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The Long Term Effects of Prefrontal Lobotomy on the Flicker Fusion Frequency of Light

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THE LONG TERM EFFECTS OF PREFRONTAL LOBOTOMY ON THE FLICKER FUSION FREQUENCY OF LIGHT

by

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LIFE

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He was graduated from St. Thomas Military Academy, St. Paul, Minnesota, in 1943, and from the University of Minnesota in 1948 with the degree of Bachelor of Arts. The major field of concentration was psychology.

From 1945 to 1947 the author was in the Medical Corps of the United States Army. The last year of army service was spent at the Tripler General Hospital in Honolulu, Hawaii, where he served under the supervision of the psychiatrist, administering and interpreting psychological tests and assisting in the therapy program of the psychiatric unit. During part of 1949 the writer took graduate courses in psychology at the University of Minnesota. From January, 1950, to January, 1951, he held the position of psychologist at the Willmar State Hospital at Willmar, Minnesota. He began his graduate studies at Loyola University in February, 1951.

The author has one article currently in publication dealing with the late social and psychological features of prefrontal lobotomy: "The Long Term Evaluation of Prefrontal Lobotomy in Chronic Psychotics," Journal of Nervous and Mental Disease (accepted for publication September 14, 1951).

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CHAPTER I

INTRODUCTION

Flicker fusion frequency is defined for the purposes of this study as the number of light-dark cycles per second at which a physically intermittent light is just perceived as a steady light. The retinal response to every separate light stimulus is slightly longer than the duration of the light phase. This phenomenon is known as "retinal lag." At a certain speed of the light-dark cycles the dark phase is not registered as such, and the rapid series of light flashes produces the subjective impression of an uninterrupted, continuous stimulus.

The bulk of previous work with flicker phenomena has been concerned largely with the peripheral or retinal factors influencing flicker fusion frequency and the theoretical implications of the findings for visual physiology. Since 1945 there has been an ever-growing interest in the application of flicker measures to such clinical problems as fatigue, anoxia, anxiety, and cardiovascular pathology.

Recently, however, there has developed an interest in the central processes of the brain and their effect on fusion frequency. There has been some evidence to indicate that cerebral trauma influences this phenomenon; however, this area of investigation has scarcely been touched. Actually, there have been only two studies dealing with the removal of frontal lobe tissue in humans and its effect on flicker fusion. One by Halstead with

frontal lobectomies (removal of both cortical and subcortical structures) has pointed to a permanent depression of the fusion point together with less variability within the individual (that is, greater accuracy) in locating this point, when comparison is made with normals and nonfrontal lobectomies. Halstead has interpreted his findings to show a less efficient functioning of the brain as a result of frontal lobe injury. He has combined the flicker fusion test in a battery to yield an "impairment index" which supposedly reflects damage to the frontal lobes which is not apparent from clinical neurological examinations, formal psychometric studies, pneumoencephalography, electroencephalography or clinical biochemical tests. If it is possible to use flicker fusion determinations to detect frontal lobe lesions which may remain behaviorally "silent" for many years of the individual's life, the practical value as well as the theoretical value would be enormous. Halstead believes that such is the case. However, another investigation, by the Columbia-Greystone Associates, dealing with topectomy, a procedure involving the surgical removal of presumably healthy cortical areas for the relief of psychosis, has found no evidence for a lasting depression of fusion point nor for decreased intra-individual variability. They did find, however, that some patients showed a transient loss in this function which returned to normal three months postoperatively.

These two studies served as the impetus for the present investigation. Since lobectomy, where both cortical and subcortical tissue is removed, yielded a lasting depression of fusion level together with decreased variability, and topectomy, where <u>only</u> cortical areas are removed, did <u>not</u> yield this

depression in fusion point nor the decreased variability, the question quite reasonably arose as to whether or not prefrontal lobotomy, where damage to the cytoarchitectural areas of the cortex is negligible but damage to subcortical structures is extensive, would reveal a depression in fusion frequency and reduced variability in locating this point. Thus, it would appear that since the ablation of large cortical areas is not reflected in subsequent flicker fusion determinations, then if the extensive damage to subcortical structures incurred in lobotomy is not reflected either, one may well question the validity of Halstead's conclusion of a linkage between flicker fusion frequency and frontal lobe function, and along with it, the value of an impairment index which is so grossly insensitive to lesions of this magnitude. If, on the other hand, there is evidence to show that disruption of the frontal white fibers is reflected in flicker fusion determinations there will have been gained new insight into the problem of frontal lobe damage, and one can examine with renewed interest the possibilities of an impairment index and the concept of "biological intelligence" which Halstead has advanced.

To the interested observer familiar with psychosurgical patients it has been a frustrating experience to note that despite the extensive damage to brain tissue, which _a priori_ could be expected to be reflected in objective physiological or psychological measures, such damage is not found with consistency by the use of the usual tests, despite the fact that there may be alterations in the patient's behavior and interpersonal relationships. Another point in this connection is the postconcussion syndrome which is an extremely challenging problem for diagnostic differentiation. One finds severe subjective complaints contrasted with the absence of definite neurological findings

which can be obtained by conventional clinical methods. The problem of detecting the malingerer has made this a crucial issue. Halstead's findings have held forth some hope that perhaps such an indicator has been found in the determination of the flicker fusion frequency. The first question posed for the present study then is this: Do the frontal lobe lesions sustained in prefrontal lobotomy result in a lowered fusion point and in a reduced variability in detecting this point when the lobotomized subject is compared with normal and psychotic control subjects of comparable background?

It is hoped also to discover what effect age has on the flicker fusion frequency. While there have been a number of investigations dealing with this relationship most of them have fallen far short of the controlled study. That is to say, most of the studies have dealt with relatively small numbers of subjects, or only with narrow age ranges, or there has been an uncontrolled auditory component in the apparatus, or a failure to maintain a constant light-dark ratio throughout the experiment. It is believed that these factors have all been controlled or eliminated in the present study. One especially arresting omission in previous studies dealing with age has been the failure to determine the effect of age on the degree of accuracy which the subject shows in locating his fusion point on successive trials. All in all, it was strongly felt by the present investigator that a study of the effect of age on fusion frequency would be well worth the effort, especially since lobotomized and nonlobotomized psychotic subjects were available in addition to the normal subjects with which the age factor study was primarily concerned.

The present investigation was designed to answer the following specific questions:

1. Do frontal lobe lesions incurred in lobotomy result in a lasting depression of flicker fusion frequency when lobotomized patients are compared with psychotic control and normal subjects?

2. Do lobotomized subjects display a reduced variability within the individual (i.e., greater consistency) in locating the fusion point when compared with psychotic control and normal subjects?

3. What effect does age have on the fusion level of normal and psychotic subjects?

4. What effect does age have on the degree of variability within the individual (the accuracy) in locating the fusion point?

To answer these questions and to assess the relevant findings in the light of previous research is the purpose of the present investigation.

CHAPTER II

REVIEW OF THE LITERATURE

When an observer looks at any source of intermittent illumination, the light may appear to flicker or it may appear to be steady, depending on a number of factors. The point where some change in physical stimulation causes the flickering sensation to disappear, or the flickering light to become steady, has been referred to variously as critical flicker frequency, fusion frequency limen, and flicker fusion frequency. The last of these terms is the one which will be employed throughout the present paper. At a very slow rate each flash of light can be perceived separately. With an increasing rate a coarse flicker is experienced at first, then a fine flicker, and when the rate is further increased the flashes become superimposed and the intermittent light is perceived as a steady illumination, a stage that is referred to as fusion. The rate at which this phenomenon takes place is called the fusion point.

The experimental study of flicker fusion may be properly considered to begin with the work of Talbot[1]. Talbot formulated the relationship between the period of light and the period of darkness as they are combined to provide

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1 H. F. Talbot, "Experiments on Light," London and Edinburgh Philosophical Magazine and Journal of Science, 3rd Series, V, 1834, 321-334.

the level of luminous intensity. This formulation is now generally referred to as Talbot's law. He wrote: "The intensity of light and the time of the body's remaining at any given point of the circle are each inversely proportional to the circumference of the circle it [a burning coal] describes; it follows that they must be directly proportional to each other. This suggests a very important idea, namely, that time may be employed to measure the intensity of light."[2] Talbot's law, concerned as it is with the magnitude of the sensory impression, has been experimentally verified by different investigators. When the sensory effect is one of fusion, the level of illumination is equivalent to the original illumination multiplied by the fraction which the actual duration of illumination is of the total duration of a complete cycle of illumination and darkness. From this stated relationship, it is evident that a reduction in the duration of illumination results in a reduction of perceived intensity.

The next important step in this area was that which related the frequency of intermittence and intensity of the light, the so-called Ferry-Porter law. Ferry, in 1892, stated that "Retinal persistence varies inversely as the logarithm of the luminosity."[3] Porter, ten years later, phrased it as "The speed with which the disc must be driven in order that flicker may just vanish varies directly with the logarithm of the illumination of the disc."[4]

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2 Ibid., 328.

3 Ervin S. Ferry, "Persistence of Vision," American Journal of Science, XLIV, 1892, 207.

4 T. C. Porter, "Contributions to the Study of Flicker," Proceedings of the Royal Society, LXX, July 29, 1902, 318.

Thus there is a second measurable relationship: the critical frequency is proportional to the logarithm of the illumination intensity. In plotting this relationship, the critical frequency tends to rise with an increase in intensity, forming a plateau in the middle of the curve, then rises again with the intensity up to a certain point, from which it declines with further increases in intensity. The lower portion of the curve apparently represents the function of the rods, and the upper portion the function of the cones.[5] Hecht and Smith[6] found that the relation of critical frequency to intensity is a single function for foveal areas between two degrees of visual angle, where the retina contains only cones, and a dual function for the larger regions, which contain rods in addition to cones. Besides Talbot's law and the Ferry-Porter law there are several other regular findings or laws, so that it may be said that from the standpoint of physical optics flicker phenomena have been intensively studied and the results well formulated in terms of physical laws.

The relative duration of light and dark periods also affects flicker fusion frequency. For a given intensity, the frequency is maximal when the light-dark ratio is equal, i.e., one to one. When the light phase is longer than the dark phase, the flicker fusion frequency is lowered. In terms of intensity, the longer the light phase, the higher the intensity required for

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5 S. H. Bartley, Vision, A Study of Its Basis, New York, 1941, 117-119.

6 Hecht and E. L. Smith, "Intermittent Stimulation by Light. VI. Area and the Relation Between Critical Frequency and Intensity," J. Gen. Physiology, XIX, 1936, 979-989.

a given flicker fusion frequency.[7] Granit and Harper[8], 1930, have pointed to the size of the test patch as another factor influencing fusion frequency. The larger the area, the higher the maximum fusion frequency. The explanation of this relationship has been in terms of the neural structure of the retina.

The above results have been interpreted by Hecht, for one, in terms of a photochemical theory of visual processes. He states: "The general form of most of the existing relationships in the effects of intermittent illuminations are already apparent in the characteristics of the behavior of the initial photochemical event."[9] Others have utilized the material to demonstrate features of retinal processes.

The physical conditions giving rise to the sensation of flicker or to the sensation of steady illumination (fusion) can be stated with some degree of precision. What is essentially involved is a light source which can deliver an intermittent intensity of luminosity to the eye. This source may be a constant beam of light cut periodically by a revolving sector disc (episcotister) just as an electric fan revolving in front of a light bulb gives the impression

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7 P. W. Cobb, "The Dependence of Flicker on the Light-Dark Ratio of the Stimulus Cycle," J. of the Optical Society of Amer., XXIV, 1934, 107-113.

8 R. Granit and P. Harper, "Comparative Studies on the Peripheral and Central Retina: II. Synoptic Reactions in the Eye," Am. J. Physiol., XCV, 1930, 211-228.

9 S. Hecht, A Handbook of General Experimental Psychology, Worcester, Mass., 1934, 704.

of flicker and the impression of dimming the brightness of the light. It is also possible to use a special form of lamp, such as that suggested by Henry[10] which goes on or off completely at a rapid rate when properly energized. Whichever type of light source is used, so long as the light is in the range of moderate brightness and the flashing is maintained at a rate of twenty times on and off each second, it will appear to flicker to any observer with normal vision. If the rate is raised to seventy times a second practically everyone will see a steady light. The transition point from a flickering light to a fused or steady light may be found for any observer somewhere between two light-dark cycles and eighty cycles, depending on certain determining conditions. What this transition point signifies depends on the theoretical frame of reference of the investigator. Until late in the nineteenth century the point was considered to be the place where persistence of vision formed or failed. Sherrington[11] in 1897 developed the idea that flicker was a psychological contrast phenomenon, the presence or absence of contrasting experience of light and of dark. McDougall[12] studied flicker in terms of the physiological duration of the retinal impression. More recent workers have regarded

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10 F. Henry, "An Electronic Apparatus for Testing Fatigue by the Visual Flicker Method," J. of Exp. Psychol., XXXI, 1942, 538-543.

11 C. S. Sherrington, "On Reciprocal Action in the Retina as Studied by Means of Some Rotating Discs," Journal of Physiology, XXI, 1897, 33-54.

12 W. McDougall, "The Sensations Excited by a Single Momentary Stimulation of the Eye," British Journal of Psychology, I, 1904, 78-113.

flicker as the vanishing point of illumination differences, as experiential temporal homogeneity versus heterogeneity, as time differentiation threshold, and as discontinuous illumination with temporal induction of continuity. As Landis has aptly commented: "Seemingly this experience [flicker-fusion] which seems essentially so simple is open to a variety of interpretations, no one of which is completely satisfactory."[13]

Aside from the strictly physical characteristics of flicker fusion investigations there are a host of physiological and psychological considerations which must be evaluated. One of the questions which must be raised is that of a possible practice effect. One of the most extensive investigations reporting evidence of a practice effect was that of Miller[14] who in 1942 worked with forty-four boys and thirty-four girls between the ages of six and eighteen years. These children were reportedly free of ophthalmological pathology. Over a period of five test sessions he found an increase in flicker fusion frequency for both sexes together with a reduction of the variability in the determinations. Although no tests to determine the statistical significance of the increase in frequency or the decrease in variability were performed, the author declares the differences to be significant and indicative of the presence of a definite practice effect. Aside from the obvious

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13 C. Landis, "Something About Flicker Fusion," Scientific Monthly, LXXIII, Nov., 1951, 310.

14 V. L. Miller, "The Critical Frequency Limen for Visual Flicker in Children Between the Ages of Six and Eighteen," Genetic Psychology Monographs, XXVI, Aug., 1942, 3-53.

statistical shortcomings of this study there was also an extremely crude instrument calibration for determining frequency of light-dark cycles and an inadequate handling of the acoustical problem for his apparatus.

There is overwhelming evidence by a large number of investigators pointing to the opposite conclusion of that of Miller. Lythgoe and Tansley[15] in 1929, O'Brien[16] in 1939, two studies by Simonson and Enzer[17 18] in 1941, Brozek and Keys[19] in 1944, Tyler[20] in 1947, Misiak[21] in 1948, Miles[22] in 1950,

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15 R. J. Lythgoe and K. Tansley, "The Adaptation of the Eye: Its Relation to the Critical Fusion Frequency," Special Report London Medical Council, No. 134, London, 1929.

16 B. O'Brien, "Critical Fusion Frequency and Visual Fatigue," Conference on Visual Fatigue, National Research Council, Wash., D. C., 1939, 1-14.

17 E. Simonson and N. Enzer, "Measurement of Fusion Frequency of Flicker as a Test for Fatigue of the Central Nervous System—Observations on Laboratory Technicians and Office Workers," J. Industrial Hygiene and Toxicology, XXIII, 1941, 83-89.

18 E. Simonson and N. Enzer, "The Effect of Amphetamine (Benzedrine) Sulfate on the State of Motor Centers," J. Experimental Psychology, XXIX, 1941, 517-523.

19 Josef Brozek and Ancel Keys, "Flicker Fusion Frequency as a Test of Fatigue," J. Indust. Hyg. and Toxicology, XXVI, May, 1944, 169-174.

20 D. B. Tyler, "The Fatigue of Prolonged Wakefulness," Federation Proceedings Amer. Soc. Exp. Biol., VI, March, 1947, 218-224.

21 H. Misiak, "Practice Effect on Critical Flicker Frequency Measures," J. Gen. Psychol., XXXVIII, 1948, 251-256.

22 Paul W. Miles, "Flicker Fusion Fields: II. Technique and Interpretation," American Journal Ophthalmology, XXXIII, 1950, 1069-1077.

and Fabricant and Murrows[23] in 1951, all failed to find any evidence of a practice effect, but found instead that flicker fusion frequency was a relatively stable characteristic of the individual. To be more specific, Brozek and Keys, referred to above, found readings in fifty-six normal adult subjects ranging in age from 18 to 60 years to vary less than one per cent from day to day whereas the improvement with practice on a pattern-tracing task given at the same time was striking. Tyler, in the study cited, used 600 subjects to determine the presence of a practice effect but failed to find any evidence to support such a view. Misiak tested six subjects on ten different days spread over an eight-week period with eight readings taken each day. He too found that flicker fusion frequency does not reflect a practice effect but is an "inherent and stable characteristic of the individual."[24] This is, of course, assuming that there is no change in the subject's physiological condition over the period of testing.

With regard to the question of fatigue and its effect on flicker the findings of the various investigators show a greater disparity. Brozek and Keys[25] found a slight decrease in flicker fusion frequency when their subjects were doing hard physical work on a treadmill near the limit of capacity in a

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23 N. D. Fabricant and T. R. Murroughs, "Flicker Fusion Threshold in Normal Persons," Eye, Ear, Nose and Throat Monthly, XXX, 1951, 146-148.

24 Misiak, "Practice Effect on Critical Flicker Frequency Measures," J. Gen. Psychol., XXXVIII, 255.

25 Brozek and Keys, "Flicker Fusion Frequency as a Test of Fatigue," J. Indust. Hyg. and Tox., XXVI, 169-174.

temperature of 120 degrees Farenheit. There was also a slight decrease from day to day when their subjects performed two and a half days of very hard work with inadequate food intake. The decrease was much more noticeable from day to day on a regimen of hard work and total caloric starvation. The authors conclude that flicker fusion frequency level decreases when the human organism is exposed to an intensive enough strain but that changes are small and frequently not statistically significant. They point out that flicker fusion frequency cannot be considered to be a very sensitive indicator of "general fatigue." They were concerned with the possibilities of flicker in this area because Simonson and Enzer[26], working with laboratory technicians and office workers, had earlier suggested such a relationship with "general fatigue." A later, more rigorously controlled study (1950) by Brozek, Simonson, and Keys[27] at the University of Minnesota Physiological Hygiene Laboratory involving strenuous visual work (the identification of very small moving letters) for varying lengths of time at different illumination levels revealed a marked drop in fusion point. After four hours of such strenuous work under five foot-candle illumination the decrement in fusion level was significant well beyond the one per cent level. This decrement went along with an increased number of

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26 Simonson and Enzer, "Measurement of Fusion Frequency of Flicker as a Test for Fatigue of the Central Nervous System," _J. Indust. Hyg. and Tox._ XXIII, 83-89.

27 J. Brozek, E. Simonson, and A. Keys, "Changes in Performance and in Ocular Functions Resulting from Strenuous Visual Inspection," _Am. J. Psychol._, LVIII, 1950, 51-66.

complaints by the subjects as to over-all tiredness, muscular aches, and boredom. Of all the visual-type tests employed by the examiners flicker fusion frequency was the best indicator of the fatigue state produced. Tyler[28] reported results on the effect of experimental insomnia on flicker fusion level. His 600 subjects were kept awake from thirty to sixty hours without a resulting change in flicker level. A later study by Miles[29] also failed to disclose an alteration in flicker fusion frequency relatable to fatigue effects. The evidence is by no means complete to answer the question either way. The fact that neither Tyler nor Miles found a fatigue effect may be simply because they had not imposed a sufficiently great stress, that is, that their subjects had not reached the stage of fatigue where the effects would appear in a depressed flicker rate. Brozek and Keyes had already commented that flicker was not a very sensitive indicator of fatigue and when one considers the rather severe stress conditions that they had placed upon their subjects before there was an effect on flicker rate their comment seems justified. There is the added point that Brozek and Keys had severely restricted the caloric intake of their experimental subjects along with the pressures of hard physical work and extreme temperatures. To equate the "fatigue" states resulting from this severe regimen with the states resulting from prolonged wakefulness would hardly seem

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28 Tyler, "The Fatigue of Prolonged Wakefulness," _Fed_. _Proc_., VI, 218-224.

29 Miles, "Flicker Fusion Fields: II. Technique and Interpretation," _Am_. _J_. _Ophthal_., XXXIII, 1069-1077.

legitimate. Clearly, the crucial experiment to answer the question of fatigue effects on flicker fusion remains for the future.

There have been a number of interesting applications of flicker fusion determinations to physiological and pathological conditions. Enzer, Simonson, and Blankenstein[30] in 1941 studied flicker fusion frequency in hypothyroidism. Whereas a group of forty-five normal subjects had an average score of 45.0 flashes per second (or cycles per second) with a reported low of 40.0 flashes per second, thirteen hypothyroid patients had a mean value of 36.3 with a low value of 32.8 and a high of 40.8 flashes per second for the group. It should be noted that the high point of the patient group was barely as high as the minimum reading of the normal group, giving two very nearly discrete distribution curves.

Simonson, Kearns and Enzer[31] used flicker fusion frequency as a check on the therapeutic progress of four male subjects with diminished production of sexual hormone. In tests before and after four weeks of treatment consisting of the oral administration of methyltesterone the fusion level increased in all four patients from an average of 43.0 to 46.6. This increase was found to parallel an improvement in muscular performance on graded tasks.

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30 N. Enzer, E. Simonson, and S. S. Blankenstein, "The State of Sensory Centers in Patients with Hypothyroidism," Annals of Internal Medicine, XV, 1941, 659-665.

31 E. Simonson, W. M. Kearns, and N. Enzer, "Effect of Oral Administration of Methyltesterone on Fatigue in Eunuchoids and Castrates," Endocrinology, XXVIII, 1941, 506-512.

Gellhorn and Hailman[32] measured flicker fusion frequency and brain potentials simultaneously during anoxia and found parallel changes. The fusion level dropped from 51 to 49 during ten minutes of inhalation of 8.4 oxygen and to 43 after an additional eight minutes of inhaling 7.8 per cent oxygen. Recovery in normal air proceeded rapidly and was completed in the seventh minute after removal of the experimental condition. The authors showed that conditions of anoxia leading to a decline in fusion frequency are accompanied by typical anoxic changes in the brain as demonstrated by the electroencephalogram, and that degrees of anoxia which do not alter this measure have no effect on the electroencephalogram. They view the change in this visual function as due to an actual impairment of the neurons of the retino-geniculate-striate system.[33]

Along the same lines McFarland, Halperin, and Niven[34] found flicker fusion threshold to reflect the effects of anoxia and also to reflect the modification of the anoxia effects as glucose was administered to the subjects. Krasno and Ivy[35] found that patients with hypertension or anemia have a lower

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32 E. Gellhorn and H. Hailman, "The Effect of Anoxia on Sense Organs," *Fed. Proc. Amer. Soc. Exp. Biol.*, II, 1943, 122-126.

33 E. Gellhorn and H. Hailman, "The Parallelism in Changes of Sensory Function and Electroencephalogram in Anoxia and the Effect of Hypercapnia Under These Conditions," *Psychosomat. Med.*, VI, 1944, 23-30

34 R. A. McFarland, M. H. Halperin, and J. I. Niven, "Visual Thresholds as an Index of the Modification of the Effects of Anoxia by Glucose," *Am. J. Physiol.*, CXLIV, 1945, 378-388.

35 L. R. Krasno and A. C. Ivy, "The Response of the Flicker Fusion Threshold to Nitroglycerin and Its Potential Value in the Diagnosis, Prognosis, and Therapy of Subclinical and Clinical Cardiovascular Disease," *Circulation*, I, 1950, 1267-1276.

than normal or impaired flicker fusion threshold which improves after therapy. After the administration of 0.4 mg. nitroglycerin 99% of 216 patients with hypertension or coronary arterial disease showed a rise in flicker fusion threshold whereas in 206 normal subjects, without evidence of cardiovascular disease, flicker fusion was invariably lowered. They found in addition that for several patients where other cardiovascular indicators of impairment were not particularly indicative, but where flicker fusion was increased by nitroglycerin, the patients suffered from a coronary thrombosis during the following six months.

An extremely interesting finding came from the extensive cooperative study of semi-starvation at the University of Minnesota Physiological Hygiene Laboratory.[36] The apparatus used to determine flicker fusion frequency was the same one which the present author later used in his own investigation, with a few important changes and modifications added. They used a 2.5 volt flashlight bulb as a light source which was diffused by an opal glass test patch 2.5 cm. in diameter. A rotating disc, 15 cm. in diameter, with two open sectors of 22.5 degrees located opposite each other, served to interrupt the light. The test patch was viewed with both eyes through an enclosed tube 40 cm. in length. The authors fail to give any information as to the brightness of the test patch, a serious omission in an otherwise valuable piece of work. They also fail to state the visual angle which the test patch subtended on the

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36 Ancel Keys, et al., The Biology of Human Starvation, Minneapolis, 1950, II, 1094.

retina of the subject's eye, but from the data given (size of patch and visual distance to the patch from the eye of the subject) it can be calculated that the visual angle must have been approximately 3.6 degrees, an angle too large to insure solely foveal vision. At any rate, the authors determined the fusion level of 36 adult male volunteers in three successive testing trials. The subjects were tested prior to their semi-starvation period and again later at the end of the twenty-four weeks of semi-starvation. The flicker fusion frequency dropped from a mean of 36.3 flashes per second to a mean of 35.3. This was a small but consistent and thus statistically significant change (one per cent level of probability) reflecting the deterioration found in other functions. Indeed, flicker fusion determination was found to be one of the most sensitive indicators of psychophysiological change in the whole study.[37]

From the wide range of pathological conditions and pharmacological agents which have an effect on flicker fusion frequency it is readily apparent that this measure is extremely sensitive to physiological change within the organism. The essential characteristic seems to be that any condition or agent which serves to decrease the available blood sugar or oxygen to the retina or to the brain decreases the flicker fusion frequency. And conditions or agents which serve to increase the efficiency of the vascular supply increase the flicker fusion frequency. It would seem then, that this test is a measure of the functional efficiency of either or both the retina and the cortex. More recent thinking, particularly with regard to EEG findings and

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37 Ibid., I, 684-685.

photic driving, has served to minimize the role of peripheral structures (retina) and placed the emphasis on the central nervous system. This will be taken up in detail later, but for the present there are other findings which must be evaluated here.

There has been practically nothing done in the way of correlating more or less strictly psychological factors with flicker fusion. Only two attempts are available as yet in the literature and these are largely inadequate preliminary reports suggesting the possibility of wider applications of flicker research. Krugman[38] in 1947 found a lowered flicker fusion in combat air crew personnel who were suffering from operational neuroses (anxiety reaction). Interestingly enough, this threshold increased as the neurotic symptoms disappeared. The author makes no attempt to theorize as to the relationship involved here or to explain his findings on a physiological basis. He does suggest, however, the possibility of using flicker fusion determinations in conjunction with psychotherapy as a measure of the effectiveness of therapy. No one has attempted this as yet, but the suggestion is rather an engaging one. In the same vein, Tanner[39] in 1950 reported that the light-dark ratio as a determinant of flicker fusion frequency correlated in the +.50's with intelligence as measured by the American Council on Education Psychological

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38 H. E. Krugman, "Flicker Fusion Frequency as a Function of Anxiety Reaction; An Exploratory Study," Psychosom. Med., IX, 1947, 269-272.

39 W. P. Tanner, Jr., "A Preliminary Investigation of the Relationship Between Visual Fusion of Intermittent Light and Intelligence," Science, CXII, 1950, 201-203.

Examination, College Edition, in two different groups of twenty-five and twenty-one subjects each. Tanner observes that the shortest noticeable dark period for a light flash of some critical length promises to be a significant correlate of intelligence. Again, since there is no attempt to explain or relate this finding to a theoretical framework, the reviewer is left with a frustrated desire for closure.

Reasonably enough the question of possible sex differences in flicker fusion observations arose. In 1934 Hartmann[40] used thirty young children and thirty adults with normal visual acuity and normal color discrimination. The ages of the children ranged from six to eleven years, that of the adults from eighteen to twenty-five. A disc of two 180 degree cardboards was rotated by a D. C. motor with regulated speed which could be read at any given time from a tachometer coupled to the shaft of the motor. At first the author found a higher frequency for children; but in another series of experiments no differences were observed. This led him to the conclusion that the basic mechanisms involved in flicker fusion determination mature relatively early. He found, however, higher flicker fusion frequency in males for both the children and adult group. From the average deviations computed there was less variability in adults than in children, and less in females than in males.

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40 G. W. Hartmann, "Comparison of the Flicker Threshold in Children and Adults," Child Development, V, 1934, 122-126.

In 1942 Miller[41] used a beam of light interrupted by a disc connected to a reducing friction-disc drive which in turn was driven by a synchronous motor. There were two groups of subjects, 44 boys ranging in age from eight to nineteen years and 34 girls from six to nineteen years. The subjects were set for the disappearance of flicker (determination of fusion point) which they signaled by means of a telegraph key, this point being taken as the reading. Miller found that the range of flicker fusion frequencies extended from 31.6 to 73.0 cycles per second, but with no significant change of flicker fusion frequency with age. In line with Hartmann's findings the boys scored higher than the girls over this narrow age range. Miller found that the variability of the readings decreased with successive sittings, but the average flicker fusion frequency increased markedly from the first to the second session. This the author interpreted as practice effect. But as has already been pointed out subsequent research has pointed overwhelmingly to the unlikelihood of a practice effect in this function. The explanation probably lies in Landis'[42] studied observation: "I think it possible that much that has been called 'practice,' as well as much of the variability in results, is due to the fact that untrained observers do not know what to look for in observing flicker fusion." Thus the experimenter who neglects to give adequate instructions to

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41 V. L. Miller, "The Critical Frequency Limen for Visual Flicker in Children Between the Ages of Six and Eighteen," Genet. Psychol. Monogr., XXVI, Aug., 1942, 3-53.

42 Landis, "Something About Flicker Fusion," Scientific Monthly, LXXIII, 312.

his subjects, especially when young children are employed, will frequently find shifts in fusion level in successive trials which he impulsively, and erroneously, ascribes to "practice." Another reason for regarding Miller's conclusions with justifiable scepticism lies in the extremely crude interpolations and extrapolations of his calibration procedure. Some shortcomings of Hartmann's experiment also make the critical reader question his results. For example, the apparatus and the control of speed of the rotation were inadequate. There was also a lack of control of light and dark adaptation, fixation of the eyes, and size of the pupil.

A better designed and more carefully controlled investigation of the sex factor was carried out by Misiak[43] in 1947. By profiting from the shortcomings of design in his predecessors Misiak was able to present convincing evidence against the existence of a sex factor in flicker fusion determinations. He used two groups of fifty subjects each; one group ranged in age from 19 to 30 years of age and the other from 63 to 87 years. Thus the young group had 25 males and 25 females and the old group had the same number for comparison. The young group was composed of college students and the old group of inmates of two old age homes. Foveal flicker fusion frequencies were determined on the basis of eight readings from flicker to fusion and eight from fusion to flicker. Flicker was produced by a three-watt neon glow lamp. The circular test patch was five millimeters in diameter, subtending a visual angle of

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43 H. Misiak, "Age and Sex Differences in Critical Flicker Frequency," J. Exp. Psychol., XXXVII, 1947, 318-332.

forty-eight minutes. The brightness of the patch was six foot-candles. The apparatus was equipped with a small cathode ray ocilloscope and by means of the Lissajous figures appearing on the ocilloscope the dials of the resistor were calibrated and the rate of flicker controlled. The test patch was viewed from a distance of 12.8 inches. All the subjects were reportedly free of pathological eye conditions and were supposedly light-adapted to the three-watt neon glow lamp prior to testing. Misiak applied the t test for the significance of the difference in means between the males and females of both the young and the old groups separately and found no t values which even approached the five per cent level of probability. He had determined flicker fusion means for binocular vision and for dominant and nondominant eye tested separately. Misiak[44] later confirmed this finding of no sex differences with 182 males and 137 females using the same apparatus and under the same test conditions as in his earlier work. The absence of a sex factor operating in flicker fusion determinations has been accepted on the basis of the evidence to date and there have been no further attempts in the literature to reopen this question for investigation. It seems quite certain that of the many factors which do have an effect on flicker fusion sex is not one, and experiments are now designed without regard for the sex of the subject.

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44 H. Misiak, "The Decrease of Critical Flicker Frequency with Age," Science, CXIII, 1951, 551-552.

An especially interesting point is the suggestion by some earlier investigators[45 46] that age might have an influence on flicker fusion frequency. Since the age factor is an important consideration of the present investigation it might be well to consider some of the previous experimental findings with regard to this question.

Hartmann's 1934 study[47], which has already been referred to in some detail above under the investigation of sex differences, is interesting for he found that there were no significant differences in flicker fusion frequency between children and young adults. Miller, also referred to previously in the survey of possible sex differences, failed also to find any significant change in flicker fusion frequency with age over the narrow age range of young subjects which he investigated. He presents a scatter diagram[48] with fusion frequency plotted against age, and, although he has not computed a coefficient of correlation, it is readily apparent by inspection of his diagram that any correlation between age and fusion frequency is practically negligible and as

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45 K. Koffka, Growth of the Mind, New York, 1924, 62-63.

46 L. A. Riddell, "Use of Flicker Phenomenon in Investigation of Fields of Vision," Brit. J. Ophthal., XX, 1936, 385-410.

47 Hartmann, "Comparison of the Flicker Thresholds in Children and Adults," Child Develpm., V, 122-126.

48 Miller, "The Critical Frequency Limen for Visual Flicker in Children Between the Ages of Six and Eighteen," Genet. Psychol. Monogr., XXVI, 27.

likely to be positive as negative. Jones[49], although his primary concern was fatigue measurement, did not find a marked difference in fusion level with age for 275 truck drivers ranging from twenty-five to fifty years of age.

In 1941 Simonson, Enzer, and Blankenstein[50] used forty-seven normal subjects varying in age from ten to eighty years. They divided the subjects into four groups: group one (10 to 19 years) contained four subjects, group two (20 to 29 years) contained eighteen, group three (30 to 39 years) had ten, and group four (over 40 years), fifteen subjects. According to the authors this last group had subjects as old as eighty years of age, but no measures of central tendency or variability of age are given. They used a rotator arrangement where the beam of light from a twenty-five watt bulb was interrupted by a rotating disk with four identical openings. The area of the test patch was one square centimeter which at one meter subtended a visual angle of one-half degree. The visual angle was purposely made this small to insure foveal vision, but as Landis[51] has recently pointed out, to study only foveal, cone, or photopic vision the visual angle should be between one and two degrees since at less than one and beyond two degrees of arc, complications enter into the determinations. The speed of rotation was measured by a mechanical revolution counter. In the analysis of their results they considered separately minimum,

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49 R. R. Jones and R. R. Sayers, "Fatigue and Hours of Service of Interstate Truck Drivers," U. S. Public Health Serv. Bull., No. 265, Wash., D. C., 1941, 195-208.

50 E. Simonson, N. Enzer, and S. S. Blankenstein, "The Influence of Age on the Fusion Frequency of Flicker," J. Exp. Psychol., XXIX, 1941, 252-255.

51 Landis, "Something About Flicker Fusion," Sci. Mon., LXXIII, 311.

average, and maximum values of each group and found a decrease in maximum and average values but not in minimum values. The difference between the mean values of the various age groups was not statistically significant, however, because of the great variability of the ten to twenty-nine year group as evidenced by a large standard deviation. They also found a general trend toward a decrease in variability with age; that is, the range of values and the standard deviation decreased with each successive age group. The authors interpret their results as showing "a decrease of a fundamental sensory function of the central nervous system with age."

Brozek and Keys[52] in 1945 tested fifty-six subjects ranging in age from 18 to 60 years. A flashlight bulb of 2.5 volts provided the light source. The light was interrupted by a motor-driven rotating disc with two open sectors. The opal glass test patch was 2.5 centimeters in diameter and was viewed from a distance of 40 centimeters. Unfortunately the authors do not give the intensity of illumination at the test patch nor the visual angle subtended on the retina. They divided the fifty-six subjects into four age groups: 18-25, 26-35, 36-45, and 45-60 years with nineteen, seventeen, eight, and twelve subjects, respectively, in each age group. The mean values of flicker fusion frequency for these groups were 46.70, 45.74, 45.39, and 40.92 flickers per second with standard deviations of 4.18, 3.59, 2.89, and 3.27. A statistically significant difference at the five per cent level was found between the

52 Josef Brozek and Ancel Keys, "Changes in Flicker Fusion Frequency with Age," J. Consult. Psychol., IX, 1945, 87-90.

means of the 18-25 year group and the 45-60 year group. No other statistically significant differences were found.

Misiak's[53] 1947 investigation has already been described in some detail with regard to the effects of sex differences on flicker. But his findings with regard to the effect of age on flicker were purposely left until now for presentation in the proper context. When Misiak compared his fifty young subjects ranging in age from 19 to 30 years (mean age of 23.0 years) with his fifty old subjects ranging in age from 63 to 87 years (mean age of 73.8 years) he found a highly significant difference. While he found a considerable decrease in average flicker fusion values in old age he did not find significant differences in variability among individuals or in variability within the individual performance; however, he does not indicate that any statistical tests were used to support the last two contentions. He found that the range of the old group was almost twice that of the young group and that while the minimum values differed considerably, the maximum values differed comparatively little. That is to say, two of the older subjects had fusion scores as high as the maximum scores of the young subjects, while the lowest scores recorded for the aged group were considerably below those of the young group. It should be noted that these findings are not in agreement with those of Simonson[54] nor

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53 Misiak, "Age and Sex Differences in Critical Flicker Frequency," J. Exp. Psychol., XXXVII, 318-332.

54 Simonson, Enzer and Blankenstein, "The Influence of Age on the Fusion Frequency of Flicker," J. Exp. Psychol., XXIX, 252-255.

with those of Brozek and Keys[55]. These two studies had revealed that maximum scores show the greatest drop with age while low scores (minimum values) were present in the young as well as the old.

In a later study by Misiak[56], in 1951, reported after the present author had completed his own study, the following findings came to light:

1. There is a significant difference in flicker fusion levels between subjects under thirty years and those above fifty-five years. Flicker fusion frequency drops with age and is significant in later life, i.e., after fifty-five.

2. Inter-individual variability as indicated by the standard deviation of age groups tends to increase with age. (On the basis of the data which he presents, this conclusion may be justifiably questioned.)

3. Intra-individual variability as indicated by the mean of the individuals' average deviations tends to decrease with age. (Again no statistical test was employed.)

Whereas in his earlier study (1947) Misiak had theorized that the decrease in flicker fusion frequency in old age was probably due to the degeneration of the optic nerve and cerebrum, now (1951) he suggests a dominance in old age by the parasympathetic system which results in the diminished diameter

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55 Brozek and Keys, "Changes in Flicker Fusion Frequency With Age," J. Consult. Psychol., IX, 87-90.

56 Misiak, "The Decrease of Critical Flicker Frequency With Age," Science, CXIII, 551-552.

of the pupil, in turn lowering the retinal illumination and consequently the flicker fusion frequency. Such a hypothesis is interesting, most certainly, but so far there is no direct evidence to support it.

There have been few studies dealing with the effect of removal of cortical areas on the flicker fusion frequency of light. In animal experimentation, a study of flicker discrimination before and after removal of the visual cortex in the cat has been reported by Smith[57]. Here flicker discrimination was found to be greatly impaired by the operation, especially at high illuminations. But with prolonged training the animals subjected to surgery regained their normal sensitivity at all levels of illumination. This led to the conclusion that the cortex is not absolutely necessary for cone functions in flicker vision. The suggestion was then put forth by Morgan[58] that what occurs with striate removal is an interference with the subject's ability to give his "attention" to visual stimuli, rather than with cone functions as such.

Poppelreuter[59] had previously reported that patients with injuries to the striate area of the occipital lobe show defects in visual efficiency on

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57 K. U. Smith, "The Postoperative Effects of Removal of the Striate Cortex Upon Certain Visually Controlled Reactions in the Cat," J. Genet. Psychol., L, 1937, 137-156.

58 Clifford T. Morgan, Physiological Psychology, New York, 1943, 218.

59 W. Poppelreuter, Die psychischen Shadigungen durch Kopfschuss im Kriege 1914-1916, I, 1917, cited by H. Klüver, "Visual Disturbances After Cerebral Lesion," Psychol. Bull., XXIV, 1927, 324.

many tests of visual functions; that is to say, such a patient is visually inefficient and handicapped in performance. While he can perform the required tasks, he cannot do so with the speed or effectiveness shown by a person with an intact cortex. It was his finding which suggested that the impaired flicker fusion frequency shown later in the animal study might be dependent, at least partially, on factors other than the optic mechanism itself.

Unfortunately, there has been very little reported to date dealing specifically with the effect on flicker fusion frequency of the removal of cortical tissue in human beings. However, several related studies are of prime importance here. Phillips[60] (1933) had early reported a significant decrease in flicker fusion frequency in eight cases of chiasmal tumors and in two cases of parietal brain tumors. He noted that the two parietal cases had normal visual acuity and fields. Later (1942), Werner and Thuma[61] worked with mentally deficient children. One group of these children presented evidence of brain lesions whereas the other group, while also deficient on the basis of standarized intelligence tests, presented no evidence of lesions. These subjects were tested for foveal flicker levels (two degrees of visual angle) with a motor-driven episcotister. For the three different brightness levels of 30.0, 14.5, and 7.5 millilamberts the children without brain injury showed fusion means of 40.63, 38.04, and 34.46 flashes per second. The corresponding means

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60 G. Phillips, "Perception of Flicker in Lesions of the Visual Pathways," Brain, LVI, 1933, 464-478.

61 H. Werner and B. Thuma, "Critical Flicker Frequency in Children With Brain Injury," Am. J. Psychol., LV, 1942, 394-399.

for the experimental group were 34.83, 32.01, and 28.37 flashes per second. The authors conclude that the significantly lower fusion levels of the brain-injured children point to the view that the processes involved in flicker fusion determinations are more dependent upon central neural mechanisms than upon peripheral mechanisms. Since the brain-damaged subjects showed a lower fusion level without any evidence of retinal deficiency, the authors feel that this result gives weight to the findings of Bartley[62] and of Crozier and Wolf[63] that the emphasis lies in central processes rather than in retinal structures.

Teuber and Bender[64] found the flicker fusion frequency of a group of twenty-eight naval casualties with injuries to the occipital lobes to be significantly lower than that of twenty normal subjects. The authors conclude that "neural rather than photochemical factors limit perception in brain-injured patients, and that the limiting factor is an abnormal slowness of the cerebral function subserving vision."[65]

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62 Bartley, Vision, A Study of Its Basis, 125.

63 W. J. Crozier and E. Wolf, "Theory and Measurement of Visual Mechanisms: V. Flash Duration and Critical Intensity for Response to Flicker," J. Gen. Physiol., XXIV, 1941, 635-654.

64 H. L. Teuber and M. B. Bender, "Critical Flicker Frequency in Defective Fields of Vision," Fed. Proc. Am. Soc. Exp. Biol., VII, 1948, 123-124.

65 Ibid., 124.

On the basis of two later studies[66,67] with occipital and occipito-parietal lesions it would appear that the reported effects on fusion frequency may be due to lesions outside rather than inside Brodmann area 17. There seems to be evidence that various other parts of the cerebrum in addition to the occipital lobes are implicated, and there is the suggestion that involvement of the visual pathways proper is not a necessary condition for the observed disturbances in flicker phenomena. Thus the emphasis for the physiological basis of fusion in recent experimentation is clearly placed on the activity of structures central to the retina rather than on retinal factors in themselves.

It was Halstead's study[68] published in 1947 which more than any other single factor has given the impetus to the present investigation. Because Halstead found that frontal lobe injury has a definite depressive effect on flicker fusion frequency the present investigator set out to determine if the damage sustained in frontal lobotomy would produce a depression such as that found in lobectomy.

To understand the significance of Halstead's findings it is first necessary to understand something of the task which he had undertaken. First of all, Halstead was convinced that previous attempts to relate human intelligence

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66 S. B. Wortis, M. B. Bender, and H. L. Teuber, "The Significance of the Phenomenon of Extinction," J. Nerv. and Ment. Dis., CVII, 1948, 382-387.

67 H. L. Teuber and M. B. Bender, "Alterations in Pattern Vision Following Trauma of the Occipital Lobes in Man," J. Gen. Psychol., XL, 1949, 37-57.

68 Ward C. Halstead, Brain and Intelligence, Chicago, 1947.

to brain functions had largely failed.[69] So, in order to avoid the difficulties which had beset earlier theorists, he set out to establish a rational hypothesis as to the kind and number of factors involved in "biological intelligence," as this concept is related to brain function. His objective was a definition of biological intelligence in terms of operational functions. Thus his task became one of a selection of a battery of behavioral indicators, a selection of a group of subjects for examination by this battery, the examination of the quantitative relations between performance on the various tests, and finally, the isolation by quantitative methods of the principal factors in the tests. The total battery of tests employed in these studies consisted of twenty-seven behavioral indicators. In setting up the test battery an effort was made to include a wide range and variety of items, including (a) tests which in preliminary studies had shown promise of differentiating between brain-injured and normal individuals, (b) tests of psychometric intelligence, (c) tests of various personality functions, and (d) tests of various sensory capacities. The battery of twenty-seven tests was given to fifty healthy adult

69 "The biological significance of the intelligence quotient, or IQ, remains largely undemonstrated, although the current sociological ramifications of it are numerous. An index for scaling human mentality, the IQ has been widely used in the classroom and in the psychiatric clinic. In both, and especially in the latter, it is commonplace to observe marked disparities between the measured intelligence of an individual patient and his apparent usable intelligence. The former may be very high and the latter low or vice versa. This discrepancy becomes a patent absurdity in the case of brain-injured individuals. Evidence is now on record to the effect that surgical removal of one or both prefrontal lobes—that is, a mass of brain substance constituting about one-fourth of the total cerebrum—may not significantly alter the IQ."—Halstead, Brain and Intelligence, 5.

males regarded as medically recovered from a recent concussive-type of head injury. All had experienced an interval of unconsciousness of varying duration up to one hour at the time of injury. There were detailed neurological and psychiatric examinations, including detailed sensory examinations, and complete medical histories available for each subject. From the total battery thirteen tests were finally selected which yielded objective scores suitable for treatment by means of the Pearson coefficient of correlation and which seemed likely to reflect some component of biological intelligence. By means of a "blind" factor analysis of the thirteen tests performed by both Holzinger and Thurstone at the University of Chicago, it was possible to educe four basic factors: a "central integrative field" factor or C factor, an "abstraction" or A factor, a "power" or P factor, and a "directional" or D factor. On the basis of these limited data, an elaborate and rather dogmatic picture of intellectual functioning was drawn. It is not primarily within the scope of the present study to criticize Halstead's approach to this important area of investigation; however a number of shortcomings are so obvious as to demand recognition and comment. First of all, neither the sample of tests nor the sample of subjects was adequate to provide a clear and definitive factor analysis; secondly, there was no clear, systematic attempt to relate each of the factor scores to the physiological and neurological modifications which were later studied. Thirdly, the sweeping claims of the identification of "biological" intelligence as distinct from "psychometric" intelligence are hardly supported by the evidence. It is always easier, however, to criticize a pioneer study than to plan and carry out a better one.

The flicker fusion test was included in the battery, and its correlation with the memory component of a tactual discrimination test and the central form and color components of the Halstead Dynamic Visual Field Tests comprised what Halstead has called P or the "power" factor. Halstead states:

> The P factor is a dynamic factor which, in terms of a single estimation, probably best reflects the over-all status of the brain. It is sensitive to the presence of relatively small lesions in the brain and to the effects of low-grade anoxia. There is reason to believe that it is also sensitive to certain concomitants of fatigue states. Its specific physiology is unknown, but it would not be surprising should it be found to parallel those vital processes which sustain the brain and cortex at a high level of efficiency.[70]

At a later date, in fact, in Halstead's most recent discussion of his four factors (1951), he wrote:

> Spearman, and especially Thurstone and his associates, have converged more and more on the concept of intellect as consisting of discrete but correlated functions. Probably Spearman's general factor 'g' which he interpreted as an abstraction factor, Thurstone's induction factor 'I' and my 'A' factor are the same factor. This is probably the same as Goldstein's 'abstract attitude.' The 'P' factor has not as yet been employed by them because appropriate indicators for reflecting its variance have not as yet been employed by them. It will doubtless [sic] come about in due time as the need for validation of postulated factors in terms of biological function of the organism is recognized.[71]

It should be noted here that the present investigation is not concerned with the validity of the P factor as such; the concern is with a

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70 Ibid., 98.

71 Ward C. Halstead, "Brain and Intelligence," Cerebral Mechanisms in Behavior; the Hixon Symposium, ed. Lloyd A. Jeffress, New York, 1951, 263-264.

component of this factor—that reflected in flicker fusion determinations. The reason for the initial inclusion of flicker fusion determinations in Halstead's battery derives from earlier research with primates and human subjects. Using normal and brain-operated monkeys, Halstead and his associates[72 73 74 75] determined certain essential relationships between brain wave activity as recorded by the elctroencephalogram and the flicker fusion test. They found it possible to "drive" the brain waves of the monkey in one-to-one fashion up to frequencies corresponding to flicker fusion frequency by means of intermittent photic stimulation. A similar driving effect has been described in normal man by Toman[76], by Adrian and Matthews[77], and by Jasper[78]. It was found that in the monkey the electrical activity of visual structures below the

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72 Ward C. Halstead, G. W. Knox, and A. E. Walker, "Modification of Cortical Activity by Means of Intermittent Photic Stimulation in the Monkey," J. Neurophysiol., V, 1942, 349-356.

73 Ward C. Halstead, et al., "Effects of Intensity and Wave Length on Driving Cortical Activity in Monkeys," J. Neurophysiol., V, 1942, 483-486.

74 A. E. Walker, et al., "Mechanism of Temporal Fusion Effect of Photic Stimulation on Electrical Activity of Visual Structures," J. Neurophysiol., VI, 1943, 213-220.

75 J. I. Woolf, et al., "The Effect of Lesions of the Visual System on Photic Driving," J. Neuropath. and Exp. Neurol., IV, 1945, 59-67.

76 J. Toman, "Flicker Potentials and the Alpha Rhythm in Man," J. Neurophysiol., IV, 1941, 51-61.

77 E. D. Adrian and B. H. Matthews, "The Berger Rhythm: Potential Changes from the Occipital Lobes in Man," Brain, LVII, 1934, 355-385.

78 H. H. Jasper, "Electrical Signs of Cortical Activity," Psychol. Bull., XXXIV, 1937, 411-481.

cortex, that is, in the optico-geniculo-striate system, could be driven to frequencies above the flicker fusion point for that subject. Halstead[79] had early suggested that one effect of intermittent photic stimulation might be to "drive" the pupillary and accommodative mechanisms of the eye. Their failure to "follow" flash rates might result in opening the eye to more light or in changing the extent of light distribution on the retina, thereby enhancing apparent brightness. This possibility was investigated with a normal subject by eliminating both the pupillary and accommodative reflexes by scopolamine, a drug which serves to dilate the pupil. Brightness enhancement was clearly retained in the absence of both reflexes. The conclusion was that the enhancement effect of intermittent photic stimulation could not have been due to either of the intra-ocular reflexes. Subsequent work with monkeys[80] showed a similar absence of any effect of mydriasis on the driving of cortical activity by intermittent photic stimulation. These observations served to eliminate the retina, the mechanisms of which had been regarded traditionally as providing the basis for temporal fusion, as the limiting factor on the temporal resolving power of the visual system. For Halstead there was indicated the presence of a fusion mechanism in the brain, and more specifically, in the cortex of the brain.

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79 Ward C. Halstead, "A Note on the Bartley Effect in the Estimation of Equivalent Brightness," J. Exp. Psychol., XXVIII, 1941, 524-528.

80 A. E. Walker, "Photic Driving," Arch. Neurol. and Psychiat., LII, 1944, 117-125.

For the flicker fusion determinations in his 1947 study, Halstead employed a total of thirty control subjects, some of which were described as "normals" and the rest simply as "psychiatric patients" but without organic involvement. In addition to the control subjects Halstead employed twenty-five frontal lobectomies and twenty-one nonfrontal lobectomies. The apparatus is described as electronic in type with flashes of constant intensity and duration obtained from a cold cathode neon lamp. Lamp intensity was standardized in electrical units by means of a built-in photometer, and while the light was stated to be "of a relatively low level of intensity"[81] no datum is given as to what the intensity was. The subject set the light frequency at his fusion point by adjusting a single knob. Halstead was solely concerned with the progression from a flickering light to the point at which the light became fused into a solid point of light. The setting was read directly in cycles per second (or flashes per second) from a built-in calibrated scale.

Halstead found a tendency for the nonfrontal lobectomies to fuse at lower values than the control subjects (P=.056). This tendency was even more marked for the frontal lobectomies when compared with the controls (P=.001). Of no less interest and significance is the fact that the average deviation (intra-individual variability) of the frontal lobectomies was reliably less than the combined mean deviation for the control and nonfrontal lobectomies (P=.001). Halstead writes: "This finding means that the frontal lobectomies are objectively more accurate (less variable) in locating their fusion point

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81 Halstead, <u>Brain and Intelligence</u>, 75.

on successive trials than the normal individuals or the nonfrontal lobectomies, although they fuse at relatively lower values in comparison with either."[82] Halstead views these findings as direct evidence that the processes reflected by flicker fusion are central (cerebral) processes rather than peripheral (retinal) as they had traditionally been regarded. They indicate to Halstead that injury to the frontal lobes results in a less efficient functioning of the brain. Although Halstead does not indicate how long after lobectomy his patients were tested for flicker fusion frequency, he refers continually to the low fusion level as a permanent, irreversible characteristic of such brain-damaged persons.

An especially important development of Halstead's findings was his inclusion of the flicker fusion test along with nine other tests in an "impairment index" which served to differentiate completely between frontal lobectomies and the normal group, with the nonfrontal lobectomies lying between. (Actually, Halstead used the fusion level and the individual variability as measured by the average deviation as two separate tests; hence, strictly speaking, only eight distinct additional tests were included in the index.) These ten tests were chosen as the basis for the index because they had the highest _t_ value (differentiating power) for "brain-injury" factor. In this arrangement an individual whose scores fall below the criterion scores on all ten of the key

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82 _Ibid_., 76.

tests for brain-injury factor thus has an impairment index of 0.0; while on a simple proportion basis, an individual who satisfies the criterion score on three of ten key tests has an impairment of 0.3, or on all of the key tests, an impairment of 1.0. It is of interest to note that Halstead found his control group to have an average impairment index of 0.18, with no subject showing an index higher than 0.3. The nonfrontal lobectomies had an average index of 0.3, almost twice as high as the controls; and the frontal lobectomies had an average index of 0.8. Furthermore, no frontal lobectomy had an impairment index <u>below</u> 0.5, whereas the average index for nonfrontal cases was 0.3. The value 0.5 falls at the midpoint of the range of possible variance on the index scale. It is the point at which performance on fifty per cent of the key tests satisfies the brain-injury criterion.

There are several rather obvious criticisms of Halstead's impairment index: (a) The units on the scale are not equated in terms of their behavioral significance; that is, they are not equally sensitive for a brain-injury factor. (b) There is reason to believe that some of the tests are measuring, to some extent at least, the same aspect of the brain-injury factor. (c) There is the consideration of differential localization in the brain of the functions reflected by the various tests. Doubtlessly there are other objections of an even more fundamental nature which could be leveled at this concept, but the fundamental importance of Halstead's endeavor should be appreciated. Here is an attempt to construct empirically an index which will tell whether or not a given individual has an impairment of frontal lobe functions—an impairment independent of disturbances in language functions and "psychometric intellegence" and not directly referable to sensory or motor defects.

The final study to be reviewed in this section is second in importance only to Halstead's in its pertinency to the present investigation. The Columbia-Greystone Associates[83] were concerned with the study of human brain functions as these functions were modified or altered by the surgical procedure known as topectomy. Topectomy is essentially the ablation of a certain cortical area (or areas) in the brain. Since the Greystone project limited itself to the frontal lobes there are certain features which lend themselves to comparison with Halstead's findings. Flicker fusion frequency was one of the many psychological and physiological tests employed in this extensive co-operative study and it is this measure which has bearing on the present investigation. This phase of the co-ordinated project was conducted by Young[84], in conjunction with Carney Landis, and sought to determine whether or not topectomy had any effect on flicker fusion frequency or on the variability of individual determinations of flicker. They also hoped to determine what anatomic, physiologic, or psychologic variables might be correlated with this alteration if one were to be found.

Of the forty-eight patients studied in the entire project only seventeen operatees and thirteen controls (no surgery), or a total of thirty patients, could be used for flicker determination. As the following table[85] shows, the two groups were moderately well equated as to background variables.

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83 Columbia-Greystone Associates, Selective Partial Ablation of the Frontal Cortex, ed. Fred A. Mettler, New York, 1949.

84 Ibid., 257-263, 304, 493.

85 Ibid., 260.

TABLE I

COMPOSITION OF THE GROUP, MEAN AND RANGE ON BACKGROUND VARIABLES IN THE FLICKER FUSION FREQUENCY PORTION OF THE COLUMBIA-GREYSTONE STUDY OF TOPECTOMY

Group	N	Age		Years of Schooling		Sex		Visual Anomalies
		Mean	Range	Mean	Range	M	F	
Operatees	17	43.5	18-61	9.0	6-12.5	11	6	None
Controls	13	45.2	19-59	8.5	0-19.0	10	3	None

The investigators used a stroboscopic tachometer. This is essentially a gas-filled lamp which will give a flash of light having a duration of five to ten microseconds when a condenser is discharged through it. The speed of flashing, controlled by a variable condenser, was read directly from a scale graduated in flashes per second. A knob permitted the experimenter to control the rate of flashing. The test patch had a diameter of two inches and was viewed from a distance of "approximately two feet." No data as to visual angle or light intensity of the test patch were given. The subjects were tested two or three weeks preoperatively, three weeks postoperatively, and four months postoperatively. Under these experimental conditions there were the following results:

1. There was no statistically significant difference in the mean flicker fusion frequency of operatee and control groups.

2. There was no statistically significant difference in the mean intra-individual variability between the operatees and controls.

3. Nine of the seventeen operatees showed a decreased fusion frequency after operation. This decrease was most marked in those who had an originally high fusion level. The loss was greatest three weeks postoperatively, and was largely regained within a three-month period. Interestingly enough, six of the nine who showed this change also showed clear social improvement from their psychoses.

4. There was no regular demonstrable association between flicker fusion frequency and any other psychological or physiological variable included in the study; these variables included cortical area or areas removed, amount of tissue excised, and biochemical, hematological, and electroencephalographic changes, as well as a large number of psychological tests.

5. The authors were unable to find evidence that flicker fusion frequency belonged in some combination with other psychological test results which Halstead had combined into a "P" or power factor.

It would appear that such changes in fusion level as do take place are temporary and reversible. In such a large co-operative study as that of the Columbia-Greystone Associates involving so many diversified disciplines there are bound to be significant relationships overlooked or understressed. One such instance appears to be present in the neglect of the fact that after surgery there was a significant drop in both systolic and diastolic blood pressure in more than half of the operatees. This drop was sustained throughout the first postoperative month but by the third month no significant difference was present between operatees and controls. That this drop is not peculiar to this particular group of patients is supported by Fulton's observation: "All

are agreed that in man topectomy, and especially the more radical lobotomy, is followed by a fall in systolic pressure."[86] Also, Chapman[87] and his associates found that in normal and hypertensive patients the blood pressure fell following lobotomy but generally returned to the preoperative level <u>within three months' time</u>. It should be noted that this three-month interval is also the time required for the depressed fusion level to return to its previous state. Since the studies reviewed earlier in this paper dealing with a wide range of pathological conditions and pharmacological agents having an effect on fusion frequency have pointed up the fact that conditions or agents which serve to decrease the efficiency of the vascular supply decrease the fusion level, it would not be amiss to regard the reduced systolic and diastolic pressure as the possible cause of the temporarily lowered fusion level. It thus would appear that such depression of fusion level as does occur in topectomized patients is directly related to the immediate effects of the surgery and not to the severed neurological processes <u>per se</u>. The important finding in the topectomy study appears to be that such reductions of fusion level as do occur following cortical ablation are purely transient and reversible.

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86 John F. Fulton, <u>Frontal Lobotomy and Affective Behavior</u>, New York, 1951, 114.

87 W. P. Chapman, R. B. Livingston, and K. E. Livingston, "Effect of Frontal Lobotomy and of Electrical Stimulation of the Orbital Surface of the Frontal Lobes and Tip of Temporal Lobes Upon Respiration and Blood Pressure in Man," in <u>Studies in Lobotomy</u>, ed. M. Greenblatt, R. Arnot, and H. Solomon, New York, 1950.

It should be noted that whereas Halstead with frontal lobectomies found consistently lowered fusion points, decreased individual variability, and the feasibility of the combination of fusion frequency with other psychological test results to yield an index for determining the efficiency of cerebral functioning, the Columbia-Greystone study of topectomized patients failed to corroborate any of these findings. The permanent changes in flicker fusion frequency resulting from lobectomy are seen to be of a transitory nature in topectomy (if they occur at all) and, even more puzzling, they seem somehow to be related to the regaining of mental health (or social improvement) in psychotic patients following topectomy.

SUMMARY OF THE LITERATURE

Flicker fusion frequency has been the subject of a great deal of speculation and experimentation for a long time. While the experience of fusion seems essentially so simple it has been open to a wide variety of interpretations no one of which is entirely satisfactory. Work with this phenomenon has progressed from a study of the physical laws and conditions governing its appearance to its application in physiological and psychological investigations. Flicker fusion frequency has been definitely shown to be related to the luminous intensity of the light source, the relative duration of the light and dark periods, the size of the test patch, and the visual angle which the test patch subtends on the retina.

It seems quite certain that practice as such does not affect flicker fusion determinations. There is evidence to support the view that under a sufficiently great physiological stress (for example, exhausting work in extreme temperatures) fusion level is depressed. However, the evidence so far points to the conclusion that flicker fusion frequency is not a very sensitive indicator of "general fatigue." It seems quite certain also that the sex of the subject is not one of the factors which affects fusion frequency.

Investigations using pharmacological agents, those enforcing restriction of caloric intake, and those of anoxia, while reported by a variety of workers using a variety of methods differing in exactitude, are capable of presenting one certain conclusion. They indicate that any condition or agent which acts to decrease the available blood sugar and/or oxygen available to

the retina or to the brain decreases flicker fusion frequency, whereas conditions increasing the efficiency of the vascular supply serve to increase flicker fusion frequency. The nutritional aspect of this problem has not been probed at all as yet and is clearly a subject for future research.

Puzzling and yet provocative are the preliminary findings relating fusion frequency to intelligence as indicated by a standard psychological test and to the remission of neurotic symptoms resulting from combat experiences. No one as yet has been able to incorporate such findings into the framework of knowledge which we already have concerning flicker phenomena.

While there have been a number of studies to the contrary, there seems to be evidence pointing to a general decrease of fusion frequency with advancing age. But other features associated with this decline such as the question of increased or decreased variability have only contradictory evidence marshalled as yet. No one has been able to offer a thoroughly satisfactory explanation as to why there should be a decrease with age.

Attention has shifted gradually in the light of recent work from a preoccupation with retinal mechanisms as the limiting factor on the temporal resolving power of the visual system and turned instead to a concern with more central processes located in the brain. For Halstead as a result of his study with lobectomies, an operation in which both cortical and subcortical tissue is removed, there is an indication of the presence of a fusion mechanism in the brain. The finding that fusion frequency is permanently lowered and that the individual subject becomes less variable, that is more accurate, in locating his fusion point as a result of frontal lobe lesions has led to the use of

flicker fusion determinations as an indicator of the degree of impairment of cerebral functioning at the time of testing.

Later work with topectomized patients, where in contrast to lobectomy only cortical areas are ablated, has pointed to the presence of a fusion mechanism within the brain but has failed to link it with frontal lobe processes. Cases showing lowered fusion level postoperatively regained their former level within a short time afterward, which would seem to point to the surgical trauma and its attendant conditions as the responsible agent. In addition, there was no evidence of a decrease in variability within the individual such as had been the case after lobectomy.

Since lobectomy appears to result in a permanent depression of fusion level and topectomy does not seem to effect this depression, the question reasonably arises as to what effect prefrontal lobotomy, with its extensive damage to subcortical structures and its relatively slight damage to cortical areas, has on the flicker fusion frequency of light. This is the highly significant problem which the present investigation attempts to resolve.

CHAPTER III

EXPERIMENTAL PROCEDURE

The apparatus was one in use at the Laboratory of Physiological Hygiene of the University of Minnesota, Minneapolis, Minnesota. It was borrowed from that agency and brought to the Willmar State Hospital, Willmar, Minnesota, for the present investigation. Essentially, the apparatus consisted of a motor-driven rotating disc mounted in front of a flashlight bulb which served as the light source. The bulb was a Mazda No. 14, 2.5 volts, 0.3 amperes, .75 watts. The flat black disc had a diameter of fifteen centimeters with two open sectors of 22.5 degrees placed opposite each other. The light-dark ratio was 12.5 : 87.5. The light was diffused through a circular test patch of very light milk glass located one inch in front of the light source. The test patch had a diameter of fourteen millimeters and subtended a visual angle of two degrees at forty centimeters. The intensity of illumination at the test patch as measured by a General Electric lightmeter, model DW 68, was five foot-candles. The whole unit was housed in a rectangular black box which was sealed and accoustically treated to prevent the possibility of sound clues influencing the subject's reports. The subject's head was placed against a heavy rubber eye shield which served both to keep the distance constant at forty centimeters and to eliminate extraneous light stimuli. As the subject

looked through the two eyepieces in the rubber shield his eyes were fixed on the test patch at the other end of the tube, the interior surface of which was painted a flat black. The interior surface of the tube was extremely rough to prevent the possibility of reflected glare on the eyes. A voltage regulator and voltmeter, integral parts of the apparatus, were present to assure constancy of light intensity and flicker rate. Only direct current was employed throughout the experiment. The motor and the housing itself were mounted on thick foam rubber to eliminate the possibility of vibration cues. The readings in cycles per second were taken from a built-in calibrated scale graduated in tenths of a cycle and mounted at the rear of the box which enclosed the motor and light source. The dial face was illuminated by a single small bulb and was visible only to the examiner as he sat facing the subject. Artificial pupils were not used in this experiment because of the difficulty in employing them with patients and with older subjects. The small test patch, its short distance from the eye, and the specific form of the eyepiece used made artificial pupils unnecessary. The room in which the experiment took place was a soundproof examining room located next to the author's office at the hospital. This arrangement served to eliminate the possibility of outside noises or disturbances. The testing room and the waiting room adjoining it, where the subjects were kept for one-half hour prior to testing, were both illuminated by a light intensity of approximately five foot-candles, the same illumination as the test patch they were to observe. For the normal subjects the half-hour wait under the subdued illumination served primarily as an adaptation period and secondly as a period for the dispelling of any anxiety which they might

have as to the nature of the test. This latter goal was considered advisable because some of the hospital employees serving as subjects had voiced apprehensions that their performance in a test situation might somehow affect their Civil Service rating as state employees. When the nature of the task was made clear to them, together with the use to which the results would be put, their apprehensions subsided and their co-operation was readily elicited. For this purpose an attendant working under the direction of the experimenter remained in the waiting room with the subjects and issued this information to them.

The half-hour wait posed no particular problems with the psychotic patients either for it gave them a chance to adjust to the new surroundings and to become acquainted with the task required of them. The attendant was well acquainted with each of the patients involved so his presence and reassurances helped to allay whatever suspicions the patients harbored. Also the author had spent a considerable amount of time with each patient individually in connection with another project just completed[38], so all of the patients were well known to him and almost without exception were readily co-operative. Those patients unable or unwilling to concentrate on the task, or whose extreme distractibility prevented an adequate approach to the project, were necessarily dropped from the test and further consideration.

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38 Robert F. Medina, "The Long Term Evaluation of Prefrontal Lobotomy in Chronic Psychotics," Journal of Nervous and Mental Disease. (In publication; accepted for publication September 14, 1951.)

No subject was employed who manifested any visual abnormality such as amblyopia or diplopia or for whom there was a history of neurological disease (e.g., epilepsy, poliomyelitis, meningitis, encephalitis, syphilis, etc.). All subjects who habitually wore eye glasses wore them for the test. In the case of the two patient groups this background information was obtained from the individual's case history report, medical examination report on admittance to the hospital, and from the periodic medical examination reports on file for each patient. Prior to testing care was taken to eliminate any subject who had sustained any head injury or for whom there was a period of unconsciousness as a result of physical trauma. Since hospital regulations were very strict about the reporting by attendants of even the slightest injury sustained by patients this information was readily obtainable. It is recognized that with institutionalized patients there might conceivably have been periods of unconsciousness not reported in the case history but such instances would be as likely to occur in the psychotic control group as in the lobotomized group.

There were actually three experimental groups involved in the present study:

1. A group of patients who had sustained bilateral prefrontal lobotomies and who are referred to henceforth as "operatees."

2. A group of hospitalized psychotic patients who had no surgery and who are referred to as "psychotic controls" or simply as "controls."

3. A group of normal subjects comparable in age and educational background to the other two experimental groups. These subjects were functioning

effectively in their respective jobs and social settings and had no history of psychiatric or neurological disorder. This group is referred to in the course of the study as "normals"; or, when there is the possibility of confusing this group with the younger normal group employed in the age factor portion of this study they will be referred to as "older normals." It is the older normals numbering fifty individuals with whom the operatees and controls are directly compared. (Table II shows the background variables for each of these groups—see page 60.)

In addition to the three experimental groups mentioned above which are to be considered in the comparison of fusion levels for the possible effect of lobotomy on this function, there is an additional group of twenty-two young normals ranging in age from 18 to 29 years with a mean of 21.3 years. As mentioned above, but reiterated here, this group was included not to be compared with the patient groups, but solely for the data which could be gathered in conjunction with the older normals as to the effect of age on fusion frequency. Thus when the effect of age on fusion is discussed there will be a normal group totaling seventy-two subjects ranging in age from 18 to 75 years, a sufficient spread to reveal age effects if there be any.

The lobotomized group is made up of twenty-six patients who had undergone surgery at this hospital in 1941 and 1942. The mean period of time elapsed since surgery was therefore 8.6 years, a sufficiently lengthy period of time so that there could be no question of temporary fluctuations in fusion level which are solely a "shock" effect of the surgical procedure and which do not reflect permanent, irreversible effects resulting from the severing of

subcortical fibers. A primary consideration in the selection of this group was that they all still be located in this hospital, for only then could an adequate control group be assembled. Since there may be many factors affecting flicker fusion of which we are still ignorant it is essential that as many factors as possible be identified and controlled. Thus the operatee and control groups had both been maintained at this hospital for a comparable length of time (22.9 years and 21.6 years, respectively) and since there was a uniform diet throughout the hospital for all patients, there would be more or less an equated nutritional background. The nutritional factor has never been adequately controlled in the past, indeed, as Landis[89] has pointed out, it has rarely been even considered in past studies.

Actually forty-six patients had been lobotomized, all by the same surgeon[90], during the period 1941-1942. Of these forty-six patients, some of whom had died or been discharged in the intervening period, it was possible to utilize only twenty-six for the present study after those with eye anomaly, organic involvement, or those who were so thoroughly regressed as to be unsuitable for this investigation were eliminated.

The psychotic control group was made up of patients who had been institutionalized at this hospital for essentially the same period of time as

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89 Landis, "Something About Flicker Fusion," Sci. Mon., LXXIII,311.

90 The surgeon was Harold F. Buckstein, M.D., of Minneapolis, Minn. From 1942-1946 Dr. Buckstein was absent from the hospital on Navy duty so no psychosurgery was undertaken. After his return in 1946, lobotomies were resumed and are being performed by him at this hospital at the present time.

the operatees. Table II shows how closely the two groups are equated for age, institutionalization period, years of formal schooling, and diagnosis. It is recognized by the present writer that diagnostic category for institutionalized patients is not particularly significant; nonetheless, it was thought advisable to control this factor by having a proportionate number of each of the two main groupings, schizophrenia and manic-depressive psychosis, represented in the subjects. Thus nineteen of twenty-six operatees, or 73.1%, were diagnosed schizophrenic while seven, or 26.9%, were classified manic-depressive. For the controls thirteen, or 72.2%, were schizophrenic while five, or 27.8%, were manic-depressive diagnoses. All diagnoses were taken as of 1941, prior to the surgical period of the operatees. While lobotomy did ameliorate the symptoms found in most of these operatees[91] still none of this group was sufficiently improved to be discharged from the hospital as "cured"; hence, the diagnoses, or more properly categorization, remained unchanged to the time of study. The essential feature of the control group is its close similarity to the operatee group, the crucial differentiating factor being the absence of surgery. All of the eighteen control patients had been selected for lobotomy along with those who were subsequently lobotomized, but in each case here the responsible relative who had been asked to grant permission for the operation had refused on one ground or another. Hence the two groups were essentially from the same population; that is, they were all patients that had been selected by the

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91 Medina, "The Long Term Evaluation of Prefrontal Lobotomy in Chronic Psychotics," Journal of Nervous and Mental Disease. (In publication.)

neurosurgeon and psychiatrist at the hospital as manifesting a sufficient degree of what Freeman and Watts have alluded to as "psychic tension"[92] to make them good risks from a prognostic standpoint for lobotomy. Since such a drastic treatment procedure as psychosurgery cannot be undertaken without the consent of the responsible relatives, and since this permission had not been granted for eighteen subjects, this latter group was designated as an experimental control group. Thus any effect on the determination of fusion point which might be simply an artifact of the psychotic condition of the lobotomized subjects might reasonably be presumed to appear in the performance of the psychotic control group, and contrariwise might be missed or lend itself to misinterpretation if _only_ a normal group were used for comparison purposes. Since there was no special follow-up or re-educative program for lobotomized patients at this hospital operatees and controls lived together on the same wards under essentially the same conditions up to the time of the present study. To repeat, the differentiating feature between the two groups for the purpose of this study was the fact that one had had surgery, the other group had not.

The normal group (older normals) was composed of hospital employees, male and female, working at this hospital in various occupational categories. Some were ward personnel while others were maintenance, clerical, or farm workers. None of these subjects had histories of psychiatric disorders, neurological disease, visual anomalies, nor periods of unconsciousness as a result of head injuries. It need scarcely be mentioned that subjects with any of

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92 W. Freeman and J. W. Watts, _Psychosurgery_, Baltimore, 1942, 214.

these features were eliminated from consideration before the nature or purpose of the test was made known to them, and, of course, before any experimental determinations were made. This was done to eliminate the possibility of a subjective bias in the selection of subjects.

All of these conditions held true for the young normals as well. They were all hospital employees in various capacities. The chief difference between the young and the older normals was, of course, age, and, as could be expected on the basis of the strengthening of educational laws requiring longer school attendance, the young normals showed more years of formal schooling. Since the youngest operatee was thirty-four years, and the youngest control subject was thirty years it is obvious that the young normals (maximum age of 29 years) could not be lumped together with the older normals for comparison with the patient groups.

Well over seventy-five per cent of the normal group ate all three daily meals at the hospital and all ate at least two meals daily at the hospital. Since early 1949 there has been a standard diet inaugurated, so that patients, employees, and staff all have exactly the same daily diet down to the last detail. It was thought that aside from the relative ease of securing hospital personnel for experimentation there was this factor of similar nutritional regimen which would increase the value of comparisons with patient groups. It is by no means assumed here that the nutritional background was <u>identical</u> with the patient groups, for the normals could supplement their diet from outside sources more easily than could the patients if they so desired, but the suggestion is offered that a dietary or nutritional factor is less likely to give

spurious results when all of the subjects are at least exposed to the same daily menu than when subjects with totally unknown nutritional standards are selected, such as in the general population. Indeed, no one has as yet demonstrated satisfactorily a causal connection between nutritional status and flicker fusion effects, but a thorough, thoughtful consideration of the limited literature relating to this problem clearly suggests a possible relationship; therefore, it would seem necessary that this variable should be controlled as nearly as is possible. Almost without exception the previous studies of flicker phenomena have neglected to even consider the nutritional status of the subjects involved, much less attempt to control it.

All of the 116 subjects in this study were of the white race. Sex was not considered to be of importance here in view of the recent studies cited which have failed to show any sex difference in flicker fusion performance. In the interests of complete description, however, in the present study eight of the twenty-six operatees, or 30.8%, were males, seven of the eighteen controls, or 38.9%, were males, and thirty-two of the seventy-two normals, or 44.4%, were males. All in all, the experimental groups were seemingly quite closely equated.

All of the determinations were made over a period of three weeks. Subjects were examined in the morning only, from nine o'clock to noon each day. No attempt was made to hurry through the morning's schedule, instead each subject was put thoroughly at ease and was tested only after the experimenter was satisfied that the subject harbored no anxiety about the test situation or the instrument and could attend to the task effectively. The first

TABLE II

NUMBER, AGE, PERIOD OF INSTITUTIONALIZATION, YEARS OF SCHOOLING AND DIAGNOSIS FOR THE FOUR EXPERIMENTAL GROUPS EMPLOYED IN THE FLICKER FUSION FREQUENCY STUDY AT THE WILLMAR STATE HOSPITAL

Group	N	Age			Years of School	Years Institutionalized		Diagnosis	
		Mean	Range	S. D.	Mean	Mean	Range	Schizophrenia	Manic-Depress.
Operatees	26	52.5	34-69	11.51	9.2	22.9	12-42	19	7
Controls	18	52.7	30-74	12.84	8.7	21.6	11-37	13	5
Older normals	50	52.6	30-75	11.21	9.6				
Young normals	22	21.3	18-29	3.07	14.0				
Total	116								

week was used for the examination of the operatee and control patients and the next two weeks for the normal subjects. Testing for the patients was scheduled by cottage or ward with no attempt made to keep operatee or control patients separate. The normal subjects were also scheduled according to their availability so that their work routine would be disrupted as little as possible. No attempt was made to test by age range or by any criterion other than availability for the particular time and day scheduled. The subject was seated in a chair adjustable for height so that the rubber eye shield fitted comfortably when the head was placed against it. After the subject was comfortably seated the examiner addressed him by name and gave the following directions: "Now at the end of the tube you can see a flickering light—a light that blinks as you look at it. What I want you to do is watch that bright spot." The experimenter then increased the rate of flicker from a marked flicker to a point well above the physiological limit of any subject to perceive the flicker (65 cycles per second). The subject was then asked: "Now it doesn't flicker any more, does it? It's a steady light now, isn't it?" When the subject gave an affirmative answer he was directed to look away from the instrument while the investigator again produced a marked flickering light. "Now this time I want you to tell me just when the light stops flickering or blinking; say 'Now' when it stops." Each time the frequency was increased well past the point at which the subject reported fusion. After three practice determinations to acquaint the subject with the nature of the task and just what the light looked like when flicker appeared to stop or fuse, the subject was ready for the actual determination of his fusion point. If after the three practice trials the subject was still

confused about the task or failed to give any response, three additional trials were given until he understood what he was to do, but this proved to be necessary in the case of only two individuals. The subject was directed to look directly at the test patch and not to move his head or blink his eyes while looking at it. To avoid the possibility of fatigue or lacrimation the subject was directed to look away from the instrument after each trial. But since the time of exposure was quite short and the level of light intensity relatively low, this posed no problem. Five trials for determination of fusion point were given, in each instance starting with a markedly flickering light and moving up past the reported fusion point. The frequency was increased slowly at the rate of two cycles per second from a uniform base rate of fifteen cycles per second up to the reported fusion point and then beyond. Only the increase in frequency from flicker to fusion and not the decrease from fusion to the onset of flicker is considered here, chiefly because Halstead[93] in his investigation of lobectomies utilized this method and it is with Halstead's findings, in comparison with the present findings, that this paper is directly concerned. Also most other investigators have worked with an increasing rate. In no known case were different results obtained in physiological stress situations or disease when both methods were used simultaineously. There is the additional consideration that when patient subjects are employed there is the definite possibility of confusing them when they are set alternately for the disappearance of flicker(fusion threshold) and for the reappearance of flicker (flicker

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93 Halstead, Brain and Intelligence, 71.

threshold) when the frequency is reduced from a fused level. If frequency is first increased to the fusion point and then decreased from the fused level to the reappearance of flicker, the number of trials required is doubled as is the likelihood of retinal fatigue; and the problem of maintaining the patient's attention and interest for the longer time required is also greatly increased. Regardless of the method used to ascertain it, the flicker fusion frequency is still defined as that number of light-dark cycles per second at which a physically intermittent light is just perceived as a steady light.

After five determinations of fusion point had been made an average was computed and this was taken as the flicker fusion frequency for that particular subject. The mean for each experimental group was computed and then by use of the t test for the significance of the difference between means comparisons between the various groups were possible. The extent to which an individual varies about his own mean throughout the five trials was also computed. It is simply the average deviation which is, of course, computed without regard to algebraic sign. This statistic was employed by Halstead to describe a particularly arresting feature of his lobectomized subjects' performance, and since there was to be a comparison with his findings, it was utilized in the present study also.

CHAPTER IV

RESULTS OF THE EXPERIMENT

After each individual's fusion frequency is calculated the mean of the experimental group of which he is a member is computed. Then by means of the *t* test for the significance of the difference between means it is possible to compare the various groups with one another. This has been done in Table III. Below each *t* value is listed the probability based on that particular number of degrees of freedom that a value of this magnitude will be exceeded solely through chance.[94]

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94 Since the groups were matched on the basis of the age variable and have comparable means, standard deviations, and distributions with regard to age (see Table II), it is possible to increase the precision of the *t* test by inclusion of the correlation factor between fusion and age in the ordinary standard error formula. The *t* test is thus more sensitive to a difference when it is real; consequently, there is a less likely possibility of accepting the null hypothesis when it is actually incorrect. This modification has been suggested by both Guilford, Fundamental Statistics in Psychology and Education, 2nd ed., 1950, 220, and Edwards, Statistical Analysis, 1946, 180. The modified standard error formula thus has $(1 - r^2_{xy})$ under the radical sign in addition to the usual quantity. Multiplication by the new quantity avoids overestimation of the standard error of the difference between means. Edwards has pointed out that the number of degrees of freedom then available for evaluating *t* is equal to $N_1 + N_2 - 3$ instead of the usual $N_1 + N_2 - 2$. Thus for operatees and controls combined the Pearson product-moment coefficient of correlation of fusion with age is -.40. For operatees and older normals it is -.34, and for controls and older normals it is -.41. Degrees of freedom are, respectively, 41, 73, and 65. The last comparison of experimental groups in Table III is between the older normals and the young normals. Since the differentiating element between these two groups is age naturally the correlation factor does not enter into the standard error formula here, and the number of degrees of freedom available for evaluating *t* is the usual $N_1 + N_2 - 2$.

It is readily apparent on inspection of Table III that the psychotic control group has the highest mean fusion point (38.29), the operatees next (37.10), and the older normal group with which the other two are compared has the lowest mean (36.85). The unit of measurement is, of course, cycles per second. Consideration of the young normal performance will be taken up later when the age factor is the focus of attention, but for the present our concern is with the effect of frontal lobe damage. None of the differences between means for operatees, controls, or normals even approaches statistical significance. The difference between operatee and control performance shows a _t_ of .951 and a probability that a value of this magnitude would be exceeded in terms of normal expectancy about 34 per cent of the time. The .05 and .01 level of probability would require a _t_ value of 2.020 and 2.701, respectively. The _t_ ratio between the operatees and normals is .235 which in terms of probability would occur over fifty per cent of the time. A _t_ value of 1.993 would be required to reach the .05 level of confidence. The _t_ obtained for controls and normals (1.266) has a probability of occurrence of about twenty per cent of the time; the _t_ required for the .05 and .01 levels is 1.997 and 2.654, respectively. On the basis of the evidence then, one cannot reject the null hypothesis but must note the fact that for the subjects involved here there is no evidence to support the view that lobotomy has a permanent depressing effect on the frequency at which fusion is experienced.[95]

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95 Had not the correlation factor with age been introduced into the equation for the standard error the _t_ values would be as follows: operatees and controls, $t = .871$, $P = .384$; operatees and normals, $t = .221$, $P > .549$; controls and normals, $t = 1.161$, $P = .246$. It can be seen that the refinement used would help one to avoid the error of accepting the null hypothesis when it is incorrect; however, for the differences found here this is of no real moment since statistical significance in terms of the arbitrary .05 and .01 levels is not even approached in any of the comparisons.

TABLE III

MEANS AND RELIABILITY OF THE DIFFERENCE BETWEEN MEANS FOR FUSION FREQUENCY AND VARIABILITY WITHIN THE INDIVIDUAL OF THE FOUR EXPERIMENTAL GROUPS

Group	N	Fusion Frequency		Variability Within the Individual	
		Mean	t	Mean	t
1. Operatees Controls	26 18	37.10 38.29	.951 (P=.343)	1.77 1.67	.308 (P>.549)
2. Operatees Older normals	26 50	37.10 36.85	.235 (P>.549)	1.77 1.09	3.497** (P=.001)
3. Controls Older normals	18 50	38.29 36.85	1.266 (P=.205)	1.67 1.09	2.312* (P=.020)
4. Older normals Young normals	50 22	36.85 41.58	3.071** (P=.002)	1.09 1.38	1.652 (P=.100)

* Significance beyond 5% level of probability.

** Significance beyond 1% level of probability.

P refers to the probability that t, based on n degrees of freedom, will be exceeded.

The extent to which an individual varies about his own mean in five trials is the next consideration. As pointed out previously this is essentially the average deviation of an individual from his own fusion point, but it is necessary to utilize the somewhat awkward term "variability within the individual" to avoid confusing this concept with the extent to which individuals within a particular experimental group, or as later on within a particular age group, are distributed about the mean fusion value of their group. To describe this latter situation the standard deviation will be employed.

Inspection of the last column in Table III reveals that the operatees as a group show the greatest amount of variability within the individual, 1.77 cycles per second; the controls are next with 1.67; and the normals show the least amount as a group with a value of 1.09 cycles per second. Performance of the young normals will be discussed later on. The difference between operatees and controls of 0.10 cycles per second falls far short of statistical significance. That is to say, the individuals of neither groups appear to be objectively more accurate (less variable) in locating their fusion point than the individuals in the other group. The *t* for the difference between means is .308 which has a probability of occurrence greater than fifty per cent of the time. The .05 level of probability requires a *t* of 2.018 for 42 degrees of freedom. Although operatees and controls do not differ significantly from one another with regard to this measure they both differ significantly from the individuals of the normal group. Between operatees and normals the *t* is 3.497 which has a probability of occurrence solely through chance of once in a thousand times. The .01 level of confidence is 2.644 for 74 degrees of freedom.

Between controls and normals the t is 2.312 with a probability of occurrence two per cent of the time. Since the .05 level of confidence requires a t of 1.996 and the .01 level a t of 2.653 one may reject the null hypothesis here at the .02 level of confidence for 66 degrees of freedom. It therefore appears that the normal subjects of comparable age to the operatees and the psychotic controls are more positive and consistent in their perception of fusion point than are either of the other two groups. Apparently the degree of scatter within the individual's successive experiences of fusion is not affected by age since a comparison of the young normal group (average age of 21.3 years) and the older normal group (average age of 52.6 years) does not reveal a significant difference (t = 1.652; P = .100). Later on more detailed information with regard to this point will be discussed. It should be noted, however, that the degree of variability within the individual does not appear to be dependent on the magnitude of the measurements of fusion level. This can be seen in the fact that while the young normals have the highest mean fusion frequency (41.58) they do not manifest as great variability within the individual as do the operatees and controls (1.38 as compared with 1.77 for the operatees and 1.67 for the controls). One should also note that while the controls have a higher fusion mean than the operatees they do not have as great an individual variability mean as do the operatees.

To effect closure on this phase of the problem some indication of the dispersion of the individual fusion means about the group fusion mean should be presented although it is not particularly important here. The statistic involved for such a descriptive function is of course the standard

deviation. Halstead, however, did not concern himself with this statistic since he was concerned solely with the variability within the individual and used the average deviation as above in the present investigation. For each of the three groups of comparable age there seems to be a striking uniformity of dispersion about the particular group mean. Specifically these standard deviations are as follows: operatees, 4.57; controls, 4.37; older normals, 4.88; and younger normals, 6.48. The interesting feature here is the larger standard deviation of the younger normals when compared with those of the other three groups, particularly with the older normals which have an N twice that of the younger group. This arresting feature of the young subjects will be dealt with at length when the age factor is considered.

The findings noted above are of particular interest since they are a complete reversal of Halstead's findings on lobectomized subjects. Halstead found that "the frontal lobectomies are objectively more accurate (less variable) in locating their fusion point on [five] successive trials than normal individuals or the nonfrontal lobectomies, although they fuse at relatively lower values in comparison with either."[96] The present investigation shows that lobotomized subjects neither experience fusion at a lower level nor show less variability in locating their fusion point when compared with psychotic control and normal subjects. In fact, both operatees and controls show a significantly greater degree of individual variability in locating their fusion

96 Halstead, Brain and Intelligence, 77.

point than do the normals. One is led to the conclusion that the incidental damage to the frontal cortex and the more extensive damage to the subcortical structures resulting from prefrontal lobotomy, in contrast to the reported effects of prefrontal lobectomy, do not produce either a permanent depression of the fusion point nor a decreased variability in locating that point. The suggestion offered here is that the greater variability demonstrated by both the operatees and the controls in locating the fusion point is merely a function of the psychotic condition of both these groups. That is, the variability demonstrated is largely a result of the lack of proper attention and the careful concentration on the task which marks the performance of the normal subject of comparable age. If the disruption of cortical or subcortical structures resulting from surgery brought about the higher individual variability one would not expect to see this effect in the control (nonsurgical) group, but as has been pointed out these groups do not differ significantly from one another and thus attention is directed to the psychotic condition common to both groups.

Since the present investigation has demonstrated that bilateral sectioning of the subcortical white fibers does not result in the flicker fusion effects which Halstead has observed in his lobectomies, one may legitimately look to the cortex for disturbances in this function. In frontal lobectomy both the cortex and the subcortical structures are removed, while prefrontal lobotomy is primarily a subcortical operation and apparently leaves

the cytoarchitectural areas of the cortex relatively undisturbed. But the recent study of the Columbia-Greystone Associates on topectomy, where extensive areas of the frontal cortex were ablated, has also failed to find any evidence which would serve to support Halstead's contention of a permanently lowered fusion level and decreased variability within the individual. As the present investigation has demonstrated that lobotomy does not produce a lowered fusion point, and since the removal of cortical areas solely does not effect such a change either, one must question seriously Halstead's contention of a linkage between flicker fusion frequency and frontal lobe processes in man. Secondly, if the extensive damage sustained in lobotomy and topectomy procedures fails to manifest itself in the flicker fusion test, which Halstead regards as the most reliable indicator involved in his "impairment index," one may scarcely expect this index to be sufficiently sensitive to be of value in detecting impairment which is the result of nonsurgical trauma such as a brain lesion or other closed-head injury where the area involved is frequently quite limited. In short, the failure of the flicker fusion test to reflect the rather extensive damage to frontal structures incurred through surgery, as noted here, would appear to argue against its inclusion in any such "impairment index" as Halstead has suggested.

The question quite reasonably arises as to how one explains Halstead's results in the light of the present investigation. Perhaps the answer lies in the suggestion that actually two different populations are considered in these investigations. Halstead's cases had been subjected to surgery for the removal of tumors of the frontal lobe, not for the alleviation of psychosis as in the

present lobotomy study. Brain tumor represents a slowly developing lesion over a period of time prior to surgery whereas in lobotomy the damage to cerebral structures is immediate and relatively confined in scope. Perhaps the extent and influence of the already existing damage to the brain which necessitated lobectomy in Halstead's series may have brought about the effects ascribed to the surgery.

One factor which might very possibly have affected, at least in part, Halstead's fusion-level differences is the age variable which he has apparently failed to control. Careful scrutiny of his published results and of his original data fails to disclose that attention was paid to the effect of this important variable. Analysis of Halstead's original data reveals that his "normal" group of civilian and military control subjects actually consists of only twenty-four subjects with a mean age of 27.3 years. But his twenty-five frontal lobectomies which are compared with the normal group turn out to have a mean age of 39.8 years—a difference of 12.5 years. While this does not represent a very great age discrepancy still the age factor is too important a variable to be overlooked, as the next section will point out.

The Effect of Age on
Flicker Fusion Frequency

It has already been pointed out that the fusion level of the young normal group (mean age of 21.3 years) differs significantly beyond the .01 level of probability from the fusion level of the older normal group (mean age of 52.6 years). The respective means are 41.58 and 36.85 cycles per second,

as shown in Table III, page 66. While the young normals appear to show a greater amount of variability within the individual than the older group (1.38 and 1.09, respectively), the t test fails to show that this difference is statistically significant (P = .100). We would not be justified in rejecting the null hypothesis.

Further evidence attesting to the drop in fusion level with age is obtained when the three experimental groups (i.e., operatees, controls, older normals) are divided into subjects over 45 years of age and those under 45 years. The operatees and controls are combined for this step because of the small N which would result if these groups were taken separately and because they did not differ significantly in mean fusion point or mean variability as was discussed earlier. Table IV shows that in each case the mean fusion level of those subjects under 45 years exceeds the mean of those over 45 years. Within the normal group this difference is represented by a t of 2.514 which has a probability of occurrence slightly over one per cent of the time. The null hypothesis would be rejected at the .02 level of confidence. This statistically significant higher fusion level found in the normal subjects under 45 years as compared with those over 45 years is reflected in the combined operatee-control group also. In this case the t obtained is 3.284 with a P of .001, considerably beyond the one per cent level which requires a t of 2.698. Attention to the last column in Table IV will emphasize the impression gained previously that age does not appear to affect the extent to which an individual varies about his own fusion mean. The mean variability within the individual for normals over 45 compared with normals under 45 is 1.10 and 1.08, respectively

The t is .165 which has a probability of occurrence due to chance alone of over fifty per cent. For the combined operatee-control group the two means are 1.71 and 1.78 which yields a t of .219, again with a probability over fifty per cent. It is probably important at this time to point out that the drop in fusion level with age found in the normal subjects has been demonstrated in the patient groups also; this should increase one's confidence in the technique and apparatus employed in the present study as being sufficiently sensitive to a real difference when one exists. If age does have an effect on fusion frequency, and the evidence would indicate that it does, one would expect to find the effects in all manner of populations, whether they be operatees or psychotic patients, when the older individuals of that particular sample are compared with the younger ones.

TABLE IV

MEANS AND RELIABILITY OF THE DIFFERENCE BETWEEN MEANS FOR FUSION FREQUENCY AND VARIABILITY WITHIN THE INDIVIDUAL FOR THE NORMAL AND PATIENT GROUPS DIVIDED INTO TWO AGE CATEGORIES: OVER AND UNDER 45 YEARS

Age Group	N	Fusion Frequency		Variability Within The Individual	
		Mean	t	Mean	t
Normals over 45	36	35.61	2.514*	1.10	.165
Normals under 45	14	40.06	(P=.012)	1.08	(P>.549)
Combined operatees and controls over 45	31	36.53	3.284**	1.71	.219
Combined operatees and controls under 45	13	40.11	(P=.001)	1.78	(P>.549)

* Significance at 5% level of probability.

** Significance at 1% level of probability.

P refers to the probability that t, based on n degrees of freedom, will be exceeded.

Figure 1 shows the fusion frequency means plotted for each age range of the total normal group of seventy-two subjects. Thus for the purposes of this graph the young normals (N = 22) and the older normals (N = 50) were combined. It will be recalled that the young normals range in age from 18 years to 29 years, and that the older normals, those used in the comparisons with the patient groups, ranged from 30 to 75 years. The total age range then is from 18 to 75 years. It is evident that there is a gradual decrease in fusion level with advancing age. The point where the greatest single decrease appears in the graph seems to be between 45 and 55 years of age. From 55 to 65 years the drop is much less pronounced. It would be very interesting to extend this curve further into even higher age groups to see if a gradual leveling off actually takes place. Unfortunately, at the time of this study there were no such cases available. The total drop in fusion frequency from the mean of the youngest group (41.58 cycles per second) to the mean of the oldest group (34.65) is 6.93 cycles per second. This difference is significant well beyond the .01 level of probability ($\underline{t}$ = 4.414, P = .001). Table VI lists the actual fusion value for each age group. A Pearson product-moment coefficient of correlation computed with the age and fusion data given in the Appendix yields an $\underline{r}$ of -.43. The standard error of $\underline{r}$ is .119, and $\underline{t}$ for 70 degrees of freedom is 3.613. The obtained $\underline{r}$ is significant at the .001 level of confidence and points to a substantial negative relationship between age and flicker fusion, one which we may accept with a high degree of confidence. Inspection of a scatter diagram of the regression of fusion frequency on age emphasizes the fact that the functional relationship involved is linear and negative.

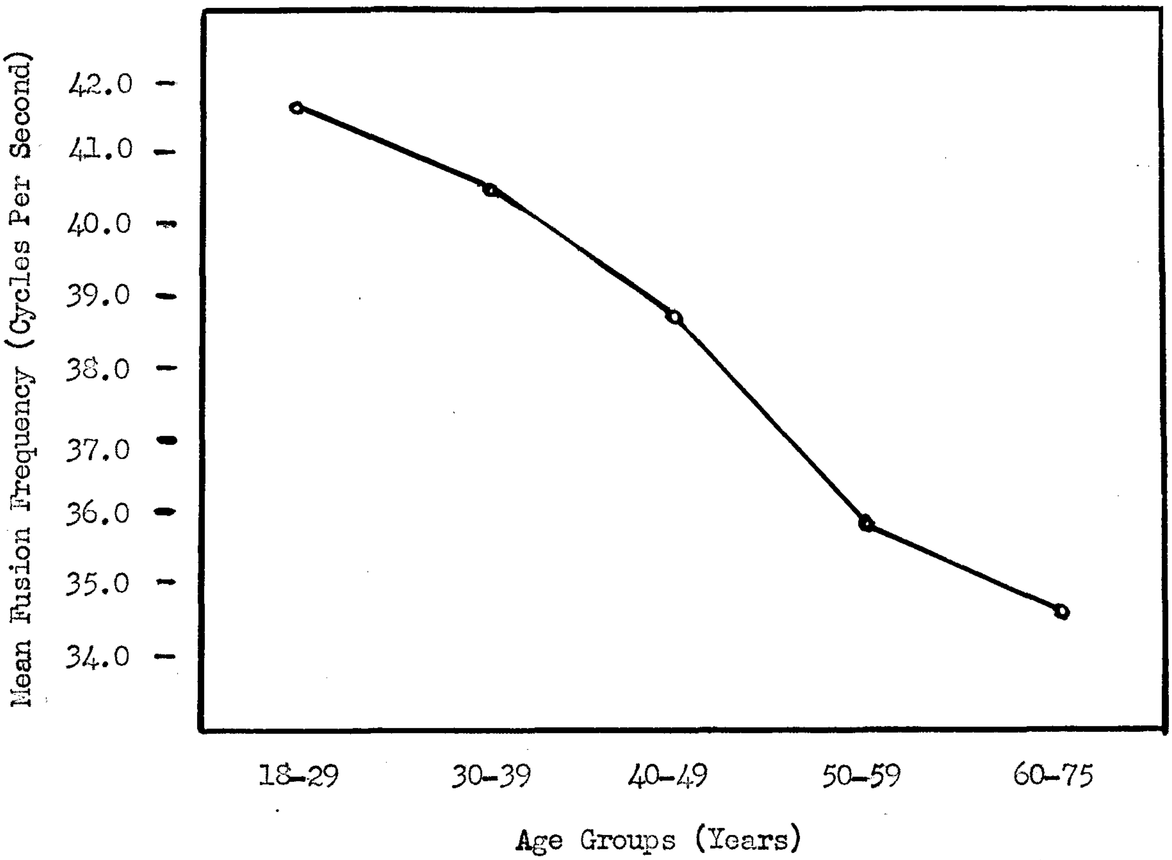

FIGURE 1

THE DECREASE IN FLICKER FUSION FREQUENCY WITH AGE FOR FIVE SUCCESSIVE AGE GROUPS TOTALING SEVENTY-TWO NORMAL SUBJECTS AT THE WILLMAR STATE HOSPITAL

The findings of the present investigation pointing to a decrease in fusion level with age are in disagreement with the conclusions of Hartmann[97], Miller[98], and Jones[99], and in close agreement with those of Simonson[100], Brozek[101], and Misiak[102]. All of the studies referred to have been examined in detail in the literature review in the first part of the present investigation. Points of divergence from the findings of the last-named workers will be taken up shortly.

Table V furnishes some interesting information with regard to the decrease of fusion frequency with age. It will be noted in this table that while maximum and average values tend to decrease markedly with age, minimum values are present in the youngest group as well as in the very old. One subject in the 60-75 group had a mean fusion point of 28.5 but the lowest value of all (28.1) was recorded for a subject only eighteen years old! Thus, it would appear that while very high values may possibly appear in any age group

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97 Hartmann, "Comparison of the Flicker Thresholds in Children and Adults," Child Develpm., V, 122-126.

98 Miller, "Critical Frequency Limen for Visual Flicker in Children Between the Ages of Six and Eighteen," Genet. Psychol. Monogr., XXVI, 3-53.

99 Jones, "Fatigue and Hours of Service in Interstate Truck Drivers," U.S.P.H.S. Bull., No. 265, 1941, 195-208.

100 Simonson, "Influence of Age on the FFF," J. Exp. Psychol., XXIX, 1941, 252-255.

101 Brozek, "Changes in Flicker Fusion Frequency With Age," J. Consult. Psychol., IX, 1945, 87-90.

102 Misiak, "Age and Sex Differences in Critical Flicker Frequency," J. Exp. Psychol., XXXVII, 318-332.

(such as the 56.6 which was recorded for one subject 33 years old) the likelihood of such appearance is greatly reduced with the increase in age, but the very low values appear at any age level, young as well as old.

TABLE V

MAXIMUM, MEAN, AND MINIMUM FUSION FREQUENCY DETERMINATIONS FOR SUCCESSIVE AGE LEVELS OF SEVENTY-TWO NORMAL SUBJECTS

Age Group (Years)	N	Maximum Frequency (Cycles/Sec)	Group Mean Frequency (Cycles/Sec)	Minimum Frequency (Cycles/Sec)	Range of Frequencies (Cycles/Sec)
18-29	22	53.3	41.58	28.1	25.2
30-39	9	56.6	40.42	35.5	21.1
40-49	11	50.4	38.68	31.1	19.3
50-59	12	40.0	35.81	31.2	8.8
60-75	18	39.7	34.65	28.5	11.2

Why these very low values can appear at any age level cannot be answered at the present time, but it is definitely a question for future research. The present author feels that there may very well be nutritional factors involved here.

It is interesting to note that Misiak[103], also using normals, reported the range of fusion frequency means among old subjects with a mean age of 73.8 years as almost twice that of young subjects having a mean age

103 Misiak, "Age and Sex Differences in CFF," *J. Exp. Psychol.*, XXXVII, 328.

of 23 years. (His concern here was with inter-individual rather than with intra-individual variability.) The present investigation disclosed that instead of increasing with age, the fusion range decreased in a rather regular fashion from the 18-29 year group with a range of 25.2 cycles per second to the 60-75 year group which had a range of 11.2 cycles per second, less than half that of the young subjects (last column in Table V). Turning briefly to Table VI, one notes that the standard deviations (S. D.) of the fusion values for each age level reflect this same decrease with increasing age, the

TABLE VI

MEAN FUSION FREQUENCY, STANDARD DEVIATION, AND MEAN VARIABILITY WITHIN THE INDIVIDUAL FOR THE SUCCESSIVE AGE LEVELS OF THE TOTAL NORMAL GROUP OF SEVENTY-TWO SUBJECTS EMPLOYED IN THE PRESENT INVESTIGATION

Age Group	N	Age Mean (Years)	Group Mean Frequency (Cycles/Sec)	S. D.	Variability Within the Individual (Cycles/Sec)
18-29	22	21.3	41.58	6.48	1.38
30-39	9	35.4	40.42	6.36	1.02
40-49	11	44.9	38.68	5.73	1.22
50-59	12	54.1	35.81	3.00	1.10
60-75	18	65.1	34.65	3.13	1.05

S. D. for the 60-75 year group being less than half that of the 18-29 year group(3.13 compared with 6.48). For each age level from the youngest to the oldest the S. D. decreases fairly regularly, i.e., 6.48, 6.36, 5.73, 3.00, 3.13. Guilford[104] has recently pointed out that for small samples the *t* test for the significance of the differences between standard deviations is not satisfactory, even with the availability of Student's distribution for *t*. Instead of testing the significance of the difference between two sigma's, one tests the significance of the ratio of the two variances that correspond to them. In computing the ratio of the larger of two variances to the smaller, the larger the difference, the further the ratio exceeds 1.00, which is what it would be if the two variances were equal. If the ratio of the variances is significant, the difference between the S. D.'s is significant. What is actually obtained is an estimate of the population variance from the two samples; then assuming that the two samples come from the same population with regard to variability (null hypothesis), one asks whether two such estimates of the population variance could differ as much as the ratio shows. Each of the estimated variances is, of course, the sum of squares from the sample divided by the number of degrees of freedom (N - 1). The name given this ratio is *F* and Snedecor's tables[105] are used for the usual significance levels.

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104 Guilford, *Fundamental Statistics in Psychology and Education*, 232.

105 George Snedecor, *Statistical Methods Applied to Experiments in Agriculture and Biology*, Ames, Iowa, 1937, 174-177.

Table VII reveals the results of the application of the F test to the various age groups from the normal-subject sample. For completeness each age level is compared with all of the others successively. Thus, for the 18-29 year group there are four comparisons to be made, three for the 30-39 year group, two for the 40-49 year group, and only one for the 50-59 year group. The S. D.'s, variances, degrees of freedom (df), and the F obtained are given for each comparison.

By careful study of Table VII one will note that age groups 18-29, 30-39, and 40-49 do not differ significantly from one another with regard to standard deviation; that is to say, the null hypothesis is not rejected; therefore, so far as group variance or variability is concerned, these three age groups could well have come from the same population. But note that all three of these age groups differ significantly from both the 50-59 and 60-75 year groups. Between the 18-29 and 50-59 year groups the F ratio is significant well beyond the .01 level; the same holds true when this young group is compared with the 60-75 year group also (.01 level). Between the 30-39 year group and the 50-59 group the difference in variance is significant at the .05 level, and with the 60-75 group the difference is significant beyond the .01 level. The big drop in variance seems to occur between the 40-49 year group and the remaining two older groups. This difference is significant at the .05 level in both cases. The 50-59 and 60-75 year groups do not even approach the .05 level when they are compared for variability ($F = 1.09$ for df of 17 and 11).

TABLE VII

F TEST FOR THE SIGNIFICANCE OF THE DIFFERENCE BETWEEN THE STANDARD DEVIATIONS OF FUSION FREQUENCY DETERMINATIONS FOR SUCCESSIVE AGE LEVELS DRAWN FROM THE TOTAL NORMAL GROUP OF SEVENTY-TWO INDIVIDUALS

Age Groups Compared†	S. D.	Variance	df	F
18-29 30-39	6.48 6.36	41.96 40.39	21 8	1.04
18-29 40-49	6.48 5.73	41.96 32.87	21 10	1.28
18-29 50-59	6.48 3.00	41.96 8.98	21 11	4.67**
18-29 60-75	6.48 3.13	41.96 9.79	21 17	4.29**
30-39 40-49	6.36 5.73	40.39 32.87	8 10	1.23
30-39 50-59	6.36 3.00	40.39 8.98	8 11	4.50*
30-39 60-75	6.36 3.13	40.39 9.79	8 17	4.13**
40-49 50-59	5.73 3.00	32.87 8.98	10 11	3.66*
40-49 60-75	5.73 3.13	32.87 9.79	10 17	3.36*
60-75 50-59	3.13 3.00	9.79 8.98	17 11	1.09

† Note that the age group having the larger variance of the pair is given first since $F = \frac{\text{larger variance}}{\text{smaller variance}}$.

* .05 level of confidence.
** .01 level of confidence.

It would thus appear evident that with age there is a definite decrease in inter-individual variability, that is, the extent to which the individuals of a particular age group scatter in flicker fusion frequency about the mean fusion level of their particular group. This decreased inter-individual variability with age as shown here, and also as reflected in the range of means discussed previously, becomes especially noticeable somewhere between 45 and 55 years of age and appears to have its basis in the gradual dropping off of the higher frequencies (maximum values) at which fusion is experienced. The experience of fusion at low frequencies (minimum values) occurs in the younger as well as the older age groups. As pointed out previously these findings represent a reversal of Misiak's report, inasmuch as he found an increase in fusion range, very little difference in maximum scores, and a considerable difference in minimum scores when his old group was compared with his young group. We may legitimately question Misiak's conclusion of reduced inter-individual variability since he simply inspected the range of fusion means and therefore was unduly influenced by two high deviant scores occurring in the aged group. These two scores led him to the conclusion that the variability in older groups is actually greater than in younger groups. Had he compared the standard deviations along with the range probably his conclusion would have been different. The present findings tend to support Simonson[106] and Brozek[107] who found in separate studies that maximum scores

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106 Simonson, "Influence of Age on FFF," J. Exp. Psychol., XXIX, 252-255.

107 Brozek, "Changes in FFF With Age," J. Consult. Psychol., IX, 87-90.

showed the greatest drop with age while minimum scores were present in the young as well as the older subjects. Actually the present investigation failed to disclose any really high fusion scores after age fifty, for none of the thirty subjects in the two oldest age levels even reached the mean fusion value of the youngest group.

A final point remains to be discussed. The last column in Table VI, page 79, shows the effect of age on the variability within the individual, that is, the extent to which the individual subject varies about his own mean fusion point in five trials. As pointed out previously this column is simply the mean of the individuals' average deviations comprising a particular age group. Broken down into five successive age levels, as in this table, one notes that the highest intra-individual variability is attained by the 18-29 year group (1.38), next by the 40-49 group (1.22), then by the 50-59 group (1.10), then by the 60-75 year group (1.05), and finally by the 30-39 group (1.02). Use of the _t_ test for the significance of the difference between means for the 18-29 year group and the 60-75 year group yields a _t_ of 1.765 with a probability of .079. The required _t_ for the .05 and .01 levels is 2.025 and 2.712, respectively. None of the other differences is statistically significant either. On the basis of these findings then, considering also the parallel lack of evidence in the patient groups, one is forced to conclude that age does not appear to affect the extent to which an individual varies or deviates from his own mean in successive trials. There is no evidence to indicate that older individuals are objectively more accurate (less variable) in experiencing fusion than are younger subjects. It will be remembered that

Misiak[108] in 1951 had concluded that the intra-individual variability as indicated by the mean of the individuals' average deviations decreased with age. But he failed to indicate that any statistical test had been employed to ascertain this change; hence, one may view this conclusion with justifiable scepticism. The present investigation, at any rate, does not support such a contention.

To summarize the findings dealing with the effect of age on flicker fusion frequency the following points should be emphasized:

1. There is a definite decrease in flicker fusion frequency with age. This decrease is found in both normal and psychotic patient subjects.

2. The functional relationship between flicker fusion frequency and age is linear and negative ($r = -.43$).

3. The age where this drop in fusion point is most pronounced occurs somewhere between 45 and 55 years.

4. The inter-individual variability as measured by the standard deviation of the age groups decreases markedly with age. The range of fusion scores in the oldest groups is less than half that in the youngest group.

5. While maximum and average frequencies at which fusion is perceived tend to decrease markedly with age, low or minimum frequencies are present in the youngest groups as well as in the older groups.

6. The extent to which an individual varies or deviates from his own mean fusion point in successive trials does not appear to be influenced

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108 Misiak, "Decrease of CFF With Age," Science, CXIII, 551-552.

by age. There is no evidence to support the contention that older subjects are objectively more accurate (less variable) than young subjects.

It would seem to be well demonstrated that any study dealing with the differential effect of various conditions on flicker fusion frequency (such as cerebral insult) must very definitely take into account, or control by exclusion, the pronounced effects of age on the subjects' performance.

Why there should be a decrease in flicker fusion frequency with age is as yet unknown. Attempts to attribute this change to strictly retinal factors are not borne out by the evidence. That the iris becomes thinner and more rigid with age is not a satisfactory explanation in view of the fact that there is a gradual decrease in flicker fusion frequency with age even before the time of diminishing pupil mobility. Dilation of the pupils in aged subjects by means of atropine serves to diminish age differences but not abolish them, indicating that other factors are involved. The findings with closed-head injuries also serve to direct attention to processes and structures beyond the retina. It appears that no single factor explanation for the physiological mechanism underlying the drop in flicker fusion frequency with age is meaningful. It would appear that future research efforts must attempt to discover the extent to which one physiological-system alteration at a time contributes to the total decrement observed.

CHAPTER V

SUMMARY

Two recent investigations with psychosurgery cases have suggested that frontal lobe damage is reflected in the flicker fusion frequency of that individual. One of these investigations, that of Halstead with lobectomized subjects where both cortical and subcortical frontal lobe structures are removed, has indicated that such cases have a significantly lowered fusion point and are objectively more accurate (less variable) in locating their fusion point on successive trials than are normal subjects or nonfrontal lobectomies. He combined the flicker fusion test with a number of other tests to yield an impairment index which would reveal loss of efficiency in brain function not detected by ordinary psychophysiological examination. The second study, that by the Columbia-Greystone Associates with topectomy, an operation involving the ablation of extensive cortical areas in the frontal lobes, failed to corroborate Halstead's findings; nor were they able to find that the flicker fusion test belonged in any such combination as Halstead had developed for his impairment index. They did find, however, some temporary fluctuations in fusion level which seem to be the immediate aftereffects of the surgical procedure itself.

The question which then confronted the present author was whether or not prefrontal lobotomy, an operation in which the cytoarchitectural areas of

the cortex are left relatively intact but damage to subcortical structures is extensive, would result in a depressed fusion level and reduced variability in determining this point. Of secondary importance, but certainly worthy of investigation, was the question of age effects in both a normal and psychotic population.

To answer these questions four experimental groups were employed. The first of these consisted of twenty-six lobotomized patients institutionalized at the Willmar State Hospital in Willmar, Minnesota. All of these patients had been operated upon by the same surgeon some eight years prior to testing. The second group was composed of eighteen psychotic control patients from the same institution closely comparable to the operatees with regard to age, period of hospitalization, amount of schooling, and diagnosis. The third group was composed of fifty normal subjects employed in various capacities at the hospital. They too were closely comparable with the other two groups. The absence of concussive-type head injuries, neurological disease, and visual anomalies was the first consideration in selecting all four groups employed in the study. The last group was composed of twenty-two younger normal adults who were too young to be included with the older normal group for direct comparison with the patient subjects. These young normals were employed in the age factor investigation along with the older normals to give a sample N of seventy-two subjects. The nutritional regimen for all groups involved was essentially the same.

The apparatus employed was a motor-driven rotator device utilizing a light of moderate brightness and a fixed light-dark ratio. The fixed viewing

range and the target area were such as to insure foveal vision. Physical conditions and setting were ideal for the determinations. The *t* test for the significance of the difference between means was largely the statistical device employed.

The results of this experimental study for these particular samples warrant the following conclusions:

1. There is no evidence to indicate that the extensive frontal lobe damage sustained in lobotomy results in a lowered fusion point.

2. There is no indication that lobotomized subjects are objectively more accurate (less variable) in locating their fusion point than are psychotic control or normals subjects. The fact that both operatees and controls are less accurate (more variable) than are normals appears to be a manifestation of their essential psychotic condition.

3. The insensitivity of the flicker fusion test to frontal lesions of this magnitude would appear to argue against its inclusion in any such impairment index as Halstead has suggested.

4. There is a definite decrease in flicker fusion frequency with age found in both normals and psychotic subjects.

5. The functional relationship between flicker fusion frequency and age is linear and negative ($r = -.43$).

6. The most pronounced drop in fusion level appears to occur somewhere between forty-five and fifty-five years of age.

7. Inter-individual variability as measured by the standard deviation of the age groups <u>decreases</u> markedly with age. The range of fusion scores

in the oldest groups is less than half that in the youngest group. This appears to be due to the gradual disappearance of the high fusion scores as one progresses along the age axis.

8. While maximum and average frequencies at which fusion is perceived decrease markedly with age, low or minimum frequencies are present at all age levels.

9. The extent to which an individual varies or deviates from his own mean fusion point in successive trials does not appear to be dependent on age. There is no clear-cut evidence to indicate that older persons are objectively more accurate (less variable) than young persons.

Single factor explanations for the physiological mechanism underlying fusion frequency changes with age are not adequate. Attempts to relate this change to purely retinal features are also rejected as inadequate. It is suggested that future research concern itself with longitudinal studies on the same subjects over a lengthy period of time so that the concomitant physiological changes can be observed in their relationship to fusion frequency changes. Another approach to this problem would be in the systematic alteration of one physiological variable at a time and the observation of its contribution to the total decrement.

With regard to frontal lobe damage and flicker fusion frequency it would appear on the basis of the present study that no pertinent relationship exists. Damage to areas of the brain other than the frontal lobes may well be

reflected in alterations of fusion frequency; indeed, the few preliminary attempts to date along this line have suggested as much. The numerous unanswered questions relating to its psychological correlates and to brain function under a host of pathological conditions would certainly point to the value of continued research utilizing the flicker fusion frequency.

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APPENDIX

DATA FOR THE SUBJECTS EMPLOYED IN THE INVESTIGATION OF FLICKER FUSION FREQUENCY AT THE WILLMAR STATE HOSPITAL

OPERATEES

Subject	Age	Fusion Mean (5 Trials)	Average Deviation
1. N. T.	51	34.0	2.80
2. S. N.	69	35.9	2.88
3. A. L.	63	31.8	.72
4. V. L. O.	44	38.2	.64
5. E. A.	48	30.3	.56
6. M. H.	52	38.0	.30
7. E. M.	52	42.4	1.52
8. M. D.	60	32.7	2.72
9. J. S.	42	38.1	3.48
10. E. V. P.	41	39.4	1.52
11. A. D.	54	37.4	2.28
12. A. G.	52	38.4	1.28
13. J. C.	69	27.2	3.84
14. M. M.	49	30.2	1.36
15. H. M.	68	43.2	1.24
16. O. T.	58	40.2	1.64
17. R. F. H.	37	33.3	1.56
18. L. E. K.	38	46.2	.72
19. A. K.	38	40.2	1.92
20. P. C.	35	41.5	1.00
21. T. C.	46	40.6	1.48
22. W. H. D.	68	31.1	2.48
23. D. S.	62	39.6	2.88
24. S. J. C.	68	38.4	.96
25. E. S.	34	37.1	1.92
26. M. K.	66	39.2	2.24

APPENDIX (continued)

PSYCHOTIC CONTROLS

Subject	Age	Fusion Mean (5 Trials)	Average Deviation
1. A. C.	50	40.4	2.68
2. M. G. B.	68	32.8	1.04
3. E. C.	60	36.0	3.20
4. M. H.	66	37.7	.36
5. M. K.	45	34.2	2.60
6. E. J.	57	41.1	.36
7. C. J.	55	39.2	.72
8. O. M.	57	36.5	1.40
9. E. H. F.	56	38.2	2.64
10. E. O. L.	51	43.3	.43
11. G. G. A.	74	36.5	1.20
12. A. A.	65	38.8	.84
13. C. W.	34	45.8	1.52
14. S. S. S.	35	45.0	3.20
15. A. W.	30	38.0	.80
16. G. G.	44	40.0	3.20
17. J. V. C.	35	38.6	1.68
18. J. A.	67	27.2	2.24

OLDER NORMAL SUBJECTS (OVER 30 YEARS OF AGE)

Subject	Age	Fusion Mean (5 Trials)	Average Deviation
1. C. B.	66	35.1	1.12
2. H. K.	50	40.0	.80
3. E. S.	44	37.2	1.24
4. S. B. L.	44	50.4	.68
5. R. S.	39	39.2	1.36
6. E. J.	45	40.4	1.28
7. N. H.	58	35.4	.72
8. R. A.	46	43.5	1.20
9. E. S. M.	49	34.0	1.10
10. R. G.	56	38.7	.68
11. E. R.	52	34.7	1.84
12. C. D.	54	32.4	1.48
13. C. J.	60	39.0	1.20
14. O. L.	65	35.8	1.16
15. M. A.	39	36.5	1.20
16. L. P.	37	35.5	1.60
17. E. J.	35	37.4	1.28
18. C. S.	49	31.1	1.12
19. M. K.	46	35.3	1.84
20. A. B.	63	36.0	.80
21. G. F.	30	40.6	.52
22. E. Q.	46	44.1	.88
23. R. B.	41	34.9	1.12
24. W. E.	65	30.6	.92
25. R. B.	56	38.5	1.20
26. A. B.	62	34.5	.60
27. A. M. A.	57	31.2	.32
28. D. P.	36	40.0	.80
29. R. H. G.	33	56.6	1.12
30. A. B.	64	28.5	.80
31. S. F.	69	36.7	1.84
32. J. W.	65	35.6	1.12
33. E. B.	55	37.9	1.48
34. G. B.	44	33.8	1.36
35. B. A.	40	40.8	1.56
36. S. C.	61	39.7	1.56
37. P. L.	65	37.3	1.32
38. C. E.	62	35.0	1.40
39. C. J.	68	34.5	.80
40. F. P.	34	40.8	.84

OLDER NORMAL SUBJECTS
(OVER 30 YEARS OF AGE)
(continued)

Subject	Age	Fusion Mean (5 Trials)	Average Deviation
41. H. S.	51	36.2	2.04
42. T. S.	51	34.4	.92
43. H. W.	52	38.6	.72
44. M. D.	36	37.2	.44
45. C. B.	60	30.1	.56
46. C. B.	57	31.7	1.04
47. V. N.	64	36.6	.88
48. H. E.	63	36.4	.48
49. F. P.	75	30.7	.64
50. H. H.	62	31.6	1.68

APPENDIX (continued)

YOUNG NORMAL SUBJECTS (UNDER 30 YEARS OF AGE)

Subject	Age	Fusion Mean (5 Trials)	Average Deviation
1. E. B.	19	52.0	1.70
2. J. S.	29	45.6	1.52
3. H. V. D.	20	46.2	.96
4. R. F. M.	24	53.3	.84
5. S. D.	23	45.0	.40
6. D. G.	23	45.6	.88
7. E. B.	25	49.0	1.20
8. A. M.	20	37.1	1.92
9. R. D.	19	41.7	2.16
10. E. H.	18	41.6	3.12
11. D. R.	23	42.3	.88
12. M. S.	18	28.1	1.28
13. G. B.	25	36.4	2.72
14. B. F.	18	47.3	.76
15. J. O.	18	30.9	2.12
16. J. B.	18	35.8	.44
17. D. P.	20	40.9	1.16
18. A. P.	19	36.0	.80
19. B. N.	19	34.2	2.56
20. T. J.	25	38.8	.64
21. A. R.	21	42.6	.96
22. R. Q.	24	44.4	1.28

APPROVAL SHEET

The thesis submitted by Robert Francis Medina has been read and approved by three members of the Department of Psychology.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form, and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Arts.

May 29, 1953
Date

Frank J Kobler
Signature of Adviser