THE INHERITANCE OF EYE DOMINANCE AND THE RELATIONSHIP TO HANDEDNESS AND VISUAL ACUITY

By

Harvey Lee Meyers, Jr.

AN ABSTRACT

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THESIS ABSTRACT

Eye dominance was determined in 153 children in the kindergarten and first grade of the Red Cedar Elementary School in East Lansing, Michigan. The parents of 79 of the children were likewise tested and the distribution of eyedness of mating pairs was compared with the eyedness of the offspring. Of the children, 64.6 percent were right-eyed; 35.4 percent, left-eyed. Of the parents, 68.4 percent were right-eyed; 31.6 percent, left-eyed. There was no significant difference between the distribution of eyedness in each generation. However, eyedness within the parental mating type was significantly associated with the eyedness of the offspring from the mating. This familial distribution of eyedness was considered genetic in etiology since no environmental influences on eyedness have ever been conclusively demonstrated. Analysis of the parents-offspring triads ruled out inheritance by means of single alleles with full penetrance, autosomal or heterosomal. However, the findings are consistent with inheritance by single alleles with no dominance, the heterozygote being randomly expressed as right-eyedness or left-eyedness.

The phenotype, eye dominance, was determined by the hole-in-paper test selected from many similar tests because of its simplicity and reliability. In a preliminary experiment on 25 subjects the hole test proved most valid among four similar tests. That the test was reliable was shown one year later by retesting 63 subjects, 92 percent of whom showed unchanged dominance.

Hand dominance was tested in 82 children and in the parents of 80 of these children. Of the children, 78 percent were right-handed; 22 percent, left-handed. Of the parents, 89.4 percent were right-handed; 10.6 percent, left-handed. The distribution of handedness proved to be significantly different in the two populations. However, the handedness of the parents was not significantly associated with the handedness of the offspring; nor was handedness significantly associated with either sex in the two generations.

Relative visual acuity was determined in 146 parents. Whereas 63 percent had grossly equal acuity in each eye, 21.9 percent had better acuity in the right eye and 15.1 percent, in the left eye. Relative acuity was not significantly associated with eyedness, handedness or sex.

The thesis also includes a history of the ideas and investigations of eye dominance, a comprehensive bibliography, a table of the raw data, a sample eye dominance test paper, and a data information sheet.

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INTRODUCTION

Human beings along with all other vertebrates and some invertebrates possess a body structure that is bilaterally symmetrical. The enigma of physiological and anatomical tendencies toward unilaterality has, therefore, long been a prominent problem in basic science. Eye dominance, the consistent and involuntary usage of one eye rather than the other, is an example of a unilateral tendency in the functioning of bilaterally symmetrical sense organs. It is the purpose of this dissertation to provide data on eye dominance and its relationship to hand dominance, to relative visual acuity, and to possible hereditary factors.

Theoretically, a physiological imbalance in any motor or sensory activity could mediate the "preference" of one eye. Pascal (1954) concluded that eye dominance may be based on sensory superiority of one eye over the other or on a finer motor coordination of one eye in maintaining greater steadiness of fixation. As early as 1884 Hall and Hartwell speculated on eight separate types of ocular asymmetry involving both motor and sensory inequalities. Duke-Elder (1932) defined eye dominance as a habit due to reliance on one eye to a greater extent because of motor imbalances or sensory inequalities involving acuity, brilliance, after-image persistence, retinal rivalry, or diplopia vividity. A definition of eye dominance from a sensory viewpoint was offered by Mills (1925), who assumed that in a pair of eyes alike in retinoscopic respects "...one possesses a greater sense of clarity, sharpness of outline

and detail and, in general, a greater power and refinement of discrimination." From tests comparing darkness intensity in each visual field, Miles (1929) concluded eye dominance to be the tendency to clear the visual field by giving the right of way to the image that belongs to the dominant eye, making it appear more substantial than the other. Schoen (1936) interpreted evidence, that both dominant and non-dominant eyes can localize objects in space, to mean that complex, dynamic interaction existed.

The definitions from a motor point of view have usually been phrased in terms of innate neural or somatic laterality. According to Wile (1942), who tested problem children having reading difficulties, eye dominance represents a residuum of unilateral organization of the organism. At Temple University, Lund (1932a), after testing his subjects with a hand-operated visual scope, defined eye dominance as the tendency for one eye to become the directing and controlling eye whenever close coordination of eye and hand is required. However, Berner and Berner (1953) have recently drawn a distinction between the "directing" or dominant eye and the "controlling" eye in terms of etiology, stability, and performance. This distinction was drawn after results from unilateral sighting tests were found to differ from results of reading-time tests with special binoculars. Schoen and Wallace (1936) tested differences in critical flicker frequencies in the eyes of eight men, then described eye dominance as a motor response mediated by cortical and subcortical shifts in electrical equilibrium. Consequently, Walls (1951) has felt that different conceptions of

eye dominance cannot possibly be reconciled with one another. He has suggested, therefore, that a sizable number of different kinds of dominance are manifested in the visual system. For instance, sensory activity is mediated by asymmetries in visual acuity, brightness perception, color discrimination, after-image vividity, retinal image size, cortical activity, retinal excitation, and attention. Furthermore, anatomical inequalities in the following may play a role: the cranial position of the eyes, the extrinsic eye musculature, the axial length of the eye, the corneal curvature, the lens curvature and position, and the indices of refraction. All such factors may theoretically affect convergence, accommodation, conjugate motion, or binocular fusion, thereby modifying or determining eye dominance. A thorough and final determination of the etiology of eye dominance would require a complex factor analysis requiring exhaustive ophthalmological and neurological examinations beyond the scope of this dissertation.

In this dissertation the author has reserved the terms, eye dominance and eyedness, for the general condition under consideration, and the terms, left-eyedness and right-eyedness, for the designation of the direction of laterality. Such traits are considered to be revealed by the relative utilization of one or the other eye in looking through a hole under given conditions. In assuming the name "eye dominance," the author is aware of prior usage of the term and many synonyms of the term, such as eyedness, eye preference, anisopia, anisodominance, and ocular

action current precedence. In referring to the individual eye, authors have called it the eye which is dominant, predominant, master, prevailing, stronger, or better. Sometimes the dominant eye is named according to the results of a certain test: the fixing eye, the fixating eye, the directing eye, the sighting eye, or the leading eye. Authors who believe that voluntary choice exists have employed the term "the preferred eye." Many researchers, referring to eye dominance in terms of laterality, have spoken of left-eyedness, for example, as sinistrocularity or visual sinistrality. The eye which is not dominant has been called the weak eye, the lazy eye, the servient eye, the recessive eye, the non-dominant eye, the non-controlling eye, and the non-leading eye. Finally, results indicating no definite dominance have lead to the following terms: ambiocularity, amphiocularity, impartial eyedness, lack of dominance, and no dominance. Consequent to conflicting beliefs in the etiology of eye dominance, extreme variations in methods have evolved, and the literature has become filled with varying and, often, conflicting terminology.

A HISTORY OF IDEAS ABOUT EYE DOMINANCE

The history of eye dominance is as old as formalized science itself. Among the Ancients, Aristotle made no direct references to ocular dominance (Miles, 1929), but his writings show that he may have been aware of such a phenomenon. In Parts of Animals, translated by Peck (1937), he wrote, "The eyes face front: this is because sight is along one straight line, and we must be able to see along the line in which we are moving, which is directly forward." Aristotle added that each of the sense organs are double, and have a right side and a left side. Furthermore, he felt that "...the right is most right-sided in man." No mention of ocular dominance has been found in English translations of Hippocrates, Theophrastus, Celsus, Pliny, or Galen.

The next hint of the idea of dominance can be seen in Roger Bacon's thirteenth century Opus Majus. After crediting Ptolemy and Alhazen with the idea, Bacon wrote concerning visual impressions ("species"), "Species of the same kind melt into one, and if opposite, then the stronger overwhelms the weaker." (Bridges, 1900).

The first direct reference to eye dominance appeared in 1593 in De Refractione optices parte written by a Neopolitan physician, Giovanni Battista Porta. Porta's works were immediately translated into several languages and disseminated throughout the scientific world. Priestley (1772), commenting on Porta's work wrote, "He (Porta) recites at length all the hypotheses

concerning the cause of single vision with two eyes, and concludes that, in fact, we never see with more than one eye at one time, as he pretends to prove by experiment." That Porta's views did not perish is attested by Priestley, who recognized them in the writings of Du Tour, Gassendi, Le Clerc, and Muschenbroeck (von Kries, 1910).

In the eighteenth century observations on differing kinds of eye dominance were made by van Leeuwenhoek, Buffon, and Gall. In 1723 in a personal letter to Dr. Jame Jurin, Secretary of the Royal Society, Anthony van Leeuwenhoek wrote, "Morever, as I generally use my right eye, I readily shut my left eye whillst making observations, wherefore my eyesight is dimmer than t'was wont to be." The naturalist, the Comte de Buffon, offered in 1743 "...une inegalite de force dan les yeux..." as one of the causes of strabismus (Buffon, 1777). He, himself, was right-eyed, in spite of greater myopia in that eye (Smellie, 1791 and 1812). During the last years of the eighteenth century, the father of phrenology, Franz Joseph Gall, lectured widely on laterality. A book by an interested listener (Hufeland, 1807) explains that Gall "...is of opinion only one eye, one ear, etc. is employed at a time; and that these succeed each other in operation." Furthermore, Hufeland reported that Gall felt that "...the right side of the body throughout, head, breast, eye, hand, arm, foot, etc., are generally the stronger."

Most nineteenth century physiologists became overly preoccupied with the logical implications of Gall's views which they attacked in the face of a dearth of experimental data. The French physiologist, Magendie, categorically stated, "Not withstanding what has been said at different periods, and the efforts which have of late been made by M. Gall to prove that we only see with one eye at a time,...both eyes concur..." (Revere, 1824). Muller, Bell, Heerman, and Volkmann also spoke for equal bilateral participation of the eyes in binocular vision. Hering (1879) reasoned that the eye used in the act of pointing during binocular vision was merely temporarily dominant, its laterality always corresponding to that of the pointing hand. However, he failed to test his ideas with experiments.

Early American opinions based only on personal experience and limited tests, nevertheless indicated new factors mediating eye dominance. Le Conte (1881), after testing himself and some friends (1884a, 1884b), declared that the dominant eye did not of necessity coincide with the eye possessing the more acute vision. Cowling (1881) experimentally showed the supposed influence of the pointing hand to be coincident with correspondence between eye and hand dominance, the handedness determining the pointing hand. His observations excited immediate interest and controversy among Callan (1881), Anonymous (1881), Wharton (1884), Le Conte (1884a, 1884b), Rider (1890), and Noyes (1890). As the nineteenth century drew to a close, the subject of eye dominance was discussed in the most widely used textbooks of ophthalmology,

physiology, and psychology by Landolt (1886), William James (1890), Javal (1896), Wundt (1896), van Biervliet (1897), and Parinaud (1898).

The first quarter of the twentieth century produced differentiation of kinds of dominance, quantification of dominance, and numerical association with visual acuity and handedness. That a given eye may be dominant in one test and not in another was demonstrated by Verhoeff (1902), who also showed with a binocular alignment test that the non-dominant eye had some influence in binocular vision. In Europe Rosenbach (1903) reported that unilateral diminution of visual acuity in subjects was accompanied by shift of eye dominance; however, he pointed out that when visual acuity is equal in both eyes, eye dominance still prevailed. Using Rosenbach's finger alignment test, Majewski (1903) published in the Russian literature the first data on the relative frequency of right and left-eyed persons in a population. However, Majewski's frequencies were reported without numerical data in an abstract by C. Zimmerman (1905). He reported 55 percent right-eyedness and 19 percent left-eyedness; 26 percent showed no definite laterality.

In America G. M. Gould, without presenting experimental data, evolved the theory that eye dominance caused hand dominance (Gould, 1904a, 1904b, 1904c, 1907, 1908). Gould also favored Humphry's (1861) theory of absolute unilaterality, that of concomitant dominance of the eye, hand and foot on the same side. Gould's views were immediately and severely criticized by Fridenberg (1904), who, without disclosing his evidence, wrote, "The anatomical

impossibility of a dominant eye would seem to be shown by the absence of all functional signs of unequal or unilateral development, muscular, optical, retinal, or central." A milder dissent was published in France by Baudouin (1904) on the basis of his own clinical observations. Stevens (1908a, 1908b, 1909) also criticized Gould's work on the basis of his experiments on subjective impressions of size in the peripheral fields of vision. Stevens' criticisms were endorsed by Flint (1904) and again by Hartshorne (1911) who published quantitative results on 75 patients. Of these many opinions, only those of Stevens and Hartshorne were supported by experimental data.

For a dozen years following the controversy between Gould and others, only speculation and minor tests were sporadically undertaken. Eye dominance came to be associated with athletic ability (Doyne, 1915), with phrenology (G. T. Stevens, 1918), with cranio-spinal alignment (Mills, 1919), with heterophoria (Dolman, 1920), with blood pressure (Quinan, 1921), and with muscle coordination (Quinan, 1922). The other papers were mainly test modifications (Dolman, 1919);(Griesbach, 1919); (Engeland, 1922); (Rochat, 1924) along with critical reviews (Lohmann, 1921; and Sheard, 1923a, 1923b).

The next impetus given to eye dominance research appeared in 1924 with Parson's book, Lefthandedness. The renewed interest centering in American and German clinics and universities stemmed from his methods and conclusions. Parson's methods included the mass testing of 877 school children with a new apparatus, the

mamuscope. His conclusions paralleled Gould's ideas of absolute unilaterality and included a claim that eye dominance was heritable. In spite of immediate endorsement by many authors, evidence against Parson's conclusions appeared. Downey (1927b) criticized Parson's inconsistencies of procedure, such as more careful testing of handedness in left-eyed children than in right-eyed children and for omission of ambiocular cases. Statistical and neurological evidence published in America, Europe, South Africa, and Japan all contradicted the theory of absolute unilaterality. More careful analyses, larger test groups, and less dogmatic conclusions began to characterize research on eye dominance and its relationship to handedness, visual acuity, reading, language, personality, and intelligence. However, controversy still exists in regards to the role played by eye dominance in each of these fields.

Although the idea of an absolute unilaterality has been discarded, the relationship between eyedness and handedness still evokes much discussion and research. Ever since Porta's sixteenth century claim (Lebensohn, 1942) that "...everyone looks with his right eye, as he uses his right hand," the view that hand usage determines eye dominance has been frequently propounded. The opposite view, that eye dominance determines handedness, has not been accepted by many investigators, Gould and Parson being the major exceptions.

The idea of a cerebral dominance controlling both hand and eye was first expressed by Le Conte in 1881, although it can be

inferred from the phrenology of Gall. This idea is still widely held, in spite of the lack of evidence for such a view. Most investigators, rather than citing causes, merely point out that a significant correlation often exists between eyedness and handedness when certain tests are employed. Still another theory, that handedness and eyedness were secondary to some other cause, not necessarily cerebral, was suggested by Jordan (1911), and Shastid (1926) speculated that eyedness was a consequence of the evolution of the speech center. Most workers testing the relationship between eye and hand dominance have favored the view that no significant correlation exists.

Early research on the relationship between eye dominance and visual acuity is difficult to interpret, since early scientists, such as Leeuwenhoek and Buffon, defined eye dominance as superior acuity of one eye. Once eye dominance was distinguished from visual acuity, arguments arose. While some workers reported that the dominant eye is the one with greater acuity, others concluded that dominance is independent of visual acuity except in cases of gross defection in one eye.

The actual mechanism involved in any theoretical participation of acuity differences in eye dominance remains obscure, since the fact of decussation of the optic fibers is evidence against the existence of such a mechanism. The decussation is actually a hemi-decussation, the fibers from the left half of each retina

proceeding to the left hemisphere of the brain, and vice versa. Even the points of sharpest vision, the foveae, are sharply divided into temporal halves, represented in the ipsalateral hemisphere, and nasal halves represented in the contralateral hemisphere. Consequently each retina, as a whole, is represented in both hemispheres, and each hemisphere serves both retinae.

SELECTION OF TESTS

The test for eye dominance was chosen from two groups of allied tests, the alignment tests which artificially prevent usage of the non-dominant eye and the fusion tests which determine dominance according to the subject's verbal report of the color, direction of movement, clarity, or brightness of the perceived image. The fusion tests were rejected because of their subjective nature, their measurement of special components of vision, and their dependence upon complicated machinery.

The most repeatable, most easily administered, and yet the simplest tests have been the alignment tests, the basis of which is the physiological diplopia occurring with the image of the aligning finger when one gazes past the finger to a far point. Since visual alignment of the finger and the far point can only be accomplished with one eye, the assumption is that the eye used for alignment is the dominant eye. According to Duke Elder (1942), such a test provides the best criterion for eye dominance. Over 350 years ago Porta explained such a test: "If anyone places a staff before him and brings it directly opposite some crack that exists in the opposite wall, and notes the place, when he closes his left eye he will not see the staff removed from the opposite crack, the reason being that every one looks with his right eye, as he uses his right hand."

Four major modifications have been developed from the alignment test: the box-string test, the hole test, the cone test, and the mirror test. According to Crider (1944) all four tests have a coefficient of reliability greater than .98.

The box-string variation of the original finger alignment test is designed to eliminate the possible effect of hand usage. The two strings at either open end of a rectangular tube are aligned by the subject who moves the tube with both hands. Its disadvantages are the more frequent occurrence of double images and the complexity of the instructions for correct usage.

In the hole test, the subject looks with both eyes open through a hole in a cardboard held with both hands a arms length. The subject, forced by the size of the hole to use only one eye, usually employs the same eye for each trial. The hole test has three important advantages: (1) the subjects are usually unaware of their choice, (2) double images are less noticeable, and (3) intermediate choices are not possible on a single trial.

In the cone test the subject places the base of the cone over his face and looks out the other end at the investigator. The investigator can tell by the slant of the cone which eye was chosen.

In the mirror test the subject binocularly fixates the image of his nose over a spot in the center of a mirror. The spot or nose will shift when the subject subsequently closes his dominant eye. Crider (1937a) found higher agreement for the mirror test in repeated tests than for any other alignment tests.

Relative validity for similar tests may be estimated by the comparison of results from any individual test within a battery of comparable tests with the results of the entire battery (Guttman, 1946). To accomplish such a comparison, the eye dominance of 25 university students was determined by testing each student with each of the four alignment tests. The dominance of each subject was decided according to the net results of the four tests on each subject. For every subject three of the four tests or all four tests corresponded in laterality. When the results of each different alignment test were compared with the results of the battery of tests on each subject, it was found that only the hole test showed 100% agreement. The cone test showed 96% agreement; the box-string test, 92%; and the mirror test, 68%.

On the basis of the results of this effort to estimate validity and similar results by Crider (1934b, 1944), Buxton and Crosland(1937), and Fink (1938), the hole test was selected as the definitive test for the research reported in this dissertation.

Four tests of hand dominance were chosen on the basis of their simplicity of performance, laterality of action, and lack of gross environmental pressures such as are involved in writing and eating motions (Spadino, 1941; Rife, 1951; and Merrell, 1957). The four tests selected were brushing the teeth, combing the hair, throwing a ball, and hammering a mallet. Following the convention of Rife (1950), each subject was classified as left-handed if he used the left hand for any of the four actions.

Relative visual acuity was tested in the parental generation using a standard Snellen chart at the same home illumination levels used for testing eye dominance. Acuity was determined at distances greater than four feet and less than seventeen feet, the optimum range for acute vision (Giese, 1946). Rigid optometric standards were not employed, since relative, rather than absolute, acuity values were desired. In each case the results were recorded in terms of the eye with the better acuity: right, left, or equal.

PROCEDURE

Eye dominance and hand dominance were tested in elementary school children from five to seven years of age in the kindergarten and first grade of the Red Cedar Elementary School in East Lansing, Michigan, during 1954 and 1955. The children were offspring of a parental population consisting of university students, university staff members, and local suburban residents. In cases where siblings were included in the tests, only the first sib tested was retained for the genetic analysis.

Eye dominance in the children was determined by the hole test in the form of an 8" X 11" cardboard with a 3/4" hole in the center. Rapport was established by talking and playing games. Seated across from the author at a small table, each child was given the following instructions orally: "Hold the cardboard in both hands. Hold out your arms with your elbows straight. Now slowly bring up the cardboard and look at me through the hole. Then bring the cardboard back to your lap." Continued responses were then elicited by saying, "Up again. Now down," until five responses had been obtained, at which time the subject was told to rest. After a few words of encouragement the test was repeated five times in the same way. Each response was noted and tabulated when the child had finished ten responses. The majority of responses determined the dominant eye.

After one year, 63 first-grade children who had been tested for eye dominance while in the kindergarten were retested in order to estimate the test's reliability.

Handedness was tested in each child whose parents had been contacted by asking him to pretend to brush his teeth, comb his hair, throw a ball, and hammer a mallet. The child was classified as left-handed if any of the four actions was performed with the left hand.

The parental generation was contacted through information available in each child's school record. In each case the parents were contacted, visited, and tested without the author's knowledge of the child's performance. The parents were all of the white race and middle socio-economic class. Religion was not determined. Parents of the three Negro children and two Oriental children were not included because of possible genetic differences in different races.

Parental eye dominance was ascertained with ten trials with the hole test following the instructions similar to those given to the children. Parents had been told the test was a scientific experiment involving vision, and very few ever realized that they had used only one eye in looking through the hole.

Parental handedness was determined by observing the adult demonstrating his method of carrying out the same four actions tested in each child.

Since more than a third of the parents wore spectacles to correct deficiencies of vision which possibly could be associated with their eye dominance, their relative visual acuity was tested. The acuity of each eye, unaided by spectacles, was determined at

normal illumination levels by the monocular reading of a standard Snellen chart at about ten feet. The better eye was judged to be the eye which could read farther down the chart than the other.

All eye dominance, handedness, and acuity tests in children and adults were carried out by the author. The total number of tests is shown in Table 1.

TABLE 1. TOTAL NUMBER OF TESTS.

Group	Eyedness	Handedness	Acuity
Children	153	82	-
Adults	158	151	151
Totals	311	233	151

TESTING RESULTS

The results of all the tests have been tabulated, and pertinent comparisons have been tested for homogeneity with contingency tables using the chi square statistic. Where only one degree of freedom exists, the absolute value of each difference was reduced by 0.5 before it was squared. This modification, the Yates correction, more nearly approximates the chi square statistic to the estimated frequency distribution of chi square (Dixon and Massey, 1951).

A total of 153 children were tested for eye dominance. Both parents of 79 of the 153 children were tested, and their results have been utilized for genetic analysis. The 79 children compose the genetic group. The 74 children whose parents were not tested due to the lack of time, the absence of one spouse, the presence of gross eye defects, or classification in non-white race compose the excluded group. Table 2 compares the results of eye dominance tests in the two groups.

TABLE 2. RESULTS OF EYE DOMINANCE TESTS IN CHILDREN.

Group	Dominant Eye: Number Right	Dominant Eye: Number Left	Totals
Genetic Group	46	33	79
Excluded Group	53	21	74
Totals	99	54	153

$\chi^2 = 2.44$ $\quad 0.2 > p > 0.1$

The distribution of eyedness in the two groups is not significantly different. In this group of 153 children, 64.6 percent were right-eyed and 35.4 percent were left-eyed.

The test for eye dominance was repeated after one year in 63 children in order to estimate the reliability of the test. At the time of retesting, the prior test results were not known to the author. Only 5 of the 63 children showed a change of dominance according to the hole test. According to Guttman (1946) a good estimate of a test's reliability is the coefficient of reproducibility, (r).

$$r = 1 - \frac{\text{(number of errors)}}{\text{(number of subjects)} \times \text{(number of tests)}}$$

Only one test, the hole test, was used on 63 subjects, 5 of whom made "errors." Therefore,

$$r = 1 - \frac{5}{1 \times 63} = .92$$

According to Guttman, the lower acceptable limit of the coefficient of reproducibility is .90, so the results of retesting show that the hole test, as used in this study, is reliable. The result compares favorably with the results obtained by W. Miles (1929) and Crider (1937a) with the same dominance test. Miles obtained

a coefficient of reproducibility of .95 on retesting 59 subjects after one week, and Crider obtained a coefficient of .92 on retesting 113 children after two months.

The results of tests for hand dominance in the 80 children whose parents were also tested for hand dominance plus 2 children whose parents were not tested are shown in Table 3.

TABLE 3. RESULTS OF HAND DOMINANCE TESTS IN CHILDREN.

	Dominant Hand		
	Right	Left	Totals
Number of Children	64	18	82
Percentages (%)	78	22	100

Results of tests of eyedness, handedness, and relative visual acuity in parents are shown in Table 4.

TABLE 4. RESULTS OF LATERALITY TESTS IN PARENTS.

Test	Dominant Side						
	Right		Left		Equal		Total
	Number	%	Number	%	Number	%	Tested
Eyedness	108	68.4	50	31.6	-	-	158
Handedness	143	89.4	17	10.6	-	-	160
Relative Acuity	32	21.9	22	15.1	92	63.0	146

ANALYSIS OF DATA

Analysis of the test results has been carried out in two general categories, the analysis of factors within each of the populations (parents and the offspring), and analysis of genetic features. The two sections have been presented separately.

Analysis of factors within groups:

Within the population of children the distributions of eyedness in each sex (Table 5), of handedness in each sex (Table 6), and of eyedness in each category of handedness (Table 7) have been examined in chi square contingency tables.

TABLE 5. EYE DOMINANCE AND SEX OF CHILD.

Sex of Child	Dominant Eye Right	Left	Totals
Boy	52	23	75
Girl	47	31	78
Totals	99	54	153

$\chi^2 = 1.01$ $\quad .50 > p > .30$

TABLE 6. HAND DOMINANCE AND SEX OF CHILD.

Sex of Child	Dominant Hand Right	Left	Totals
Boy	27	10	37
Girl	37	8	45
Totals	64	18	82

$\chi^2 = 0.546$ $\quad .50 > p > .30$

TABLE 7. EYE AND HAND DOMINANCE IN CHILDREN.

Hand Dominance	Eye Dominance Right	Left	Totals
Right	40	23	63
Left	10	7	17
Totals	50	30	80

$\chi^2 = 0.005$ $\quad p > .90$

The analyses indicate that eyedness, handedness, and sex of child are not associated with each other to an extent greater than would be expected by chance.

Within the parent population the distributions of relative acuity according to sex (Table 8), to eyedness (Table 9), to handedness (Table 10); and of eyedness according to sex (Table 11), to handedness (Table 12); and of handedness according to sex (Table 13) have also been examined by chi square contingency tables.

TABLE 8. RELATIVE ACUITY AND SEX IN PARENTS.

Sex of Parent	Eye with Better Acuity Right	Left	Equal	Totals
Male	16	10	51	77
Female	18	14	42	74
Totals	34	24	93	151

$\chi^2 = 1.638$ $\quad .50 > p > .30$

TABLE 9. RELATIVE ACUITY AND EYEDNESS IN PARENTS.

Dominant Eye	Eye with Better Acuity: Right	Left	Equal	Totals
Right	25	14	65	104
Left	9	10	28	47
Totals	34	24	93	151

$\chi^2 = 1.604$ $\quad .50 > p > .30$

TABLE 10. RELATIVE ACUITY AND HANDEDNESS IN PARENTS.

Dominant Hand	Eye with Better Acuity: Right	Left	Equal	Totals
Right	32	19	83	134
Left	2	5	10	17
Totals	34	24	93	151

$\chi^2 = 3.194$ $\quad .30 > p > .20$

TABLE 11. EYEDNESS AND SEX IN PARENTS.

Sex of Parent	Dominant Eye: Right	Left	Totals
Male	53	26	79
Female	55	24	79
Totals	108	50	158

$\chi^2 = 0.03$ $\quad .90 > p > .80$

TABLE 12. EYEDNESS AND HANDEDNESS IN PARENTS.

Dominant Hand	Dominant Eye Right	Left	Totals
Right	95	39	134
Left	9	8	17
Totals	104	47	151

$\chi^2 = 1.51$ $\quad .30 > p > .20$

TABLE 13. HANDEDNESS AND SEX IN PARENTS

Sex of Parents	Dominant Hand Right	Left	Totals
Male	70	9	79
Female	68	11	79
Totals	138	20	158

$\chi^2 = 0.057$ $\quad .90 > p > .70$

The analyses indicate that relative visual acuity, eyedness, handedness, and sex within the parental group are not associated with each other to an extent greater than would be expected by chance.

Analysis of heritability:

According to the Hardy-Weinberg law, the distribution of a genetically-determined trait within the population is theoretically

the same in both the parent and offspring generation provided selective mating and differential fertility did not occur (Neal and Schull, 1954). Consequently, the distribution of eyedness and handedness in fathers and mothers has been examined in Table 14 and 15, respectively, in order to detect whether selective mating occurred with respect to the two traits. The method of collection of data did not permit analysis of fertility.

TABLE 14. PARENTAL MATINGS WITH RESPECT TO EYE DOMINANCE.

Mother's Dominant Eye	Father's Dominant Eye: Right	Left	Totals
Right	36	19	55
Left	17	7	24
Totals	53	26	79

$\chi^2 = 0.043$ $\quad .90 > p > .70$

TABLE 15. PARENTAL MATINGS WITH RESPECT TO HAND DOMINANCE.

Mother's Dominant Hand	Father's Dominant Hand: Right	Left	Totals
Right	63	10	73
Left	7	0	7
Totals	70	10	80

$\chi^2 = 0.20$ $\quad .70 > p > .50$

The analyses reveal that eyedness or handedness in one spouse is not associated with that in the other spouse to an extent greater than would be expected by chance.

To ascertain whether eyedness or handedness is distributed in the same proportions in both parent and offspring generations, Tables 16 and 17 were constructed. Analysis of Table 16 reveals no statistically significant difference between offspring and parent generations with respect to eyedness.

TABLE 16. EYEDNESS IN OFFSPRING AND PARENT GENERATION.

Generation	Dominant Eye Right	Left	Totals
Offspring	46	33	79
Parent	92	66	158
Totals	138	99	237

$\chi^2 = 0.01$ $\quad p > .90$

TABLE 17. HANDEDNESS IN OFFSPRING AND PARENT GENERATION.

Generation	Dominant Hand Right	Left	Totals
Offspring	63	17	80
Parent	143	17	160
Totals	206	34	240

$\chi^2 = 4.12$ $\quad .05 > p > .02$

On the other hand, analysis of Table 17 reveals a significant difference in the distribution of handedness between the two generations; the offspring having a greater proportion of left-handers than the parents. This may reflect a relaxation of pressure by parents and teachers to convert left-handed children into right-handers.

An inherited trait is more frequent among offspring of parents both of whom show the trait than among offspring of parents one or neither of whom show it. Table 18 compares the distribution of handedness in pairs of parents of right-handed and left-handed children. There were no matings in which both spouses were left-handed. Analysis reveals no significant relationship between the handedness of the children and that of their parents.

TABLE 18. HANDEDNESS OF PARENTS OF RIGHT- AND LEFT-HANDED CHILDREN.

Parental Handedness	Child's Handedness Right	Left	Totals
Both Right	51	12	63
Only One Right	12	5	17
Totals	63	17	80

$\chi^2 = 0.35$ $\quad .70 > p > .50$

In Table 19, mating types with respect to eye dominance in parents of right-eyed children are compared with mating types of parents of left-eyed children.

TABLE 19. EYEDNESS IN CHILDREN AND IN THEIR PARENTS.

Eyedness of the Child	Eyedness of the Parents of each Child: Both Right	Right & Left	Both Left	Totals
Right	27	15	4	46
Left	9	21	3	33
Totals	36	36	7	79

$\chi^2 = 8.228$ $\quad .02 > p > .01$

Chi square computation indicates that there is a relationship between the eye dominance of the children and that of their parents. Of the parents of right-eyed children, 75 percent were right-eyed compared to 59 percent right-eyed parents of left-eyed children. The excess of right-eyedness in parents of right-eyed children and the concomitant excess of left-eyedness in parents of left-eyed children are deviations from randomness in the directions expected for heritable traits.

Analysis of the mode of inheritance:

Examination of the distributions of eyedness in the two generations permits conclusions to be drawn in respect to the mode of inheritance. In particular, heritability due to a single pair of alleles with full penetrance can be closely examined.

Single autosomal dominant gene:

If right-eyedness is determined by a single autosomal dominant gene with complete penetrance, then left-eyedness would be determined by the recessive allele in a homozygous state. Therefore no L x L mating types would be found as parents of a right-eyed child. However, 4 of 46 right-eyed children had parents both of whom were left-eyed. Therefore, right-eyedness, as determined by the hole test, is not genetically determined by a single autosomal dominant gene with complete penetrance.

Single autosomal recessive gene:

If right-eyedness is determined by a single autosomal recessive gene in the homozygous state and left-eyedness by the dominant allele, then no R x R matings should be found among parents of left-eyed children. Since 9 of 33 left-eyed children have parents both of whom are right-eyed, then right-eyedness could not be determined by a single autosomal recessive gene with complete penetrance.

Y-linked gene:

Y-linked, or holandric, inheritance is ruled out since neither right-eyedness nor left-eyedness is limited to the males.

Sex-linked recessive gene:

Right-eyedness due to a sex-linked recessive gene would be possible if all the fathers of right-eyed girls were right-eyed. However, 8 of 21 right-eyed daughters have left-eyed fathers. Therefore, right-eyedness is not due to a sex-linked recessive gene.

Sex-linked dominant gene:

Right-eyedness due to a sex-linked dominant gene would be possible if all the mothers of right-eyed sons were right-eyed, since the X-chromosome with the gene causing right-eyedness in sons must come from the mother. However, 8 of 25 right-eyed sons have left-eyed mothers. Thus, right-eyedness is not due to a sex-linked dominant gene.

Thus the distribution of eyedness in mating pairs of parents of the children does not fit any scheme describing inheritance of eye dominance due to a single gene with complete penetrance with dominant or recessive, autosomal or heterosomal.

No dominance:

The trait, as determined by the hole test, cannot be due to one pair of alleles with no dominance, because there is no intermediate phenotype to correspond to the heterozygote. It might be argued that those showing mixed responses represent an intermediate class and that the assignment of these into right or left categories has artificially hidden the intermediate phenotype. Table 20 compares the distribution in children and adults of mixed responses with responses which were all right or all left.

TABLE 20. MIXED AND UNMIXED RESPONSES TO TEN TESTS OF EYE DOMINANCE.

	Responses to Ten Tests						
	Mixed		Unmixed				
			Right		Left		
Population	No.	%	No.	%	No.	%	Totals
Children	14	9.15	91	59.48	48	31.37	153
Adults	7	4.43	104	65.82	47	29.75	158

The sum of the proportion of mixed responses (H), the all right responses (D), and the all left responses (R) equals unity. If those showing mixed responses are represented as heterozygotes and those with unmixed responses as homozygotes, then the formula,

$$H^2 = 4DR \quad \text{(Li, 1948)}$$

describes the relationship of heterozygotes to homozygotes. The proportions of right and left unmixed responses shown in Table 20 can be used in the formula to calculate (H), the proportion of mixed responses expected if inheritance is due to a single pair of alleles with no dominance.

Table 21 compares the expected proportions of mixed responses with the observed proportions in children and adults.

TABLE 21. EXPECTED AND OBSERVED PROPORTIONS OF MIXED RESPONSES (NO DOMINANCE).

	Proportion of Mixed Responses	
Population	Expected	Observed
Children	86.4%	9.1%
Adults	88.4%	4.4%

The expected values far exceed the observed values. They are, in fact, too high to fit an assumption in Hardy's Law, that

$$H + D + R = 1$$

in which (H) never exceeds 50 percent (Li, 1948). Therefore, inheritance due to one pair of alleles with no dominance does not explain the distribution of the trait, eye dominance.

The simplest genetic model which cannot be ruled out is single allele inheritance, the heterozygotes of which become phenotypically right-eyed or left-eyed according to the sum total of an unknown number of minor genetic and environmental factors. Rife (1951) suggested this mode of inheritance for hand dominance.

The appendix contains the expected phenotypic frequencies in children as calculated for such a mode of inheritance. Estimates of gene frequencies were obtained from the distribution of eyedness in the randomly selected parent generation. The estimated frequency of heterozygotes was arbitrarily divided, half being assigned to the right-eyed phenotype class and half to the left-eyed class. The observed phenotypic frequencies of children within the various parental mating groups are all within the 95 percent confidence limits of the expected frequencies. Therefore, such a mode of inheritance is consistent with the data obtained. As in most physiological mechanisms, genetic modifier genes and environment theoretically influence the expression of the heterozygote.

DISCUSSION

This is not the first evidence indicating genetic influence in eye dominance. Similar conclusions, most of them lacking supporting data, have appeared in the literature over the last fifty years.

Very soon after the rediscovery of Mendel's classic work, Gould (1904b) invited study of the heredity of eyedness..."by the method of Mendel." Such a possibility was reaffirmed by Hartshorne (1911) and Jordan (1911), although no investigations were carried out. Based on a misunderstanding of Jordan's words concerning gene frequencies and random mating, Parson (1924) wrongly interpreted a 3:1 frequency distribution of right- and left-eyedness in his subjects as evidence of simple Mendelian inheritance. Mills (1925) agreed with Parson after he obtained a similar frequency ratio. Again in 1928 when he found a 4:1 frequency of right- and left-eyedness, Mills spoke of Mendelian inheritance, the usual proportions of which were supposedly altered by training. From such erroneous reasoning the idea of a genetic basis for eye dominance was accepted by Ludwig (1932) in Germany, Wile (1942) in America, and Rothschild and Streifler (1952) in Jerusalem. None of these investigators presented any evidence for their conclusions.

Actually, the first genetic analysis of eye dominance was done by G. A. Litinsky (1929b), who proposed simple recessive inheritance of left-eyedness based on his analysis of two

generations in 23 families. His results are shown in Table 22. The lack of right-eyed children from matings of left-eyed parents suggested to Litinsky that left-eyedness was inherited as a simple recessive trait. The distribution of eyedness among children from matings of right-eyed parents did not contradict his conclusion. Litinsky employed Hardy's Law and calculated probable gene frequencies from the phenotypic frequencies he had previously (1929a) found; namely, .30 left-eyedness, .70 right-eyedness and ambiocularity. He calculated the gene for left-eyedness to possess a frequency of .55 and the dominant gene for right-eyedness to possess a frequency of .45.

TABLE 22. EYE DOMINANCE OF CHILDREN FROM DIFFERENT PARENTAL MATING TYPES. (AFTER LITINSKY)

Eyedness of Parents		Number of Families	Number of Offspring			
			Right-eyed		Left-eyed	
Male	Female		Male	Female	Male	Female
R	x R	4	5	1	2	0
R	x L	10	5	8	5	5
L	x R	7	5	5	6	5
L	x L	2	0	0	3	2
	Totals	23	15	14	16	12

The absence of right-eyed children among L x L matings is evidence for complete recessivity of the gene for left-eyedness, but the small numbers prevent any definite conclusions.

Franceschetti (1949), although apparently unaware of Litinsky's work, added "the directing eye" to the list of 21 heritable traits for genetic linkage studies. Taillard (1951), after testing 171

sibpairs in 20 families, assumed "highly probable" autosomal linkages between the directing eye and hair form and between the directing eye and hair whorl. These conclusions were entered in a list of possible autosomal linkages by Neel and Schull (1955).

Merrell (1957) concluded that a definite influence of genetic factors existed in the trait of eye dominance. Testing 103 sibships for eyedness he found 23.7 percent left-eyedness in children from R x R matings, 43.9 percent from R x L matings, and 54.2 percent from L x L matings.

Phenotypic differences between racial and ethnic groups are suggestive of genetic differences. Downey (1927a) found among seven tribes of North American Indians a larger proportion of right-handedness yet a smaller proportion of right-eyedness (59 percent) than among similarly-tested white Americans. Quinan (1930) and Miles (1930) both compared the frequency of right and left eye dominance in American and Chinese university students. No significant differences between the two groups in respect to eye dominance were discovered.

In conclusion, the data in this dissertation lend further support to the scanty prior evidence that eye dominance is influenced by genetic components. The exact mode of inheritance is still undetermined, but is unlikely to be due to a single pair of alleles with full penetrance. However, inheritance due to a single pair of alleles with no dominance cannot be excluded, if it is assumed that the heterozygote has equal chance to be expressed as right-eyed or left-eyed. Further research is indicated, especially with twins and complete family pedigrees.

SUMMARY

Eye dominance was determined in 153 children in the kindergarten and first grade of the Red Cedar Elementary School in East Lansing, Michigan. The hole-in-paper test was chosen for testing eye dominance, after preliminary tests showed its simplicity and reproducibility. The parents of 79 of the children were tested for eye dominance and the distribution of eyedness of mating types was compared with the eyedness of the children from the matings.

Hand dominance was tested in 82 children and in the parents of 80 of these children.

Relative visual acuity was tested in 146 parents.

Results of laterality tests in the two populations revealed the following distributions:

1. Eyedness: 64.6 percent of the children were right-eyed; 35.4 percent, left-eyed. Of the parents 68.4 percent were right-eyed; 31.6 percent, left-eyed.

2. Handedness: 78 percent of the children were right-handed; 22 percent, left-handed. Of the parents, 89.4 percent were right-handed; 10.6 percent, left-handed.

3. Relative visual acuity of adults: 21.9 percent had better acuity in the right eye, 15.1 percent in the left eye, and 63 percent had grossly equall acuity in each eye.

Eyedness, handedness, and sex were distributed independently in the children. Eyedness, handedness, sex and visual acuity were distributed independently in the adult population.

Parental mating pairs were random in respect to eye dominance and hand dominance.

No significant difference was found in the distribution of types of eyedness in the offspring and parental generation.

Left-handedness was found to be significantly more frequent in children than in adults.

Right-handedness and left-handedness in parents was not significantly associated with the handedness of their child.

Right-eyedness and left-eyedness in parents was significantly associated with the eyedness of their child, although the relationship was less pronounced in the small group with parents both of whom were left-eyed.

Inheritance was shown not likely to be due to a single pair of alleles with full penetrance. The data did not permit differentiation between inheritance due to a single pair of alleles with some degree of reduced penetrance and inheritance due to more than a single pair of alleles. However, the phenotypic distributions are consistent with a single allele mode of inheritance, provided that the heterozygote has equal chance to develop either right-eyedness or left-eyedness.

APPENDIX

CALCULATION OF EXPECTED PHENOTYPIC FREQUENCIES AMONG CHILDREN OF THE THREE PARENTAL MATING GROUPS

Assumptions 1. The distribution of eyedness types in both generations, as described by Hardy's Law, is

$$p^2 + 2pq \quad q^2 = 1$$

$$p + q = 1$$

2. The observed distribution of eyedness in the parents is a valid starting point for estimates of parental genotype frequencies.

3. Calculations are based on an arbitrarily selected distribution of heterozygotes; 50% becoming right-eyed and 50%, left-eyed.

Let r = gene for right-eyedness with a frequency of p.

Let l = gene for left-eyedness with a frequency of q.

Let p^2 = frequency of homozygous right-eyed persons, rr.

Let pq = frequency of heterozygous right-eyed persons, rl.

frequency of heterozygous left-eyed persons, lr.

Let q^2 = frequency of homozygous left-eyed persons, ll.

Then $p^2 + pq = p$ = frequency of right-eyed phenotypes, R.

$q^2 + pq = q$ = frequency of left-eyed phenotypes, L.

And the frequency of R x R matings = $p \times p = p^2$,

the frequency of R x L matings = $2 \times p \times q = 2pq$,

the frequency of L x L matings = $q \times q = q^2$.

CALCULATION OF THE EXPECTED DISTRIBUTION OF EYEDNESS IN CHILDREN

Mating Types			Distribution of eyedness in children	
Phenotype	Genotype	Frequency	R	L
R x R	rr x rr	p^4	p^4	
	rr x rl	$2p^3q$	$1\frac{1}{2}p^3q$	$\frac{1}{2}p^3q$
	rl x rl	p^2q^2	$\frac{1}{2}p^2q^2$	$\frac{1}{2}p^2q^2$
R x L and L x R	rr x ll	$2p^2q^2$	p^2q^2	p^2q^2
	rr x lr	$2p^3q$	$1\frac{1}{2}p^3q$	$\frac{1}{2}p^3q$
	rl x ll	$2pq^3$	$\frac{1}{2}pq^3$	$1\frac{1}{2}pq^3$
	rl x lr	$2p^2q^2$	p^2q^2	p^2q^2
L x L	ll x ll	q^4		q^4
	ll x lr	$2pq^3$	$1\frac{1}{2}pq^3$	$\frac{1}{2}pq^3$
	lr x lr	p^2q^2	$\frac{1}{2}p^2q^2$	$\frac{1}{2}p^2q^2$

From Table 19, the proportion of right-eyed parents, R/R L, can be calculated: $108/158 = 0.6835 = p$

Therefore $0.4672 = p^2$

$1 - p = 0.3165 = q$

$0.1002 = q^2$

$0.2163 = pq$

Expected distribution of eyedness in children from R x R matings:

$$R = p^4 + 1\tfrac{1}{2}\, p^3q + \tfrac{1}{2}\, p^2q^2 = 0.8417$$

$$L = \tfrac{1}{2}\, p^3q + \tfrac{1}{2}\, p^2q^2 = 0.1583$$

Expected distribution of eyedness in children from R x L matings:

$$R = p^2q^2 + 1\tfrac{1}{2}\, p^3q + \tfrac{1}{2}\, pq^3 + p^2q^2 = 0.5918$$

$$L = p^2q^2 + \tfrac{1}{2}\, p^3q + 1\tfrac{1}{2}\, pq^3 + p^2q^2 = 0.4082$$

Expected distribution of eyedness in children from L x L matings:

$$R = 1\tfrac{1}{2}\, pq^3 + \tfrac{1}{2}\, p^2q^2 = 0.3418$$

$$L = q^4 + \tfrac{1}{2}\, pq^3 + \tfrac{1}{2}\, p^2q^2 = 0.6582$$

Distribution of eyedness in children within each parental mating group - calculated according to the scheme of single pair of alleles with random distribution of the heterozygote among the two phenotypes:

Parental Mating Type	Eyedness of Children	Frequencies Expected	Observed	95% * Confidence Limits
R x R	R	.842	.750	.578 to .879
	L	.158	.250	.121 to .422
R x L	R	.592	.417	.407 to .744
	L	.408	.583	.256 to .593
L x L	R	.342	.571	.184 to .901
	L	.659	.429	.099 to .816

* Confidence limits from Hald, A., Statistical Tables and Formulas, John Wiley & Son, Inc., N.Y.(Table 11,pp 66-67)

SAMPLE TEST

Case Number.....45.....

Child's Name.....

Age..... Sex..... Handedness..... Visual Acuity R.....
L.....

Eye Preference:	1	2	3	4	5	6	7	8	9	10
	–	–	–	–	–	–	–	–	–	—

Total Score :	Right	Left	Preference
	.....	....	.....
	.....	....	.....

Sibs:	Name	Sex	Age	Eye Preference	Case Number
1.					
2.					
3.					
4.					
5.					

Father's Name.....Phone.....

Address.....

Age..... Handedness..... Visual Acuity: R.....
L.....

Eye Preference:	1	2	3	4	5	6	7	8	9	10
	–	–	–	–	–	–	–	–	–	–

Total Score:	Right	Left	Preference
	.....	....	.....

Mother's Maiden Name.....

Age..... Handedness..... Visual Acuity: R.....
L.....

Eye Preference:	1	2	3	4	5	6	7	8	9	10
	–	–	–	–	–	–	–	–	–	–

Total Score:	Right	Left	Preference
	.....	.....	.....

Remarks:-

RAW DATA

Case	Child Sex	Left-eyed responses	Dom. Hand	Parents Left-eyed responses Father	Mother	Handedness Father	Mother	Relative visual acuity Father	Mother
1.	F	10-10	L	10	0	R	R	E	E
2.	M	0		0	10	R	R	E	L
3.	F	0	R	0	0	R	R	E	E
4.	M	10							
5.	M	0-0	R	10	0	L	R	L	E
6.	M	8							
7.	F	8-1	L	0	0	R	R	R	E
8.	F	0	R	0	0	R	R	E	R
9.	F	0-0	R	0	0	R	R	E	R
10.	M	0	L	0	0	R	R	R	L
11.	F	10	L	0	0	R	R	R	R
12.	F	0							
13.	F	10		6	10	R	L	R	
14.	M	0-0	R	0	0	R	R	R	
15.	M	0-0	R	0	0	R	R	R	E
16.	M	0-0	R	0	10	R	R	L	L
17.	M	0-4	R	0	0	R	R	E	L
18.	M	10-10		0	0	R	R	R	R
19.	M	10							
20.	M	0-0		0	0	R	R	R	E
21.	M	0	L	0	0	R	R	E	R
22.	M	10		0	10	L	R	L	E
23.	F	0	R	0	0	R	R	L	E
24.	F	0-0							
25.	M	10-10	R	0	10	R	R	E	R
26.	M	0-0		0	0	R	R	R	E
27.	F	0-0	R	10	0	R	R	E	R
28.	M	0	L	0	10	R	L		
29.	M	10-10	R	0	10	R	R	E	E
30.	F	10-10		10	0	R	R	E	E
31.	F	0	R	10	10	R	R	E	R
32.	M	10-10	R	4	10	R	L	E	R
33.	M	0-0	L	0	0	R	R	E	E
34.	F	0-0		0	0	R	R	E	E
35.	M	0							
36.	M	10		10	10	R	R	E	E
37.	M	0-0	R	1	1	R	L	E	E
38.	F	0-0	R	0	0	R	R	L	R
39.	F	10	R	0	6	L	R	E	E
40.	F	10-10	R	10	0	R	R	E	E
41.	F	0		0	0	L	R	L	E
42.	M	0							
43.	F	0-0		0	0	R	R	E	E
44.	M	0							
45.	F	10							
46.	F	0-3							
47.	F	0-2		0	0	R	R	E	E
48.	M	0-0		0	0	R	R	E	E
49.	F	0-0	R	0	0	R	R	E	E
50.	F	10-10	R	0	0	R	R	E	L

	Child			Parents					
				Left-eyed responses		Handedness		Relative visual acuity	
Case	Sex	Left-eyed responses	Dom. Hand	Father	Mother	Father	Mother	Father	Mother
51.	M	0-0	R	10	10	R	R	L	E
52.C	M	4							
53.	F	0-0	R	0	10	R	R	R	E
54.	M	0-0	R						
55.	F	0-0	R	10	0	R	R	R	R
56.	M	0-0		0	0	R	L	E	E
57.	M	0	R	0	0	R	R	E	E
58.	M	0-0							
59.	M	10-10		10	0	R	R	L	R
60.	F	10-10	R	0	10	R	R	E	E
61.	F	10-10							
62.	F	10-10	R	0	10	R	R	R	E
63.	F	10-10	R	10	0	R	R	E	R
64.	M	10-10	R	10	0	R	L	L	
65.	M	10-10		0	10	R	R	E	E
66.	M	0-0	L	0	0	L	R	E	L
67.	F	3							
68.	F	0							
69.	F	0-0							
70.	F	3-0	R	10	0	L	R	E	E
71.	M	0-0		0	0	R	R	E	E
72.N	F	10	L						
73.	M	0-0		10	10	L	R	E	L
74.	F	10	R	0	10	R	R	E	L
75.	F	0-0	R	10	0	R	R	E	E
76.	F	10-10							
77.	M	6-1		10	10	L	R	E	R
78.	M	0-0	L	10	0	R	L	E	E
79.	M	10-10		0	0	R	R	E	L
80.	F	10-10	R	0	0	R	R	E	E
81.	F	0-0		8	0	R	R	E	R
82.	M	0-0	R	10	10	R	L	E	R
83.	M	7-0	R	0	0	R	R	L	E
84.	F	0-6	R	10	0	R	R	E	E
85.	F	10-10	R	0	10	R	R	E	R
86.	F	0-0	R	0	0	R	R	E	R
87.	F	10-10	R	0	10	R	R	E	E
88.	M	0							
89.	M	10		10	0	R	L	E	L
90.	F	0-0	L	0	0	R	L	E	E
91.	F	10	R	1	0	R	R	R	L
92.	M	0-0		0	10	R	L	E	L
93.	F	10	R	0	0	R	R	R	E
94.	F	10	R	10	0	R	R		E
95.	M	0		0	10	R	R	E	L
96.	F	10-10	R	10	0	R	R	E	
97.	F	0	R	10	0	L	R	E	E
98.	F	0		0	0	R	R	R	L
99.	F	10-3							
100.	F	10		10	0	R	R	R	E

	Child			Parents	
				Handedness	
Case	Sex	Left-eyed responses	Dom. Hand	Father	Mother
101.	F	0			
102.	M	0			
103.	F	0			
104.	M	0			
105.	F	0			
106.	F	0			
107.	F	3			
108.	F	0			
109.	M	0			
110.	M	0	R	R	R
111.	M		R	R	R
112.	M		R	R	L
113.N	M				
114.	M		R	R	R
115.	M		R	L	R
116.	M		R	R	R
117.	M		R	R	R
118.	F		R	R	R
119.	F		R	R	R
120.	F		R	R	R
121.	F		L	R	R
122.	F		R	R	R
123.	M		L	R	R
124.	F		R	R	L
125.	F		R	R	L
126.N	F				
127.	M		L	R	R
128.N	F				
129.	M		R	R	R
130.	M		L	R	L
131.	M		R	R	R
132.S	M				
133.	M		R	R	L
134.	M		R	R	R
135.	M		R	R	R
136.S	F				
137.	M		L	R	R
138.	F		L	R	R
139.	F		R	R	R
140.	M	0			
141.	M	10			
142.	M	0			
143.	F	0			
144.	F	10			
145.	M	2			
146.	M	10			
147.	F	0			
148.	M	0			
149.	F	3			
150.	F	0			

Child

Case	Sex	Left-eyed responses
151.	F	0
152.	M	0
153.	M	10
154.	M	0
155.	M	1
156.	F	10
157.	F	10
158.	M	0
160.	F	0
161.	F	0
162.	M	0
163.	M	10
164.	M	0
165.	M	9
166.	M	0
167.	F	0
168.	F	7
169.	M	0
170.	F	0
171.	M	0
172.	F	10
173.	M	0
174.	F	10
175.	M	0
176.	M	0
177.	F	10
178.	F	0
179.	F	0
180.	M	1
181.	M	0
182.	M	3

Note: The letters following the case numbers represent Negro (N), Chinese (C), and Strabismus (S).

Where the number of left-eyed responses is followed by a second number (ie. 7-0), the second number is the result of repeat testing.

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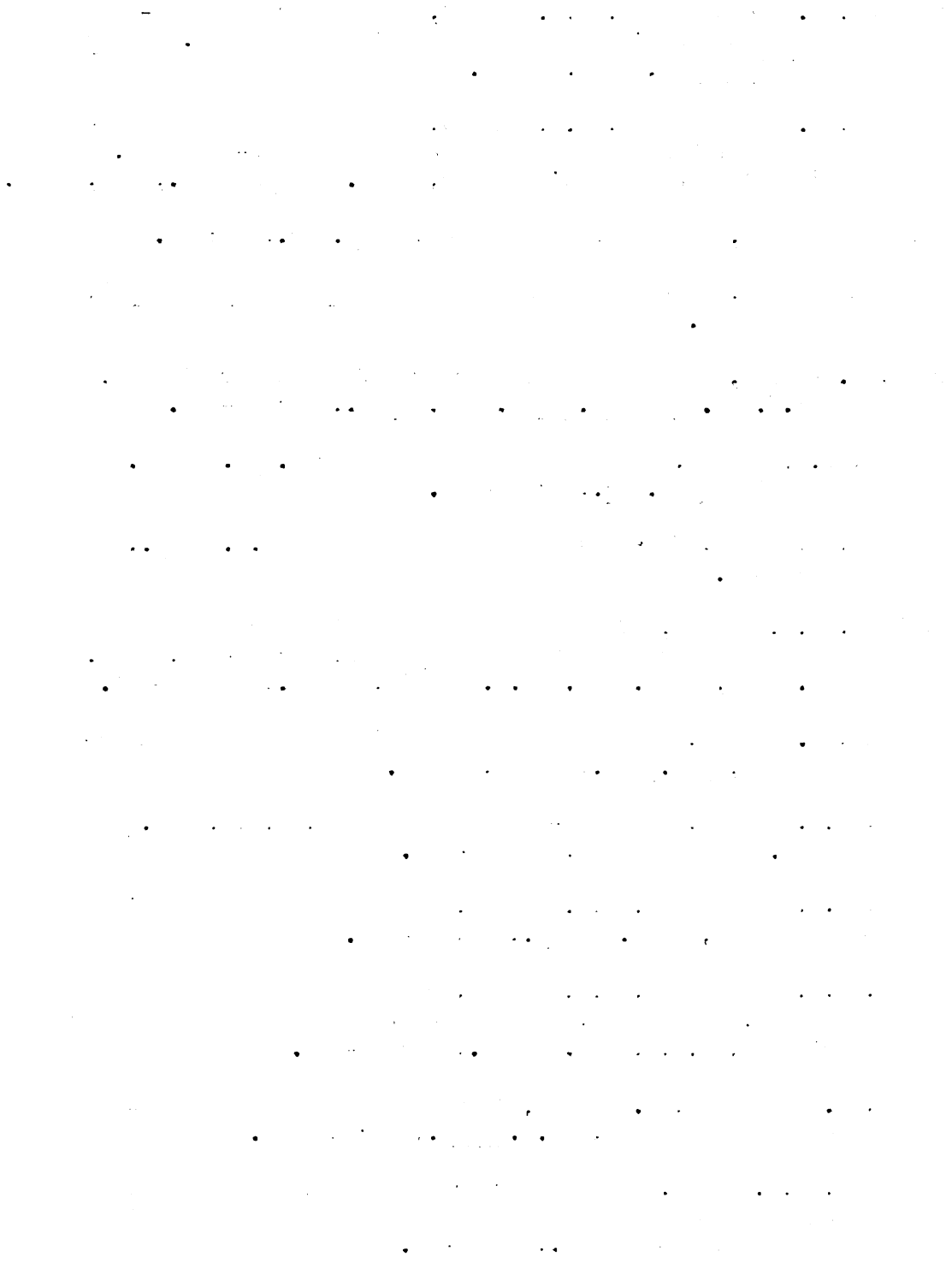

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