An Analysis of Some Refractive Error Trends in U.S. Air Force Pilots and Navigators

By

IRVING L. DUNSKY AND JOHN R. LEVENE

Prepared under Contract No. NAS 9-8078 by
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BLOOMINGTON, INDIANA
for Manned Spacecraft Center, Houston, Texas
National Aeronautics and Space Administration

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I.L. D.

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INTRODUCTION

Nature of the Study

Until comparatively recently, flying has been performed in relatively simple vehicles. In these circumstances, the various visual tasks encountered took place outside the cockpit. At present however, flying tasks are performed in vastly different types of vehicles, varying from piper cubs to the very sophisticated space capsules. Therefore, critical visual tasks and performance are increasing within the cockpit or space capsule.

The visual scientists' (i.e. ophthalmologist, optometrist) role in classifying vision for flying has been, and still is, to some extent, based on the combined expert judgments of ophthalmologists and optometrists in establishing screening selection requirements.[1] Because the requirements have been based on a somewhat arbitrary and empirical basis, the visual parameters required for flying, may possibly have been set too high, or even higher than really necessary, purely in the interest of safety. The system of high selection standards established by the "pooled" expert judgment, has consequently resulted in an efficient and safe performance.

The importance of visual classification tests and standards have been questioned many times. There appear to exist variations in the degree of perfection required for the different visual capabilities, as established in the standards for flying.[2]

In addition to the changing visual requirements for flying in the present and future "air age" the particular problems for space travel are, and will continue to be, unique.[3] This calls for extensive research to investigate trends and standards for the selection, assignment, and retention of flying personnel. Therefore, the purpose of this research is to take one small, but highly important, aspect of the problem, namely refractive error, and to attempt to establish its trends on the basis of predictability. Hence, this study is an analysis of the changes of meridional refractive error with age. It is based on a sample of military personnel, namely pilots and navigators, of the United States Air Force.

The National Aeronautics and Space Administration (NASA) is interested in the accurate prediction of refractive error trends with age. A quantitative approach may not only allow one to predict the degree that a given individual's refractive error is likely to change, but also whether the particular individual will or will not be permitted to continue to meet specified standards at a given age. In other words, information will be instantly available, for any given refractive error, of the likely changes that may occur over a given span or period of time. This could be highly significant.

Statement of the Hypothesis

At present, the United States Air Force has two standards for refractive errors, one for pilots and one for navigators. It seems logical to assume that the originator(s) of these two standards considered that, with respect to refraction, these two groups were different. This assumption was taken as the research hypothesis for this study.

The present Air Force regulation reveals no refractive error standard for either pilots or navigators once training has been completed, which could indicate that "refractively" speaking the two groups are identical. The aims of the present study are to show first that there is no significant refractive error difference between trained pilots and navigators. Hence a formal null hypothesis (Ho:) can be stated as follows: there will be no significant difference between the mean meridional refractive error and age of pilots and navigators of the United States Air Force. A second purpose of the study is to show what evidence exists concerning the "pairedness" of the two eyes of pilots or navigators.

HISTORICAL BACKGROUND

It has been said that "no single ideal study of the distribution of refractive status has been made."[4] However, a sufficient number of investigations have been reported which show how refractive status is generally distributed.

Steiger[5] introduced the concept of refractive status as a biological variable, concluding that refractive status is normally distributed. However, Baldwin[4] states that it is abnormally distributed, showing skewing towards the myopic side and leptokurtosis.

The first studies of the incidence of various degrees of spherical refraction were those of Betsch[6] and Scheerer[7] in Germany. Their sample consisted of 25,000 adult subjects who were clinical patients. Figure I shows the distribution obtained, the clear area represents the total number of right eye spherical components, while the shaded area indicates the distribution of eyes having a "myopic" conus. It should be noted that the total area distribution shows marked leptokurtosis and skewing towards the myopic side.

A comparable study in sample size of Scheerer[7] and Betsch[6] was the one done in the United States by Brown and Kronfeld.[8] Their data were obtained from the files of a private practice and were unusual in that refractions were done after atropine was administered four times a day for three and one half days. They analyzed the refraction for each of the two principal meridians in each eye as did Scheerer and Betsch, thus providing four findings for each subject. The sample data was taken from two groups of subjects under twenty-five and over twenty-five years of age respectively. In considering each group separately, Brown and Kronfeld found no significant difference between the two age groups. Neither did their findings differ significantly from other investigators, except that the mean refraction was slightly greater. This could be due to the nature of the sample, or that the refractions were done under cycloplegia. Figure 2 represents the distribution curves for both groups in the Brown and Kronfeld study.

Tassman's[9] study on the frequency of the various types of refractive errors also used a sizeable sample of approximately 10,000 cases. His subjects were patients who were examined during 1931 in the refraction department at Wills Hospital, Philadelphia. All patients under forty years of age were tested using either 1% atropine, 2% homatropine, or 1/8% scopolamine. The purpose of Tassman's study was "not to establish any definite rule of change of the refractive state of the patients over a great number of years, but to record in the various age groups the incidence of the recognized ametropias, and the frequency of the average spherical correction according to hyperopia, myopia and astigmatism".[9] His findings indicate that in each succeeding age group, up to the age of thirty, hyperopia decreases while myopia increases. In the over forty age group, the reverse seems to be true. In a separate analysis of 3,062 myopic eyes, he found that myopia predominated in all age groups, but the percentage of myopia was never as high as that of hyperopia. Tassman also noted that up to the age of forty, astigmatism against the rule occurs in greater proportion in myopia than in hyperopia, but that after forty a change takes place with astigmatism against the rule occurring in greater proportion in hyperopia.

A similar study, to that described above, was carried out by Jackson.[10] His sample consisted of cases from his private practice. The observations were made on eyes that were used for vision in many occupations and pursuits. Eyes, that were damaged by injury or disease, which could change the refractive error, were excluded. The study was based on the average spherical refraction, obtained by averaging the refraction of the two principle meridians. Thus, an eye requiring a lens of plus one sphere with a plus two cylinder, that is, plus one in one meridian and plus three in the other, was counted as having an average hyperopia of two diopters. Jackson's cases were divided into age groups, one of them being from age twenty to sixty. The data for this group was presented in 10 year periods. A study of the statistics, in his investigation, shows that after age 20 there begins a slow increase of average hyperopia that continues until old age. Such an increase of hyperopia has been explained by Priestly Smith[11] as simply the result of growth of the normal crystalline lens. In his study of the myopia statistics, it was noted that after 20 years of age, the average amount of myopia continues to increase. This may be due to myopia increasing when correcting glasses are not constantly worn and care is not taken to prevent excessive near work. With regard to astigmatism, Jackson reports a norm for this refractive condition on only those subjects before 24 years of age and after 50 years of age respectively. He states that "the period between these two groups would be very difficult to determine norms for astigmatism until more changes in single cases have been observed."[10]

Brown[12] in 1938, became interested in the net average yearly change of the static refraction in atropinized eyes from birth to the end of the 51st year. His method of calculating the data was similar to that described in Jackson's study.[10] The results of his study indicated a .04 diopter per year increase in myopia, or decrease in hyperopia, for the 21-33 year group; a .03 diopter decrease in myopia, or increase in hyperopia per year, in the 34-42 year groups; and a .09 diopter change per year increase in myopia, or decrease in hyperopia, for the 43-51 year groups. The decrease of myopia or increase in hyperopia in the 34-42 year group is perhaps conceivable if the accommodation is weak, the cycloplegic is more effective or both. In the 43-51 year group the increase in the rate of change may be attributed to the increase of the index of refraction, although deductions are scarcely permissible due to the small number of observations in Brown's sample.

Slataper[13] in 1950, reported the results of multiple examinations from ophthalmological practices. His sample total was 11,328 mean spherical refractions between the ages of 2 and 30 and included the previous data of Brown.[12] The citation of data from an earlier author on the assumption that it represents the findings of a later author[14] has led researchers to believe that Slataper's data confirms Brown's, when in fact it has only been requoted.

Walton[15] in 1950, presented a distribution curve showing the incidence of various degrees of a refraction for one thousand residents of a home for the indigent. The age range of his sample was from 30 to 100 years and was selected on the basis of no visual symptoms. The distribution is given in Figure 3. An analysis of his findings, with regard to the type of errors, are in close agreement with the findings of Jackson[10] and Tassman.[9]

Hirsch[16] has provided another study of an adult population with respect to mean refractive status at various ages. He showed that for a twenty-five year span there was a .034 diopter per year change. This figure is in close agreement with Walton's[15] higher value of .037 diopters per year and Slataper's[13] value of .04 diopters per year. Hirsch also points out the fact that his second and third year groups (50-54 and 55-59) shows an increase in hyperopia between .08 and .09 diopters per year. It should be noted that neither Walton[15] nor Slataper[13] mention a hyperopic change occurring more at one age than another.

One of the more outstanding studies of the incidence and degree of astigmatism was done by Hirsch in 1959.[17] Using 803 subjects, he found that there was more astigmatism of higher degree among men than among women. This fact substantiates Donders'[18] earlier observation. The data of Hirsch can be summarized as follows: for the 40 year span, from ages 40-80, the average astigmatic error changes from .25 diopters with the rule to approximately .75 diopters against the rule, and this against the rule astigmatism increases with increasing age. This is in agreement with the findings of most investigators. To ascertain the cause of this change in astigmatism would be speculative. However, most authorities attribute the change to the crystalline lens and this seems to be the best theory at present.

HISTORICAL REVIEW OF AVIATION: SELECTION AND STANDARDS

The history of aviation medicine is so closely linked with that of aviation, that it is impossible to tell the story of one without giving at least a brief outline of the other.

Few such seemingly impossible ideas have persisted so stubbornly in the human mind as man's desire to fly. Long before the dawn of civilization, efforts were made to imitate the eagle soaring high above one's head. In the latter part of the 13th century Roger Bacon[19] wrote confidently of aviation and made many predictions which had since come true. Leonardo Da Vinci[20] was famous, among other things, for his work on what could be considered the precursor of the helicopter. He drew designs of other types of aircraft which in some respects were very similar to those in use today.

The first successful flight, if gliding from the rooftop to the ground can be called a flight, was made by Besnier,[21] a Frenchman, using a pair of crudely shaped wings which he hoped to fly by flapping them in a bird-like manner. In the latter part of the 1700's the Montgolfier Brothers, of France, constructed a silk bag and filled it with gas.[22] These men, encouraged by their simple results, constructed larger bags and sent their first air passengers aloft in September 1783. These first passengers were, in order of their ascent, a chicken, a duck and a sheep.

In the development of aviation medicine it was not until 1862, that Glaisher and Coxwell[23] made a balloon ascent to an altitude of approximately 29,000 feet during which Glaisher noticed a series of strange symptoms developing. These were loss of visual acuity and hearing, paralysis of the legs and arms, and finally unconsciousness. Glaisher published his accounts of this flight and they came to the attention of Paul Bert,[24] a French physiologist, who began a study of the effects of increase and decrease of barometric pressures. Bert was the first to prove that the effect of high altitude was due to the decrease of partial pressure of oxygen.

The origin of aviation medicine really did not come into being until after the invention of the airplane. The first scientific paper on aviation medicine was published in 1907,[25] and the second in 1910.[26] During 1911 there were 11 papers published on various medical aspects of flying. In 1912 there were 6, in 1913, 7, and in 1914, 7. Thus, when World War I began, which was 11 years after the Wright Brothers' first flight, the world literature devoted to medical aspects of aviation consisted of 31 papers and one small book.[27] Yet there was considerably more medical interest developing in this field than one might suspect from a review of literature for that period. On 2 February 1912, the United States War Department published its first instructions concerning the physical examinations for candidates for aviation duty.[28] This was followed by the United States Navy publishing similar instructions,[29] although as early as 1910, minimum standards for military pilots had been drawn up in Germany.[30] In France the first official circular with reference to the medical examination of aviators appeared in 1912, but was not put into effect until 1914.[31] The Royal Flying Corps was established in England in 1912, and medical regulations soon followed.[32] In the United States of America the attempt of early investigators to devise suitable physical standards for flying were forgotten in the first years of

World War I, for we find that not only were unselected individuals utilized for flying training, but that men who were unfit for the ground branches were frequently transferred to the air service.[33] The disasters resulting from this practice became very apparent in about 1916, and it was at that time that all countries of concern began an intensive study of pilot selection.[34]

It is General Theodore Lyster, Medical Corps, United States Army, who is acknowledged as being the father of aviation medicine in the United States of America.[35] He was one of the first individuals to appreciate the medical problems in flying. In September 1917, Lyster became the first Chief Surgeon, Aviation Section, Signal Corps, United States Army, in which capacity he guided the development of aviation medicine during the period of World War I.[36] In 1916 Lyster, assisted by Colonels Wilmer and Jones, devised a new record sheet, established new standards, and wrote new regulations for the physical examinations of pilots.[37] These were issued in May 1917, in time for use during the war period, when 100,000 applicants were being "processed" in medical examining centers located throughout the United States.[38] The physical standards that were established for pilots by Lyster and his associates in 1916, were based largely on empirical grounds.[39] They felt that the whole question of standards should be given further study. At the same time, an appalling death rate resulting from aircraft accidents was taking place among flying cadets at training centers in the United States and among the allies in France.[40] This seemed to indicate the need for an extensive research program, and thus the Aviation Medical Board was appointed on 18 October 1917.[41] The powers delegated to this board were as follows:-

1. To investigate all conditions which effect the efficiency of pilots.

2. To assist and carry out such experiments and tests that would determine the ability of pilots to fly at high altitudes.

3. To carry out experiments and tests in order to provide suitable apparatus for the supply of oxygen to pilots at high altitudes.

4. To act as a standing medical board for the consideration of all matters relating to physical fitness of pilots.[42]

The first act of this board was to establish a research laboratory in Long Island which opened early in January 1918.[43] One of the major items of equipment in this new laboratory was a low pressure chamber. This was used in studying the effects of oxygen and lack of oxygen at high altitudes, and to classify pilots in accordance with their altitude tolerance. The other principle field of study was the physical standards for flying.[44] The work of the Research Section in Ophthalmology consisted principally of studies to determine the relationship between various functions of the eye, and the piloting of aircraft.[45] Studies were carried out with respect to color vision, visual acuity, eye muscle balance, fields of vision and depth perception under normal conditions and under conditions simulating high altitudes.[46] The work on depth perception resulted in the development of the Howard Dolman depth perception apparatus.[47] It was this Aviation Medical Research Laboratory that placed aviation medicine on a sound scientific basis in America.[48]

In Italy, emphasis was placed on reaction time as a standard for flying.[49] To investigate this, an apparatus was used consisting of a telegraph key connected to a timing device which recorded the time required for a candidate to press the key in response to a light which flashed at intervals. Those who showed a slow response were disqualified. Also, the Barany chair was used to test the vestibular mechanism.[50] If the candidate developed reverse peristalsis (vomiting) after rotation of the chair, he was immediately disqualified. A test for vision at night was done in a darkroom and determined either by the illumination being moved further and further away from the test card or by using cards with darker backgrounds.[51]

Except for certain special tests, pilot selection for foreign countries have followed, or paralleled, that of the United States.[52] The physical examination for flying in the United States began in 1912, and records show that the requirements for vision and hearing were obtained from the regulations of the military and naval services and that a text book of physiology was used as the principle source of information.[53] In 1916 a new examination form for flying was devised and specialists in eye and ear were appointed for this purpose. Of the three pages and additional 33 paragraphs of this new examination form, over half of the required information was devoted to the eye and ear. The nervous system, on the other hand, was allotted but one line.[54] The eye examination comprised a history of the use of glasses, headaches, lacrimation, scotoma, photophobia and previous or present eye trouble.[55] If these symptoms were marked, they were considered as disqualifying. Depth and distance discrimination were tested with objects printed on test cards held in and looked at through a stereoscope.[56] The subject was required to name the sequence of objects from front to rear, and errors resulted in disqualification. Eye muscle balance at 20 feet was measured by means of a phorometer, Maddox rod and rotary prism.[57]

More than one prism diopter of hyperphoria or more than two prism diopters of esophoria or exophoria was disqualifying. At the close of World War I, a tabulation was made of the results of the physical examination of all men who had applied for flying. From this it was learned that 69.7% were qualified and 30.3% were rejected.[58] The causes for rejection are shown in Table 1, while the specific causes for rejection for eye defects are shown in Table 2. Both Tables 1 and 2 are somewhat misleading due to the fact that where a candidate had two or more defects, the exact nature of these defects are not specified. From a study of the statistic of individual units, it was noted that where the candidate failed on two or more counts, visual defects were present in at least half of the cases. In other words, 50% of those rejected, failed to meet the eye requirements.[59]

In 1938 Schwichtenberg,[60] in his paper on the evaluation of orthoptic training for aviators, suggested that the static eye tests now being employed in aviation examinations be replaced by dynamic tests. He found that persons having a normal optical apparatus when tested by conventional methods sometimes showed gross errors when tested on orthoptic equipment. Since the eyes in flying are almost in a constant dynamic state, this suggestion by Schwichtenberg appeared to have considerable merit at that time.

For a ten year period following the end of World War I, aviation medicine was in a period of stagnation, and was kept from utter decay only by the efforts of a few individuals who had the foresight to realize that aviation and aviation medicine were more than just a transient necessity of World War I.[61] Of the few advances made in aviation medicine during the post-war years of World War I, two are of special significance. The first was the development, by Mashburn, of a serial action time machine to measure an individual's aptitude for flying training.[62] This was by far the most effective method developed up to this time of measuring this trait.[63] The other great advance of this period was the work of Myers who produced significant studies on the physiology of "blind" flying. This latter work was not published until 1936, but had been applied twelve years earlier.[64]

The revival of interest in aviation medicine in the United States following World War I was as a direct result of the eventual expansion of commercial aviation, as well as the increase in performance of the newer aircraft.[65] One of the first signs of this revival was the establishment of the medical section in the Bureau of Air Commerce, in the Department of Commerce, when the Bureau was established in 1926. The Bureau of Air Commerce only had a handful of civilian flight surgeons and it was these surgeons who were determined to advance their profession by forming the Air Medical Association in 1929.[66] They began, at that time, the publication of the professional journal, The Journal of Aviation Medicine, now called The Journal of Aerospace Medicine. A second important sign of the revival of aviation medicine occurred in 1934, when the Aero Medical Research Laboratory was established at Wright Field, Ohio,[67] now known as Wright-Patterson Air Force Base. As a result of increased performance of the newer aircraft, it became apparent that there should be studies concerning the effects of high performance flight on the human organism and the methods of neutralizing or eliminating those factors which were detrimental to the efficiency, health or safety of flying personnel. The first head of this new laboratory was Major (later Major General) Malcolm C. Grow, who served as the first Surgeon General of the United States Air Force.[68] The third important development of this period was the establishment in 1939, of the United States Navy School of Aviation Medicine at Pensacola, Florida.[69] This institution contained excellent facilities for research as well as teaching, and its establishment at that particular time was in response to a need generated by a marked increase in aviation in the Navy during the proceeding decade.

With the onset of World War II, the previous activities in aviation medicine were greatly expanded and intensified. It was soon learned that many of the known problems had not been adequately solved, and a great variety of new problems began to manifest themselves.[70] Streamline methods of selecting trainees for the thousands of aircrews needed for the war effort became urgent. Emotional breakdowns, as a result of fear of flying, or combat, also became a major consideration. The temporary loss of vision and consciousness from high speed turns during dogfights, was of vital concern and demanded renewed attention. All of this was complicated by the advancement of newer and faster aircraft, and the necessity for flying most combat missions at maximum speed and altitude. Near the end of the war this particular problem was compounded by the development of jet airplanes with a performance which greatly exceeded anything that had been ever imagined previously. As is usual in war, certain areas of medicine make great strides forward, and aviation medicine was in the forefront of this advance. That this is so, is evidenced by the fact that when all the work of this period was documented after the war, the bibliography of aviation medicine had grown to more than 15,000 articles, which had appeared in some 1100 different medical journals.[71] In addition, there was in existence about

150 books or monographs on the subject. Following World War II, aviation medicine did not fade into insignificance, as it had after the first World War, but on the contrary, gained stature and importance. This was due to the phenomenal growth of civil aviation and the fact that the air arm had emerged from World War II as the acknowledged first line of a nation's military defense.[72]

The war in Korea was the first in which jet aircraft were utilized in combat on a fairly large scale, and served to emphasize the medical problems of extremely high altitude and high speed flight. From the view point of new technical problems, the events of the Korean war were soon overshadowed by the concurrent development of new experimental rocket propelled aircraft. These new types not only broke the sound barrier, but all unofficial speed and altitude records held to date.

Today, with aircraft flying at very high speeds and all altitudes, there appears to be no reason to change the opinion that a high standard of visual acuity is necessary, particularly as man's reaction time has not changed appreciably since the days of the horse and cart.[73] Ruffell Smith in 1948,[74] indicated graphically the relationship between the speed of the nerve impulses and the increasing speed of flight. With the world's air speed record standing at approximately 21,000 miles per hour, it might well be considered that man is no longer a match for the increasing load imposed upon him by aviation. If one accepts the figures of Burns and Moseley,[75] it can be shown that a pilot flying an X-15 at 1800 miles per hour will travel at least 17,169 feet in the time between first sighting an object and changing his flight path to avoid it. (Table 3.) Thus, two aircraft flying at this speed on a head on collision course would need at least 6.5 miles of sky to avoid a fatal accident.

The problems of heterophoria in flying are equally as complicated. Since the earliest days of flying there has been a great interest in the effect of heterophoria on the ability to land an aircraft. The detection of large amounts of heterophoria on physical examinations had led to the exclusion from flying training of about 4-15% of applying personnel.[76] This has also led to the removal of fully qualified pilots. There has been a wide difference of opinion about the importance of heterophoria in flying and the standards that should exist.[77] Heterophorias are of interest in flying for four reasons.[78] First is the so called eye strain, headaches or other symptoms that are likely to occur. Second, heterophorias may progress to a transient heterotropia when the individual is subject to stress from such things as hypoxia, anxiety, fatigue or high G forces. Third, the heterophoria may develop into a more or less permanent heterotropia. Fourth, the heterophoria may impair distant judgment in landing operations. Hence, individuals with large amounts of heterophoria are excluded from flying training because of the likelihood of the occurrence of one or more of the above events.

The fourth aspect of heterophoria, its effect on landing performance, has been the chief reason for setting standards on heterophoria on flying personnel.[79] Since heterophoria supposedly does not change in individuals within the age range for flying, the important problem then seems to be the effect of a static heterophoria on landing. The reasoning for placing a limit on the amount of heterophoria that can be permitted has been the following: High heterophoria is associated with poor fusion; poor fusion results in poor stereopsis; and poor stereopsis results in poor distance judgment in landing aircraft. This logic breaks down in two places. First, a high heterophoria is not necessarily associated with poor fusion. In fact, in cases of high heterophoria, the reverse may be true, that is, the fact that there is a high heterophoria demonstrates that fusion is good enough for the eyes to overcome a large deviation. A more accurate measure of the fusional ability is the latent deviation, plus the deviation in the opposite direction that can be produced by a prism duction test.[80] This, however, no longer takes place in the physical examinations of personnel applying for flying training or those who have already completed flying training. The second place in which the logic breaks down is in the relation of stereopsis to ability to land an aircraft. It has been known for some time that stereopsis is only one of many cues used in distant judgment. It is not helpful beyond a certain distance, in fact, over the nose of the aircraft the distance from pilot to ground is too great for effective stereoscopic vision until the beginning of flareout and by this time other cues may be more efficient.[81] In numerous studies of the relationship of heterophoria to success in landing an aircraft, very little positive correlation has been found between the two. One study has shown that stereopsis is used in forced landings, but not in normal landings on prepared runways.[82] However, the importance of heterophoria even here is doubtful because other studies have shown that there is little or no relationship between heterophoria and stereopsis.[83] Heterophoria test standards are important chiefly in selecting personnel for flying training rather than in determining flying competence of trained personnel. For the latter, the question to be considered is whether the heterophoria is causing an unacceptable eye strain, a heterotropia or a decrement in landing performance. Further studies of the incidence of heterophoria symptoms according to dissociated position and a measurement of fusional amplitude should give standards that would be more realistic.

Specific military visual standards would appear to date from about 1942. Table 4 summarizes, by class, some of the visual standards in existence from 1942 to the present. Class I are standards of selection for pilot training; Class IA are standards for navigator training; while Class II are standards for pilots and navigators who have completed training.

The present refractive error standards, which are used in the selection of individuals for pilot training, has also been adopted by the National Aeronautics and Space Administration in choosing future astronauts. The standards which are employed for Class I are shown in Table 5. These limitations are used for individuals applying for pilot training. Once training has been completed, there exists no further refractive error limits. Due to the apparent correlation between refractive error and visual acuity, the refractive error standard after training becomes transferred to a visual acuity standard. This new standard, for the fully trained pilot, can be seen in Table 5. Hence, after training, there are no limits of refractive error. It can be appreciated that it would be the simple myopes or compound myopic astigmats who would be most affected by this acuity restriction. The simple hyperope or compound hyperopic astigmat, whose amplitude of accommodation is within normal limits for his age could have any degree of refraction and still be qualified to fly under the acuity standard.

Similarly, the individual who is applying for navigator training has no refractive error standards. He is only required to meet the same distant visual acuity restriction during and after training as the pilot has to meet after training. This means a distant visual acuity of not less than 20/50 in each eye correctable to 20/20 in each eye. This standard can perhaps lead one to rationalize that the primary visual task for the pilot is at distance and those for the navigator lies at near. However, the navigator has no "near" refractive error standards. He has exactly the same visual acuity limitation at "near" as exists for him at distance.

In turning to the present motility standards for Class I, IA or II, a similar situation exists. Here there are no fusional amplitude standards. This means that a candidate for pilot training can have qualifying heterophoria, but yet poor fusional amplitude reserves to maintain single binocular vision. Conversely, the prospective pilot candidate, who was eliminated because of excessive heterophorias, could have sufficient fusional amplitude reserves to maintain single binocular vision. Hence, motility standards are based only on a heterophoria measurement, with no consideration of associated fusional amplitude reserves.

The limitations of refractive error and heterophoria, as described above, have been in existence for many years and have not changed with the newer aerodynamic concepts of flight. The research in this thesis aims to indicate the need for change in these standards, in order to adequately select, assign, and retain future pilots, navigators, and astronauts. These standards are but a small aspect of the total problem, yet without them, crew selection and future space missions can be easily jeopardized.

COMMENTARY ON STANDARDS

Regardless of the various specific jobs for which standards exist, three basic purposes pervade all standards. These are safety, proficiency and longevity. Physical standards should provide reasonable assurance that qualified candidates will have no defects which would interfere with their becoming safe, proficient and successful military aviators. Selection must be based not only on whether the man will be able to operate an aircraft, but also on his ability to do so at peak efficiency under the stresses he will encounter.

The background for development of physical standards includes a detailed job analysis to provide insight in selecting the measuring instrument or test. These must be validated against the appropriate performance measures with reference to each of the purposes the standards are intended to serve. Cutting scores must then be established for each test; these are actually the physical standards. The efficiency of the standards, thus defined, to discriminate successful from unsuccessful pilots must still be ascertained as a consideration separate from the validity of the instruments.

The question of validity of our physical standards have always been a difficult one. To validate physical standards properly, large numbers of applicants should be examined and all enter into training regardless of findings. Naturally, any defect representing an obvious hazard would require elimination. Follow up studies could be conducted to check the outcome of the test group as to safety, longevity and proficiency as a pilot study over a given period.[84]

The type of study referred to above, would provide normative data allowing the construction of tables useful in predicting the risk involved in selecting a person for flying status.

Frequently a standard must be set without prior validation, since necessary data are not available. This will be the situation in the case of standards for the first space pilots. Probably extremely rigid at the outset, they will be modified on the basis of experience.

The value of thorough job analysis, including study of the job environment, is inestimable, but in addition, more needs to be learned of the demands of present aircraft. In a report Moseley stated: "It is apparent from accident data that we do not have at present adequate, objective measurements of the task imposed upon the pilot in high performance aircraft. Nor do we have adequate information regarding the pilots ability to cope with those tasks."[85] The design and thus the task, have great import for the standards necessary to select an operator of the vehicle. An example of this is the limitations of present Air Force pilot trainees to a sitting height of 38 inches. This is necessary by the limited canopy - head clearance in some training and combat aircraft. Through job analysis we can estimate the demands on human performance and tolerance of a particular vehicle.

In aviation today, at least two types of flight conditions having distinct associated stresses may be differentiated: (1) High performance jet and rocket flying and (2) Conventional transport flying. Various agencies concerned with standards have coped with the problem of developing reasonable standards. As far as the Air Force appraisal is concerned, most significant is the fact that only a small number of actual major changes have been suggested by reviewers of present standards. The following is a summary of some of the comments made on the suggested changes of standards as pertaining to the eye.

Inability to pass visual acuity standards have been the most common cause of physical rejection in pilot selection. There has been no true validation of physical standards, but studies which have been done indicate that our present visual standards could not be called standards for flying fitness.[86] Because radar enables the monitoring of distant objects, which spectacles and telescopes do not necessarily allow, the speed and performance characteristics of jet and rocket aircraft require superior visual acuity and will do so until an enclosed cockpit with only television and radar presentation is a reality. If the pilot of the future will be driven into the role of monitoring electronic devices for gathering information, integrating this information and translating the results in terms of precision responses and actions, then myopia greater than the present limit might be acceptable.[87] In the final analysis, the standard must be high enough to eliminate the unfit and low enough to insure accomplishment of the Air Force[88] objective.

PRESENT STATUS: REVIEW AND STANDARDS

The eleventh meeting of the Armed Forces National Research Council Vision Committee, in April 1945, was a significant one as far as military visual standards were concerned. Presented at that time was a thorough review of the existing standards from the ophthalmological and optometric point of view. It was pointed out that the status of visual testing was impossible to evaluate when results were so variable. The variability is caused by (1) test object differences, (2) differences in physical condition of the subjects, (3) differences among test administration procedures, and (4) variation in illumination.[89] Also presented at the meeting was Vitele's[90] study correlating measures of visual characteristics, training success, and flight performance of aircraft pilots. His hypothesis was "other things being equal, persons with various degrees of visual deficiency will learn to fly as well as persons with normally perfect vision". The results of his study indicated that all subjects with visual defects cannot attain acceptable flight proficiency, the probability of failure increasing as the visual defect becomes more extensive.

Following the meeting described above, there was immediate committee action relative to visual standards in the Armed Forces. Standard procedures for visual testing were developed, as were the production of manuals of instruction for testing visual acuity, heterophoria, and depth perception. These manuals were subsequently modified, evaluated, and recommended to the Armed Forces.[91]

The vision committee of the NRC had proposed visual standards and specific acuity requirements for service personnel at various times. These standards were designed for the use of aviators in 1947 and later, for pilots of NATO in 1954.[92] The committee at the 22nd meeting recommended that a comprehensive analysis be made of the naval skills required for various specialized military tasks, together with adequate measures of proficiency in such tasks.[93] In the records of the vision committee there are several reports of job analysis completed for the military services. Some of them are: (1) the relationship of visual efficiency and flight performance[94] (2) the minimum visual acuity requirements for enlisted submariners,[95] (3) the visual standards for Navy ratings,[96] and (4) the methodology for determining visual standards for Navy battleship assignments.[97]

In the light of this brief history, it seems clear that the objective was to determine the visual requirements of various military visual jobs. This objective was met by the various military branches defining the visual skills needed in the performances of different military occupations. The skills or standards are identified in terms of: entrance requirements into the military, retention of military personnel, and military assignment.

In examining applicants who wish to enter into the military, a distinction is made between visual standards for officers and those for enlisted personnel. The Air Force standards, for officers, are more stringent than for enlisted personnel.[98] The reason for these differences seem to be rooted in the differences between expected career terms of enlisted and officer personnel. Officer personnel are expected to serve 20 - 30 years, while enlisted personnel may enter for relatively shorter periods (about 4 years). Thus, the standards for officers reflect not only concern for effective performance of duties in so far as they may depend on visual function, but also a concern for decrease in functional efficiency with aging.

In the event that a person already in the military service incurs a disability in vision, a question arises concerning his retention. The general principle that has been followed, seems to be to utilize the affected person as far as possible in duties which would not effect his disability. In other words, the visual requirements for retention are lower than for entrance into the service.[99]

While steps to validate the visual standards, thus specified, are anticipated, no procedure for conducting such validation has been established.[100] The military services are attempting to collect detailed information on man's performance of various duties. Such information has promise for developing suitable performance measures in the future, and the employment of such performance measures should make it possible to relate visual factors to performance, and in turn to define visual job performance standards.[101]

PROCEDURE

A random sampling of pilots and navigators was obtained by the arbitrary selection of ten Air Force bases at random. The ten bases chosen were: Blythville AFB, Arkansas; Homestead AFB, Florida; Mac-Dill AFB, Florida; Grissom AFB, Indiana; Luke AFB, Arizona; Nellis AFB, Nevada; Vandenburg AFB, California; McConnell AFB, Kansas; Westover AFB, Massachusetts; and George AFB, California. No consideration was given to the types of aircraft at any one base, since no relationship exists between a pilot's or navigator's refractive error and the type of aircraft he flys.

Subjects at each base were selected at random from those pilots and navigators who were not required to perform "alert" or flying duties for a twenty-four hour period. Examination and selection of the subjects were made by the investigator with the support and co-operation of the individual "Squadron Flight Surgeon" and base "Operations Officer", respectively. Their assistance was required, in order to eliminate those subjects who had 'health problems', as well as to determine from flying schedules which pilots and navigators were not required for flying duties at that particular time. The remainder of the flying personnel were requested to report to the base hospital eye clinic for eye examination.

The samples for this study were composed of 153 pilots and 55 navigators. The age ranges for each group were 22-51 and 23-47, respectively.

Each subject was taken into the refracting examination room and a test for ocular dominance was performed. This test determined which eye was to be used in the subsequent calculation of the refractive spherical equivalent. Other recorded data included name, rank, date of birth, race, aeronautical rating, and, if applicable, length of time subject had been wearing spectacle correction, (see Figure 4). The date of birth was converted to the subject's age corresponding to his nearest birthday. Thus a subject 23 years and 4 months old was recorded as 23 years, while a subject 23 years and 7 months was recorded as 24 years. This data, as well as the dominant eye data, were obtained prior to instillation of the cycloplegic (Mydriacil). Two drops of 1% mydriacil were then instilled into each eye, five minutes apart, and after waiting twenty-five minutes, a cycloplegic refraction was performed. The cycloplegic refraction was recorded in terms of sphere power, cylinder power (in minus cylinder form) and axis. The results of the dominant eye tests and cycloplegic refraction were recorded together with the date that these tests were carried out.

The controls that were used in this study were based on the following criteria. 1. All subjects were in excellent general and ocular health. 2. Subjects had successfully passed a flight physical examination within the past twelve months. 3. Only male subjects were used, since female pilots and navigators were not eligible for selection. 4. All cycloplegic refractions were done both objectively and subjectively to the best monocular acuity with maximum plus lens acceptance. 5. Refracting room illumination was kept constant by using a 40 watt frosted bulb in the overhead lamp of the refracting unit, as the sole illumination source. 6. The Snellen acuity letter size was determined appropriate for the refracting distance. 7. Reflectance of the Snellen letters, using the projection type chart, were kept at approximate 5% and 80% respectively. 8. The projection chart illuminance was also kept at

20 ft. candles.

Although two types of dominancy test, and phoria measurements, were made on each subject, these data are not included, as it is considered inappropriate to the main theme of the present study.

Handling of the Data

Many methods have been used in classifying refractive errors. Hofstetter[102] employed the mean spherical equivalent of the spectacle refraction, while Blum, et al.,[103] used the spherical component of the spectacle refraction with the prescription written in minus cylinder form. Sorsby[104] used the ocular refraction in the vertical meridian under cycloplegic.

In this study, a problem was encountered in using the dominant eye as the one in which to determine its spherical equivalent. This was due to the fact that slightly more than 7% of the total number of subjects had a mixed ocular dominance finding in the two tests.

In order not to reduce the sample size of pilots and navigators, it was decided to analyze the refractive finding by using the meridional powers of each eye separately. If, after using an appropriate correlational statistical test, it should be observed that no correlation of meridional powers exists, this would indicate the non existence of a "paired" relationship between the right and left eyes. It is interesting to note that previous investigators have assumed a paired refractive error relationship between eyes, without any appropriate statistical evidence.

For this study, the axes of the meridians were set either at 180 degrees (horizontal) or 90 degrees (vertical). This was done by considering all cylinder axes within thirty degrees on either side of vertical to be vertical, and all cylinder axes within thirty degrees on either side of horizontal to be horizontal. All randomly selected subjects who showed cylinder power under cycloplegia had axes which fell within this defined range of horizontal and vertical.

APPARATUS

The equipment used for data collection was a standard combined phoropter refracting unit and chair; and accessory cylinder powers and cross cylinders; visual acuity projection type chart with screen and slides; retinoscope. These items were available at all Air Force eye clinic medical facilities.

RESULTS AND DISCUSSION

The scatter plots of the vertical and horizontal meridians for each eye of pilots and navigators are seen in Figures 5, 6, 7 and 8. In Table 6 can be seen the regression coefficients, correlations, means and standard deviations of the meridional data for each eye of the two groups. It can be seen that the correlations of age and meridional powers, as well as regression coefficients for both groups, are all low, and are considered insignificant.

Table 6 reveals the correlations and regression coefficients in a comparison of pilots against navigators, with respect to meridional powers. The various meridional data of each eye reveals a very low correlation, and regression coefficient to exist between the two groups.

Comparison of the mean meridional powers of pilots and navigators shows that all are significantly different from each other at the 0.05 level of confidence. This means that there are 95 chances out of 100 that one would find a significant difference in meridional power between pilots and navigators. This result seems to support the previous claim made in this report, that the samples come from two distinctly different populations.

Observation of Table 7 reveals the correlations between the [same] meridional powers of the right and left eyes of pilots. The same table also shows the same information for navigators. The results show a high correlation between the two eyes, for each group. The navigator correlations are slightly higher than for the pilots, due to less refractive meridional power differences. From these high correlations, the inference can be made that the two eyes of pilots, are, from a refractive error standpoint, with respect to meridians, paired organs.

The same inference can be made with respect to the eyes of navigators.

	per cent
Eye	6.9
Ear	1.2
Nose and throat	0.8
Equilibrium	2.0
Vascular system	1.5
Urinalysis	0.4
Other and general subnormalities	1.9
Disqualified on two tests	7.0
Disqualified on three or more tests	8.6
Total	30.3

Table 1. The causes for rejection for all men who applied as cadet flyers during the World War (Armstrong).

	per cent
History of eye trouble	0.03
Stereoscopic vision	0.5
Ocular movements	0.04
Pupillary reactions	0.01
Intraocular tension	0.003
Visible lesion of eyes	0.08
Ocular nystagmus	0.02
Field of vision	0.003
Color vision	1.
Muscle balance	0.7
Visual acuity	3.3
Ophthalmoscopic findings	0.3
Total	5.986

Table 2. The specific causes of rejection for eye defects among all men who applied as cadet flyers during the World War (Armstrong).

Table 3. Time Intervals Required between First Sighting of Object and Changing Flight Path to Avoid and Distances Travelled in these Intervals. (WADC, Technical Report.)

Operation	Time, in sec.		Distance Travelled, in feet			
			at 600 m.p.h.		at 1,800 m.p.h.	
	For Operation	From 1st Sighting	During Operation	From 1st Sighting	During Operation	From 1st Sighting
Sensation light travels from retina to brain	0.10	0.10	88	88	315	315
Focusing with Central Vision						
Motor Reaction to Prearrange Eye Movement	0.175	0.275	154	242	552	867
Eye Movement	0.05	0.325	44	286	158	1025
Focusing with Fovea	0.07	0.395	62	348	221	1246
Perception minimum recognition	0.65	1.045	572	920	2050	3296
Deciding What to Do estimated min.	2.0	3.045	1760	2680	6306	9602
Operating Controls	0.40	3.445	352	3032	1261	10863
Aircraft Changes Flight Path	2.0	5.445	1760	4792	6306	17169

Table 4. Flying Standards: Visual Acuity, Refractive Error, Motility

	Distant Visual Acuity	Refractive Error	Motility
Class I Flying Training (Pilot)	8/42: 20/20 each eye unaided 3/43: 20/30 each eye correctible to 20/20 each eye 5/57: Present 20/20 each eye unaided	8/42: H. ≠ 1.50 M. 0 Ast. ≠ .50 3/43: H. ≠ 1.50 M. 0 Ast. ≠ .50 5/57: H. ≠ 1.75 M. - .25 Ast. ≠ .75 Present: H. ≠ 1.75 M. - .25 Ast. ≠ .75	Eso Xo Hyper 8/42: 10 5 1 Prism divergence can't be greater than 15 or less than 3 when esophoria exists. No standard prism convergence. 3/43: 12 7 0 Prism divergence can't be greater than 15 or less than 2 when esophoria exists. Prism convergence. No standard. 5/57: Present: 10 5 1 Prism divergence/convergence. No standards.
Class IA Flying Training (Observer)	8/42: 20/40 each eye corrected to 20/20 each eye. 3/43: Same as 8/42 5/57: Present: 20/50 O.U. corrected to 20/20 O.U.	8/42: Same as C/I 3/43: Same as C/I 5/57: Present: No Standards	8/42: Same as C/I 3/43: " " " 5/57: Present: Same as C/I
Class II Flying Training Complete	8/42: Same as C/IA 3/43: Same as C/IA 5/57: Present: Same as Class IA	8/42: No standard 3/43: No standard 5/57: Present: No standard	8/42: Same as C/I 3/43: " " " 5/57: Present: 10 5 1½
Class III Flying Personnel not in primary control of aircraft	8/42: 20/100 O.U. corrected to 20/20 O.U. 3/43: Same as above 5/57: Present: 20/400 O.U. corrected to 20/20 one eye and 20/30 other	8/42: No standard 3/43: No standard 5/57: No standard 2/64: Present: ≠ 5.50 3.00 astig. 3.50 aniso	8/42: 12 7 2 Prism diverg/conver. No standard. 3/43: Same as above 5/57: No standard 2/64: Present: 15 8 2 Prism diverg/conver. No standard.

	Distant Vision	Near Vision	Refractive Error	Motility
Flying training (pilot), class I	20/20 each eye	20/20 each eye	Total: + 1.75 - 0.25 Astig. 0.75	Eso. 10 Exo. 5 Hyper. 1 Pc. 70 or less
Flying training (observer), class IA	20/50 each eye Correctible to 20/20 each eye	Same as Class I	X	Same as Class I
Flying (training completed), class II	Same as Class IA	20/50 each eye. Correctible to 20/20 each eye	X	Eso. 10 Exo. 5 Hyper. 1.5 Pc. 70 or less
Flying (for personnel not in primary control of aircraft), class III	20/400 each eye Correctible to 20/20 and 20/30	Correctible to 20/20 and 20/30	Same as Commission	Same as Commission
Air Force Academy	Same as Flying Class I	See also par. 15		
Commission (non-flying)	20/400 each eye. Correctible to 20/30 and 20/40	Correctible to 20/20 and 20/40	Total: + 5.50 - 5.50 Astig. 3.00 Aniso. 3.50	Eso. 15 Exo. 8 Hyper. 2 Heterotropia
Enlistment	Correctible to 20/40 and 20/70 or 20/30 and 20/100 or 20/20 and 20/400 or less if not due to progressive disease	Correctible to 20/40 in better eye	+ 8.00 - 800	Heterotropia greater than 15° is disqualifying

X No standards.

Table 5. Eye Requirements (Air Force Manual).

LINEAR REGRESSION COEFFICIENTS

REGRESSION LINE Y = (A)X +(B)
X = AGE IN YEARS
Y = OPTICAL POWER

VARIABLES	PILOTS (A)	PILOTS (B)	PILOTS STD. ERROR 1 OBS.	NAVIGATORS (A)	NAVIGATORS (B)	NAVIGATORS STD. ERROR 1 OBS.
RIGHT EYE, (HORIZONTAL)	-0.06023	0.09449	0.693	0.00277	-0.28186	0.894
RIGHT EYE, (VERTICAL)	0.01114	-0.19169	0.636	0.00466	-0.39243	0.839
LEFT EYE, (HORIZONTAL)	-0.00354	0.27350	0.690	0.00983	-0.44841	0.911
LEFT EYE, (VERTICAL)	0.01066	-0.12875	0.637	0.00806	-0.45344	0.830

REGRESSION LINE Y = (A)X +(B)
X = PILOT OPTICAL POWER
Y = NAVIGATOR OPTICAL POWER

VARIABLES	(A)	(B)	STD. ERROR 1 OBS.
RIGHT EYE, (HORIZONTAL)	-0.02026	-0.18997	0.894
RIGHT EYE, (VERTICAL)	0.02059	-0.24388	0.840
LEFT EYE, (HORIZONTAL)	0.06573	-0.14128	0.913
LEFT EYE, (VERTICAL)	0.11827	-0.21467	0.830
PILOT RIGHT, NAV. LEFT HORIZNTL	0.03517	-0.13292	0.914
PILOT RIGHT, NAV. LEFT VERTICAL	0.11453	-0.20321	0.830
PILOT LEFT, NAV. RIGHT HORIZNTL	0.06056	-0.20278	0.893
PILOT LEFT, NAV. RIGHT VERTICAL	0.10449	-0.27725	0.835

MEAN OPTICAL POWERS AND STANDARD DEVIATIONS
PEARSON PRODUCT CORRELATION COEFFICIENTS OF POWER TO AGE

PILOTS: MEAN AGE = 32.28, STD. DEV. = 7.92

NAVIGATORS: MEAN AGE = 32.45, STD. DEV. = 6.50

VARIABLES	PILOTS OPTICAL POWERS (MEAN)	S.D.	(R)	S.D.	NAVIGATORS OPTICAL POWERS (MEAN)	S.D.	(R)	S.D.
RIGHT EYE, (HORIZONTAL)	0.087	0.693	-0.003	0.081	-0.192	0.894	0.020	0.134
RIGHT EYE, (VERTICAL)	0.168	0.642	0.137	0.080	-0.241	0.840	0.034	0.133
LEFT EYE, (HORIZONTAL)	0.159	0.690	-0.041	0.081	-0.129	0.914	0.070	0.133
LEFT EYE, (VERTICAL)	0.215	0.643	0.131	0.080	-0.192	0.832	0.063	0.133

CROSS-CORRELATION COEFFICIENTS

VARIABLES	(R)	S.D.
RIGHT EYE, (HORIZONTAL)	-0.009	0.134
RIGHT EYE, (VERTICAL)	0.017	0.134
LEFT EYE, (HORIZONTAL)	0.033	0.133
LEFT EYE, (VERTICAL)	0.070	0.133
PILOT RIGHT, NAV. LEFT HORIZNTL	0.016	0.134
PILOT RIGHT, NAV. LEFT VERTICAL	0.068	0.133
PILOT LEFT, NAV. RIGHT HORIZNTL	0.031	0.133
PILOT LEFT, NAV. RIGHT VERTICAL	0.111	0.132

Table 6. Statistical Data, showing means, standard deviations, correlations and regression coefficients of meridional powers in pilots and navigators.

LINEAR REGRESSION COEFFICIENTS

REGRESSION LINE Y = (A)X +(B)
X = RIGHT EYE
Y = LEFT EYE

	HORIZONTAL				VERTICAL				
	(A)	(B)	(S.D.)	(R)	(S.C.)	(A)	(B)	(S.D.)	(R)	(S.D.)
PILOTS	0.734	0.098	0.488	0.707	0.041	0.707	0.097	0.455	0.706	0.041
NAVIGATORS	0.923	0.048	0.393	0.903	0.025	0.916	0.029	0.318	0.924	0.019

T-TESTS BETWEEN LEFT AND RIGHT EYES

	HORIZONTAL	VERTICAL
PILOTS	0.910	0.647
NAVIGATORS	0.366	0.311

T-TESTS BETWEEN PILOTS AND NAVIGATORS

	HORIZONTAL	VERTICAL
RIGHT EYE--RIGHT EYE	2.374	3.733
LEFT EYE--LEFT EYE	2.443	3.733
PILOT RIGHT--NAV. LEFT	1.327	3.297
NAV. RIGHT--PILOT LEFT	2.997	4.168

Table 7. Statistical Data, showing T-tests between the two eyes of pilots and navigators.

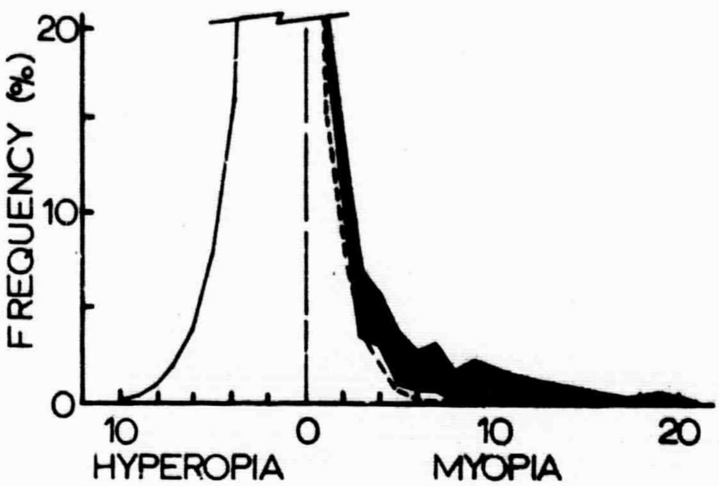


Figure 1. Distribution curve of refractive status for 25,000 adult eye clinic patients. (Betsch and Scheerer's data.)

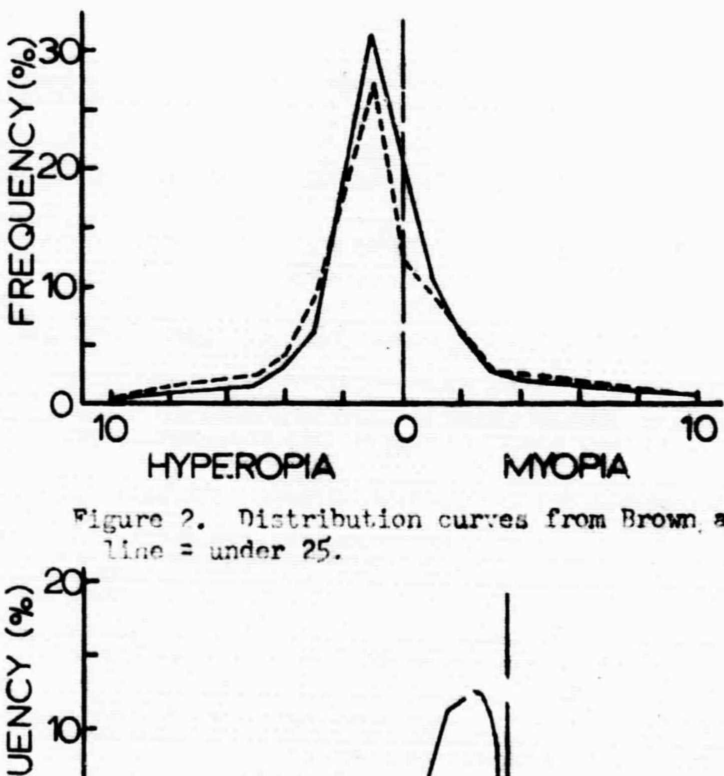


Figure 2. Distribution curves from Brown and Kronfeld. Dotted line = under 25.

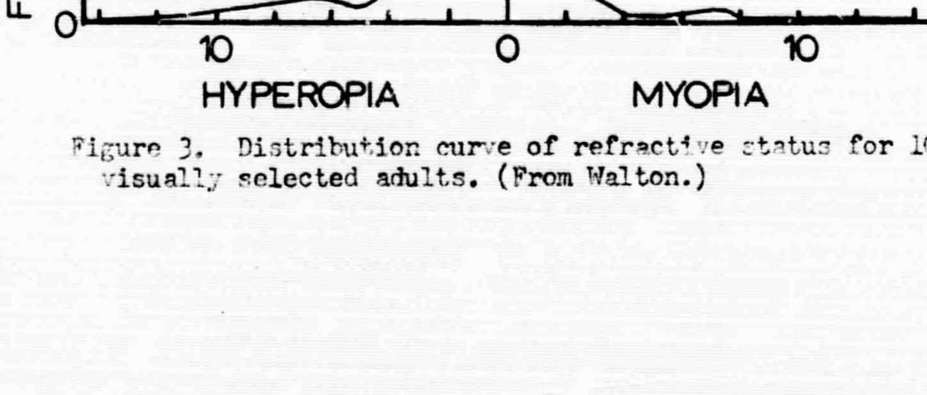


Figure 3. Distribution curve of refractive status for 1000 non-visually selected adults. (From Walton.)

Figure 4. Data Sheet (Modified)

DATA SHEET

Name	Rank	Serial No.	Age	Aero-Rat.	Test Date		Cyclo Refr.			Dom Eye Test					Sph Eqv Dom Eye	Remarks
										Tact.		Non-Tact.		Mix		
					M	D	Sph	Cyl	Axis	R	L	R	L			

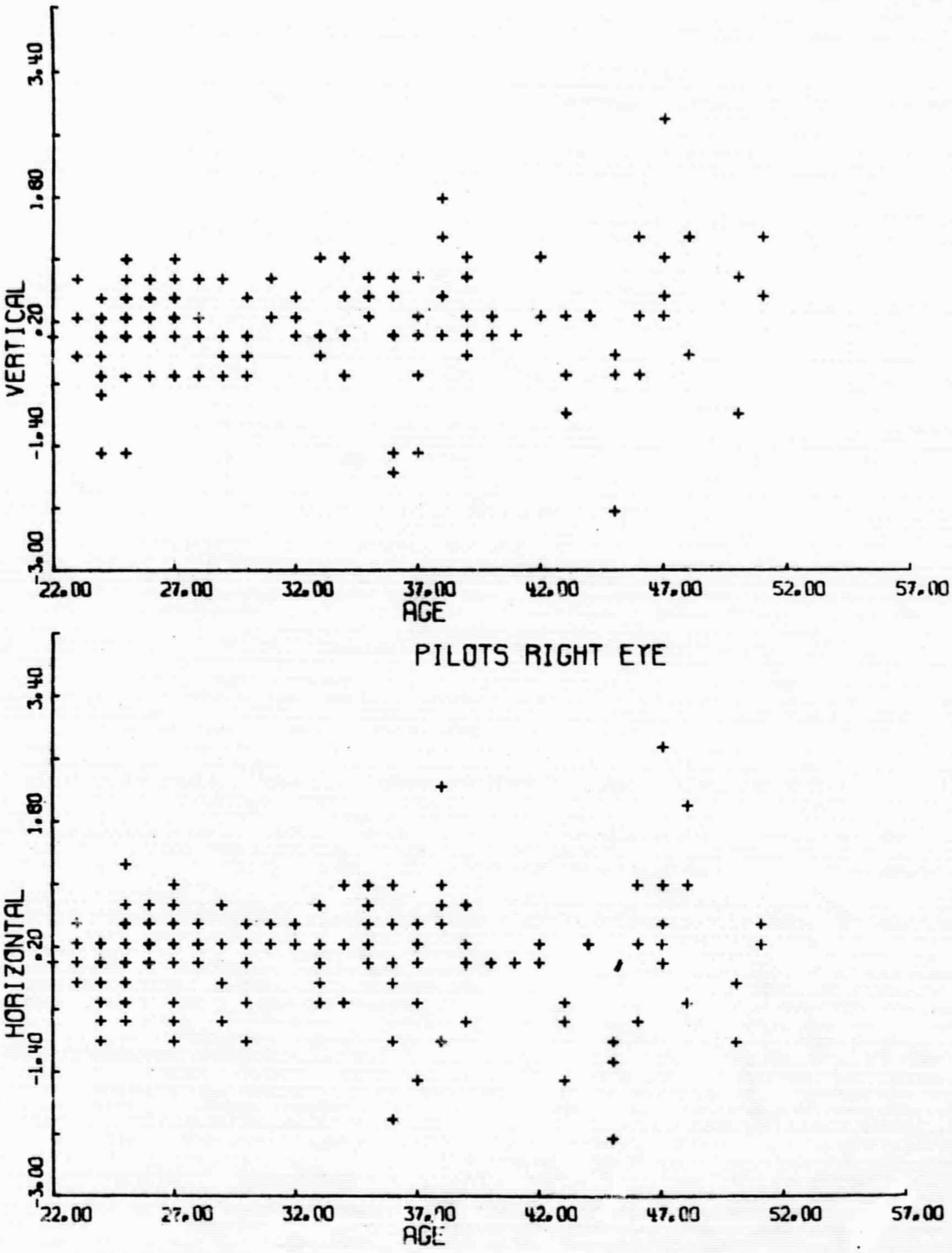


Figure 5. Scatter plot of pilots right eye, vertical and horizontal meridians.

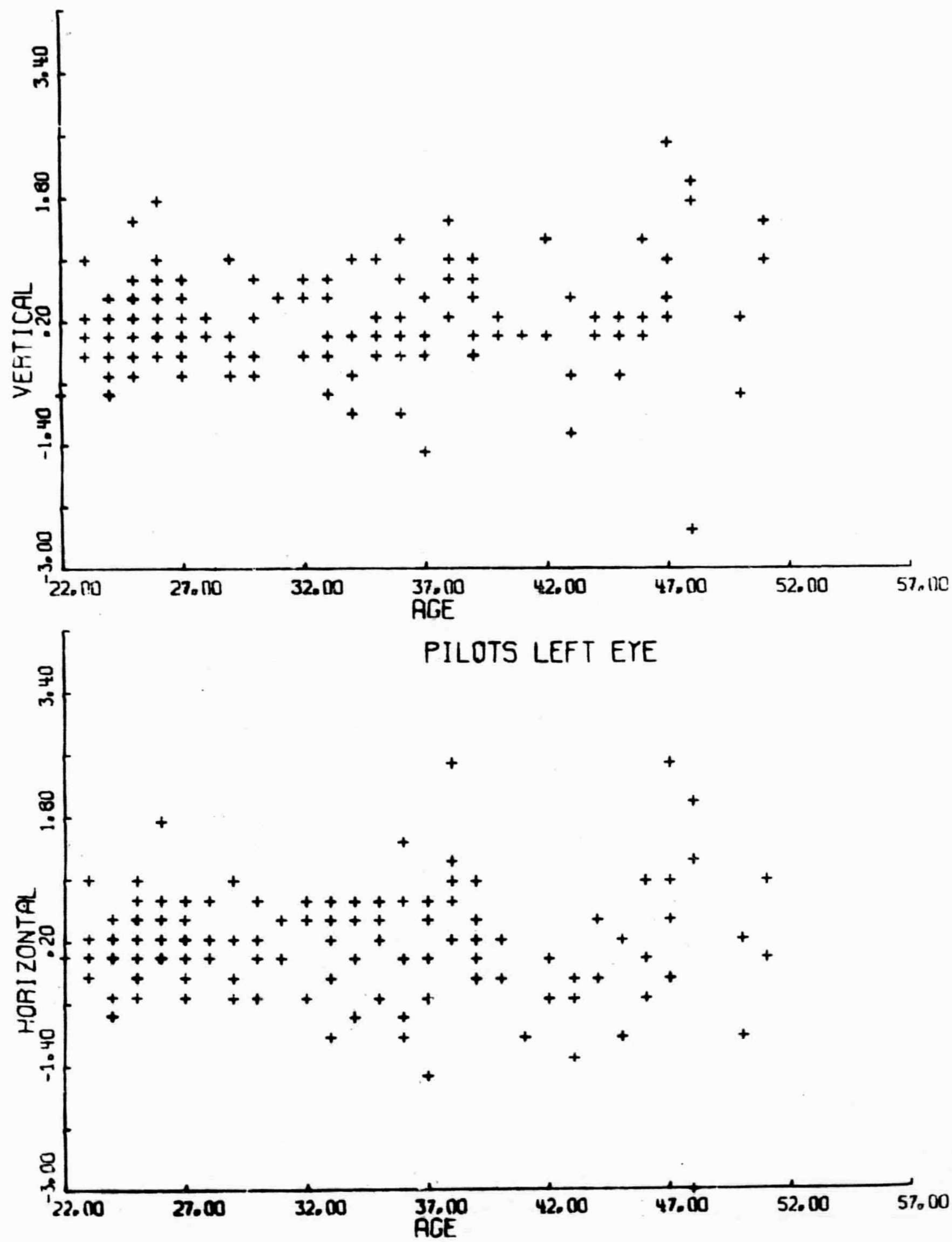


Figure 6. Scatter plot of pilots left eye, vertical and horizontal meridians.

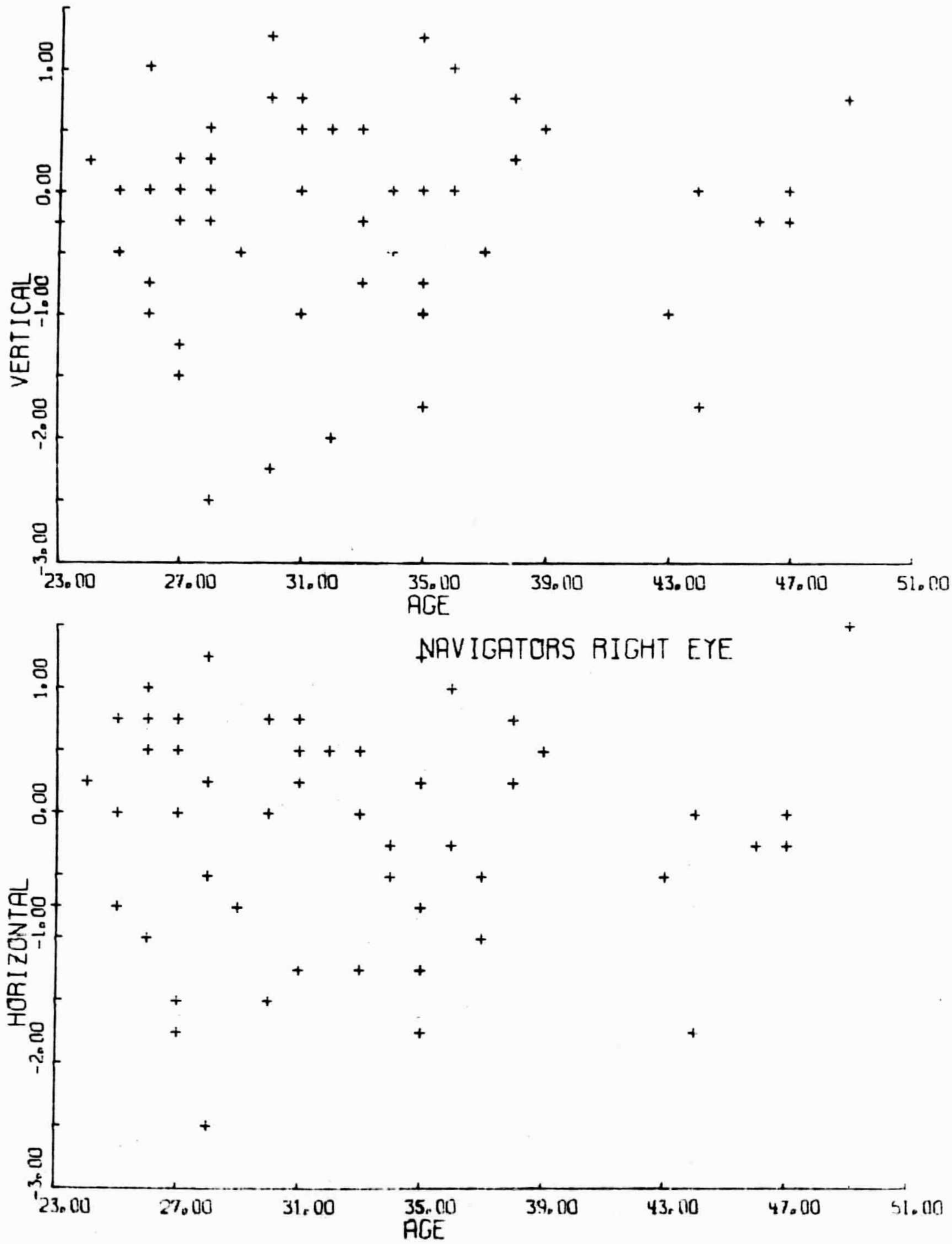


Figure 7. Scatter plot of navigators right eye, vertical and horizontal meridians.

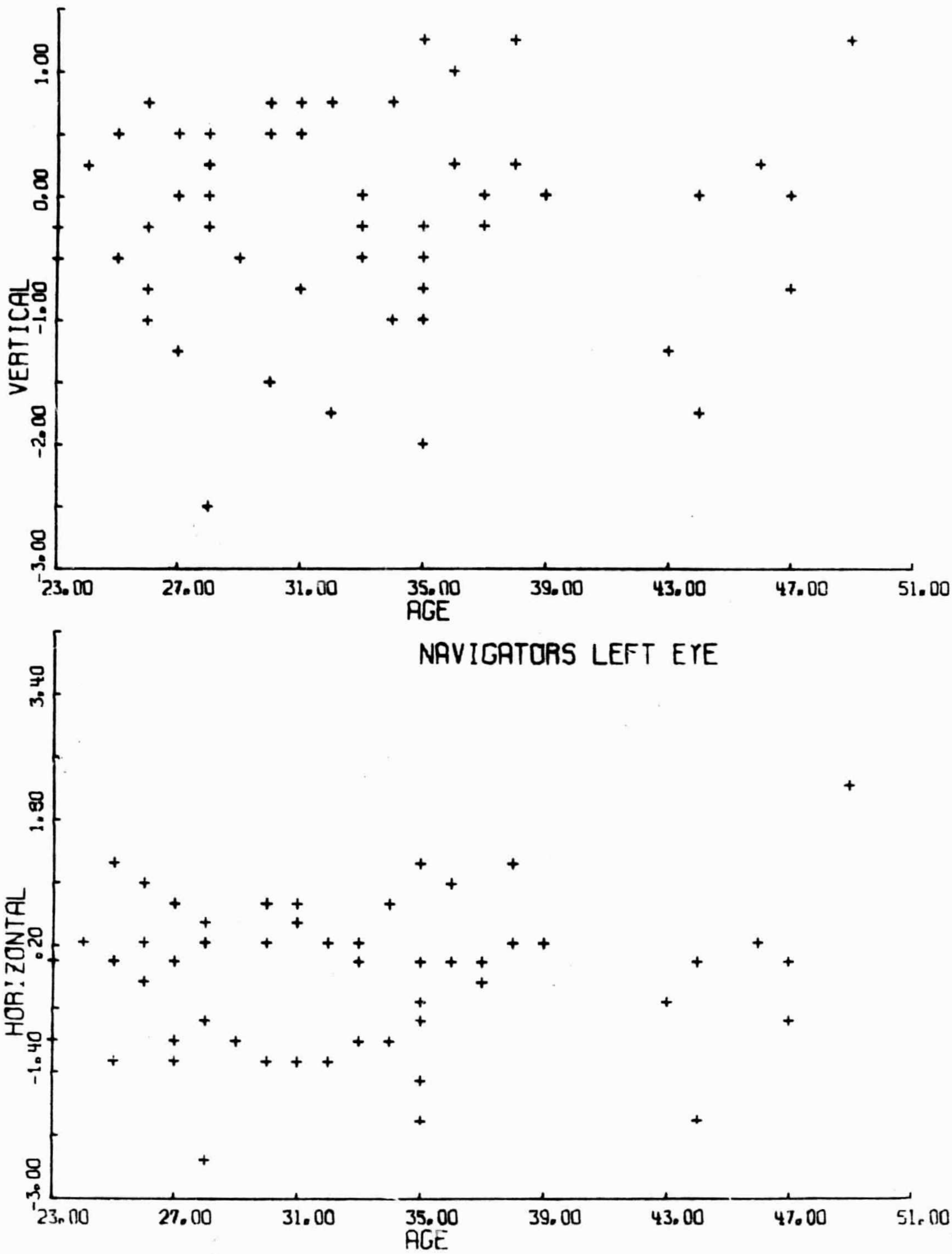


Figure 8. Scatter plot of navigators left eye, vertical and horizontal meridians.

CONCLUSIONS

Pilots and navigators were randomly chosen as subjects for an investigation of the trends of meridional power, as related to refractive error. The data were analyzed by testing each mean meridional power for significant differences. The correlations and regression coefficients were analyzed.

1. Correlations and regression coefficients of age and meridional power are all very low and do not differ significantly from zero.
2. Cross correlations and regression coefficients between the same meridional powers of pilots against navigators are all very low and differ insignificantly from zero.
3. Correlation and regression coefficients between the two eyes of pilots are high and significant, indicating, on a refractive error basis, that the two eyes are paired organs. The same conclusion applies to navigators.
4. There is a significant difference between the mean meridional refractive error powers (right and left eyes) of pilots and navigators respectively. This indicates that the two samples come from two different populations and that the null hypothesis, i.e. that the mean meridional power of pilots is not significantly different from the mean meridional powers of navigators, must be rejected.
5. Correlation of refractive error and age, for pilots and navigators, are very low.
6. There is a significant difference between the mean spherical refractive error of pilots and navigators (t = 3.02

and 3.40, p = .01 for right and left eye respectively) indicating that the two samples come from two different populations and that the null hypothesis must be rejected.

7. There is no significant difference in sphere and cylinder power between the two eyes of pilots and navigators. This indicates that the eyes are essentially paired organs in terms of refractive error.

SUMMARY

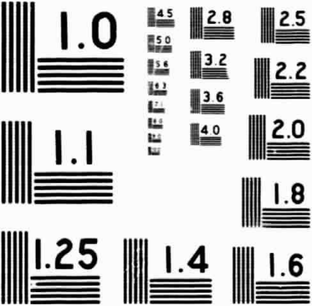
An analysis of the refractive powers of the horizontal and vertical meridians of the eye with age, on 153 pilots and 55 navigators of the United States Air Force indicated (a) very low regression coefficient and correlation between age and meridional refractive powers for the two groups, (b) meridional powers of refractive error in the right and left eyes of pilots showed a "paired" relationship. The same paired relationship also exists between the right and left eyes of navigators and (c) the mean meridional refractive powers (right and left eyes) of pilots and navigators are significantly different from each other. This indicated that the two samples came from two different populations.

APPENDICES

A, B, and C

APPENDIX A

RESEARCH PROPOSAL DATA SHEET



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS—1963

APPENDIX B

SCATTER PLOTS: PILOTS AND NAVIGATORS

Upper figure: right eye. Lower figure: left eye.

	PLANO	-.25CYL	-.50 CYL.	-.75 CYL.	-1.00 CYL	-1.25 CYL.	-1.50 CYL.
+2.75	1/0						
+2.50	0/1				0/1		
+2.25			1/0		0/1		
+2.00	0/1			1/0			
+1.75	0/1	1/0	0/1				
+1.50		0/1		1/1			0/1
+1.25		4/2	1/0			0/1	
+1.00	3/6	3/4	3/2		1/0		
+ .75	7/7	4/4	0/2	1/3	1/0		
+ .50	19/14	3/5	2/4	0/1	0/2		
+ .25	22/15	6/9	1/3	1/1	1/0	0/1	
Pl.	23/14	4/12	4/3	0/2	2/1		
- .25	5/6	2/5	1/1		1/0		
- .50	2/4	3/0	3/1				
- .75	1/3	1/3		1/0			
-1.00	1/0		2/0				
-1.25		0/1					
-1.50	1/1		1/0				
-1.75							
-2.00							
-2.25	1/0						
-2.50			0/1				

SCATTER PLOT OF CYCLOPLEGIC REFRACTION ON PILOTS (N=153)

SCATTER PLOT OF CYCLOPLEGIC REFRACTION (NAVIGATORS, N=55)

Upper figure: right eye. Lower figure: left eye.

SPHERE	Pl	-.25	-.50	-.75	-1.00	-1.25	-1.50	-1.75
+1.25	1			1		1		0
	2			0		0		1
+1.00	2	0						
	0	0						
+0.75	3				1	1	1	
	3	1	1	1				
+0.50	4	1	1					
	2	3	1					
+0.25	3	2	1	1				
	4	3	2					
Pl	5	3	1					
	5	2						
-0.25	2		1					
	1		2	1				
-0.50	2	2	2					
	1		3	2				
-0.75	1		1					
	2		1					
-1.00	1	3						
	1	1	1					
-1.25			1					
	1	1	1					
-1.50	1		1	1				
-1.75	2							
		1						
-2.00								
	1							
-2.25								
-2.50	1							
	1							

CYLINDER

APPENDIX "C"

The following appendix represents works relating to the topics discussed in the thesis, but not included in the maintext. Although not exhaustive, it does aim at presenting all of the major material on the subject.

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I was born on [redacted] in [redacted], where I received my elementary education and graduated from high school in June 1946. My undergraduate college education began in July 1946 at the University of Illinois. In 1949 I entered Chicago College of Optometry (now known as Illinois College of Optometry) with advanced standing and graduated with the degrees of Bachelor of Science (B.S.) in Optometry and Doctor of Optometry (O.D.) in February 1951. After spending one year in the graduate division of the Chicago College of Optometry, I was awarded the degree Doctorate of Ocular Science (D.O.S.) for research in ocular dominance.

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I am a member of the Optometric Extension Program, Contact Lens Association for Optometry, American Optometric Association and the American Academy of Optometry.

In 1952 I married Miss Lee Newman and at present have three children ages 12, 10 and 8.