photic stimulation have been the subject of intensive study. For the most part, research in this area has been concerned with flicker fusion thresholds rather than the effects of sub-fusion flicker. Bartley (1941) states, "it has been an unfortunate circumstance that attention has been focused almost exclusively on the critical flicker frequency." In an annotated bibliography of flicker fusion phenomena covering the period from 1740 to 1952, Landis (1953) reported a few studies referring to phenomena associated with flickering light below the fusion frequency but the greater emphasis was on fusion threshold.

The earlier studies of sub-fusion flicker were directed to visual effects, while later research has included studies of more complex processes such as the relation of sub-fusion photic stimulation to central nervous system activity. The effects of intermittent photic stimulation include visual, physiological, and psychological phenomena. The visual effects of sub-fusion flicker include brightness effects, glitter, afterimages, color changes, and movement. Among the physiological effects, photic driving of the brain and the precipitation of seizures or epileptic phenomena have received the greatest attention. The psychological effects have been investigated through studies of tension states, perception, anxiety, performance, and cognitive functioning. However, relatively few studies have been conducted to study the effects of sub-fusion flicker on learning in normal individuals.

The present study has been designed to ascertain the effects of sub-fusion flicker on learning in man, and to discover whether or not these effects are a function of the flicker frequency. A review of the research on the effects of sub-fusion flicker is included as background for the current research. While some of these studies do not bear directly on the problem of the effects of flickering light on learning, they have given rise to research in this area and may be involved in the explanation of the current findings.

For the purposes of this paper the term "intermittent photic stimulation" is defined as light stimuli repeated at regular intervals and is expressed as "flashes per second." The range of intermittent photic stimulation includes repeated light stimuli at sub-fusion, fusion, and above fusion frequencies. At frequencies below fusion, intermittent photic stimulation is referred to as "flicker." Fusion frequencies are those points at which the stimuli are no longer seen as individual flashes but as a continuous light. This threshold value is called the "critical flicker frequency" (c.f.f.) and is a function of the intensity of the light and its surrounds, the area of the object that is flashing, the part of the eye stimulated, and the ratio of light and dark period of the cycle or the light/dark ratio.

Photic driving is defined as the rhythmic cortical response recorded by electroencephalograph as a result produced by intermittent photic stimulations. Waves driven at the same frequency as the intermittent light are termed responses at the fundamental whereas exact multiple second or third responses are termed harmonics or sub-harmonics.

Bartley (1939) made a comprehensive study of the effects of intermittent photic stimulation in which he points out the major qualitative sensory changes throughout the range from isolated flashes to critical flicker frequency for test-objects both with and without illuminated surrounds. When the test-object is surrounded by darkness the sequence of changes passes through nine phases, but the light/dark ratio determines the nature and emerging place of each phase. When the test-object is surrounded by an illuminated field the sequence of phenomena is somewhat more complicated but it is possible to indicate the range of flicker frequency in which the phenomena tend to emerge.

A composite of the two diagrams presented by Bartley (1941) indicating the phenomena emerging under both conditions is presented in Figure 1. In addition to the phenomena enumerated by Bartley, other effects that have been reported have been included in the figure in an effort to facilitate the understanding of this review of the literature.

FPS	VISUAL EFFECTS	PHYSIOLOGICAL EFFECTS	PSYCHOLOGICAL EFFECTS
25			
	Painful Flicker		
20	Residual Flicker	Up-trend driving	Up-trend learning*
	Critical Flicker Frequency Brucke Effect		
15		Down-trend driving Paroxysmal activation Decreased oxygen Saturation	Learning impaired
	Flicker-Glitter Boundary		
10			
	Brightness enchancement Gamma Maximum	Optimal Photic driving	Better learning* Subjective effects Drowsiness Tension Maximum
	Bidwell's Phenomena	Decreased Oxygen Saturation Borderline driving	Best learning*
5			
	Moment Threshold	No driving	Learning impaired*

Fig. 1. Composite diagram of sensory changes at different flicker frequencies including the findings of the current study. Findings of the current study are designated by an asterisk.

Visual Effects

Talbot demonstrated, in 1834, that the apparent brightness of flickering light above fusion is reduced (from that of steady illumination) by the ratio between the period during which the light actually reaches it and the whole period, but Brucke, in 1864, reported that the white areas of a rotating disk made up of alternate black and white sectors become more brilliant at approximately 17.6 rotations per second than when stationary. Bartley (1938) following this same line of research but using transmitted light rather than black and white disks, reported that the maximum Brucke effect, which he called apparent brightness enhancement, is a reciprocal of the Talbot effect and occurs when the stimuli are given at about eight to ten per second.

Barley felt that this effect was not produced by photo-chemical mechanisms since it was difficult to see how two opposing processes producing a lower concentration of the light product required to give the Talbot effect, could, at a lower rate of alternation between light and dark, produce an increased concentration of the substance required to give enhancement to apparent brightness. It was his contention that the effect was neural and brought about by an intrinsic periodicity in the visual pathway.

Jahn (1944) presented evidence that photo-chemical changes in the sense cells could be the causative mechanism since the photo-chemical equation which Bartley considered to be inadequate is apparently that for the dark-adapted eye and should not be used for explaining visual phenomena in the light-adapted eye. However, Jahn contended that if the explanation was to be made on a purely chemical basis the frequency of maximum enhancement should vary with both intensity and light/dark ratio. The fact that apparent brightness enhancement remains in the frequency range of eight to ten per second at all intensities and at all light/dark ratios would substantiate Bartley's contention of a neural basis.

Bartley (1951), working on the theory that brightness enhancement could be due to the number and readiness to respond of retinal-neural paths, contended that intermittent stimuli should be more effective under conditions which enhance or are enhanced by photic driving. His experiment failed to confirm his hypothesis.

Since the maximum ocular tension is coincident with flash frequencies producing maximal brightness enhancement, Halstead (1941) investigated the possibility of a muscular origin by eliminating pupillary and accommodative reflexes by scopolamine. Brightness enhancement was not affected and Halstead concluded that it was not due to either of the intra-ocular muscle reflexes.

In a more recent study, Gersthewohl and Taylor (1953), using flicker frequencies of nine and fifteen, investigated the question of whether brightness enhancement would help contrast print on background. They found that flicker reduced the number of lines read and increased the discrimination threshold for finer details. They further concluded that brightness enhancement was subjective and without physical correlate which is in keeping with Bartley's use of the term apparent brightness enhancement.

Although brightness enhancement has received continuing attention, the effects of glitter, luster, afterimages, and change of color have also been the subject of considerable research. Rood (1863), using a sectored disk made up of seven white and seven black sectors, reported that revolutions of 1.75 per second resulted in a loss of definition, and revolutions of 4.2 per second resulted in glittering. Grunbaum, continuing in this same area of research, reported in 1897 (Landis, 1953) that by studying the ratio of the breadth of the sector area to that of the aperture through which the observations were made, flicker and glitter are distinct.

Bidwell (1897) reported on a series of experimental demonstrations of afterimage phenomena now known as Bidwell's ghosts. He used a twenty-five candle power electric lamp and a rotated, two-sectored disk that had a forty-five degree sector removed at the junction of the black and white sectors so that the open sector was preceded by black and followed by white. With the lamp at two feet and the disk revolving at six revolutions per second, the black letters appeared red. As the lamp was moved nearer, the letters began to shimmer and take on a silvery, lustrous, metallic appearance. With the lamp at four inches, the letters appeared greenish blue. He also demonstrated that it was possible to match the letters that appeared red with ones that were actually red. He further concluded that the speed for obtaining this phenomena was not the same for all persons but that the optimum range was from six to eight revolutions per second.

Fry (1936), continuing in this line of research, studied the color sensations obtained with intermittent spectral stimuli when the frequency wave length, purity of the stimulus, and the brightness of the surrounding field are varied. He used flash frequencies of four, six, eight, and ten per second. He found that bright flashes alternate with dark intervals and that the hue of the bright flash is that characteristic of the wave length used and that the dark intervals are tinged with purple or violet. For example, at four per second a white flash has a dark violet interval, at six and eight per second the interval becomes blue-green, turning to greenish-white at ten per second, andreaching white at fifteen per second. When the intermittent flashes are exposed on a white area instead of a dark area, the secondary images are complementary to the primary ones.

Another of the visual effects that reaches its maximum in the six to eight flashes per second range is one of apparent motion and is called "gamma movement." This apparent expansion and contraction effect of light has been reported as beginning in the fifteen to seventeen flashes per second range and reaching a maximum in the eight to ten flashes per second range. There have been other types of phenomena reported in the area of apparent or actual motion such as that reported by Ansbacher (1944) who found that an illuminated area of thirty-six degrees rotating at less than fusion speed appears to shrink to a fraction of its actual length. Ansbacher concludes that this phenomenon is related to illumination in that increasing illumination facilitates the shrinkage. Teuber and Bender (1948) in a study of twenty-eight cases of occipital brain injury reported that the same functional mechanism determines perception of flicker, apparent motion, and actual motion after cerebral trauma, and concluded that such perception has a neural rather than a photo-chemical basis.

In discussing the visual effects that accompany the use of sub-fusion flicker, it should be pointed out that there is no sharp distinction between flicker and fusion. In 1937, Brecher reported three distinct thresholds of sensory experience (Landis, 1953). First, there is the shift from fusion to an unsteady impression which he called the critical flicker frequency. Next there is a shift from the flicker to a pulsing sensation which he called the pulsation-flicker threshold. Finally, he defined the shift from pulsation to the perception of discrete flashes as the moment threshold.

Bartley (1938) demonstrated that even when the critical flicker frequency was as low as four per second, the subjective or perceived flicker manifested a relatively high rate. When at higher intensities the critical flicker frequency was about fifty per second, the perceived or residual flicker appeared to occur at the same frequency as in the former case, namely, about twenty per second. Here again Bartley felt that this phenomenon was not predicted by present day photo-chemical theory, but is determined by the intrinsic discharge characteristic of the retinal ganglion cells rather than the flash rate.

As has been shown in this brief review of the research on the visual effects that accompany the use of sub-fusion flicker, there is a strong case for a neural rather than a photo-chemical basis. Although retinal fusion has been measured by the electroretinogram by Babel and Monnier (Landis, 1953), there has been relatively little investigation of retinal processes involved in the visual effects other than those cited above on brightness enhancement and residual flicker (Bartley, 1938; Jahn, 1944). In consideration of the criteria presented by Jahn (1944) for a photo-chemical basis it is evident that a definite conclusion cannot be reached. However, many of these visual effects reach their maximum in the same frequency range as the alpha rhythm, and it is considered possible that these visual effects are central responses related to mechanisms that may be involved in the effects of flickering light on more complex processes such as learning.

Complex Physiological Effects

With regards to cortical and sub-cortical responses to sub-fusion flicker, the phenomenon of photic driving is of chief importance. It was not until the development of adequate electrical instrumentation and the electroencephalographic studies of Berger in 1930 that the objective data relating to the effects of sub-fusion flicker and brain wave potential were demonstrated. Although Berger noted that photic stimuli to the retina could block spontaneous alpha rhythms, Adrian and Matthews (1934) were the first to demonstrate photic driving by intermittent light stimulation in man. They further reported a great deal of individual variation both in the degree, nature, and conditions for establishing this phenomenon.

Since that time, numerous studies have been done describing the photic driving response and related physiological and psychological effects. A similar phenomenon has been demonstrated repeatedly in cats, rabbits, monkeys, and other animals (Bartley, 1940; Knox, 1950; Walker, Woolf, Halstead and Case, 1944).

Walter and Walter (1949) reported that this stimulation could be described in terms of five componenets, any or all of which could be present at any one time. First there is a series of discrete, elementary evoked responses; second, there is the fusion of evoked responses giving an accidental appearance of rhythmicity; and third, there is the instrumental summation of evoked response and spontaneous rhythms. The fourth component is true augmentation or driving of local rhythms at the frequency of the stimulus and the fifth is the augmentation of harmonically related rhythms in other areas.

In this same piece of literature Walter and Walter also classified the subjective effects that had been reported by subjects receiving photic stimulation throughout the range of 3.5 to 25 flashes per second with a flash duration of fifteen microseconds. Their classifications were as follows:

1. Visual sensations with characters not present in the stimulus, such as, color, pattern, movement

2. Simple sensations other than visual

    a. Kinesthetic: swaying, spinning, jumping, vertigo
    b. Cutaneous: tingling, pricking

c. Auditory: rare
d. Gustatory and olfactory: doubtful
e. Visceral: connected with auditory

3. General emotional and abstract experiences, such as, fatigue, confusion, fear, disgust, anger, pleasure, disturbance of time sense

4. Organized hallucinations of various types

5. Clinical psychopathic states and seizures

Walter and Walter contended that the subjective visual effects were due to interference between rhythmic evoked responses and spontaneous rhythms at cortical and possibly thalamic levels. The non-visual effects in normal and abnormal subjects, they felt, were due to interaction between the evoked activity and harmonically related spontaneous rhythms in other circuits at a thalamic level.

Mundy-Castle (1953), using the same frequency range (3.5 to 25 flashes per second) in a study designed to further delineate the chief characteristics of responses to photic stimulation in normal adults, reported experiences during photic stimulation similar to those found by Walter and Walter (1949). He also found that clinical psychopathic states and organized hallucinations were not as a rule elicited from normal subjects. Mundy-Castle further concluded that abnormal and questionable electroencephalographic responses were usually accompanied by more vivid and disturbing sensations, and that photic stimulation provides a valuable means for studying the behavior of different rhythmic processes during changing mental content.

Ulett and Johnson (1958) used flicker frequencies ranging from three to 33 flashes per second with a one to one light/dark ratio. The photic driving survey consisted of a 40 second exposure to each of 24 different frequencies with a 40 second interval between each exposure. With a sample population consisting of 182 adult males and 53 psychiatric patients they found that photic driving is a universal phenomenon with a peak response in the alpha range. In the control group, they found that neither photic driving, photic activation, nor changes in photic activation were related significantly to resting electroencephalographic patterns, changes in pulse or blood pressure, self-evaluation of psychologic state, or of positive items in personal or family neuropsychiatric history.

Althugh Ulett and Johnson found no significant relationship between photic driving and pulse or blood pressure, Doust, Schneider and Harris (1952) found that oxygen levels varied critically with the flicker rates. Flicker rates between three and nine, and between twelve and seventeen produced a decrease in blood oxygen saturation values, which were normal at nine to eleven, and eighteen to twenty-two flashes per second. They also reported depressing the oxygen levels by the use of optimal stimulation frequencies and eliciting spontaneous comments by the subjects which revealed considerable changes in affect and levels of awareness.

The principal use of intermittent photic stimulation in relation to its physiological effects, has been in photic driving and eliciting paroxysmal discharges in the electroencephalographic studies of brain wave phenomena. Since these physiological effects seem to be related to cortical and sub-cortical functioning, it becomes a mechanism for studying the neural correlates of complex psychological processes such as, learning, emotion, and motivation.

Effects on Performance and Learning

The effects of flickering light on performance and complex processes has been widely studied with most of the study being directed toward the effect on performance. The comparatively recent innovations of fluorescent lighting and television viewing have given some impetus to this area of flicker research.

One of the earliest studies of the effects on performance was that of Hartridge, Lythgoe and Matthews (1926) in which a comparison was made between continuous and flickering light on a variety of visual tasks. They used flicker frequencies of nine flashes per second and 24.2 flashes per second with an intensity of six foot candles. On three of the tasks, perception of small black and white objects, color perception of both large and small objects, and peripheral color vision, they compared the continuous light with flicker at nine flashes per second. In determining the least perceptible intensity difference in the case of large objects and in steroscopic vision, they compared the continuous light with flicker at 24.2 flashes per second. In two tasks, appreciation of movement by the periphery of the retina and speed of reading, they compared continuous light with flicker frequencies of both nine and 24.2 flashes per second.

Their results indicated that performance was practically identical for the two types of illumination except that the appreciation of movement diminished in flickering light in the periphery of the retina. They further concluded that the performance of one individual on the speed of reading task indicated that a more extensive study of individual differences might show more pronounced effects of flicker in certain cases.

The field of television has introduced a new area of research in the effects of flicker. Theoretically in television, fields must be presented at a rate greater than fifteen per second in order not to be jerky, but in practice the frequency must be higher than fifteen per second because of flicker. Condon (1950) presents four kinds of flicker that occur in television tubes: large area flicker, small area flicker, interline flicker, and line crawl. Studying the effects of flicker in television tubes, Condon had eight observers rate tubes of differing brightness and frequency on a scale where the steps were painful, objectionable, appreciable, noticeable, and none. He used three levels of brightness, i.e., five, ten, and twenty foot candles. His findings are summarized below:

Brightness Level (foot candles)	Approximate Upper Limit of Range of Flicker rated as Painful. (FPS)
5	23
10	26
20	32

These findings indicate that the threshold for painful flicker is a function of the intensity of the light.

In general flickering light is reported to have a disturbing effect, and it is common experience to hear reports that the flickering of fluorescent lighting is distracting or annoying. However, these effects have not been systematically studied.

Bach, Sperry and Ray (1954) using intermittent photic stimulation at varying frequencies in a series of experiments designed to determine the effects on subjective discomfort, tapping rates, walking, pursuit rotor performance and rifle firing, reported that unpleasant subjective effects are consistently reported when subjects are exposed to diffuse flickering light; and that the most consistently effective flicker frequency for the production of subjective effects is nine flashes per second.

Their results further indicate that hand-eye coordination was significantly impaired by a flickering light for a simple tapping task but not affected on another supposedly more complex tapping task; and that the rate of walking under conditions of diffuse flickering light did not seem to be significantly affected even in the presence of obstacles and with a continuously moving light source. However, their results indicate that rifle firing accuracy was significantly depressed when a six cycles per second flickering light was placed behind the target and directed at the subject. When the diffuse flickering light was directed at the target, rifle firing accuracy was increased.

While these reports indicate the marked effects which intermittent photic stimulation may have on behavior, feelings, and certain physiological measures, there have as yet been relatively few studies directed to performance efficiency in situations involving learning. Alexander and Chiles (1959), in an exploratory study of prolonged intermittent photic stimulation, gave a simple addition test at fifteen minute intervals during the exposure. They reported that the performance on the addition test showed no systematic trends as a function of length of exposure to the light. However, they state, "performance was in general somewhat below the expected levels, which since the task was highly visual in nature, was probably a result of the adverse lighting conditions," and further conclude, "because of the exploratory nature of the investigation, adequate measures of performance efficiency were not obtained."

The present investigation was stimulated by the work of Johnson, Ulett, Sines and Stern (1960) who in a study of cortical activity and cognitive functioning used a number of tasks involving learning. They hypothesized that the activation of abnormal rhythms (hypersynchrony and paroxysmal waves) would interfere with memory trace mechanisms in the brain. Using the flicker frequency at which most activation occurred for the group called "activators" and a flicker frequency of fifteen per second for the group called "non-activators," the researchers measured performance on a number of tasks involving cognitive functioning such as paired-associates learning, memory for stories, digit span, serial seven's, and arithmetic problems. They reported that the effect of photic stimulation on performance for the "activators" and "non-activators" combined showed some impairment due to the distracting and sometimes noxious quality of the flickering light on all tasks except one--memory for stories. However, the scores were significantly different from zero only on the paired associates and arithmetic tasks.

The last three studies in this brief review, using tasks involving learning, performance, and cognitive functioning, have indicated that the effects of intermittent light either do not impair these functions, impair some and enhance others, or were not conclusive. However, it is interesting to note that in all of these studies the comparison has been between one condition of flickering light and no flickering light. In contrast, the present study has been designed to ascertain the effects of differing flickering conditions on the same type of learning in the same individuals.

Although no hypotheses are being tested specifically, the current research will attempt to answer the following questions:

1. What are the effects of sub-fusion flicker on learning in man?

2. Are these effects a function of the flicker frequency?

METHOD

Fourteen students from the summer session introductory psychology course at the University of Arizona served as subjects in this study. Participation was on a volunteer basis without remuneration. All subjects were familiar with experimental techniques through lecture. However, none had ever participated in an experiment involving a learning situation. The fourteen subjects consisted of ten females and four males.

Each subject was exposed to seven different conditions of flickering light while seated in a darkroom with eyes closed. During each condition a list of ten nonsense syllables was presented twice through the speaker attachment of a tape recorder. A different list of nonsense syllables was used with each condition of flicker. After each double presentation, the subject stepped into an adjoining room where the amount of learning was tested by the recognition method.

The stimulus light was produced by a Grass Photostimulator, Model P2S, Intensity Setting at two, which produces a spike wave of ten microseconds duration and a peak intensity of 131,250 candle power. Conditions of no light, no flicker and 75 flashes per second flicker were used as terminal points of the range. In between flicker frequencies of three, six, nine, fifteen, and twenty flashes per second were used. Seven conditions of flicker were used ranging from no flicker to above flicker fusion (75 fps).

The learning material was presented to the subjects by means of a Wollensak Magnetic Tape Recorder, Model T-15000, Balanced with a Volume Setting of six. The sequence of presentation was as follows: Ready--five second pause--one syllable every four seconds (approximate), and the list of ten syllables presented twice with no pause between presentations, for a total of 76 seconds for the list plus the five second preliminary period.

The choice of seven conditions of flicker necessitated the use of seven learning tasks of approximately the same degree of difficulty. The learning of nonsense syllables was chosen as the task to be measured by the recognition method. The nonsense syllables used were taken from those groups having an association value of 27 per cent or less as set forth in the list prepared by Glaze and published by Stevens (1951). The seven lists of ten nonsense syllables each were constructed in accordance with the rules developed by Luh, revised and extended by Melton, and published by Stevens (1951). Since the use of the recognition method as a means of measuring learning necessitates the presentation of an equal number of unfamiliar nonsense syllables, these syllables, were chosen from the same lists as those used for the learning materials. The criterion for their choice was that an unfamiliar nonsense syllable beginning with the same consonant as a familiar nonsense syllable appear in the list. The seven lists of ten nonsense syllables each are shown in Figure 2.

Learning was measured by the recognition method with the subject picking out the ten familiar syllables from a list composed

LIST	1	2	3	4	5	6	7
	FAF	YIQ	MEC	TOV	YUN	ZID	TAH
	MIV	GOK	ZUT	QID	GEB	FOZ	NUB
	BEH	JAT	YIB	GEF	XAR	CUK	KIG
	XON	FUH	SAJ	MUW	VOH	MEJ	VEQ
	RUY	VEP	POH	KAJ	PIY	YAB	YOT
	CIW	XOC	RUQ	YIC	JUF	WOG	JUC
	KAZ	NIJ	TEF	XOQ	QAM	SIH	ZAW
	GEK	ZAS	JIK	SEB	KEX	QUN	BIP
	NOJ	HUW	NAX	NAH	ZIS	VAK	XEY
	WUQ	LEB	QOD	JUZ	WOJ	BEP	QOM

Sequence of administration:

READY Flicker started

Five second pause

First Syllable

One syllable every four seconds (approximate)

List repeated (no pause between repetitions)

Total of 76 second for list plus five second preliminary period for a total of 81 seconds of flickering light

Fig. 2. Seven lists of nonsense syllables and sequence of administration.

of the random ordering of ten familiar syllables and ten unfamiliar syllables. Learning was measured after the double presentation of each list. The lists were scored according to the formula published by Stevens (1951) which corrects for guessing and ranges from zero at chance level to 100 per cent at perfect recognition. The seven lists of ten learned nonsense syllables embedded randomly with ten unfamiliar nonsense syllables as required by the recognition method of testing are shown in Appendix I.

Instructions to the subjects were given in an informal manner by a brief explanation of the purpose of the experiment. Each subject was assured that his particular learning would not be compared with other subjects on the basis of personal ability to learn but only studied in relation to the effects of the flickering light. The subjects were briefly questioned regarding their interests in the field of psychology. The questions were why he was taking introductory psychology, whether or not he had any particular interest in clinical psychology, and whether or not he planned to take abnormal psychology.

Subjects were told that the learning material consisted of nonsense syllables that would be presented by means of a tape recorder, that the list of ten syllables would be presented twice, and that their learning would be tested by one of the easier methods--that of recognition. They were also informed that guessing was permissible because a correction formula would be used in scoring the results.

Subjects were instructed to close their eyes, and those wearing glasses were asked to remove them during the flicker conditions. Although the subjects were not told what conditions of flicker would be used they were told that one of the conditions consisted of no light. This information was included to prevent the subject's leaving the darkroom to tell the experimenter that the equipment was not working properly.

The subjects were tested individually by the same experimenter. The subject was seated in a comfortable position in the darkroom. The stimulus light was at eye level and positioned approximately ten inches from the subject's eyes. The tape recorder was installed in an aperture in the wall and separated from the darkroom by a thin panel which served to mask the direct source of the sound as well as to conserve the darkness of the room. Both the photostimulator and the tape recorder were controlled from outside the darkroom.

At the work, Ready, on the tape recorder, the flickering light was started and continued until after the second presentation of the list. The subject was then taken to an adjoining room where he was presented with a printed list of nonsense syllables and instructed to mark the syllables that he had just heard. His choice of syllables was by either circling or checking those familiar to him. This procedure was repeated until all seven frequencies had been presented.

At the conclusion of the experiment, each subject was presented with a questionnaire and asked to indicate whether or not he had experienced any of the particular phenomena listed. He was told that at one time or another all of these phenomena had been reported, but, it was also quite possible that he could have experienced none of these things. The questionnaire was compiled from the many subjective accompaniments of flicker that have been reported by such experimenters as Walter and Walter (1949), Ulett and Johnson (1958), Mundy-Castle (1953), and Bach, Sperry and Ray (1954). The Questionnaire used in this study is presented in Appendix II.

The use of differing flicker frequencies and learning tasks with the same individuals introduced the problem of designing an experiment that would equate for the effects of order, trials, practice, and fatigue. The present study has attempted to do this through the choice of a Graeco-Latin Square Design in which each treatment in any classification is combined once and only once with each treatment in each other classification. Using seven flicker conditions and seven lists of nonsense syllables, a seven by seven Graeco-Latin Square was set up with flicker conditions systematically randomized according to the formula developed by Williams (1949).

In the Graeco-Latin Square shown in Figure 3, the seven flicker conditions are represented by Latin letters, the seven lists of nonsense syllables are represented by Arabic numerals, the orders of presentation are represented by Roman numerals, and the trials are represented by Greek letters. Each square requires seven subjects, each of whom receives all seven flicker conditions and learns all seven lists. Each subject receives a different order of presentation, as well as a different combination of flicker frequency and list. Each replication of the experiment requires seven additional subjects

TRIALS

ORDER	α	β	γ	δ	ε	ζ	η
I	A-1	B-7	G-2	C-6	F-3	D-5	E-4
II	B-2	C-1	A-3	D-7	G-4	E-6	F-5
III	C-3	D-2	B-4	E-1	A-5	F-7	G-6
IV	D-4	E-3	C-5	F-2	B-6	G-1	A-7
V	E-5	F-4	D-6	G-3	C-7	A-2	B-1
VI	F-6	G-5	E-7	A-4	D-1	B-3	C-2
VII	G-7	A-6	F-1	B-5	E-2	C-4	D-3

Fig. 3. Graeco-Latin Square Design used in the study of the effects of intermittent light on learning. The seven flicker conditions are represented by Latin letters (A-0fps; B-3fps; C-6fps; D-9 fps; E-15fps; F-20fps; and G-75fps), the seven lists of nonsense syllables are represented by Arabic numerals, the orders of presentation are represented by Roman numerals, and the trials are represented by Greek letters.

and results in two or more subjects receiving each order and each combination of flicker frequency and list, or two subjects in each cell of the square. The analysis of variance of this design is based on 48 degrees of freedom for one replication or 97 degrees of freedom for two replications.

RESULTS

The results will be presented in three parts. The first part will be concerned with the number of recognitions related to rate of flicker. The second part will consist of the analysis of responses to the questionnaire and the relation between subjective responses and recognition scores. The third part will be concerned with individual differences in response to flicker conditions.

Before elaborating on these specific findings, the overall results of this study may be summarized. The greatest number of syllables were learned under conditions conducive to photic driving and the least number of syllables were learned under conditions where no photic driving normally occurs. However, individual differences in the effects of flicker on the learning of the individual as well as his responses to the questionnaire were found. It was also found that the subjects who learned poorly made the majority of the subjective responses both in number and intensity. In regards to flicker conditions it became evident that the two theoretically "no flicker" conditions, that of no light, no flicker (0 fps) and steady light, no flicker (75 fps) are not the same.

Number of Recognitions Related to Rate of Flicker

Analysis of variance showed flicker effects to be significant in the second Graeco-Latin square and to contribute the second greatest portion of the variance in the combined data. The results of the analysis of variance are presented in Table 1.

The mean number of syllables learned and the matrix of critical ratios by flicker condition are given in Table 2. Learning is best at six and nine flashes per second and poorest at three and 75 flashes per second. The mean number of syllables learned at no flicker is slightly above the grand mean (5.2), whereas the mean number learned at 15 flashes per second is below the grand mean, and the mean number learned at 20 flashes per second coincides with the grand mean. This distribution is graphically presented in Figure 4.

A comparison of performance under conditions of no light, no flicker (0 fps) and steady light, no flicker (75 fps) indicates that these two theoretically "no flicker" conditions are not the same, since the critical ratio for these two conditions (2.08) is very significant (.025 level of probability). The only other condition that differs significantly from no light, no flicker is that of three flashes per second with a critical ratio of 1.67 which is of borderline significance (.10 level of probability). Three flashes per second flicker does not differ significantly from steady light, no flicker.

A comparison of performance under conditions of no light and flickering light indicates that there is no significance since there is only one borderline probability of .10. However, there is a significant difference between steady light and flickering light with flickering light improving recognition at six and nine flashes per second.

Table 1

Analysis of Variance of the Individual Squares and Combined Data on the Effects of Flicker Condition on the Learning of Nonsense Syllables.

SOURCE OF VARIATION	SUM OF SQUARES	df	MEAN SQUARE	F	P
Graeco-Latin Square 1					
Subjects	88.69	6	14.45	3.39	.05
Trials	37.24	6	6.21	1.46	
Flicker	34.41	6	5.74	1.35	
Lists	10.41	6	1.74		
Residual	102.23	24	4.26		
Total	272.98	48			
Graeco-Latin Square 2					
Subjects	359.14	6	59.86	19.23	.01
Trials	26.44	6	4.41	1.89	
Flicker	55.71	6	9.29	2.97	.05
Lists	26.00	6	4.33	1.39	
Residual	74.75	24	3.11		
Total	542.04	48			
Combined Data					
Subjects	451.67	13	34.74	7.79	.01
Trials	23.38	6	3.90		
Flicker	40.39	6	6.73	1.51	
Lists	11.96	6	1.99		
Graeco-Latin Square	3.63	1	3.63		
Residual	290.07	65	4.46		
Total	821.10	97			

Table 2

Mean Number of Syllables Learned and Matrix of Critical Ratios by Flicker Condition

FLICKER FREQUENCY	MEAN	0	3	6	9	15	20	75
0	5.6	X	1.67*	NS	NS	NS	NS	2.08***
3	4.6		X	2.14***	1.48*	NS	NS	NS
6	6.4			X	NS	1.67*	1.50*	2.68****
9	5.9				X	1.32*	NS	1.72**
15	4.9					X	NS	NS
20	5.2						X	NS
75	4.5							X

* significant at the .10 level of probability
** significant at the .05 level of probability
*** significant at the .025 level of probability
**** significant at the .01 level of probability

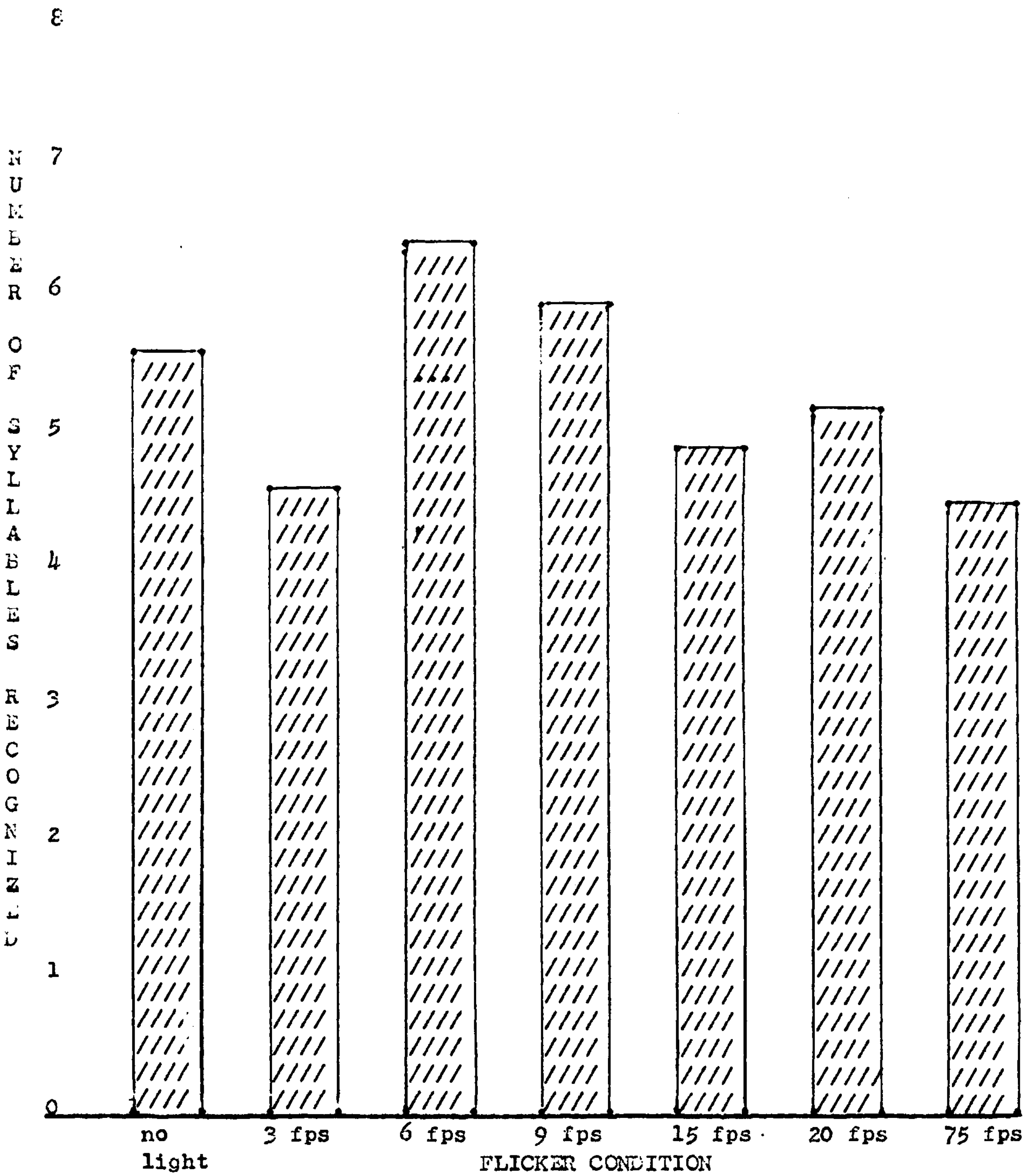

Fig. 4. Amount of learning (mean number of syllables recognized) for each condition of flicker.

<u>Analysis of Responses to the Questionnaire</u>

The responses from the questionnaires were classified as follows:

A. Sensations involving consciousness (hypnotized, strange, panic, dizzy, hazy, woozy, pass out, drowsy, mind blank, could not concentrate, loss of orientation, paralyzed, enclosure)

B. Sensations involving the eyes (fatigue, sting, watery, hurt, pressure, pain, functionless)

C. Sensations involving the muscles (blinking, twitching, jumping with light, violent or driven blinking, head and jaw muscles pulsating with light, tired)

D. Sensations involving unpleasant effects without specific reference to body part (headache, tense, nausea, queasy, chills up and down spine, turning in pit of stomach, muscles tense in back of neck, bad feeling, depressing)

The responses were also rated as to intensity on a scale of one through five, with anticipatory effects rated as one, slight effects as two, moderate effects as three, large effects as four, and extreme effects as five. The varieties and intensities of subjective responses reported by subjects as a result of exposure to flickering light are given in Table 3.

The number and intensity of subjective responses by classification according to subject are given in Table 4. The patterning of responses indicates no particular likenesses between subjects receiving

Table 3

Varieties and Intensities of Subjective Responses Reported by Subjects as a Result of Exposure to Flickering Light

CLASSIFICATION	INTENSITY	RESPONSES	TOTAL INTENSITY
A. Sensations involving consciousness			
Hyponotized	5	1	5
Strange	3	1	3
Hazy	5	1	5
Woozy	5	1	5
Pass Out	5	1	5
Could Not Concentrate	2	3	6
Enclosure	4	1	4
B. Sensations involving eyes			
Watery	5	1	5
Hurt	5	1	5
Pressure	3	3	9
C. Sensations involving muscles			
Blinking	2	3	6
Twitching	2	2	4
Tired	2	1	2
D. Sensations involving unpleasant effects without specific reference to body part			
Headache	4	1	4
Tense	4	2	8
Queasy	3	1	3
Muscles tense in back of neck	4	1	4
Depressing	3	1	3

Table 4

Number and Intensity of Responses by Classification According to Subject

SUBJECT	TOTAL		A		B		C		D	
	R	I	R	I	R	I	R	I	R	I
1	1	2	1	2						
2	2	9	1	4	1	5				
3	6	23	1	5	2	8	1	2	2	8
4	6	18	2	7			2	4	2	7
5	-	-								
6	-	-								
7	2	4					2	4		
8	1	3			1	3				
9	3	10	1	3	1	3			1	4
10	-	-								
11	4	12	2	10			1	2	1	2
12	-	-								
13	1	2	1	2						
14	-	-								

R: Responses

I: Intensity

the same order of presentation.

The number of responses and total intensity of the responses of the seven subjects whose mean number of syllables learned was greater than the grand mean (Group 1) was compared with the number of responses and total intensity of the seven subjects whose mean number of syllables learned was less than the grand mean (Group 2). Group 1 accounted for 24 per cent of the responses and 25 per cent of the intensity, while Group 2 accounted for 76 per cent of the responses and 75 per cent of the intensity. Correlation between mean number of syllables learned and intensity of subjective responses was -.81 which is very significant. These findings indicate that those subjects who learned poorly made the majority of the subjective responses both in number and in intensity. These responses showed no particular concentration in any one area of sensation.

Individual Differences in Response to Flicker Condition

In all areas of behavior individual differences among subjects constitute an important factor. This is particularly true of learning in general and was clearly indicated by this study. The analysis of variance showed significant contribution for subjects in the individual squares and in the combined data.

Since two subjects served in each condition, it was possible to compare the performance of two individuals under the same set of conditions. Individual differences were evidenced not only in the basic learning process but also in the effects of the flicker. The mean number of syllables learned by each subject and the correlation coefficient for pairs of subjects receiving the same order by flicker condition are given in Table 5.

The mean number of syllables learned by the fourteen subjects ranged from .8 to 8.9, with significant differences between the means of all subjects receiving the same order except the two subjects (four and eleven) who received Order IV. The mean number of syllables learned by subject four was 3.8 and the mean number learned by subject eleven was 3.7, but the correlation coefficient for Order IV was zero, with subject four learning best at nine and 15 flashes per second, and subject eleven learning best at zero and 20 flashes per second. Since their responses to the questionnaire indicate some similarity, it seems that although their total performance was similar, they actually reacted differently to the rates of flicker.

The correlation coefficient for Order II (.82) was very significant, but the mean number of syllables learned by subject two differed significantly from the mean number learned by subject nine. Subject two, with a mean of 5.4, learned best at six flashes per second and subject nine, with a mean of 8.9, learned equally well at zero, three, and six flashes per second. In terms of subjective responses, subject two reported one sensation involving consciousness with an intensity of four and one sensation involving the eyes with an intensity of five. Subject nine reported one sensation involving the consciousness with an intensity of three, one involving the eyes with an intensity of three, and one sensation involving unpleasant effects with no specific

Table 5

Mean Number of Syllables Learned by Each Subject and the Correlation Coefficient for Pairs of Subjects Receiving the Same Order of Conditions.

ORDER	SUBJECT	MEAN	R	p
I	1	6.7	-.75	.05
	8	3.3		
II	2	5.4	.82	.05
	9	8.9		
III	3	4.6	.29	NS
	10	7.7		
IV	4	3.8	.00	NS
	11	3.7		
V	5	6.8	.32	NS
	12	..8		
VI	6	4.8	-.50	NS
	13	7.4		
VII	7	2.8	-.70	NS
	14	6.7		

reference to body part with an intensity of four.

The correlation coefficient for Order I (-.75) was significant at the .05 level of probability, but the mean number of syllables learned by these two subjects also differed significantly. Subject one, with a mean of 6.7, learned best at zero and 15 flashes per second, and subject eight, with a mean of 3.3, learned best at six flashes per second. In terms of their subjective responses, subject one reported one sensation involving consciousness with an intensity of two, and subject eight reported one sensation involving the eyes with an intensity of three.

DISCUSSION

Although no specific hypothesis was to be tested, an assumption was made that learning in man would be affected by sub-fusion flicker. While the results of this study do not offer conclusive evidence to support this assumption, they do indicate a tendency that might, with a larger sample and certain revisions, become significant. The variance due to flicker was not significant in the first seven subjects, but it was significant in the second seven subjects and contributed the second greatest portion of the variance in the combined data. Recognizing the fact that the current research was an exploratory attempt to find trends that would warrant further research and also the fact that small differences have greater practical significance with fewer replications, further analytic procedures were justified to learn what are the effects of sub-fusion flicker on learning in man and whether or not these effects are a function of the flicker frequency.

The results of this study indicate that learning is best under flicker conditions conducive to such visual effects as Bidwell's phenomena, gamma maximum, brightness enhancement, and change of color. However, the experiment was administered with eyes closed to eliminate as many visual effects as possible and the results of the questionnaire indicate success in this maneuver. The only sensations involving the eyes reported by the subjects were tearing, pressure, and pain.

Although the questionnaire was not adequately designed to fully record visual effects it is reasonable to assume that if such effects had occurred repeatedly the subjects would have reported them.

Studies by Ulett and Johnson (1958) and Mundy-Castle (1953) indicate that the peak driving response occurs in the region of eight to ten flashes per second and that very few individuals drive at frequencies below four flashes per second. There have been no reports of driving at 75 flashes per second. Relating the research findings to the conditions used in this study, it is indicated that there is no driving at three flashes per second, borderline driving at six flashes per second, optimum driving at nine flashes per second, reduced driving at 15 flashes per second, increased driving at 20 flashes per second (but not as great as at nine flashes per second), and above driving range at 75 flashes per second (steady light, no flicker). The findings of this study indicate a mean performance under up-trend driving (six, nine and 20 flashes per second) of 5.8 as compared with 4.6 for no driving including down-trend (three, 15 and 75 flashes per second).

From the evidence advanced it seems indicated that there are two effects of sub-fusion flicker on learning in man. One might be the distracting or noxious effect referred to by Johnson et al., (1960) and is acting at three, 15 and 75 flashes per second. The other effect seems to be an enhancement effect and is acting at six, nine, and somewhat at 20 flashes per second.

Two possible explanations of why photic driving at six and nine flashes per second would improve learning have been considered. First, other studies (Bach et al., 1956; Johnson and Ulett, 1958) have indicated that photic driving, especially at nine flashes per second, has a drowsy or related effect. It may be that if subjects were too anxious or tense, this effect may alleviate some of the anxiousness or tenseness, thus improving performance. The second explanation considered was that the subjects may have increased their effort to overcome unusual effects or difficulties due to drowsiness or related effect, and by so doing improved their performance. However, neither of these two explanations can be fully accepted because the findings indicated that subjective effects seemed to make performance worse.

Johnson et al., (1960) in their study were primarily concerned with the relation of paroxysmal activation to learning and memory. They reported that paroxysmal activation is rare with stimulation below ten flashes per second and that the most paroxysmal activation occurs at or near 15 flashes per second. Since the results of the current study indicate that learning at 15 and 20 flashes per second was significantly less than learning at six and nine flashes per second, it is possible that learning is deterred by paroxysmal activation. However, since this is not a common electroencephalographic response in normal subjects, and since electroencephalographic recordings were not available for the fourteen subjects, this remains but a slight possibility.

Explanation of better learning in photic driving ranges, and poorer learning in paroxysmal activation ranges will not account for the poorest learning occurring at three and 75 flashes per second. Comparison of learning at steady light, no flicker (75 fps) and no light, no flicker (0 fps) indicates that these two theoretical "no flicker" conditions are not the same. Neither can the poorer learning at 75 flashes per second be explained in terms of greater intensity of light causing greater noxious effect because learning at three flashes per second is also significantly less than learning at zero flashes per second. While there may be special distractive effects with three flashes per second flicker and with steady light, it is not clear from this study why six and nine flashes per second flicker should not also have such effects.

The individual differences in the effects of flicker on the learning of the individual and his responses to the questionnaire is consistent with the findings of Johnson et al., (1960) and Bach et al., (1956). In a study designed to investigate cortical activity and cognitive functioning, Johnson et al., reported that with respect to the distracting effect of intermittent photic stimulation per se on cognitive functioning, there was no consistent impairment in performance during flicker. However, they further reported that although impairment during flicker was significant on only two of the tasks, approximately half of the subjects showed some impairment during one or more of all the tasks. They were using flicker frequencies most conducive to paroxysmal activation for "activators" and 15 flashes per second for "non-activators."

Their findings were consistent with those of Bach et al., (1956) who in a study designed to investigate some of the effects of flicker on a motor task, speed of tapping, found impairment on a simple form of the task but no impairment on a more complex form. Although the number of trials per subject was large, the actual number of subjects in the simple and complex procedures was small, four and three, respectively. Their consistent findings were significant individual differences in the responses to flicker, and while not conclusive, indicated a need to investigate further the effects of flicker.

The results of the current study indicate that an inverse relationship exists between the number of recognitions and the number of subjective responses. Although subjective responses of subjects have been reported and classified by Walter and Walter (1949), Mundy-Castle (1953), and Bach et al., (1956), there have been no studies directed toward the relation between subjective responses and performance level. It is possible that the poorer learners were aware of their performance level and were more prone to justify it by reporting subjective responses. However, the simplicity of the learning task and the nature of the measuring device would indicate that this is not an adequate explanation. The questionnaire was used chiefly as a means of securing information about visual effects that might occur despite the closure of the eyes, and was not incorporated into the experimental design as a means of quantifying subjective responses. Therefore, although the questionnaire can only be considered as an auxiliary device in this study, it has indicated a trend that would warrant further research.

The attempt, in this study to ascertain the effects of differing flickering conditions on the same type of learning in the same individuals, indicates that it is possible to use this type of experimental design for this purpose. However, the following changes and revisions are recommended:

1. Use of a combined factorial and Graeco-Latin Square design to provide more extensive analysis of interactions.

2. Administer the experiment in two sessions counterbalanced to control for experimental error.

a. Design one session to test learning under conditions of no light, no flicker and steady light, no flicker; and to record subjective responses to each of the sub-fusion flicker conditions.

b. Design one session to test learning under the subfusion flicker conditions.

3. Revise and counterbalance the questionnaire to provide more adequate control of subjective response quantification.

4. Obtain electroencephalographic recordings in order to determine the degrees of photic driving or paroxysmal activity during learning session.

5. Secure a psychologic test measure of personality for each subject.

With the additional information secured through the above revisions to the basic research design it would be possible to correlate the findings with both psychological and psychophysiological research in this area.

SUMMARY AND CONCLUSIONS

The effects of differing flicker conditions on the same type of learning in the same individuals were studied in fourteen students from the introductory psychology class at the University of Arizona with the following findings:

1. Marked individual differences exist in the effects of flicker on the learning of the individual and his responses to the questionnaire.

2. An inverse relationship exists between number of recognitions and number and intensity of subjective responses.

3. The greatest number of syllables were learned under conditions conducive to photic driving, and the least number of syllables were learned under conditions where no photic driving occurs. Learning was greater during flicker at six and nine flashes per second than during steady light.

4. The two theoretically "no flicker" conditions, that of no light, no flicker and steady light, no flicker are not the same. More syllables were learned during no light than during steady light conditions.

5. Several explanations for the effects of these varying light conditions on verbal learning were advanced, but the data from this study does not provide conclusive evidence relating to the interpretation of the results obtained.

APPENDIX I.

LISTS OF NONSENSE SYLLABLES USED IN RECOGNITION METHOD

LIST	1	2	3	4	5	6	7
	GUC	YIQ	MEC	JIH	YIK	MEJ	VEQ
	XOF	NIJ	SAJ	MEQ	XOB	SUQ	YIJ
	WEF	ZOP	TIV	XOQ	GIY	FUB	ZEH
	NUK	LIW	ZUT	TUH	YUN	VIH	NIZ
	MIV	ZAS	MIB	NIQ	KIH	YAB	YOT
	PIW	YOJ	RUW	JUZ	XAR	ZER	KAQ
	GEX	VUM	QOD	SEB	JUF	BEP	TAH
	KEH	JAT	JIK	XAY	VOH	QIY	KIG
	NOJ	LEB	TEF	KIH	QOY	QID	XEY
	BEH	GOK	YIB	GEF	ZIS	BOF	TEV
	CUY	XID	JEZ	YIC	JIW	WOG	VIB
	RUY	FUH	YUG	QID	WUT	CUK	BIP
	WUQ	HIF	PAQ	SIJ	PEH	SIH	QEY
	MEZ	NUX	SIW	MUW	KEX	YOH	ZAW
	PAF	VEP	QUP	QEB	PIY	VAK	JEG
	BUQ	XOC	NAK	KAJ	VUZ	CEK	BEJ
	RIX	HUW	RUZ	YUW	QAM	WUK	NUB
	CIW	GUW	NEH	GIC	ZAT	QUN	QOM
	XON	JEH	ZIN	TOV	WOJ	FOQ	JUC
	KAZ	FEP	POH	NAH	GEB	MIF	XUJ

APPENDIX II

QUESTIONNAIRE

SUBJECT____________________

EYES:

FATIGUE____ STING____ WATERY____ HURT____

PRESSURE____ PAIN____ FUNCTIONLESS______

OTHER______________________________(describe briefly)

MUSCLE:

BLINKING____ TWITCHING____ JUMPING (with light)____

VIOLENT OR DRIVEN BLINKING_____

HEAD AND JAW MUSCLES PULSATING WITH LIGHT______

OTHER______________________________(describe briefly)

CONSCIOUSNESS:

HYPNOTIZED____ STRANGE____ PANIC____ DIZZY____

HAZY____ WOOZY____ PASS OUT____ DROWSY____

MIND BLANK__________ COULDN'T CONCENTRATE____

LOSS OF ORIENTATION______ PARALYZED________

OTHER______________________________(describe briefly)

GENERALIZED:

HEADACHE____ TENSE_____ NAUSEA_____ QUEASY____

CHILLS UP AND DOWN SPINE_____ TURNING IN PIT OF STOMACH__

MUSCLES TENSE IN BACK OF NECK__________ BAD FEELING____

OTHER______________________________(describe briefly)

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