Influence of Heredity + Invironment on Sight

UNIVERSITY OF LONDON
FRANCIS GALTON LABORATORY FOR NATIONAL EUGENICS

EUGENICS LABORATORY MEMOIRS. V.

A FIRST STUDY OF THE INHERITANCE OF VISION AND OF THE RELATIVE INFLUENCE OF HEREDITY AND ENVIRONMENT ON SIGHT.

BY
AMY BARRINGTON,
OF THE GALTON EUGENICS LABORATORY
AND
KARL PEARSON, F.R.S.

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A FIRST STUDY OF THE INHERITANCE OF VISION, AND OF THE RELATIVE INFLUENCE OF HEREDITY AND ENVIRONMENT ON SIGHT. By AMY BARRINGTON and KARL PEARSON, Galton Eugenics Laboratory, University of London.

(1) *Introductory.* According to Mr Galton's definition of the science of National Eugenics, this new study is concerned with the influence not only of nature but of nurture on racial qualities. In seeking to illustrate the relative intensity of the two factors, heredity and environment, it occurred to us that eyesight might form a suitable character for investigation. We must at once confess that the suitability in question arose from the subject matter and not from the investigators. As our attempt may appear over bold to the specialist in the field of ophthalmology, we must briefly state the reasons for our selection of this topic. In the first place a relatively large amount of data, wholly unreduced from the standpoint of modern statistics, was available. In the second place much of this material was associated with observations of home and school conditions which would possibly throw light on the influence of the environment factor. Thirdly we found a large number of statements as to age, town and school surroundings, heredity and home, which are doubtless more or less accurate, but appear to have been given hitherto no quantitative relationship, and to be occasionally wanting in adequate statistical basis. From this standpoint the material possessed considerable fascination for the student of modern statistical methods. Lastly while much of the data bearing on other human characters has been collected by the layman, the measurement of vision has been, owing to its practical importance, a favourite study of the medical expert. This advantage, however, is accompanied by the inconvenience, that our material is drawn rather more from abnormal than normal sources.

In dealing statistically with the data available we have endeavoured to avoid gross blunders of interpretation by appealing for technical knowledge to specialists. Among these we have in the first place to thank Mr E. Nettleship for his ready answers to many questions placed before him, and for his copious references to ophthalmic literature; it is, perhaps, needless to add that he is in nowise responsible for any conclusions drawn or opinions expressed in this memoir, the data and methods of which were only placed before him for his ever useful and friendly criticism after the completion of the manuscript.

(2) *Material.* The scope of this memoir being twofold, we turned first to the question of heredity and sought for the best material available on the inheritance

of visual characters. This must be sought for in two directions: vision of the adult and vision of the child. While much information as to the latter can be gained from the reports of medical officers of schools, we must trust for the former to the work of the ophthalmic surgeon in hospital or private practice.

The most complete statistical results that we have found from this side are due to Dr Adolf Steiger of Zürich. In 1895 he published:

(A) *Beiträge zur Physiologie und Pathologie der Hornhautrefraction.* I. Theil (Wiesbaden, Bergmann),
and in 1906–7 a memoir:

(B) *Studien über die erblichen Verhältnisse der Hornhautkrümmung* in Kuhnt and Mechel's *Zeitschrift für Augenheilkunde*, Bd. XVI. S. 229–42, S. 333–59, Bd. XVII. S. 307–17, 444–59.

Steiger in his memoir goes so far in modern statistical methods as to give correlation tables and even "fourfold" tables and uses them to insist in a general way on the inheritance of corneal refraction. He has not, however, applied modern notions of correlation, and his methods of grouping are occasionally such as to give considerable trouble to the statistical investigator.

At the very outset also we are encountered by the difficulty that his material is intensely selected. The normal individual is most inadequately represented, because in most cases one or other member of the related pair came to the ophthalmic surgeon on account of defective vision. This statement is not made in order to detract from the great merit of Steiger's work, but to guide our judgment in forming conclusions when we come to interpret the statistical constants. Indeed the fact that Steiger's material for adults is not a random sample of the population would we believe be at once admitted by him*. The defect is one which is common to all medically collected data, and we can only place against it the greater accuracy attained by a prolonged and careful examination of the individual by a first class specialist. Unfortunately we have in this case no means of supplementing Steiger's material by a general knowledge of the distribution of astigmatism and corneal refraction in the community at large. We must simply recognise that we are dealing with heredity in highly selected material.

Steiger deals not only with material from his private practice, but with observations of Swiss school children. With regard to school children elsewhere the reports we have used are:

(C) *Errors of Refraction among Children attending Elementary Schools in London.* By A. Hugh Thompson, M.A., M.D. (London, Bale, reprinted from the *British Medical Journal.*)

Dr Thompson's conclusions as to the influence of age on refraction and astigmatism may be correct, but they are not demonstrated by the statistical method he has employed. He has found that among children of defective vision, the relative

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* Mein Material wurde eben nicht zu dem ausgesprochenen Zwecke gesammelt, die hereditaren Verhältnisse zu studiren, (B) Vol. XVII. p. 454.

percentage of myopic children increases with age. It does not necessarily follow that there is an increase of myopia with age; we require first to know whether the number of children with defective vision is the same at each age, and no data for answering this question is provided in the paper. It is in fact the old story, the absence of the distribution of the normal children renders the conclusions of little value. We shall discuss below what further data we have been able to find on the relation of vision to growth and age in children.

(D) *Eyesight of School Children. Report on the Examination of the Eyes of Five Hundred Children in the Glasgow General Assembly Normal Practising School.* By John Rowan, M.B. *The Educational Times*, April, 1906.

This paper deals with normal as well as defective vision, and the group of children may be taken as a fairly random sample of a Scottish urban primary school. Dr Rowan deals with acuteness of vision as well as refraction. He has formed a list of diseases and taken the colour of the iris. He has not, however, given the data by which we might determine whether there is any correlation between colour of iris and eyesight.

(E) *Report of the Education Committee to the London County Council*, 1904, p. 31 et seq.

This gives the relation between age and acuteness of vision for 10,469 boys and 10,275 girls (p. 32) and more roughly for large series on p. 33. We have only used the former series, as the latter do not lend themselves to contingency calculations, the acuteness of vision being only classed as "good," "fair," and "bad."

(F) *Report on the Physical Condition of Fourteen Hundred School Children in the City together with some account of their Homes and Surroundings.* City of Edinburgh Charity Organisation Society. (King, London, 1906.)

This appears to be a thoroughly reliable, well designed and well executed piece of work, providing a rich quarry for the student of Eugenics. Very little reduction is made of the immense mass of material, and our present correlation investigations deal with only a relatively small part of what we hope to ultimately publish from this source. While exception may possibly be taken to this or that feature of the work, we know no collection of data which covers the same ground, or is on the whole so statistically self-consistent as that contained in this Report. It will always be easy to criticise "appreciations" and "qualitative statements," but for many years to come sociological inferences can only be drawn from estimates and classifications of this character; and the association of attributes deduced from them, if not as convincing as in the case of measurable characters, is a far better director of social reform than any purely ethical discussion, or philanthropic appeal. In the present case relatively few schools have been examined, but the children have had their environment exhaustively discussed, and their ailments have been medically investigated on a uniform plan. We shall draw largely upon this memoir in our present enquiry, and after experience of several school surveys (not here discussed) have little hesitation in placing this Edinburgh Report easily first for completeness and reliability.

(3) *On the Inheritance of Visual Characters.* The general impression among ophthalmologists appears to be that the characteristics of vision are inherited, but what the intensity of inheritance, and whether it is the same as that for other physical characters does not yet appear to have been settled. Writing as late as 1907 Messrs Swanzy and Werner* state with regard to myopia that: "Heredity also plays a certain part, which, however, is not quite clear; but it would seem some anatomical or constitutional predisposition must be transmitted to the offspring."

Mr J. Herbert Parsons† cites from a variety of observers the percentages of myopia "in one or both parents" of myopes, and observes that: "Analysis of these statistics leads to the conclusion that only 10 °/ₒ show hereditary influence, which is too small a number to be decisive considering the numerous factors which are not taken into account" (p. 1409).

We may remark here as we have had occasion to do elsewhere that apart from these disturbing factors, no such percentage statistics can possibly settle the problem of the intensity of inheritance. The distribution of parents of the normal and the proportion of myopes to normal in the general population (or at any rate in the "universe under discussion") must be found before any appreciation of the effect of heredity can be made. The actual percentages of abnormal in the parents of the abnormal may vary from one abnormality to a second and yet the force of heredity really be the same.

Parsons has further pointed out‡ that myopia is not due to a single cause, and that even the commonest of the forms of myopia, axial myopia, has varieties, and that we hardly yet know whether these clinical varieties differ from each other fundamentally or only in degree. It is possible that some of these varieties are hereditary and others due to environmental conditions. But even here the reader must be reminded that the modern student of heredity will hardly press for the inheritance directly of a diseased condition. We do not consider the inheritance of phthisis or insanity, but of the constitution or diathesis, which leads to these abnormal conditions in the course of growth or in the appropriate environment. This point will be borne in at once on the student of deaf-mutism; he will find so-called congenital and non-congenital cases, the latter frequently following on special environmental conditions occurring in early life. But the non-congenital cases occur largely in special stocks and not infrequently in stocks where congenital cases also occur. Thus the inheritance is one of a constitutional weakness, the defect becoming actual with growth or a suitable environment; or possibly in uterine existence. Ultimately no doubt distinction will be made between various types of myopia, but it is not unreasonable in the present state of our knowledge to test the intensity of inheritance

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* *A Handbook of the Diseases of the Eye and their Treatment*, 1907.

† *Pathology of the Eye*, Vol. IV. 1908, pp. 1409, 1410.

‡ *loc. cit* Vol. I. 1904, p. 968 et seq.

on the basis of broad classifications. Further, if non-hereditary varieties exist and have been included in our classification it follows that we shall not be over- but underestimating the numerical value of the hereditary factor*.

Groenouw and Abelsdorf are cited by Steiger† to show that at the time of his memoir (1906) inheritance in the cases of myopia and astigmatism was still an unsettled problem. Steiger himself has advanced the question immensely and our first object will be to render his results comparable with our knowledge of heredity in other physical characters.

Steiger deals with the two problems of refraction and astigmatism, and he considers the distributions among parents and offspring, and among the members of a sibship (or fraternity). The comparatively steady value of astigmatism in the individual precludes the suggestion of a post-uterine origin of the character, and the fact that the father is as influential as the mother leads us, using Occam's razor, to accept heredity rather than an intra-uterine source for astigmatism. That Steiger definitely demonstrates the inheritance of both refraction and astigmatism should, we think, be fully accepted. The real problem before us is to determine what the intensity of inheritance may be according to Steiger's data and the difficulty of solution lies in the fact that these data do not provide a random sample of the general population.

The first mootpoint that occurs in dealing with the inheritance of refraction, concerns the determination of the unit, which we shall use to obtain a quantitative scale. The refractive power of the corrective lens is inversely as its focal distance, and this refractive power is now universally adopted in the measurement of refraction, the unit being a lens of one metre focal distance, of which the refractive power is termed a diopter. Under an older system the actual focal length of the lens needed for correction was stated. In other words expressed mathematically the character to be measured in the former case is expressed by C/x and the latter case by x, where C is a mere constant due to change of scale. Now if x_1 and x_2 be the values of the character in two individuals, it is not the same thing to correlate x_1 and x_2 as to correlate C/x_1 and C/x_2; the resulting intensity of association will only be the same if the deviations of x_1 and x_2 from the mean values in the population are small compared with that mean value. Now an examination of

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* Further references to the heredity of visual characters will be found in: H. Cohn, *The Hygiene of the Eye in Schools*, Chap. x. 1883. Cohn gives percentages of myopic parents of myopic children, but considers the question of the heredity of myopia not yet decided.

Opinions on the heredity of myopia without mass statistics are given by:

Priestley Smith: "Diagnosis, Prognosis and Treatment of Pernicious Myopia," *Brit. Med. Journal*, Oct. 19, 1901, p. 1162. ("Tendency to myopia frequently inherited.")

C. A. Oliver: Norris and Oliver: *System of Diseases of the Eye*, London, 1897, Vol. IV. p. 425.

S. D. Risley: *Ibid.* Vol. II. p. 362. ("Therefore if heredity has any important place in the history of the near-sighted eye, it lies in production of these anatomical defects. I am of opinion congenital anomalies in the form of the eyeball are hereditary rather than myopia or any tendency to myopia." Dr Risley attributes the myopic tendency to certain distortions in the form of the skull, which affect the shape of the orbits.)

Fuchs: *Textbook of Ophthalmology*, trans. by A. Duane, 3rd ed. 1908, p. 758. (Inheritance of correlated anatomical conditions giving rise to myopia.)

† (B) Bd. XVI. p. 229.

our table on p. 22 shows that the variation in corneal refraction is about 3 $^\circ/_\circ$ of the mean value. For statistical purposes therefore it would not matter very much whether we considered the character to be measured by C/x or by x. On the other hand for corneal astigmatism the variation is 75 $^\circ/_\circ$ of the mean value, and whether we use C/x or x may make a sensible difference*. We have examined at some length whether the refractive power of the lens or its focal length ought to be considered as the more fitting *organic* measure of the character. In practice for both refraction and astigmatism the inverse of a certain length is taken now as the measure of the character. This measure has been adopted for its convenience, not because of its physiological significance. We cannot, however, assert that the focal length itself is the better standard, merely because in current anthropometry we are accustomed to measuring actual lengths in the human organism, and determining the degree of inheritance of these lengths. The lengths determined by the correcting lenses are not simple measurable lengths of the eye itself, but complex functions of the lengths of the parts of the eye (radii of curvature, thickness of the lenses, distances of lenses apart and from the retina, etc.). Nor is it possible to deduce from the focal length of the corrective lens, any simple dimension of the given eye. Yet as a matter of fact values obtained for the inheritance coefficients in the case of refraction appear to be somewhat more consonant with the values obtained for the inheritance of other measurable characters in man, if we use direct focal lengths instead of the refractive powers of the correcting lenses. For example: the resemblance in corneal refraction of brothers and sisters falls from ·63 to ·40 if we use focal lengths instead of diopters as the measure of the character. It seems, however, better to avoid questions of "fitter" organic scale—as "fitness" itself is a matter of definition—by using whenever it is possible the method of contingency, fundamentally, or for purposes of control. In this case, whether we classify by diopters or focal lengths, our results are precisely the same.

In taking either diopters or focal lengths as the measure of the defect, we are fully aware that we are not dealing with an anthropometrically simple character of the eye. But if a quantity z be a function of any number of simple quantities $x_1, x_2 \ldots x_n$ which are inherited at the same rate and have variabilities small relative to their mean values, then it has been shown† that z will be inherited at precisely the same rate as these other simple characters, provided the coefficient of cross-heredity is equal to the product of the coefficient of direct heredity into the organic correlation of any two organs. The latter condition does not appear to be absolutely satisfied in the case of physical measurements on man‡, but it is certainly approximately true, and the degree of approximation is close enough to enable us to test heredity on complex characters as well as on simple lengths.

(4) *On a measure of the Selection used when we deal with the cases of Corneal*

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* A similar problem arises when we use "magnitude" instead of "amount of light" in stellar statistics.

† Pearson, *R. S. Proc.* Vol. 62, p. 411; *Phil. Trans.* Vol. 187, A, p. 259.

‡ Pearson and Lee, *Biometrika*, Vol. II. pp. 383, 393.

Astigmatism collected by the Ophthalmologist in place of a Random Sample of the General Population.

Steiger (B) Bd. XVI. S. 236 gives a table of the distribution of 3170 Berne school children not selected for visual defect. This includes:

(α) 882 ♂ eyes, from a boys' secondary school, ages 11—16
(β) 620 ♂ ,, ,, ,, primary ,, ,, 9—15
(γ) 1034 ♀ ,, ,, girls' secondary ,, ,, 12—16
(δ) 634 ♀ ,, ,, ,, primary ,, ,, 9—15

The characteristic investigated was corneal astigmatism.

TABLE I. *Corneal Astigmatism in General Child Population.*

Diop.	− 0·5	− 0·25	0	0·25	0·5	0·75	1	1·25	1·75	2·625	3·5	Totals
(α)	—	7	51	100	275	238	97	65	26	15	8	882
(β)	4	8	39	94	153	175	67	38	29	9	4	620
(γ)	—	14	43	79	264	310	108	85	90	22	19	1034
(δ)	1	4	32	60	125	206	82	60	44	10	10	634

We have selected after some consideration 3·5 D to centre the last group which Steiger classes as "more than 3·0 D." His previous group is 2·25—3·0 inclusive, and his observing unit appears to be $\frac{1}{4}$ D. There results from this Table:

	Mean	Standard Deviation	Coefficient of Variation
(α) Boys, 11—16 years	·715 ± ·012	·520 ± ·008	72·7
(β) Boys, 9—15 years	·695 ± ·014	·529 ± ·010	76·2
(γ) Girls, 12—16 years	·848 ± ·013	·605 ± ·009	71·3
(δ) Girls, 9—15 years	·829 ± ·016	·585 ± ·011	70·6

We can conclude at once from these results that:

(i) The girls are more astigmatic than the boys and more variable, if we judge as, I think, is needful in this case (owing to the possibility of negative values) by the standard deviation and not the coefficient of variation.

(ii) In both cases there is possibly a slight reduction of astigmatism with age, but it is hardly sensible and not determinable on the data provided. Change in variability with age is doubtful, and different for the two sexes.

We may conclude that for the general child population we may take for corneal astigmatism:

	Mean	Standard Deviation	Coefficient of Variation
Boys	·705	·525	74·5
Girls	·839	·595	70·9

The question that next arises is: What change in these constants is made when such material passes through the hands of the ophthalmologist, who selects and deals only with that portion of his material which he considers abnormal?

An apparent answer is given by Steiger ((B) XVI. S. 237). 32,654 Zürich school children were examined, and the boys (16,233) showed in 8·5 °/o of cases, the girls (16,421) in 10·6 °/o of cases an astigmatism which alone or to a great part affected their keenness of vision. Now if the selection were simply made on the basis of excessive astigmatism "according to the rule" we should find the mean increased but the standard deviation decreased after the ophthalmologist had made his selection. But this is very far from the fact. In all cases of material selected as possessing defective vision the mean of the corneal astigmatism is raised, but at the same time the standard deviation is very largely raised also. This follows because the classes of astigmatism "against the rule," *i.e.* the persons with the greater curvature in the horizontal meridian, noted in the above table with a minus sign, are also largely selected. Excess of astigmatism "according to the rule" is more frequent than excess "against the rule"; the curve of distribution in the general child is not very widely different from normality, but the tail "according to the rule" is sensibly exaggerated beyond the tail "against the rule," *i.e.* there is skewness in the sense of the positive astigmatism. The selection curve is actually U-shaped and the resulting standard deviation much increased. Unfortunately we have not the numbers but only Steiger's diagram of the percentages of each class in the selected children ((B) XVI. p. 237), but it is sufficient to indicate that if these could be reduced to percentages of each class in the normal Berne population we should find a skew U-curve for our selection curve. The following is our rough attempt to reach this from Steiger's diagram taking Boys ((*a*) above) as the normal population.

Ophthalmological selection from general boy population of 8·5 °/o of astigmatics:

	'Against the Rule'	0	0·25	0·5	0·75	1	1·25	1·75	2·625	Over 3
Distribution of 8·5°/o	·17	·24	·33	·57	·46	·46	·66	2·27	1·76	1·58
Percentage of each class of normal population taken	21·2	4·1	2·9	1·8	1·7	4·2	8·9	78·3	103·5	175·6

This brings out the skew U-shaped nature of the selection curve. The two last percentages exceeding 100 °/o show that all the individuals at Zürich with 2·0 D or more were actually selected and that in the Berne population there were fewer of these cases than existed in Zürich. The mean of the selected Zürich boy population is 1·89 D and the standard deviation 1·08 D*; thus indicating that the mean has been more than doubled, and the standard deviation not quite doubled.

Of course this rough result cannot be directly applied from children to adults, but it may suffice to indicate the direction of ophthalmological selection. It is not a simple selection which cuts off one tail only of the distribution. Another point is also to be noticed. In actual practice the selection will most generally be of adults, and the corneal astigmatism of these will be different from that of children. Steiger's results ((A) p. 22) are very regular and show sensible decrease of

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* Based on the values of the 8·5 °/o distribution given above.

corneal astigmatism from the year 10, onward to the end of life. His published data do not permit of our ascertaining the exact correlation between age and astigmatism*; it is probably less than that between refraction and age and will not therefore be further considered here†.

(5) *On Parental Inheritance. Corneal Astigmatism.* Unfortunately Steiger does not give very detailed tables for this. A correlation table is given for mothers and sons only and this for comparatively few cases and for rather large groupings. For the three other parental cases we have only fourfold tables.

On S. 347 (B) XVI. we have the following table:

TABLE II. *Corneal Astigmatism, Mothers and Sons.*

		Mothers						
		Against the rule and 0—1·0	1·25—2·0	2·25—3·0	3·25—4·0	4·25—5·0	5·25—6·0	Totals
Sons	Against the rule and 0—1·0	29	8	3	—	—	—	40
	1·25—2·0	26	16	6	1	3	—	52
	2·25—3·0	13	4	3	4	—	—	24
	3·25—4·0	10	7	4	6	—	1	28
	4·25—5·0	4	4	2	2	2	1	15
	5·25—6·0	1	2	—	—	2	—	5
	Totals	83	41	18	13	7	2	164

Dealt with by the product-moment method we find:

Sons: Mean 2·1402, S.D. 1·4051;
Mothers: Mean 1·4390, S.D. 1·2282.
Correlation = ·3760 ± ·0452.

Throwing the small groups 4·25—5·0 and 5·25—6·0 together and using mean square contingency we find: $C_2 = \cdot 3848$. This is sufficiently close to the value of

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* We have sought in vain for reducible statistics on this point.

† Steiger himself says that astigmatism according to the rule is congenital. It has never been found to occur after birth, and no statistics demonstrate a more intense astigmatism according to the rule in later years. A reduction, sometimes very sensible, may occur in its value. (B) XVI. S. 231.

the correlation coefficient to make us conclude that ·38 is a fair value of the relationship.

The material is obviously highly selected. In the general boy population (α) we have 87 °/o of astigmatism of 1·0 D or less, and 79 °/o in the general girl population (γ). In our present table the boys with less than 1·0 or 1·0 D are 24 °/o and their mothers 51 °/o of the total. This suggests that the selection has been by the children rather than by the mothers*. It would follow from this that we ought to obtain from the data the true regression line of mothers on sons. Let r_{ms}, σ_m, σ_s be the unselected values of the correlation and standard deviations of mothers and sons; $\bar{r}_{ms}$, $\bar{\sigma}_m$, $\bar{\sigma}_s$ the selected values, then

$$r_{ms}\,\sigma_m/\sigma_s = \bar{r}_{ms}\,\bar{\sigma}_m/\bar{\sigma}_s = \cdot 3760\,\frac{1\cdot 2282}{1\cdot 4051} = \cdot 3287.$$

Hence, if the character were equally variable in ♂ and ♀, the correlation r_{ms} would be $\frac{1}{3}$. If, however, we give the variabilities the ratio determined on p. 7, this is reduced to ·29.

It must be admitted that this value, while quite significant and demonstrating the inheritance of corneal astigmatism, is considerably less than what has been found for other physical characters in man. The data however are sparse and we cannot be certain of the exact nature of the selection which has taken place, *i.e.* there are probably cases in which the mother is the selected and the son only the indirectly selected individual. Such a process it is easy to show would substantially lower the correlation. For if the mothers had been the directly selected individuals the slope of the regression line of sons on mothers would be unchanged by selection or:

$$r_{ms}\,\sigma_s/\sigma_m = \bar{r}_{ms}\,\bar{\sigma}_s/\bar{\sigma}_m = \cdot 4301,$$

whence

$$r_{ms} = \cdot 4301 \times \sigma_m/\sigma_s = \cdot 49.$$

Thus the true value of the correlation can range from ·29 to ·49 according to the amount and nature of the selection. As we have seen, however, there appears to be a greater selection of children than of mothers, and the true value probably approaches somewhat nearer the lower limit.

We may see as far as our means extend how far the other parental relations confirm or modify the result just reached. Steiger gives the following four fourfold tables of which the second is the material already discussed ((B) XVI. p. 348).

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* Steiger writes ((B) XVI. p. 234): "Unser Material stammt zum Teil aus der Sprechstunde, zum weitaus grössten Teil aber aus den stadtischen Schulen von Zürich, und besteht in erster Linie aus den Schulkindern selbst, dann aber auch aus begleitenden Eltern oder Geschwistern." In all material of this sort it is for statistical purposes essential that the "directly selected" and the not directly selected individuals should be distinguished in the data.

TABLE III. *Inheritance of Corneal Astigmatism.*

		(i) Fathers			(ii) Mothers		
		Up to 2·0 D	More than 2·0 D	Totals	Up to 2·0 D	More than 2·0 D	Totals
Sons	Up to 2·0 D	83	17	100	79	13	92
	More than 2·0 D	45	17	62	45	27	72
	Totals	128	34	162	124	40	164

		(iii) Fathers			(iv) Mothers		
		Up to 2·0 D	More than 2·0 D	Totals	Up to 2·0 D	More than 2·0 D	Totals
Daughters	Up to 2·0 D	95	19	114	126	23	149
	More than 2·0 D	51	19	70	55	40	95
	Totals	146	38	184	181	63	244

These give for uncorrected correlation coefficients:

$$r_{fs} = \cdot 218, \qquad \bar{r}_{ms} = \cdot 446^{*},$$
$$r_{fd} = \cdot 220, \qquad \bar{r}_{md} = \cdot 478.$$

The correction, supposing we take as before the offspring as selected, becomes more hypothetical in this case because we have no values for $\bar{\sigma}_d$ or $\bar{\sigma}_f$. It is clear that the $\bar{\sigma}_f$ whether found from the son or daughter table will be much the same; this also applies to $\bar{\sigma}_m$. Further $\bar{\sigma}_d$ as found from the father table will be probably much the same as that found from the mother table: this is suggested by the ratio of the frequency in the two classes remaining much the same in the two tables in which each individual appears. But this is not the case for the sons in the tables of fathers and mothers. Still we have no possibility of finding $\bar{\sigma}_s$ from the father table and can only assume it equal to the value found from the mother table in its extended form[†]. The best we can do to find a value for $\bar{\sigma}_d$ is to take the known $\bar{\sigma}_s$ and increase it in the ratio of sex variabilities, and to find a value for $\bar{\sigma}_f$ to take the known $\bar{\sigma}_m$ and reduce it in the ratio of the sex variabilities. Thus we have:

$$\bar{\sigma}_f = 1 \cdot 0837, \qquad \bar{\sigma}_m = 1 \cdot 2282,$$
$$\bar{\sigma}_s = 1 \cdot 4051, \qquad \bar{\sigma}_d = 1 \cdot 5924.$$

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[*] This is considerably in excess of the value found by the product-moment method, *i.e.* ·378.

[†] Table III (i) suggests from its row totals that the son in the father-son series was less frequently the selected member than in the case of the mother-son series.

For fathers and sons, assuming as before that $\sigma_f = \sigma_s$, of which we have no satisfactory evidence:

$$r_{fs} = r_{fs} \frac{\sigma_f}{\sigma_s} = \bar{r}_{fs} \frac{\bar{\sigma}_f}{\bar{\sigma}_s} = \cdot 168,$$

$$r_{ms} = \frac{\sigma_s}{\sigma_m} r_{ms} \frac{\sigma_m}{\sigma_s} = \frac{\sigma_s}{\sigma_m} \left(\bar{r}_{ms} \frac{\bar{\sigma}_m}{\bar{\sigma}_s} \right) = \cdot 344,$$

$$r_{fd} = \frac{\sigma_d}{\sigma_f} r_{fd} \frac{\sigma_f}{\sigma_d} = \frac{\sigma_d}{\sigma_f} \left(\bar{r}_{fd} \frac{\bar{\sigma}_f}{\bar{\sigma}_d} \right) = \cdot 170,$$

$$r_{md} = r_{md} \frac{\sigma_m}{\sigma_d} = \bar{r}_{md} \frac{\bar{\sigma}_m}{\bar{\sigma}_d} = \cdot 369.$$

The results for father with son and for father with daughter are consistent with each other, and the two results for mother with son and with daughter are fairly close and not so widely divergent from that previously found by a different method. But one can hardly accept as final these low values nor believe that this is an exceptional case, where the influence of mother is twice as great as that of the father. It seems more reasonable to suppose that the selection has not been made wholly by children, and that the direct selection of parents has been greater in the case of fathers than in that of mothers.

(6) *On Fraternal Inheritance. Corneal Astigmatism.* The most satisfactory table given by Steiger for our present purposes is the following* ((B) XVI. p. 238):

TABLE IV. *Resemblance of Sisters.*

Astigmatic ♀	Astigmatic's Sister							
	Against the rule	0·25—1	1·25—2	2·25—3	3·25—4	4·25—5	5·25 and over	Totals
Against the rule	1	—	—	—	—	—	—	1
0·25—1	4	33	1	—	—	—	—	38
1·25—2	4	47	37	5	2	—	—	95
2·25—3	1	23	44	19	3	—	—	90
3·25—4	—	15	30	32	8	—	—	85
4·25—5	—	3	10	10	7	2	—	32
5·25 and over	—	—	9	1	1	1	—	12
Totals	10	121	131	67	21	3	—	353

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* In reducing this table Sheppard's corrections were used; they seemed hardly legitimate in Table II, owing to want of high contact. If used the correlation is ·3952 instead of ·3760 as entered.

Mean of astigmatics = 2·656, S.D. = 1·2451,

Mean of their sisters = 1·560, S.D. = ·9342.

Correlation = ·5838.

$$r_{ss} = r_{ss} \frac{\sigma_s}{\sigma_s} = \bar{r}_{as} \frac{\bar{\sigma}_s}{\bar{\sigma}_a} = \cdot 438.$$

Thus we find a substantial relation between sisters in the unselected population, but somewhat below the value ·5 we are accustomed to find for physical characters in man.

For a fivefold × fivefold table the use of mean square contingency gave $C = \cdot 556$, which is in quite good agreement with the value given for r. To test the influence of neglecting the fact that the material is an ophthalmological selection of one member of the pair, we destroyed the difference between the two sisters by making the table symmetrical. We found $r = \cdot 2504$ or the correlation has fallen more than 50 %. This effectively illustrates how great the influence in destroying the traces of heredity must be if there be a partial selection of unknown amount from *both* the correlated groups.

For pairs of brothers Steiger unfortunately only gives a 3 × 3 fold table, namely ((B) XVI. p. 240):

TABLE V. *Resemblance of Brothers.*

		Astigmatic's Brother			
		1·0 and below	1·25—4·0	Over 4·0	Totals
Astigmatic ♂	1·0 and below	33	—	—	33
	1·25—4·0	54	105	—	159
	Over 4·0	6	18	2	26
	Totals	93	123	2	218

This does not lend itself to a satisfactory fourfold division. It shows, perhaps, higher correlation than in the case of sister and sister, but the value by a fourfold table will depend largely on where the division is made*.

For brother and sister Steiger ((B) XVI. p. 335) gives a table, which would have been useful had he indicated the selected individuals.

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* The mean value does not differ much from that of sister pairs, but the range is roughly from about ·84 to ·30!

TABLE VI. *Resemblance of Brother and Sister.*

Brother \ Sister	0	0·25—1·0	1·25—2·0	2·25—3·0	3·25—4·0	4·25—5·0	5·25—6·0	Totals
0	6	14	9	1	2	—	—	32
0·25—1·0	1	43	47	27	5	5	2	130
1·25—2·0	—	28	67	43	36	6	—	180
2·25—3·0	1	11	36	23	25	8	2	106
3·25—4·0	—	5	26	16	25	7	4	83
4·25—5·0	—	4	2	6	4	3	—	19
5·25—6·0	—	—	1	—	—	2	—	3
Totals	8	105	188	116	97	31	8	553

We find:

Mean of brothers: 1·891, S.D. = 1·2250,
Mean of sisters: 2·193, S.D. = 1·2204.
Correlation = ·3303.

Comparing this with the Berne results we see that there has been very considerable selection. But there is no means of correcting for this, because we have no measure of how many or which individuals have been directly selected. We have seen that in the case of the sisters (p. 13), the effect of confusing the directly and indirectly selected material reduced the uncorrected correlation from ·58 to ·25, or to less than half. Hence it is not unreasonable to suppose that the uncorrected correlation is over ·6, or at least as great as between sister and sister.

(7) *General Conclusions as to the Inheritance of Corneal Astigmatism.* There is certainly inheritance of corneal astigmatism, as evidenced by minimum limits of ·3 to the parental and of ·4 to the fraternal coefficients. But the present material is neither sufficient nor sufficiently classified to enable us to determine with any degree of certainty the accurate value of the inheritance coefficients.

It is ophthalmologically selected, and although it would be possible to allow for this, if we had the raw data, and were told in each case which member of the pair was the "selected" individual, this information is not really given in any of Steiger's tables* and can only be roughly assumed in the case of a few of them.

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* We are not certain that the "astigmatic" is in all cases the selected individual, although it is generally the individual with the excess of astigmatism.

Steiger has enormously advanced the conception of what the ophthalmologist can do for heredity by taking the ophthalmic characters of the relatives of his patients. But for statistical reduction it is needful in every case to separate "patient," the "selected" individual, from the relative the "indirectly selected" individual. Tables correlating the characters of these two will not in themselves suffice to demonstrate the intensity of heredity, as Steiger occasionally seems to assert, but they will serve to determine when properly corrected for the "selection" the values of the inheritance coefficients.

The present discussion will at any rate suffice to indicate two conclusions:

(i) That there is a splendid field for a man who will measure the corneal astigmatism in a non-selected population.

(ii) That failing this the ophthalmologist can provide useful results, if he will carefully distinguish between "patient" and relative.

(8) *On the Inheritance of Corneal Refraction.* Steiger has treated his data on this point with more detail than his material for astigmatism. He has indicated that there is not only a sexual difference, but a change with age.

From his data we reach the following results*.

TABLE VII. *Age, Sex and Corneal Refraction.*

	Males			Females		
Group of Ages	To 8 years	10—16	16—88	To 8 years	10—16	16—88
No. of Eyes	248	882	232	252	1034	363
Mean	42·88	42·71	42·42	43·59	43·14	42·99
S.D.	1·324	1·287	1·289	1·451	1·204	1·360

General Mean = 42·75	General Mean = 43·17
General S.D. = 1·291	General S.D. = 1·293
Correlation of Refraction and Age $r = \cdot 174$	Correlation of Refraction and Age = ·155

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* The following is the Table of Frequencies, reconstructed from Steiger's percentages:

	Males			Females		
	To 8 years	10—16	16—88	To 8 years	10—16	16—88
Up to 40	8	21	10	4	8	5
40·25 — 41	14	60	30	13	45	23
41·25 — 42	41	180	53	24	155	72
42·25 — 43	78	279	76	16	294	110
43·25 — 44	66	194	35	68	321	69
44·25 — 45	33	120	24	53	154	57
Over 45	8	28	4	44	57	27
Totals	248	882	232	252	1034	363†

† Steiger gives on his diagram (A. p. 46) 368, but we think this must be a misprint.

Now these results show that there is less than $\frac{1}{2}$ diopter difference between the sexes, and that as a whole they are almost equally variable. The females show rather more change in their variability with age, extreme childhood and age are the more variable periods. While the decreasing value of the refraction with age is well marked and the correlation, about ·16, quite sensible, it is not of a value to involve serious corrections in the inheritance correlations. For the correction will depend upon $(\cdot 16)^2$, or introduce only modifications of order ·02 to ·03 into the coefficient, and these are in this case of the order of the probable errors of the results.

Steiger gives us throughout no information as to which individual is the "selected" member of a pair. We shall now proceed to discuss his data.

(9) *Parental Inheritance. Corneal Refraction.* Steiger has given four tables of parental heredity. They are reproduced as VIII, IX, X and XI below. We find the statistical constants tabled in XII on p. 18.

Tables of Parental Heredity, Corneal Refraction. Steiger.

TABLE VIII. *Father and Son.*

Father

Son	39·25—40	40·25—41	41·25—41·5	41·75—42	42·25—43	43·25—44·25	44·5—45	45·25—46	46·25 and over	Totals
39·25—40	—	3	1	2	—	—	—	—	—	6
40·25—41	—	3	—	1	1	—	—	—	—	5
41·25—41·75	1	3	4	4	1	2	—	—	—	15
42·0—43	—	2	7	8	11	11	4	3	—	46
43·25—44·25	—	2	2	4	6	9	1	4	—	28
44·25—45	—	—	—	1	2	4	6	2	2	17
45·25—46	—	—	—	—	—	3	2	2	—	7
46·25 and over	—	—	—	—	—	—	—	—	—	—
Totals	1	13	14	20	21	29	13	11	2	124

TABLE IX. *Mother and Son.*

Mother

Son	Up to 40	40·25—41	41·25—41·75	42—43	43·25—44·25	44·5—45	45·25—46	46·25—47	47·25 and over	Totals
Up to 40	2	—	—	2	2	—	—	—	—	6
40·25—41	1	1	1	3	2	—	—	—	—	8
41·25—41·75	1	1	—	1	1	1	—	—	—	5
42—43	1	5	—	16	8	2	—	2	—	34
43·25—44	1	—	2	10	9	4	—	—	—	26
44·25—45	—	—	2	—	4	3	1	—	2	12
45·25—46	—	—	—	—	—	—	1	—	—	1
46·25—47	—	—	—	—	1	1	—	—	—	2
47·25 and over	—	—	—	—	—	—	3	1	—	4
Totals	6	7	5	32	27	11	5	3	2	98

TABLE X. *Father and Daughter.*

Father

Daughter	39·25—40	40·25—41	41·25—41·5	41·75—42	42·25—43	43·25—44·25	44·5—45	45·25—46	46·25 and over	Totals
Up to 41	—	2	—	1	—	—	—	—	—	3
41·25—42	2	4	—	3	2	—	—	—	—	11
42·25—42·5	—	4	—	2	2	—	—	—	—	8
42·75—43	—	—	—	2	5	2	—	—	—	9
43·25—44	—	—	3	—	7	5	1	—	2	18
44·25—45·5	—	3	—	—	5	9	4	—	4	25
45·75—47	—	—	—	—	4	4	2	—	—	10
47·25—48	—	—	—	—	—	—	2	—	2	4
48·25 and over	—	—	—	—	—	2	—	—	—	2
Totals	2	13	3	8	25	22	9	0	8	90

TABLE XI. *Mother and Daughter.*

Mother

Daughter	Up to 40	40·25—41	41·25—42	42·25—43	43·25—44	44·25—44·5	44·75—45	45·25—46	46·25 and over	Totals
Up to 40	—	—	—	—	—	—	—	—	—	0
40·25—41	1	3	1	1	1	—	—	—	—	7
41·25—42·25	—	5	5	5	4	1	—	—	—	20
42·5—43	1	—	1	—	8	—	—	—	—	13
43·25—44		—	2	1	21	5	3	1	1	34
44·25—45·25	—	2	—	1	8	7	2	3	3	26
45·5—46	—	—	—	2	3	5	—	2	3	15
46·25—47	—	—	—	—	—	3	1	—	7	11
47·25 and over	—	—	—	—	—	—	—	1	1	2
Totals	2	10	12	10	45	21	6	7	15	128

TABLE XII. *Coefficients of Inheritance, Corneal Refraction.*

Class	No.	Means	Standard Deviations	Correlation	
				Product Moment	Contingency
Fathers of Sons	124	42·95	1·565	·610	·601 (5 × 6)
Sons of Fathers	124	42·90	1·406		
Mothers of Sons	98	43·13	1·699	·510	·585 (5 × 5)
Sons of Mothers	98	42·99	1·710		
Fathers of Daughters ...	90	42·99	1·684	·584	·623 (5 × 6)
Daughters of Fathers ...	90	43·78	1·842		
Mothers of Daughters ...	128	43·71	1·660	·718	·646 (5 × 5)
Daughters of Mothers ...	128	43·88	1·668		
			Mean.........	·605	·614

Now it must be at once admitted that two factors affect the striking heredity exhibited in these results. The first is the remarkable system of sub-ranges selected by Steiger to tabulate his results. No reasonable explanation is given of this system, and it is utterly unsuited to statistical reduction. The group ranges are occasionally 1·25, occasionally ·75, occasionally 1, and again ·5. And these ranges vary from table to table, even when one of the pair is the same. It would appear as if some attempt had been made to smooth the frequencies in this manner, possibly in order to get rid of a tendency to read to $\frac{1}{2}$ instead of $\frac{1}{4}$ diopters, from which Steiger, notwithstanding his criticism of Chauvel (A, p. 18), does not himself seem wholly free. Whatever the source of this choice of sub-ranges*, it enormously increases the labour of the statistician and renders his correction of the moments of doubtful application†.

Secondly, there are anomalies of which no explanations are forthcoming. We should expect to find roughly mothers of sons and of daughters to be alike, approximately fathers of sons and of daughters give the same constants; but the mothers of daughters have sensibly higher refraction than mothers of sons. Again, we note that sons of mothers are sensibly more variable than sons of fathers, and daughters of fathers sensibly more variable than daughters of mothers. This increased variability when we deal with the offspring of the opposite sex may be the source of the reduced heredity, in this case between the opposite sexes. It is impossible to say whether this result—important if it were true—is in whole or part produced by the changing of sub-range systems to which we have just referred.

We have verified the generally high values of the correlation between parents and offspring by recalculating the coefficients by mean square contingency. Their high values are thus confirmed. The high values of the variabilities for refraction in Table XII compared with those in Table VII, show that we are dealing with *highly selected* material, but the slight changes of means seem to indicate that the selection is largely one of extremes. The parental variability is raised almost as much as that of the offspring and one hesitates to assert that parents have in the bulk been indirectly selected by selection of their offspring, or that offspring have been indirectly selected by direct selection of their parents. There is nothing in the text to assist us to a conclusion.

In the discussion on corneal astigmatism we noticed that at a maximum the correction for selection might reduce the correlation by about 25 %. This would reduce our rough value of ·61 to ·46, a value strikingly close to the average value found for other physical characters in man‡.

We may safely conclude that corneal refraction is inherited at the same rate as other physical characters in man.

Of course the same point impresses itself upon us here as in dealing with astigmatism, the urgent need to measure a large random sample, not an ophthalmological selection, of the general population of parents and offspring. Such a system of measurements combining astigmatism and refraction would offer splendid material also for testing theories of cross heredity.

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* We find no justification for it in Steiger's remarks in (B) XVII. p. 445.

† Sheppard's correction has been made for an approximate average sub-range.

‡ Stature ·51, span ·48, forearm ·42, eye colour ·50, each based on 4000 to 5000 measurements.

(10) *Collateral Heredity, Corneal Refraction.* Steiger provided three tables of fraternal resemblance, which we reproduce as Tables XIII, XIV and XV. The following table, Table XVI on p. 22, sums up the values of the deduced statistical constants. As we could find no consistent difference between the pairs tabled by Steiger, nor any evidence as to the "selected" member, we have made Tables XIII and XIV symmetrical. Thus they contain twice the numbers in Table XVI.

Tables of Fraternal Resemblance. Corneal Refraction. Steiger.

TABLE XIII. *Pairs of Brothers.*

2nd Brother \ 1st Brother	39·25—40	40·25—41	41·25—42	42·25—43	43·25—44	44·25—45	45·25—46	46·25—47	47·25—48	48·25—49	Totals
39·25—40	6	2	1	2	—	—	—	—	—	—	11
40·25—41	2	4	10	4	1	—	—	—	—	—	21
41·25—42	1	10	16	11	7	5	2	2	—	—	54
42·25—43	2	4	11	22	17	14	2	1	—	—	73
43·25—44	—	1	7	17	30	21	5	—	—	—	81
44·25—45	—	—	5	11	21	—	3	3	1	—	47
45·25—46	—	—	2	2	5	3	4	—	1	2	19
46·25—47	—	—	2	1	—	3	—	2	1	—	9
47·25—48	—	—	—	—	—	1	1	1	—	—	3
48·25—49	—	—	—	—	—	—	2	—	—	—	2
Totals	11	21	54	73	81	47	19	9	3	2	320

TABLE XIV. *Pairs of Sisters.*

1st Sister

2nd Sister	40·25—41	41·25—42	42·25—43	43·25—44	44·25—45	45·25—46	46·25—47	47·25—48	Totals
40·25—41	4	4	1	4	—	—	—	—	13
41·25—42	4	8	9	14	3	3	—	—	41
42·25—43	1	9	30	28	15	11	—	—	94
43·25—44	4	14	28	42	34	7	6	2	137
44·25—45	—	3	15	34	38	12	2	2	106
45·25—46	—	3	11	7	12	8	8	4	53
46·25—47	—	—	—	6	2	8	—	—	16
47·25—48	—	—	—	2	2	4	—	—	8
Totals	13	41	94	137	106	53	16	8	468

TABLE XV. *Brother and Sister.*

Brother

Sister	39·25—40	40·25—41	41·25—42	42·25—43	43·25—44	44·25—45	45·25—46	46·25—47	47·25—48	Totals
39·25—40	3	3	3	1	—	—	—	—	—	10
40·25—41	4	5	6	3	3	—	—	—	—	21
41·25—42	3	7	18	9	1	—	2	—	—	40
42·25—43	5	8	15	29	13	2	2	—	—	74
43·25—44	—	—	11	18	29	9	3	—	2	72
44·25—45	—	1	7	26	27	17	9	4	—	91
45·25—46	—	2	1	5	14	11	8	5	—	46
46·25—47	—	—	—	3	—	2	3	—	2	10
47·25—48	—	—	—	2	—	4	1	5	—	12
Totals	15	26	61	96	87	45	28	14	4	376

It is a noteworthy feature of these tables that whereas 10 sisters out of 376 with brothers have a refraction 40 D or under, not a single sister out of 468 with a sister occurs in this group. It is difficult to see how the existence of a brother could lower the sister's refraction, but as we indicate later there is something anomalous about Table XIV.

TABLE XVI. *Corneal Refraction. Fraternal Resemblance.*

Class	No.	Means	Standard Deviations	Correlations	
				Product Moment	Contingency
Pairs of Brothers	160	43·14	1·516	·628	·553 (5 × 5)
Pairs of Sisters	234	43·79	1·397	·407	·423 (5 × 5)
Brother and Sister	376	Brother 43·10 Sister 43·64	1·652 1·717	·632	·577 (5 × 5)
			Mean ...	·556	·518

Again we mark the same sort of anomalies arising as in the parental tables, when we compare members of different sexes, the variabilities being greater with different sexes than with like sexes. The low value of the sister-sister correlation is remarkable, but we see no explanation of the result in the tabled data.

We have here also no possibility of correcting for selection, but the reduction will be less than in the case of the parental tables. The sister pairs are the weak point, but on the whole the constants may be said to be in good agreement with those hitherto found for fraternal resemblance*.

The results taken all round are quite sufficient to indicate that corneal refraction falls well into line with other human characteristics and would amply repay full investigation not only by the scientific value of the results, but by the importance of the subject from the eugenic standpoint.

(11) *Interrelations of Refraction, Keenness of Vision and Age.* The chief objection to Steiger's data lies in the fact that it consists of an ophthalmological selection and that the individuals selected are not defined. There is in the material cited by us in Section (1) data for approaching the problem from the side of collateral heredity without the difficulty of this selective action. That material also provides us with interesting relations between age, keenness of vision and refraction. It seems desirable to consider these interrelations before returning to the problem of heredity.

(*a*) *Keenness of Vision and Refraction.*

We take first Keenness of Vision and Refraction in its various forms. Table XVII for boys and Table XVIII for girls are based on the material provided in (F)

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* Stature ·51, span ·55, forearm ·49, eye colour ·52.

the *Edinburgh Charity Organisation Report*. The children are classed under *Emmetropia*, *Hypermetropia*, *Hypermetropic Astigmatism*, *Mixed Astigmatism*, *Myopia* and *Myopic Astigmatism*. We have two methods of determining the relationship between these classes of refraction and keenness of vision as measured in the usual way by Snellen's test type at 6 metres. Namely we may treat the material as a contingency table without using quantitative measures, or we may look upon keenness of vision as a continuous quantity—not very well determined indeed by existing ophthalmological methods—and find the mean value of each refraction class and thence the correlation ratio.

TABLE XVII. *Keenness of Vision and Refraction. Boys.*

Refraction	Keenness of Vision						
	6/6	6/9	6/12	6/18	6/24	6/36	Totals
Emmetropia	391	15	5	21	5	1	438
Hypermetropia	53	34	5	9	—	1	102
Hypermetropic Astigmatism ...	21	13	10	18	1	—	63
Mixed Astigmatism	3	4	2	5	2	4	20
Myopic Astigmatism	—	2	2	4	2	—	10
Myopia	1	1	1	2	1	3	9
Totals	469	69	25	59	11	9	642

TABLE XVIII. *Keenness of Vision and Refraction. Girls.*

Refraction	Keenness of Vision						
	6/6	6/9	6/12	6/18	6/21	6/36	Totals
Emmetropia	291	13	—	25	7	3	339
Hypermetropia	43	21	15	3	—	—	82
Hypermetropic Astigmatism ...	30	25	12	9	2	—	78
Mixed Astigmatism	3	5	4	7	2	1	22
Myopic Astigmatism	—	3	3	1	2	—	9
Myopia	—	1	2	3	—	1	7
Totals	367	68	36	48	13	5	537

We have the following results.

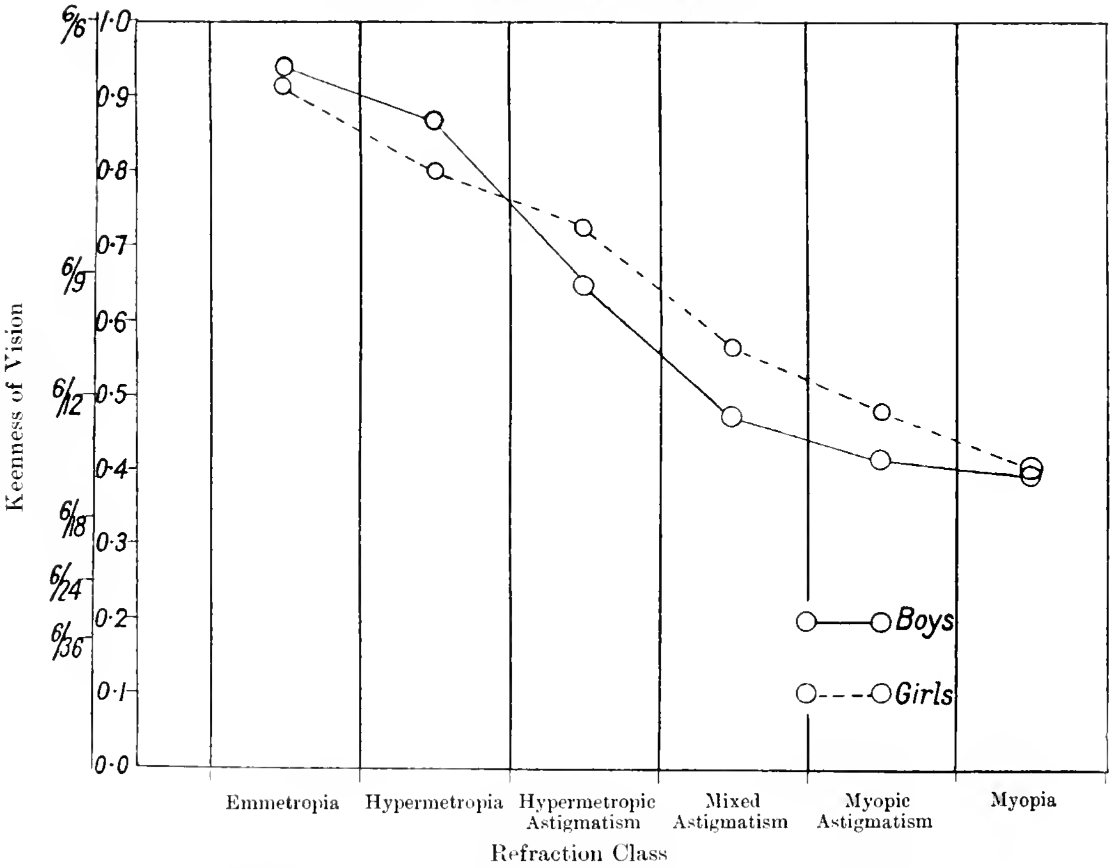
TABLE XIX. *Refraction and Keenness of Vision.*

	Keenness of Vision		Correlation of Refraction and Keenness of Vision	
	Mean	S.D.	Contingency (5 × 6)	Correlation Ratio
Boys ...	·859	·249	·582	·569
Girls ...	·839	·254	·536	·431 *

Mean values of Keenness of Vision for each refraction group		*Boys*	*Girls*
	Emmetropia	·940	·915
	Hypermetropia	·870	·799
	Hypermetropic Astigmatism	·650	·727
	Mixed Astigmatism	·475	·563
	Myopic Astigmatism	·417	·482
	Myopia	·398	·405

DIAGRAM I.

Keenness of Vision and Refraction Class.



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* Reworked, but we failed to discover any error in this curiously low value.

We may conclude from these results that the vision of the girls is possibly slightly less keen than that of the boys; both are equally variable. The two methods, while leading to somewhat different results for the girls, show that there is a close relationship between refraction and keenness of vision; in girls it may be slightly less than boys, but till further data are forthcoming we may take the degree of contingency as ·56 for both sexes. The accompanying Diagram I expresses graphically the relationship; of course no attempt at anything of the nature of a horizontal scale is supposed to exist in this diagram.

The results show at once how much more influence myopia has on keenness of vision than hypermetropia, and they indicate that refraction defects contribute more than half the abnormality of keenness of vision.

(*b*) *Age and Refraction.*

We have already found (p. 15) a relation between corneal refraction and age. We have now to consider the relationship between the various types of refraction and age. It is well known that young children are hypermetropic and tend with age to become emmetropic or occasionally myopic. We have three sets of data we can use here: (i) Tables formed from the Edinburgh data with the six classes of Tables XVII and XVIII. In Tables XX and XXI the data are given for boys and girls respectively. This material is from rather poor class schools, but there is no selection whatever. (ii) Rowan's material cited as (D) on p. 3. There appears to have been no selection of the children, but the results show more defective sight than the Edinburgh returns. (iii) Thompson's material cited as (C) on p. 2. This is "selected" material; no returns are unfortunately made of the number of normal children of each age in the schools examined, and we have again all the difficulties connected with Steiger's data. Rowan's material is given in Tables XXII and XXIII, and Thompson's in Tables XXIV and XXV. Unfortunately Rowan only gives three age groups.

TABLE XX. *Refraction Class and Age. Edinburgh Boys.*

Refraction Class	Age					
	4—7	7—9	9—11	11—13	13—15	Totals
"Normal"	54	112	134	114	41	455
Hypermetropia	19	24	27	26	7	103
Hypermetropic Astigmatism	12	19	10	13	10	64
Mixed Astigmatism	4	6	4	4	1	19
Myopia and Myopic Astigmatism	0	5	5	4	4	18
Totals	89	166	180	161	63	659

TABLE XXI. *Refraction Class and Age. Edinburgh Girls.*

Refraction Class	Age					
	5—7	7—9	9—11	11—13	13—15	Totals
"Normal"	56	83	107	76	29	351
Hypermetropia	15	23	28	12	6	84
Hypermetropic Astigmatism	24	21	10	15	6	76
Mixed Astigmatism	10	4	4	3	1	22
Myopia and Myopic Astigmatism	0	4	2	11	3	20
Totals	105	135	151	117	45	553

TABLE XX *bis**. *Refraction Class and Age. Edinburgh Boys.*

Refraction Class	Age					
	5—7	7—9	9—11	11—13	13—15	Totals
Emmetropia	23	66	84	73	24	270
Hypermetropia	37	46	56	48	19	206
Hypermetropic Astigmatism	20	30	18	28	12	108
Mixed Astigmatism	15	7	9	5	3	39
Myopic Astigmatism and Myopia	—	5	8	10	5	28
Totals	95	154	175	164	63	651

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* The Tables XX and XXI are drawn from the "Summary of Facts," under column "Eyes." In these detailed accounts of individual children apparently a less stringent standard of defective sight was taken, many children being recorded as normal in whom slight amounts of hypermetropia, or myopia or astigmatism occurred. Tables XX *bis* and XXI *bis* are taken from Table XI "Eyes," of the Tables of Medical Inspection, and they represent a more stringent classification. In the same way the Keenness of Vision results in Tables XXXII and XXXIII taken from the "General Summary" differ, but to a less extent, from the Table XI of the Medical Inspection just referred to.

Table XXI *bis*. *Refraction Class and Age. Edinburgh Girls.*

Refraction Class	Age					
	5—7	7—9	9—11	11—13	13—15	Totals
Emmetropia	16	45	72	47	23	203
Hypermetropia	28	40	49	19	12	148
Hypermetropic Astigmatism	41	34	27	27	8	137
Mixed Astigmatism	16	9	4	9	3	41
Myopic Astigmatism and Myopia	1	8	9	17	2	37
Totals	102	136	161	119	48	566

Tables XXII and XXIII. *Refraction Class and Age. Glasgow.*

Refraction Class	Boys				Girls			
	Age				Age			
	6—9	9—12	12—15	Totals	6—9	9—12	12—15	Totals
Emmetropia	33	60	29	122	52	70	27	149
Hypermetropia	8	22	25	55	3	15	16	34
Hypermetropic Astigmatism	3	11	9	23	2	8	10	20
Mixed Astigmatism	—	3	5	8	—	7	5	12
Myopic Astigmatism and Myopia	2	3	7	12	6	1	6	13
Totals	46	99	75	220	63	101	64	228

TABLE XXIV. *Refraction Class and Age. London Boys**.

Refraction Class	Age							
	7—8	8—9	9—10	10—11	11—12	12—13	13—14	Totals
Hypermetropia	11	24	22	20	32	37	28	174
Hypermetropic Astigmatism	12	35	37	24	26	27	25	186
Mixed Astigmatism	8	40	24	25	26	27	22	172
Myopia and Myopic Astigmatism	9	33	27	31	43	47	56	246
Totals	40	132	110	100	127	138	131	778

TABLE XXV. *Refraction Class and Age. London Girls**.

Refraction Class	Age							
	7—8	8—9	9—10	10—11	11—12	12—13	13—14	Totals
Hypermetropia	10	35	34	32	36	64	52	263
Hypermetropic Astigmatism	15	33	30	35	26	39	25	203
Mixed Astigmatism	14	40	30	31	48	30	35	228
Myopia and Myopic Astigmatism	12	27	38	41	45	57	40	260
Totals	51	135	132	139	155	190	152	954

In order to reduce the material the method of contingency was first applied and we obtained the results given in Table XXVI.

Thompson's data, except in so far as they confirm the result that the refraction class is correlated with age, are of little service, since they exclude the normals. It will be clear that the correlation between age and refraction class is about ·20—·25

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* Assuming these Tables to give the whole numbers of defective refraction cases in 10,416 boys and 11,498 girls, we have the following percentages from Thompson's Tables:

	Boys	Girls
"Normals"	92·5	91·7
Hypermetropia	1·7	2·3
Hypermetropic Astigmatism	1·8	1·7
Mixed Astigmatism	1·7	2·0
Myopic Astigmatism and Myopia	2·3	2·3

Thus it will be seen that while all the defective categories are below the Scottish, it is the Hypermetropia and Hypermetropic Astigmatism which in the Scottish returns so vastly exceed the English. Thompson allowed anything under 2 diopters in Hypermetropia to be "normal." We are not told what was used at Edinburgh. In Glasgow 1 diopter was the test. Rowan and Thompson both used 1 D for Hypermetropic Astigmatism, Mixed Astigmatism and Myopia. This difference in the test for Hypermetropia explains partly but far from entirely the great divergence between the English and Scottish results.

for boys and somewhat greater, ·30 to ·35, for girls. This is quite a sensible amount and should have some influence on the values of fraternal correlation. If we may accept the values deduced from Steiger's material, the effect of age on corneal refraction is not the sole source of the high value between refraction class and age. It should be noticed, however, that Steiger's material only provides three age groups, one of which is adult.

TABLE XXVI. *Refraction and Age.*

Characters	Material	Method	♂	♀
Corneal Refraction	Zurich (Steiger: see our p. 15)	Product Moment	·17	·16
Refraction Class	Edinburgh	Contingency	·25 (·17)*	·34 (·28)*
,, ,,	Glasgow (Rowan)	,,	·27	·36
,, ,,	London (Thompson)	,,	·21	·17

We can arrange our material in two other ways which show less concisely the relationship of age to refraction class.

TABLE XXVII. *Mean Age of each Refraction Class.*

Refraction Class	Edinburgh				Glasgow				London			
	Boys †		Girls †		Boys		Girls		Boys		Girls	
Emmetropia	10·1	(10·0)	9·7	(10·2)	10·4		10·0		?		?	
Hypermetropia	9·6	(9·6)	9·3	(9·3)	11·4	11·4	11·6	11·6	11·0	10·8	11·2	10 9
Hypermetropic Astigmatism	9·7	(9·7)	8·9	(8·9)	11·3		11·7		10·6		10·7	
Mixed Astigmatism	9·1	(8·7)	8·3	(8·7)	12·4		11·75		10·6		10·8	
Myopic Astigmatism	10·7	(11·1)	10·3	(10·6)	13·5	11·7	10·5		11·3		11·0	
Myopia	10·9		10·7		10·9							
All Children	10·0	(9 9)	9·5	(9·6)	10·9		10·5		10·9 ?		10·9 ?	

The Edinburgh data (see Diagram II) appear here to give the smoothest and most reasonable results, namely the hypermetropic and mixed astigmatic are below the mean age; the myopic are above and the normals at the mean age. Rowan and Thompson's abnormals give the myopic at or above the mean age, but do not indicate decisively that the hypermetropic are below the mean age. To obtain any very definite

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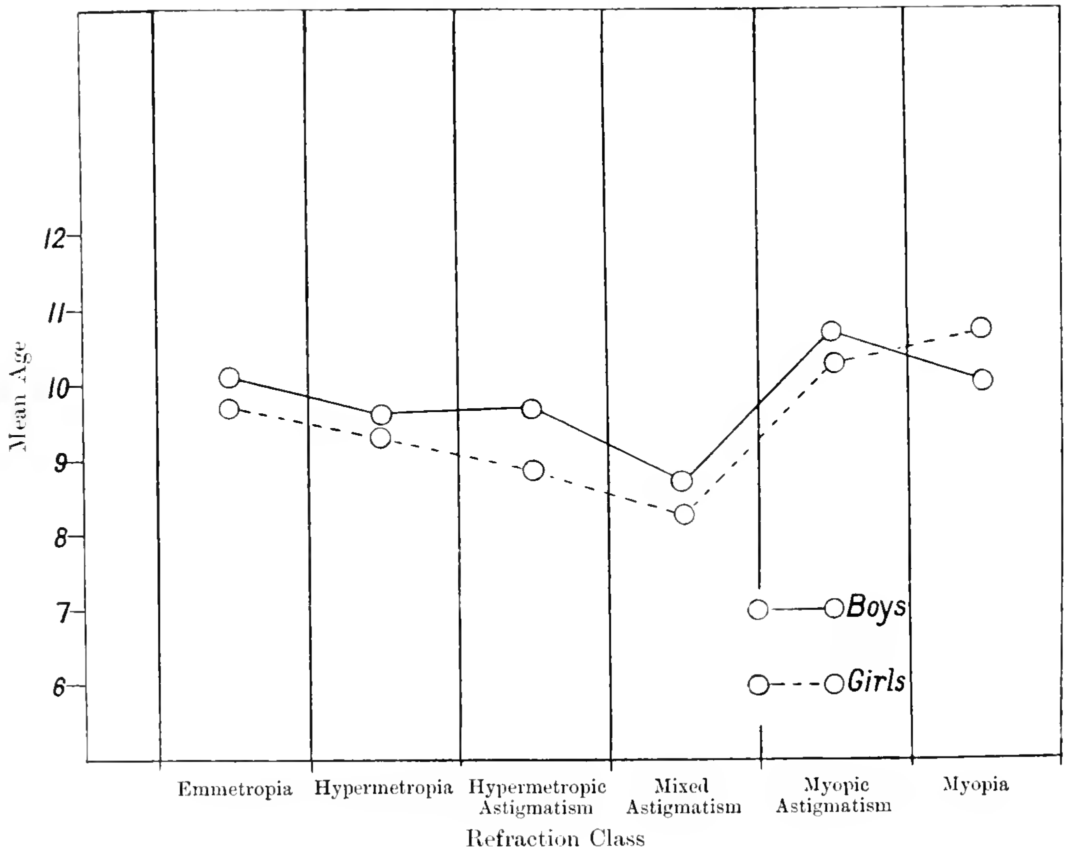
* The first values are from Tables XX and XXI, and the bracketed values from Tables XX *bis* and XXI *bis*.

† The figures in brackets are from Tables XX *bis* and XXI *bis*, and serve to confirm the other results.

DIAGRAM II.

Change of Refraction Class with Age.

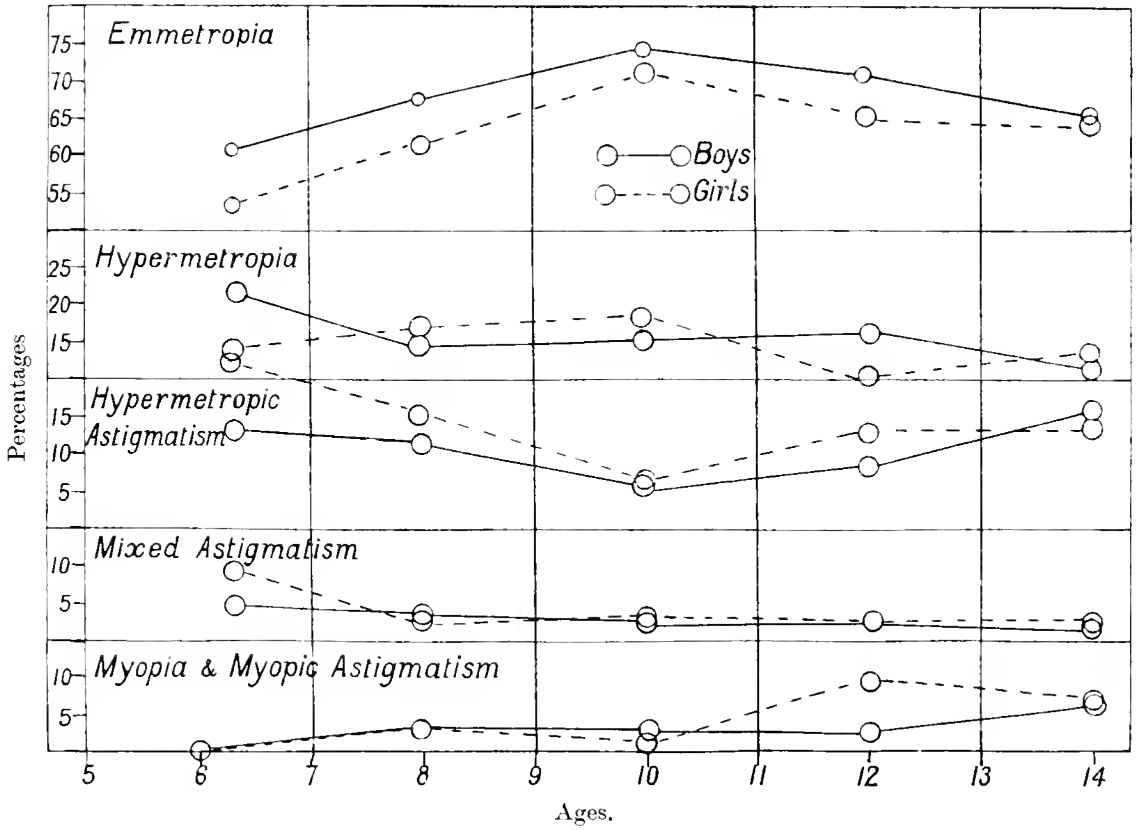


results from this method of approaching the problem much larger numbers would be required. We may also consider the problem from the standpoint of the percentages of each class at each age (Tables XXVIII and XXIX). Thompson's statistics cannot be dealt with as we have not the number of normals at each age. He found 778 cases of defective vision on a register of 10,416 boys and 954 on a register of 11,498 girls. In Edinburgh 204 cases of defective sight occurred among 659 boys and 202 among 553 girls; in Glasgow 98 among 220 boys and 79 among 228 girls. Hence either defects of refraction are far greater in number among the Scotch, or a much higher standard of what ought to be classified as emmetropia was used in Scotland. On both counts: the absence of normals and the wide difference of percentages, it does not seem possible to compare Thompson's with our other data. Unfortunately Rowan's data only provide three age classes.

Now if we were to take the Glasgow results as typical we should certainly have an apparently very bad case against school environment. It amounts to asserting that normal eye-sight decreases by almost 50 °/。 between 6 and 15 years of age, and that

DIAGRAM II *bis*.

Age and Percentages of each Refraction Class.



The above diagram shows graphically the results of Tables XXVIII and XXIX. The reader will see at once the rapid gain in Emmetropia between the ages of 6 and 10, and recognise that this gain must be chiefly due to the loss in the hypermetropic categories. The partial fall again in the Emmetropia is due to two sources: (i) a rise in the amount of Myopia and Myopic Astigmatism, and (ii) a hardly less serious rise in the Hypermetropic Astigmatism. The Hypermetropia itself continues to fall and there is but little change after the age of 8 in the mixed Astigmatism.

To face p. 31.

TABLE XXVIII. *Percentages at each Age of each Class. Boys.*

Refraction Class	Age. Edinburgh						Age. Glasgow			
	4—7	7—9	9—11	11—13	13—15	All ages	6—9	9—12	12—15	All ages
Normal	60·7	67·5	74·4	70·8	65·1	69·05	71·7	60·6	38·7	55·5
Hypermetropia	21·3	14·5	15·0	16·1	11·1	15·6	17·4	22·2	33·3	25·0
Hypermetropic Astigmatism	13·5	11·4	5·6	8·1	15·9	9·7	6·5	11·1	12·0	10·4
Mixed Astigmatism	4·5	3·6	2·2	2·5	1·6	2·9	0·0	3·0	6·7	3·6
Myopia and Myopic Astigmatism	0·0	3·0	2·8	2·5	6·3	2·75	4·4	3·0	9·3	5·5

TABLE XXIX. *Percentages at each Age of each Class. Girls.*

Refraction Class	Age. Edinburgh						Age. Glasgow			
	5—7	7—9	9—11	11—13	13—15	All ages	6—9	9—12	12—15	All ages
Normal	53·3	61·5	70·9	65·0	64·5	63·5	82·5	69·3	42·2	65·3
Hypermetropia	14·3	17·0	18·6	10·3	13·3	15·1	4·8	14·9	25·0	14·9
Hypermetropic Astigmatism	22·9	15·5	6·6	12·7	13·3	13·7	3·2	7·9	15·6	8·8
Mixed Astigmatism	9·5	3·0	2·6	2·6	2·2	3·9	0·0	6·9	7·8	5·3
Myopia and Myopic Astigmatism	0·0	3·0	1·3	9·4	6·7	3·6	9·5	1·0	9·4	5·7

practically every form of eye defect increases, especially the hypermetropic*. The Edinburgh data show that it is only in the young children, possibly in those below Rowan's minimum age, that there are reductions in the two hypermetropic contingents, which apparently swell the number of normal eyes. After the earlier ages, however, hypermetropic astigmatism steadily increases in the Edinburgh as well as in the Glasgow series. This increase is almost as marked as in the myopic class and shows that the conclusion reached by Thompson, namely: that there is a decrease of hypermetropic astigmatism with age, is not universally true†. The enormous increase in defective sight indicated by Rowan is not borne out by the Edinburgh material; we find at Edinburgh a larger number of normals between 13—15 than between 4—7, although the maximum of emmetropia is reached between 9—11. From the merely statistical standpoint the Edinburgh data appear to be the smoother and the more self-consistent. But we venture to think that while there is not the least doubt of a sensible relationship of age to each of the several categories of eye defect, yet the problem of the nature of this age relationship has not at present been properly

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* It is significant that the London, Glasgow and Edinburgh statistics agree in not showing the marked decrease in hypermetropia with age, which has been recorded in German and Russian returns. Is this a real national difference, or due to the use of different standards of emmetropia?

† His proof is not statistically valid, as the percentages ought to have been based on the number examined at each age. See our p. 3.

thrashed out. As long as such widely divergent results as those provided by London, Edinburgh and Glasgow remain unreconciled, we are not in a position to determine how far: (i) simple growth and (ii) environment, especially school environment, affect the refractive power of the eyes. It will not be easy to separate (i) from (ii). The Edinburgh statistics seem to show that school life—taking the range 5 to 15 years—does not increase the total amount of defective sight, the Glasgow data show that it nearly doubles it. Comparing the London and Glasgow data we see either (*a*) that the Scottish race has very much worse eyesight than the English, or (*b*) that the Scottish ophthalmologist takes a much higher standard for emmetropia*. As far as it

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* In forming our Tables XX and XXI we have taken our material straight from the "Summary of Facts regarding Home Life and Health of Children," Plate 5 et seq. In this summary, as we have already remarked, a wider range has been given to "Normal" than to the term "Emmetropic" in the Medical Summary in the Edinburgh Report, Table XI. The latter table shows more cases of hypermetropia, myopia, and astigmatism than appear under the description in the summary of each individual child. Table XI of the Report reduced to percentages gives us Tables XXX and XXXI:

TABLE XXX. *Percentage at each Age of each Refraction Class. Boys.*

Refraction Class of 651 Boys	Age					
	5—7	7—9	9—11	11—13	13—15	Totals
Emmetropia	24·2	42·9	48·0	44·5	38·1	41·5
Hypermetropia	38·9	29·9	32·0	29·3	30·1	31·6
Hypermetropic Astigmatism	21·1	19·5	10·3	17·1	19·0	16·6
Mixed Astigmatism	15·8	4·5	5·1	3·0	4·8	6·0
Myopic Astigmatism	0·0 } 0·0	1·9 } 3·2	2·3 } 4·6	4·3 } 6·1	4·8 } 8·0	2·6 } 4·3
Myopia	0·0	1·3	2·3	1·8	3·2	1·7

TABLE XXXI. *Percentage at each Age of each Refraction Class. Girls.*

Class of 566 girls	Age					
	5—7	7—9	9—11	11—13	13—15	Totals
Emmetropia	15·7	33·1	44·7	39·5	47·9	35·9
Hypermetropia	27·4	29·4	30·4	16·0	25·0	26·1
Hypermetropic Astigmatism	40·2	25·0	16·8	22·7	16·7	24·2
Mixed Astigmatism	15·7	6·6	2·5	7·6	6·2	7·2
Myopic Astigmatism	1·0 } 1·0	2·2 } 5·9	3·1 } 5·6	6·6 } 14·2	4·2 } 4·2	3·4 } 6·6
Myopia	0·0	3·7	2·5	7·6	0·0	3·2

These percentages confirm the results previously deduced, i.e. there is less defect at 9—11 than at earlier ages, and if school from 10 to 15 does damage sight, yet at 15 there is less bad sight than when the children first come to school. Hypermetropic Astigmatism tends to increase after the 9—11 group, at least for boys; Hypermetropia remains fairly constant after this age, so does Mixed Astigmatism, but Myopia increases.

is legitimate to draw conclusions at all, our Edinburgh data would thus lead us to say, that a great deal of hypermetropia, hypermetropic and mixed astigmatism disappears, probably owing to growth, between 6 and 10, thus swelling the number of emmetropic eyes; that after this age there is not sufficient evidence to say whether these categories remain steady or slightly vary. Myopia and myopic astigmatism increase throughout, but this increase does not balance the total gain, due to rectification by growth; thus on leaving school there are more normal sighted individuals than on entering it. This is not in accordance with Rowan's Glasgow data, but the number of eyes dealt with by him was comparatively small and there were probably special conditions connected with his Glasgow school.

An almost similar result to the above was reached long ago by Erismann* who gave the data reproduced in Table XXXII below, which, although it exhibits some carelessness in calculating percentages, still tells precisely the same tale.

Here we have with different absolute numbers the same increase during school life of the emmetropic class, owing to the decrease of hypermetropia, so that at the end of school life there are practically as many emmetropic as at the start of school life, the change taking place by the hypermetropic having passed through emmetropia to myopia, which has increased in amount to three times its original prevalency. The absolute percentages are quite incomparable with British data, but they show the same common drift. It would be as reasonable to call the decrease in hypermetropia an effect of school environment as to adduce Erismann's results as evidence of the "hot-bed theory" as expressed on p. 34 below.

TABLE XXXII. *School Class.*

	I	II	III	IV	V	VI	VII	VIII	IX
Emmetropia	18·6	28	26·4	27·3	26·4	24·2	25	21	18·3
Hypermetropia ...	67·8	55·8	50·5	41·3	34·7	34·5	32·4	36·2	40
Myopia	13·6	15·6	22·4	30·7	38·4	41·3	42	42·8	41·7

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* The data are from tests made at St Petersburg in 1871; they are cited by Cohn (*loc. cit.*), who gives further data to the same effect. Erismann's statistics are quoted by Risley in the form of a graph (Norris and Oliver, *System of Diseases of the Eye*, Vol. II. p. 353 et seq.). Risley also gives statistics of his own from Philadelphia schools showing that the amount of emmetropia is not lessened but actually increases from 7·01 °/₀ to 12·88 °/₀ during school life, the increase in myopia being due to the decrease in hypermetropia. Risley takes strongly the view that the change is pathological and not physiological, and asserts that the hypermetropia will only disappear under the stress of employments which require the protracted use of the eyes at near work. The copious statistics collected by Randal (*American Journal of the Medical Sciences*, July, 1885) contribute little to our present enquiry, as they do not give the age distribution of the population providing the percentages in each local examination. On the whole, notwithstanding different examining standards, these statistics serve to show as markedly as those of Cohn that refraction is a *racial* character. It is difficult to grasp how a character can have racial differentiation and yet be largely free of the hereditary factor.

The conclusion reached above as to change by growth must not be taken as a dogmatic assertion that eyes are not damaged by school environment*. We might have a much larger percentage of normal vision, if there were no school environment; all we can say is that the school influence does not dominate the apparent tendency of the eye to grow normal. Taking the Tables XXX and XXXI in our footnote (pp. 31–2) we may say that the hypermetropic, the hypermetropic-astigmatic and mixed astigmatic classes have for boys decreased by 24 °/ₒ and for girls decreased by 36 °/ₒ, while for boys the myopic and myopic-astigmatic classes have increased by 7 °/ₒ and for girls by 8 °/ₒ. Is it legitimate to assert that the loss of the hypermetropic character is wholly due to natural growth and the gain in myopia to school environment? May not the school environment be partially effective in the former case and natural growth partially contributory in the latter? If so, it will not be possible to establish without much further research a grave charge against school environment on the ground of its effect on eyesight. It may, indeed, be doubted whether the problem can be solved at all until elaborate observations have been made on the children of an uncivilised race at various ages. It would be interesting if an ophthalmologist beyond the range of schools would take up the question; in Africa or in districts of India, the man and the material may possibly yet be found.

To sum up, we have to note that the refractive class does change with age, and accordingly this must influence the hereditary resemblance of brothers, if these brothers are not measured at the same age but at the same epoch. This last is all that our present material provides.

Origin of the "hot-bed" theory. The theory that schools are the real source of short-sightedness is very widespread and some account of its origin and acceptance may not be considered out of place in this paper. The vast bulk of the evidence in its favour is German, and this evidence, were it beyond statistical reproach, is not directly applicable to English conditions. The persistent use by the Germans of non-hygienic characters for their type is based solely on a mistaken notion of patriotism, and possibly a want of historical knowledge. This use renders all comparison of English and German conditions unprofitable†. Fuchs (*loc. cit.* p. 763) writes:

"Schools are the main hot-beds for the propagation of near-sightedness. Cohn by his extensive researches was the first to direct general attention to this fact. New-born children are almost without exception hypermetropic. Near-sightedness is acquired later in life through straining the eyes and hence fails to occur when the strain is absent. Again in the lowest order of schools, the common schools, there are extremely few near-sighted persons and the same is true of the rural population. The school most dangerous to the eyes is the high school. It is in this that myopia develops and then increases both as regards its intensity and the number of myopes in proportion as we ascend the classes. In Germany above

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* See the brief critical and historical notes which follow in the next paragraphs.

† It is only the non-German who can properly judge of the effect of German type, and in his case he must compare the result of several days' work on German books in German characters with the like period of work on German books in Roman characters.

20 °/₀ are myopic in the lowest classes of the high schools and 60 °/₀ in the highest classes. In the university the condition of affairs is still more unfavourable. Among lithographers Cohn found 45 °/₀ and among compositors 51 °/₀ to be myopic."

Nothing can better express the environmental theory than this extract, but every fact stated needs cautious consideration. The percentages of myopes in no way apply to England. The savage is stated not to be near-sighted, but then for generations his survival has largely depended on his far-sight*. In the same way a particular class of eye may well be suited to work at a particular trade or profession, or be at least unsuited to other professions†. Extreme short sight unfits a man for the army or navy, but it would be erroneous to attribute to environment the fact that more myopes are to be found among authors than in those outdoor occupations. Again the average age at the university is higher than at the high school, and in this higher than in the common school, and very often it is higher in the urban than in the rural district school. Arguments from school statistics cannot possibly be valid unless the age factor is first allowed for, and the data provided is often too inadequate to admit this‡. It will, we think, be clear that no argument in which (i) the age factor has not been allowed for, and (ii) the problem of possible selection fully considered, is valid when it attributes myopia to a special environment. Even if the increase of myopia with age be really due to environmental conditions, it does not follow that those conditions are summed up in the length of school life.

Curiously enough while Cohn's data are always appealed to when the theory of the school as the "hot-bed for the propagation of short-sightedness" is propounded there are certain statistics of Cohn, which properly investigated, might have caused some hesitation in the acceptance of this doctrine. Cohn gives the distribution of the degrees of myopia for 1004 school children according to (*a*) their ages, (*b*) the number of years of school life§.

We reproduce these tables as Tables XXXIII *a* and XXXIII *b*. Unfortunately Cohn does not give a table correlating age and number of years at school, but

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* Survival for an animal may depend on far or near sight, and dogs have been differentiated by their sight in this manner. Compare the dogs that hunt by sight with those that hunt by scent. No one would attribute this difference to direct effect of environment.

† A good illustration of a possible inversion of the cause of association is provided by Emmert, who, finding much eye-defect in four Swiss watchmaking schools, attributed it to muscular irregularity due to the use of the magnifying lens, *this irregularity being especially apt to become hereditary.*

‡ For example an important table for our present purposes is given in Mr Arnold Lawson's *Report on the Vision of Children attending London Elementary Schools* (*British Medical Journal*, June 18, 1898, p. 1614), namely, Table VI. From this table he draws the conclusion that goodness of school construction and the healthy character of the district appear to have little to do with the amount of myopia; but the age distribution of the children in the compared schools, whereby this result might be effectively established, is not available. The same absence of age distribution appears in J. Ackworth Menzies' "The Vision of School Children," *British Medical Journal*, Jan. 14, 1899, p. 77, and in many other publications of an earlier date.

§ *Untersuchungen der Augen von 10,060 Schulkindern nebst Vorschlägen zur Verbesserungen der den Augen nachtheiligen Schuleinrichtungen*, S. 51 u. 53, Leipzig, 1867.

we are able to draw a very decided conclusion from the data as it is. If school environment is the source of myopia, then we should expect to find a high relation between degree of myopia and number of years at school. The relationship between age and myopia would only be a secondary result of the relation between age

TABLE XXXIII *a*. *Myopia and Age.*

Degree of Myopia, focal length in inches.

Age	35—24	23—16	15—12	11—8	7	6	Totals
6	5	—	—	—	—	—	5
7	20	3	1	1	—	—	25
8	31	14	5	—	—	—	50
9	39	23	6	2	—	—	70
10	51	34	8	2	—	—	95
11	51	35	10	—	—	—	96
12	74	42	12	8	—	—	136
13	72	48	23	5	2	—	150
14	48	32	22	8	1	1	112
15	29	27	18	12	—	1	87
16	17	22	16	12	—	—	67
17	12	14	14	8	—	—	48
18	8	6	11	13	1	1	40
19	6	3	3	3	—	—	15
20	1	2	—	2	2	—	7
22	—	—	1	—	—	—	1
Totals	464	305	150	76	6	3	1004

TABLE XXXIII *b*. *Myopia and Years of School Life.*

Degree of Myopia, focal length in inches.

No. of Years at School	35—24	23—16	15—12	11—8	7	6	Totals
1—2	93	44	10	4	1	—	152
3—4	99	64	19	4	—	—	186
5—6	126	81	40	7	—	—	254
7—8	96	63	30	28	3	2	222
9—10	31	37	33	20	—	—	121
11—12	15	11	14	11	1	—	52
13—14	4	5	4	2	1	1	17
Totals	464	305	150	76	6	3	1004

and number of years at school. If on the other hand age is the chief source of the relationship we should expect age and degree of myopia to be more closely correlated than number of years of school life and myopia, the association of the latter being then merely a secondary result of myopia increasing with age.

These tables are based on the old system of recording the focal length of the correcting lens. The range of the sub-groups are badly chosen for statistical purposes, and the number of divisions differ considerably in the two cases. Accordingly as the matter is very important three separate methods were used to test the relative degree of relationship between the two pairs of characters, i.e. the correlation coefficients (r), the correlation ratios (η), and the mean square contingency coefficients (C_2)* were found. The results are as follows:

Degree of Myopia and Age.	*Degree of Myopia and Years at School.*
$r = \cdot 331 \pm \cdot 019$,	$r = \cdot 244 \pm \cdot 020$,
$\eta = \cdot 356$,	$\eta = \cdot 319$,
$C_2 = \cdot 364$.	$C_2 = 328$.

Now these values show that the associations between degree of myopia and age and degree of myopia and years of school life, while quite sensible, are not by any means very marked. Further, whichever test be applied it indicates that the relationship between age and degree of myopia is closer than that between the latter and the number of school years. In fact a correlation of ·8 to ·9 between age and number of years of school life would make the association of degree of myopia and years at school for a constant age practically *zero*. Cohn provides no data by which we could determine this correlation of age and school life for his material. But in the London schools the children practically rise a standard a year, and it has been found by Mr Heron that the relationship of standard and age is practically of the above magnitude. Accordingly Cohn's statistics seem to indicate that the moderate association they exhibit between school environment and degree of myopia is solely a secondary result of a primary relation between age and degree of myopia.

This increase of myopia with age may be due to the continued action of some environmental factor or to a growth factor. Cohn's statistics, however, do not demonstrate, as has been assumed by many ophthalmological writers, that school is the hot-bed for the production of myopia. Even with the moderate association now found between degree of myopia and age, we must remember the possibility of some portion of it being spurious, i.e. myopia frequently makes the child backward and thus keeps the child to a later age at school.

(c) *Age and Keenness of Vision.*

For this most interesting relationship we have three sets of data:

(i) Material taken from the Edinburgh Report. Here we have again followed the "Summary of Facts" and find returns for 671 boys and 566 girls. The Report itself, Table XI, "Summary of Medical Evidence," gives somewhat divergent tables. Tables XXXV *a* and XXXV *b* contain our material.

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* Care was taken to have a table of 20 to 24 compartments in both cases.

(ii) Rowan's Glasgow data. He gives 184 boys and 175 girls, unfortunately only in three age classes. See Tables XXXVI *a* and XXXVI *b*.

(iii) London County Council Report (E), p. 32. The material is from the L. S. B. days. A later report, p. 33, only provides three vision classes, and is hardly suited to bring out the full relationship. These data will be found in Tables XXXVII and XXXVIII.

The collected results are given in Table XXXIV.

TABLE XXXIV. *Age and Keenness of Vision Contingency.*

Data from	Boys	Girls
Edinburgh......	·23	·18
Glasgow.........	·21	·19
London	·17	·12

TABLE XXXV *a*. *Age and Keenness of Vision. Boys, Edinburgh.*

Vision	Age					
	4—7	7—9	9—11	11—13	13—15	Totals
6/6	56	115	142	123	49	485
6/9	17	17	17	13	8	72
6/12	6	10	4	8	—	28
6/18	15	19	11	12	6	63
6/24	2	6	1	2	—	11
6/36 and under	—	2	5	2	3	12
Totals	96	169	180	160	66	671

TABLE XXXV *b*. *Age and Keenness of Vision. Girls, Edinburgh.*

Vision	Age					
	5—7	7—9	9—11	11—13	13—15	Totals
6/6	66	93	113	78	33	383
6/9	18	19	12	20	4	73
6/12	10	8	10	7	5	40
6/18	11	14	13	12	—	50
6/24	2	3	2	3	2	12
6/36 and under	1	2	3	1	1	8
Totals	108	139	153	121	45	566

TABLES XXXVI *a* AND XXXVI *b*. *Age and Keenness of Vision. Glasgow.*

Vision	Boys				Girls			
	Age				Age			
	6—9	9—12	12—15	Totals	6—9	9—12	12—15	Totals
6/6	35	64	44	143	37	56	32	125
6/9	4	10	10	24	5	8	6	19
6/12	1	2	1	4	6	6	2	14
6/18	1	3	2	6	2	4	2	8
6/24	1	1	—	2	2	1	1	4
6/36 and under	1	—	4	5	3	—	2	5
Totals	43	80	61	184	55	75	45	175

TABLE XXXVII. *Age and Keenness of Vision. Boys, London.*

Vision	Age									Totals
	6	7	8	9	10	11	12	13	14 and over	
6/6	9	172	633	1046	1328	1433	1546	1482	389	8038
6/9	15	84	210	220	219	169	173	180	35	1305
6/12	2	23	55	65	81	75	79	89	12	481
6/18	1	10	38	50	63	58	68	60	18	366
6/24	—	4	11	16	21	21	32	21	6	132
6/36	—	1	8	12	12	10	15	17	6	81
6/60 and under	—	—	4	6	4	9	18	21	4	66
Totals	27	294	959	1415	1728	1775	1931	1870	470	10469

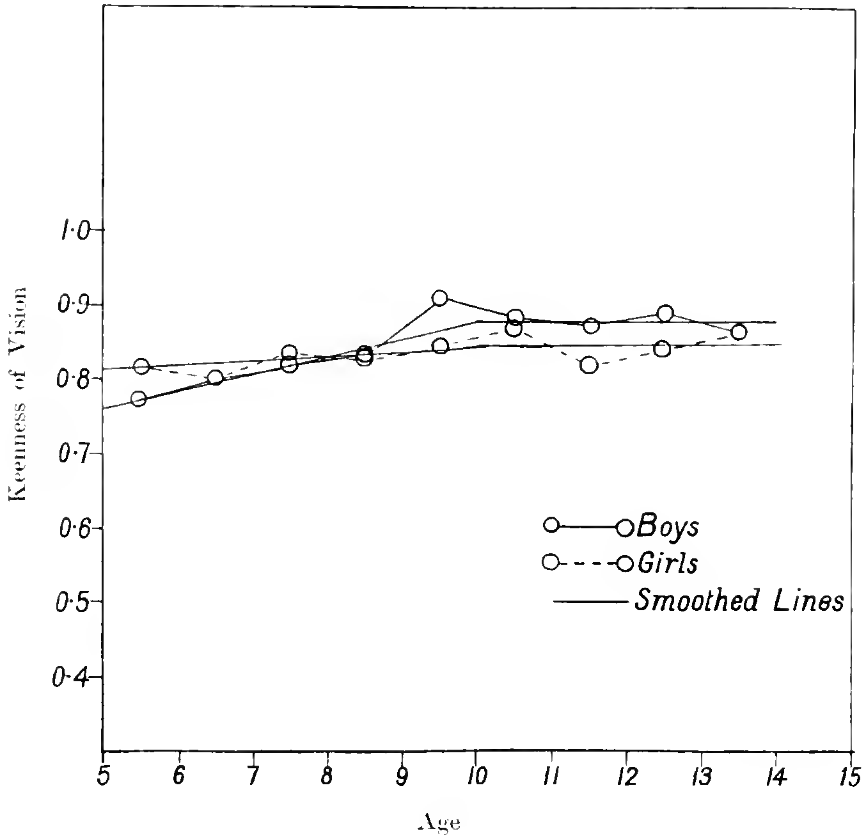
TABLE XXXVIII. *Age and Keenness of Vision. Girls, London.*

Vision	Age									Totals
	6	7	8	9	10	11	12	13	14 and over	
6/6	23	155	566	887	1268	1356	1439	1243	364	7301
6/9	12	90	199	224	245	232	219	203	51	1475
6/12	4	26	55	93	93	124	96	101	25	617
6/18	1	15	56	59	77	81	93	92	18	492
6/24	—	4	21	21	26	23	40	39	9	183
6/36	—	4	4	13	16	11	19	15	3	85
6/60 and under	—	3	6	12	21	23	20	27	10	122
Totals	40	297	907	1309	1746	1850	1926	1720	480	10275

It will be seen at once that the two sets of Scottish data are in excellent agreement, and although the London material is immensely greater, I believe that on this very account it is not so reliable. I think we may say that the relationship between and age keenness of vision is about ·20, being slightly above this value for boys and below it for girls. It is possible that oncoming puberty in girls disturbs the relationship more than in the case of boys. The London statistics confirm the lesser value for girls.

DIAGRAM III.

Age and Keenness of Vision.



The question now arises: Does goodness of vision increase continuously with age? We find, exactly as we should expect from the refraction results*, that this is not so; there are cross tendencies at work. Taking the boys we see that goodness of vision (Diagram III) increases uniformly up to 9·5 years and then remains stationary. With the girls the increase is less regular and decisive, but this is probably due to the paucity of data. We may look at the matter from the standpoint of percentages as follows:

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* i.e. because the correlation between refraction class and vision is so large.

TABLE XXXIX. *Percentages of Good Vision.*

Ages

Vision	Boys						Girls					
	4—7	7—9	9—11	11—13	13—15	All	4—7	7—9	9—11	11—13	13—15	All
Good, 6/6	58·3	68·0	78·9	76·9	74·2	72·3	61·1	66·9	73·8	64·5	73·3	67·7
Fair, 6/9 + 6/12	24·0	16·0	11·7	13·1	12·2	14·9	25·9	19·4	14·4	22·3	20·0	20·0
Bad, 6/18 and over	17·7	16·0	9·4	10·0	13·6	12·8	13·0	13·7	11·8	13·2	6·7	12·3

The boys show exactly the same result here as in the age and refraction classes, i.e. improvement of vision up to 10 and then a falling off, leaving the boy population, however, with better vision on leaving school than when it came. The same remarks apply to the girls although the paucity of data does not enable us to follow clearly the irregularity at 12 and 14; it may possibly have to do with the general physical development of girls at this age.

Thus the Edinburgh statistics seem to show that whether the change at 10 years be peculiar to growth or the effect of school environment, it does not counteract the earlier tendency to improved vision. As far, therefore, as these statistics reach—and the children are not from the best stocks—there does not appear to be definite and conclusive evidence of a markedly bad effect of school life on eyesight.

We may look at this from the standpoint of diseases of the eye and eyelids. Table XI of the Edinburgh Report provides us with the following results:

TABLE XL. *Age and Eye-Disease.*

Ages

	Boys, 715						Girls, 615					
	5—6	7—8	9—10	11—12	13—14	All	5—6	7—8	9—10	11—12	13—14	All
Normal	94	163	171	162	59	649	97	133	150	114	48	542
Diseased	11	15	20	12	8	66	12	19	17	20	5	73
Percentage Diseased	10·5	8·4	10·5	6·9	11·9	9·2	11·0	12·5	10·2	14·9	9·4	11·9

The results are very irregular and show no definite relationship between age and amount of eye-disease*. They present no proof that school environment is in any way responsible for eye disease.

Thus the assertion that school environment is the source of defective vision is not borne out by the Edinburgh statistics, although the sight of these school children is distinctly bad and some forms of eye disease are widely spread.

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* They appear to indicate that more female than male children are diseased.

(12) *Heredity as a factor in Refraction Class.* Having seen in the previous section, that the refraction class is correlated with age, and possibly more highly than the simple corneal refraction, we now turn to the heredity factor as far as it concerns refraction class. The Edinburgh data provide 206 pairs of brothers, 162 pairs of sisters, and 325 pairs of brothers and sisters. The tables in the first two cases being made symmetrical gave 412 and 324 pairs respectively.

The relationship was calculated by contingency involving 5 × 5-fold tables and by a fourfold division into emmetropic and ametropic individuals. The results are given in Table XLIV. The actual tables are given as XLI, XLII, XLIII; and the excess or defect of each category from an independent chance distribution in italic figures.

TABLE XLI. *Refraction Class. Brother and Brother.*

1st Brother

2nd Brother

Class	Normal	Hypermetropia	Hypermetropic Astigmatism	Mixed Astigmatism	Myopic Astigm. and Myopia	Totals
Normal	230 (+ *34·2*)	30 (– *17·6*)	15 (– *11·2*)	4 (– *1·5*)	5 (– *4·0*)	284
Hypermetropia	30 (– *17·6*)	24 (+ *12·4*)	8 (+ *1·6*)	3 (+ *1·7*)	4 (+ *1·8*)	69
Hypermetropic Astigmatism	15 (– *11·2*)	8 (+ *1·6*)	10 (+ *6·5*)	1 (+ *·3*)	4 (+ *2·8*)	38
Mixed Astigmatism	4 (– *1·5*)	3 (+ *1·7*)	1 (+ *·3*)	0 (– *·16*)	0 (– *·25*)	8
Myopic Astigm. and Myopia	5 (– *4·0*)	4 (+ *1·8*)	4 (+ *2·8*)	0 (– *·25*)	0 (– *·41*)	13
Totals	284	69	38	8	13	412

TABLE XLII. *Refraction Class. Sister and Sister.*

1st Sister

2nd Sister

Class	Normal	Hypermetropia	Hypermetropic Astigmatism	Mixed Astigmatism	Myopic Astigm. and Myopia	Totals
Normal	168 (+ *33·1*)	23 (– *13·8*)	12 (– *13·8*)	3 (– *4·1*)	3 (– *1·5*)	209
Hypermetropia	23 (– *13·8*)	18 (+ *8·0*)	11 (+ *4·0*)	3 (+ *1·1*)	2 (+ *·8*)	57
Hypermetropic Astigmatism	12 (– *13·8*)	11 (+ *4·0*)	12 (+ *7·1*)	4 (+ *2·6*)	1 (+ *·1*)	40
Mixed Astigmatism	3 (– *4·1*)	3 (+ *1·1*)	4 (+ *2·6*)	0 (– *·4*)	1 (+ *·8*)	11
Myopic Astigm. and Myopia	3 (– *1·5*)	2 (+ *·8*)	1 (+ *·1*)	1 (+ *·8*)	0 (– *·2*)	7
Totals	209	57	40	11	7	324

TABLE XLIII. *Refraction Class. Brother and Sister.*

		Brother					
	Class	Normal	Hypermetropia	Hypermetropic Astigmatism	Mixed Astigmatism	Myopic Astigm. and Myopia	Totals
Sister	Normal	190 (+ *24·5*)	23 (− *9·8*)	12 (− *7·6*)	2 (− *4·3*)	0 (− *2·8*)	227
	Hypermetropia	23 (− *4·7*)	7 (+ *1·5*)	3 (− *·3*)	5 (+ *3·9*)	0 (− *·5*)	38
	Hypermetropic Astigmatism	14 (− *15·9*)	14 (+ *8·1*)	9 (+ *5·5*)	2 (+ *·9*)	2 (+ *1·5*)	41
	Mixed Astigmatism	3 (− *3·6*)	1 (− *·3*)	4 (+ *3·2*)	0 (− *·3*)	1 (+ *·9*)	9
	Myopic Astigm. and Myopia	7 (− *·3*)	2 (+ *·5*)	0 (− *·9*)	0 (− *·3*)	1 (+ *·9*)	10
	Totals	237	47	28	9	4	325

TABLE XLIV. *Resemblance of Siblings in Refraction Class.*

Pair	Contingency (5 × 5)	Correlation (Fourfold)
Brother and Brother ...	·41	·59
Sister and Sister.........	·44	·66
Brother and Sister	·48	·57
Mean......	·44	·61

On examining Table XLIV we notice the relatively higher values obtained by adopting a fourfold division, and we can trace possibly the source of this difference. The fourfold tables are given below:

		1st Brother		
		Emmetropic	Ametropic	Totals
2nd Brother	Emmetropic	230	54	284
	Ametropic	54	74	128
	Totals	284	128	412

		1st Sister		
		Emmetropic	Ametropic	Totals
2nd Sister	Emmetropic	168	41	209
	Ametropic	41	74	115
	Totals	209	115	324

		Brother		
		Emmetropic	Ametropic	Totals
Sister	Emmetropic	190	37	227
	Ametropic	47	51	98
	Totals	237	88	325

The cross product is swollen because of the considerable number of ametropic pairs in which one brother is hypermetropic and the other myopic. That is to say, under the broader category of ametropia we have classed a number of things as "like," which at first sight are really unlike. If we accept the view that a considerable number of the hypermetropic become merely normal, we could not put this appearance of hypermetropic and myopic siblings down to a growth effect; we should have to say that it was an illustration of the principle of the correlation of "unlike imperfections" in heredity*. Examining the italic figures in Tables XLI—XLIII we find: (i) that a normal individual has always brothers and sisters with a defect of frequency in the hypermetropic and myopic classes. (ii) That hypermetropic brothers have a defect of normal brothers and not only an excess of hypermetropic brothers but of brothers with mixed astigmatism and myopic astigmatism and of myopia. This is also true of the hypermetropic sister's sisters. It is true on the whole—there are certain exceptions, due probably to paucity of data—in the pairs of brothers and sisters. Again a mixed astigmatic or a myopic individual has an excess of hypermetropic or hypermetropic astigmatic brothers and sisters. His or her excess of myopic brothers and sisters is slight and becomes even a defect in the brother-brother table. Now we really want tenfold larger numbers to reach a *definite* conclusion, but taken in conjunction with the facts observed in our discussion of age and refraction class, it does seem possible to make a suggestion of the following character. The fact that hypermetropic eyes decrease in number with age and the myopic increase, whereas the hypermetropic individual has a redundancy of myopic siblings, suggests that there are two broad classes of eyes in children, those that vary their refraction and those that do not. The former are in infancy hypermetropic and tend to become myopic with age, passing *beyond* the normal stage; the bulk of the normal in infancy do not change. A large part—say $\frac{1}{3}$ of the resemblance between siblings—would thus be due to the fact that pairs of siblings belong to stocks in which the refraction starts normal and remains normal, or to stocks in which a continuous change from hypermetropia to myopia goes on during childhood. This is a suggestion only,

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* Pearson, *The Scope and Importance to the State of the Science of National Eugenics*, p. 38. Note also Risley's very definite statement: "Myopic children have quite as frequently had parents afflicted with hypermetropic as myopic refraction. It is rare, however, to find myopic children in families where both parents have normal eyes." (Norris and Oliver, *System of Diseases of the Eye*, Vol. II. p. 362.)

but if demonstrated on large numbers would suffice to explain the excess of myopic siblings of hypermetropic individuals. If it were the longer school environment which made the elder sibling myopic, we should expect to find normal brothers with an excess of myopic brothers, but this is not the case, it is essentially the hypermetropic individuals who have this excess.

Of 51 cases in which one of a pair of siblings was hypermetropic or possessed hypermetropic astigmatism and the other sibling myopia, myopic astigmatism or mixed astigmatism, the *younger* sibling was the hypermetropic individual in 30 cases and the elder in 21 cases only. This is not conclusive, but it indicates that the suggestion is worth fuller consideration.

Finally it may be noted that we have worked out the partial correlation coefficient between refraction classes of two brothers for constant age of each. This required the following additional coefficients:

Correlation of ages of two brothers = ·65.

$$\left.\begin{array}{l}\text{Correlation of age of elder and refraction of younger} = {\cdot}18\\ \text{Correlation of age of younger and refraction of elder} = {\cdot}29\end{array}\right\}\text{Mean } {\cdot}23.$$

If $\bar{r}_{12}$ be the correlation between refraction classes of the two brothers as observed and r_{12} the value for constant ages, then in round numbers, using the value ·2 for age and refraction correlation*,

$$r_{12} = 1{\cdot}05\,\bar{r}_{12} - {\cdot}051.$$

Hence if $\bar{r}_{12} = {\cdot}44$, the corrected coefficient would be ·41, and if $\bar{r}_{12} = {\cdot}61$, the corrected fraternal correlation would be ·59. I do not think, however, that this method of making the correction, even if it were more sensible, is valid, because the effect of change with age is not a simple proportional change, and we cannot assert that either the contingency or the correlation values of the fraternal resemblance is the true quantitative measure. We can only conclude that the effect of change with age will probably not largely modify the observed relationship between siblings, and the values obtained for this relationship lie on either side of the average value found for fraternal resemblance in a variety of other human characters.

(13) *Heredity as a factor in Keenness of Vision.* Tables XLV—XLVII give the relationship between siblings for keenness of vision drawn from the Edinburgh "Summary of Facts." We have seen that keenness of vision is closely related to refraction class, although it is far from being wholly determined by it. Hence we should expect some resemblances between the contingency tables for refraction classes and keenness of vision, but again also certain special divergencies. On the whole refraction class appears a more definite character than keenness of vision, and the inheritance of it is more marked. Thus the fact that myopics have an excess of hypermetropic siblings appears in the keenness of vision tables as individuals of bad vision having siblings of moderate vision. If we were able to take siblings when they reached fourteen years of age, we should probably find a larger number of pairs with

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* If we use the value ·3, we get $r_{12} = 1{\cdot}10\bar{r}_{12} - {\cdot}074$, but precisely the same final values ·41 and ·59.

TABLE XLV. *Keenness of Vision. Brother and Brother.*

1st Brother

2nd Brother	6/6	6/9	6/12	6/18	6/24	6/36 & under	Totals
6/6	252	21	9	28	5	3	318
6/9	21	12	2	4	2	—	41
6/12	9	2	2	2	1	1	17
6/18	28	4	2	6	—	1	41
6/24	5	2	1	—	—	—	8
6/36 & under	3	—	1	1	—	—	5
Totals	318	41	17	41	8	5	430

1st Brother

2nd Brother	Normal	Defective	Totals
Normal	252	66	318
Defective	66	46	112
Totals	318	112	430

TABLE XLVI. *Keenness of Vision. Sister and Sister.*

1st Sister

2nd Sister	6/6	6/9	6/12	6/18	6/24	6/36 & under	Totals
6/6	184	21	14	18	5	1	243
6/9	21	14	3	3	—	—	41
6/12	14	3	8	3	1	—	29
6/18	18	3	3	4	2	—	30
6/24	5	—	1	2	—	—	8
6/36 & under	1	—	—	—	—	2	3
Totals	243	41	29	30	8	3	354

1st Sister

2nd Sister	Normal	Defective	Totals
Normal	184	59	243
Defective	59	52	111
Totals	243	111	354

TABLE XLVII. *Keenness of Vision. Brother and Sister.*

Brother

Sister	6/6	6/9	6/12	6/18	6/24	6/36 & under	Totals
6/6	195	19	7	17	7	2	247
6/9	18	9	1	7	1	—	36
6/12	12	2	1	—	—	1	16
6/18	23	5	2	4	—	1	35
6/24	4	—	—	—	—	—	4
6/36 & under	4	—	1	—	—	—	5
Totals	256	35	12	28	8	4	343

Brother

Sister	Normal	Defective	Totals
Normal	195	52	247
Defective	61	35	96
Totals	256	87	343

very bad vision, and the effect of this would be to emphasise the resemblance in the manner in which it is emphasised in the sister-sister case, where two pairs both with bad vision alone produce a most marked effect on the contingency. There is little doubt, I think, that young adults would give better results than pairs of children with ages ranging from 6 to 15, the period during which growth changes are so marked. Still we can only make the best of such material as is at present available, and this shows a marked resemblance between siblings even in keenness of vision. In forming the fourfold tables, we have grouped together all with 6/6 vision and all with less vision.

TABLE XLVIII. *Inheritance of Keenness of Vision.*

Class	Contingency (6×6)	Fourfold Correlation Table
Brother-Brother......	·32	·34
Sister-Sister	·58	·36
Brother-Sister	·29	·27
Mean.....	·40	·33

The values are less than those for refraction class and this was to be expected, as the sources of defective vision are more general.

If we attempt to allow some correction for age we find that there is no correlation between age of elder brother and keenness of vision of younger; the correlation between age of younger brother and keenness of vision is again small but negative and probably is due only to random sampling. We have therefore for the partial correlation coefficient for constant ages:

$$r'_{12} = \frac{\overline{r}_{12}(1-\rho_1^2)+\rho_1\rho_2^2}{1-\rho_1^2-\rho_2^2}$$

where ρ_1 = correlation of ages of siblings = ·65

ρ_2 = correlation of age and keenness of vision

= ·2 about.

Thus we have:

$$r'_{12} = 1{\cdot}0744\,\overline{r}_{12} + {\cdot}049$$

leading to $r'_{12} = {\cdot}48$ and $r'_{12} = {\cdot}40$ from the contingency and fourfold mean results respectively.

Without laying any stress on these special numerical values I think we may take it that they generally confirm the previous conclusion: that the physical characters of the eye are hereditary qualities, and that the intensity of inheritance is probably exactly the same as that for other physical characteristics in man.

The special difficulty of these school data is that young children are undergoing growth changes in the refractive powers of the eye, and we are comparing children at different ages, without at present any sufficiently accurate knowledge of the law of growth (or influence of growth in conjunction with environment, if this view be preferred). Such knowledge can only be satisfactory when a large number of the same children have been *individually* tested year by year from the age 5—6 to 14—15. Even then, for the scientific purposes of heredity, it might be more satisfactory to take young adults and avoid the growth correction altogether.

Summing up our total results for heredity we may say: that the correlations due to the heredity factor amount to about ·4 to ·6.

(14) *Influence of Environment on Sight.* In the previous sections we have seen that notwithstanding a disturbing growth factor with a correlation between age and sight of about ·2, the heredity factor is perfectly definite and compatible in value with other physical inheritance. We have seen reasons for questioning whether the school environment is really very prejudicial to sight, and the suggestion has been made that the age changes are not due or largely due to school influence, but to the fact that possibly eyes consist of two classes, one type of stock having fairly steady normality of refraction, the other tending to pass from hypermetropia to normal and to overshoot the normal and pass into myopia. We might speak of such stocks as stocks of stable and unstable refraction respectively, and their existence would, if established, tend to elucidate several points in age-change and the resemblance of siblings.

We now pass to the next stage of our enquiry. Are the environmental factors, as far as we can trace them, at all comparable with the influence of heredity? We have most heartily to thank our colleague, Miss Ethel M. Elderton, for much assistance in preparing the tables and working out the constants for this part of the discussion.

The following are the characters which were chosen as possibly affecting sight, combined we shall speak of them as the "home environment."

(*a*) Number of people per room of the home. This information is given in the Edinburgh data. Of course the size of the rooms which we do not know may form an important element. Still in a general sort of manner we have a measure of the space in the homes in this character.

(*b*) Economic condition of the home; we divided the homes by the information given in the "Summary of Facts" as to wages, appearance of home, etc., from employer, police, charity officials and others. Of course the division is subject to personal equation and can only be an approximate one, but it suffices as a rough estimate of the influence of poverty on eyesight.

(*c*) We next divided the parents by their physical condition into good or bad, in order to get some measure of the influence of the health of parents on the childrens' eyesight. The Report states whether they are broken down in health, suffering from tuberculosis, etc. Persistent alcoholism was included in bad physique.

(*d*) Moral condition of parents. The chief difficulty here is how far alcoholism is to be treated as a moral or physical complaint. Generally we treated presence of illegitimate children, loose living of husband or wife or the known nature of their house, frequent appearance before the police magistrate, or conviction for crimes as evidence of bad moral condition of the home. Thus "conviction for brutal assault on wife," "house a regular brothel" would lead us to place a "heavy drinker" in the category of moral failure. Drinking in itself was in the parents of these children so prevalent that it is impossible to take it as determining in itself bad moral conditions. "Man a good workman but goes on spree from time to time, is in two thrift clubs and attends church," or "old soldier and widower who takes a nip now and then, but is good to his girls,—very nice, tidy clean people" can hardly suffice for placing the described in the category of moral failure. On the other hand:

> "Very dirty untidy home.... Man teetotal, keeps well at his work.... China and clothes lying piled about room, thick with dust; air very bad. Children sickly (eldest imbecile); wife a slattern,"—

seems to be a case where there is a moral deficiency likely to affect the condition of the children. But, as we have said, we have had to trust in each case to personal judgment in classifying, and while we believe the bulk of cases would be put in the same categories if we went through the data again, it is possible that in some doubtful cases our judgment would not be the same. We think, however, that our classification will amply suffice to show whether there is any *high* degree of association between eye defect and the home environment as represented by overcrowding, poverty, physical health of parents or their moral delinquency. Tables XLIX—LXIV give the tabulated data, and Table LXV sums up the results. In some cases the value of the relationship has been reached by two different methods. It will be seen at once that the influence of home environment is very slight, in some cases insensible.

TABLE XLIX. *Refraction Class and Persons per Room. Boys.*

		Persons per Room					
		1 and 2	3	1	5	6, 7, 8, and 'overcrowded'	Totals
Refraction Class	Normal	115·5 (−*1·2*)	164 (−*2·0*)	91 (+*3·4*)	31·5 (−*2·0*)	45 (+*1·9*)	147
	Hypermetropia ...	22·5 (−*4·1*)	40 (+*2·1*)	21 (+*1·0*)	7·5 (−*0·2*)	11 (+*1·2*)	102
	Hypermetropic Astigmatism	23·5 (+*6·5*)	22 (−*2·1*)	9·5 (−*3·2*)	7 (+*2·1*)	3 (−*3·3*)	65
	Mixed Astigmatism	5 (−*0·5*)	9 (+*1·2*)	3·5 (−*0·6*)	0·5 (−*1·1*)	3 (+*1·0*)	21
	Myopia & Myopic Astigmatism	4 (−*0·7*)	7·5 (+*0·8*)	3 (−*0·5*)	2·5 (+*1·2*)	1 (−*0·7*)	18
	Totals......	170·5	242·5	128	49	63	653

TABLE L. *Refraction Class and Persons per Room. Girls.*

Persons per Room

Refraction Class	1 and 2	3	4	5	6, 7, 8, and 'overcrowded'	Totals
Normal	80·5 (*−5·9*)	113 (*−5·7*)	84·5 (*+7·2*)	36 (*+2·4*)	33 (*+2·0*)	347
Hypermetropia ...	24 (*+3·3*)	25 (*−3·4*)	18·5 (*−0·0*)	7·5 (*−0·5*)	8 (*+0·6*)	83
Hypermetropic Astigmatism	20·5 (*+1·3*)	34·5 (*+8·2*)	10 (*−7·1*)	6 (*−1·5*)	6 (*−0·9*)	77
Mixed Astigmatism	6 (*+0·5*)	6·5 (*−1·0*)	6 (*+1·1*)	2·5 (*+0·4*)	1 (*−1·0*)	22
Myopia & Myopic Astigmatism	5·5 (*+0·8*)	8·5 (*+2·0*)	3 (*−1·2*)	1 (*−0·8*)	1 (*−0·7*)	19
Totals	136·5	187·5	122	53	49	548

TABLE XLIX *bis. Boys.*

Persons per Room

Refraction Class	1—3	4 and more	Totals
Normal ...	279·5	167·5	447
Ametropic	133·5	72·5	206
Totals ...	413	210	653

TABLE L *bis. Girls.*

Persons per Room

	1—3	4 and more	Totals
Normal ...	193·5	153·5	347
Ametropic	130·5	70·5	201
Totals ...	324	224	548

TABLE LI. *Keenness of Vision and Persons per Room. Boys.*

Persons per Room

Vision	1 and 2	3	4	5	6, 7, 8, etc.	Totals
Normal	133·5 (*+4·5*)	162·5 (*−9·6*)	105 (*+8·7*)	32·5 (*−3·4*)	46·5 (*−0·2*)	480
6/9	23·5 (*+3·9*)	27·5 (*+1·3*)	10 (*−4·6*)	5·5 (*+0·0*)	6·5 (*−0·6*)	73
6/12	6·5 (*−1·0*)	10 (*−0·0*)	4·5 (*−1·1*)	3 (*+0·9*)	4 (*+1·3*)	28
6/18	13·5 (*−3·7*)	28·5 (*+5·6*)	9·5 (*−3·3*)	7·5 (*+2·7*)	5 (*−1·2*)	64
6/24 and under	2·5 (*−3·7*)	11 (*+2·8*)	5 (*+0·4*)	1·5 (*−0·2*)	3 (*+0·8*)	23
Totals...	179·5	239·5	134	50	65	668

TABLE LII. *Keenness of Vision and Persons per Room. Girls.*

Persons per Room

Vision	1 and 2	3	4	5	6, 7, 8, etc.	Totals
Normal	89 *(−7·5)*	129 *(−3·1)*	92 *(+6·6)*	34 *(−2·3)*	38 *(+6·4)*	382
6/9	21 *(+2·1)*	26 *(+0·1)*	15·5 *(−1·3)*	8·5 *(+1·4)*	4 *(−2·2)*	75
6/12	13·5 *(+3·7)*	13 *(−0·5)*	6·5 *(−2·2)*	6 *(+2·3)*	0 *(−3·2)*	39
6/18	13·5 *(+0·1)*	22 *(+3·7)*	10·5 *(−1·4)*	4 *(−1·0)*	3 *(−1·4)*	53
6/24 and under	6·5 *(+1·7)*	6·5 *(−0·1)*	2·5 *(−1·8)*	1·5 *(−0·3)*	2 *(+0·4)*	19
Totals...	143·5	196·5	127	54	47	568

TABLE LI *bis*. *Boys.*

Persons per Room

Vision	1—3	4 and more	Totals
Normal...	296	184	480
Abnormal	123	65	188
Totals ...	419	249	668

TABLE LII *bis*. *Girls.*

Persons per Room

Vision	1—3	4 and more	Totals
Normal...	218	164	382
Abnormal	122	64	186
Totals ...	340	228	568

Refraction Class and Economic Condition of Home.

TABLE LIII. *Boys.* TABLE LIV. *Girls.*

Refraction Class	Boys: Economically good	Boys: Economically bad	Boys: Totals	Girls: Economically good	Girls: Economically bad	Girls: Totals
Normal	233	215	448	163	184	347
Hypermetropia...	48	55	103	43	40	83
Hypermetropic Astigmatism	36	29	65	38	39	77
Mixed Astigmatism	8	13	21	16	6	22
Myopic Astigmatism & Myopia	11	7	18	13	6	19
Totals.........	336	319	655	273	275	548

In fourfold table separated into normal and ametropic.

Keenness of Vision and Economic Condition of Home.

TABLE LV. *Boys.* TABLE LVI. *Girls.*

Vision	Economically good	Economically bad	Totals	Economically good	Economically bad	Totals
Normal	240	242	482	193	189	382
6/9	36	37	73	44	31	75
6/12	11	17	28	19	20	39
6/18	34	30	64	28	25	53
6/24 and under	13	10	23	4	15	19
Totals.	334	336	670	288	280	568

In fourfold table separated into normal as against 6/9 and under.

Refraction Class and Physical Condition of Parents.

TABLE LVII. *Boys.* TABLE LVIII. *Girls.*

Refraction Class	Physically good	Physically bad	Totals	Physically good	Physically bad	Totals
Normal	199	250	449	155	192	347
Hypermetropia ...	42	57	99	38	46	84
Hypermetropic Astigmatism	30	27	57	32	43	75
Mixed Astigmatism	9	12	21	11	11	22
Myopic Astigmatism & Myopia	6	12	18	8	11	19
Totals.........	286	358	644	244	303	547

In fourfold table separated into normal and ametropic.

The numbers included in Tables XLIX—LXIV vary from table to table; in some cases the refraction or keenness of vision was not definitely stated, in others, it was not possible to determine the home conditions for one or other character with anything like certainty.

If for the moment we confine our attention solely to myopia and myopic astigmatism and again to the worst vision group (6/24 and under) we see that in three out of the four tables XLIX—LII the larger percentage of bad sight comes from the less crowded homes, i.e. homes with 1—3 persons per room.

In all but one of the four tables connecting economic condition and sight

Keenness of Vision and Physical Condition of Parents.

TABLE LIX. *Boys.* TABLE LX. *Girls.*

		Boys: Physically good	Boys: Physically bad	Boys: Totals	Girls: Physically good	Girls: Physically bad	Girls: Totals
Vision	Normal	209	267	476	164	216	380
	6/9	32	39	71	35	39	74
	6/12	11	15	26	14	25	39
	6/18	29	33	62	26	27	53
	6/24 and under	8	15	23	5	15	20
	Totals......	289	369	658	244	322	566

In fourfold table separated into normal as against 6/9 and under.

(LIII—LVI) the greater percentage of extreme bad sight, whether of refraction or of vision, comes from the good homes. In the four tables connecting the physical condition of the parents with the bad sight of the children (LVII—LX) a larger percentage of the *extreme* bad sight is associated with physically bad parentage, but a slightly larger percentage of the lesser degrees of defective sight occurs in all cases with the physically good parentage!

Refraction Class and Moral Condition of Parents.

TABLE LXI. *Boys.* TABLE LXII. *Girls.*

		Boys: Morally good	Boys: Morally bad	Boys: Totals	Girls: Morally good	Girls: Morally bad	Girls: Totals
Refraction	Normal	196	253	449	147	200	347
	Hypermetropia ...	51	48	99	38	46	84
	Hypermetropic Astigmatism	33	24	57	33	42	75
	Mixed Astigmatism	10	11	21	12	10	22
	Myopic Astigmatism & Myopia	9	9	18	8	11	19
	Totals.........	299	345	644	238	309	547

In fourfold table separated into normal and ametropic.

Keenness of Vision and Moral Condition of Parents.

TABLE LXIII *Boys.* TABLE LXIV. *Girls.*

		Boys			Girls		
		Morally good	Morally bad	Totals	Morally good	Morally bad	Totals
Vision	Normal	210	266	476	170	210	380
	6/9	39	32	71	33	41	74
	6/12	12	14	26	14	25	39
	6/18	31	31	62	25	28	53
	6/24 and under	10	13	23	4	16	20
	Totals	302	356	658	246	320	566

In fourfold table separated into normal as against 6/9 and under.

The morally bad homes produce a higher percentage of the very worst class of vision, but this is no longer true for the boys, if we consider 6/18 as bad vision. There is little significance if we consider only the myopia and myopic astigmatism, morally good homes producing the worst sight for boys and morally bad the worst sight for girls. If we include the mixed astigmatism the worst refraction comes in both cases from the good homes.

In every case, considering Table LXV, the correlation of environment and sight is negligible as compared with that of heredity and sight.

TABLE LXV. *Effect of Home Environment on Sight.*

Element of Home Environment	Refraction Class		Keenness of Vision		Mean
	Boys	Girls	Boys	Girls	
Number of Persons per Room	−·00 (·13)*	−·15 (·14)*	−·06 (·14)*	−·14 (·15)*	−·09 (·14)*
Good Economic Conditions	+·03	−·12	−·00	−·01	−·02
Good Physical Condition of Parents...	−·00	+·00	−·00	+·00	·00
Good Moral Condition of Parents......	−·14	−·05	−·10	+·06	−·06
Means......	−·03	−·08	−·04	−·02	−·04

N.B.—The negative sign throughout means that the worse environment is associated with the better sight.

* Contingency values only possible for this factor, and deduced from somewhat irregular tables. The signs of course must be judged from the bracketted figures in Tables XLIX—LII.

First taking number of persons per room, we note that its influence is very insignificant, but in every case *negative*, i.e. *the more persons per room the better the eyesight*. This may merely mean that the more persons per room the bigger the family and that large families spring generally from more normal stock. At any rate overcrowding does not appear in these data as the source of defective vision. If we examine the contingency tables XLIX—L we shall find generally slight excesses of the normal refraction in the overcrowded rooms and defects in the sparsely filled rooms; on the other hand there appear to be deficiencies of myopia and mixed astigmatism in the crowded rooms and excesses in the sparsely filled rooms. These excesses and deficiencies of frequency are slight, and it would be reasonable to say that for practical purposes no relationship exists*. The same results generally are shown in the contingency tables for keenness of vision. Turning to good economic conditions we find that they produce insensible effect in three out of the four cases, and in the fourth case, that of girls' refraction, it is more abnormal when the economic conditions are good! We may again assert that home environment as measured by poverty is not the source of defective vision.

Taking the general physical condition and health of the parentage we can find absolutely no relationship between this and the goodness of sight; the first significant figure is for each series in the third place of decimals and this is far beyond the probable errors of the results.

Lastly we turn to the moral condition of the parents. In three out of the four values a better condition exists in the case of those whose parents belong to the immoral category. Looking at this table as a whole we say that any of the home-factors we have dealt with is certainly not largely productive of defective vision. Normal vision is on the whole *slightly* associated with overcrowding, bad economic conditions, and morally defective parentage. Can it be that these bad home conditions keep the children in the streets, and so relatively away from the bad environment and in relatively fresher air? Be this as it may the Edinburgh data show that the intensity of the effect of home influence is not one-tenth that of heredity and what exists, if it be considered appreciable at all, is in the exactly opposite direction to what one would *a priori* have anticipated.

(15) *Influence of Vision on Intelligence.* Thus far we have seen that heredity is apparently the main factor in determining the character of sight. We may conclude the present investigation by enquiring to what extent this heredity factor influences the intelligence or rather the teacher's estimate of the intelligence of children.

The Edinburgh children are classed by their teachers into groups of Excellent, Good, Medium, Dull and Defective Intelligence. Tables† have been formed showing the relation of these categories to keenness of vision and to refractive class. They

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* The remarkable irregularity of the excesses and defects in the contingency tables XLIX to LII shows how little stress can be laid on the values of the contingency coefficients found.

† See Tables LXVI—LXIX.

have been reduced by contingency and by fourfold division and the values found are given in Table LXX. It will be seen that Keenness of Vision has slightly more influence than Refractive Class on intelligence. Further, although the relationship is not as large as some writers would lead us to believe, it is quite sensible and no doubt bad sight does lead occasionally to a child being classed as dull, careless or lazy.

It has been shown that the resemblance in intelligence between brothers and sisters is about ·48[*]. It is interesting to notice how much of this resemblance might possibly be due to defective vision influencing the teacher's judgment, supposing there were no real correlation between defective vision and intelligence. If we assume the inheritance of defective vision to be at least ·4, the contribution would be ·4 × ·16 = ·06, or possibly $\frac{1}{8}$ of the value found for resemblance in intelligence might be due to

TABLE LXVI. *Refraction Class and Intelligence. Boys.*

		Intelligence					
		Excellent	Good	Medium	Dull	Defective	Totals
Refraction Class	Normal	42	174	160	59	9	444
	Hypermetropia	6	37	40	17	2	102
	Hypermetropic Astigmatism	5	24	23	14	1	67
	Mixed Astigmatism	—	6	10	3	1	20
	Myopic Astigmatism and Myopia	—	6	8	3	1	18
	Totals......	53	247	241	96	14	651

TABLE LXVII. *Refraction Class and Intelligence. Girls.*

		Intelligence					
		Excellent	Good	Medium	Dull	Defective	Totals
Refraction Class	Normal	27	131	124	47	11	340
	Hypermetropia	4	26	39	12	—	81
	Hypermetropic Astigmatism	3	25	32	13	1	74
	Mixed Astigmatism	1	10	6	4	1	22
	Myopic Astigmatism and Myopia	—	5	7	6	2	20
	Totals......	35	197	208	82	15	537

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[*] *Biometrika*, Vol. III. p. 155. See also Vol. V. p. 473.

Fourfold Tables.

TABLE LXVI *bis.* *Boys.*

Refraction Class	Intelligence: Excellent, Good	Intelligence: Medium, Dull, Defective	Totals
Normal.........	216	228	444
Ametropic ...	84	123	207
Totals......	300	351	651

TABLE LXVII *bis.* *Girls.*

Refraction Class	Intelligence: Excellent, Good	Intelligence: Medium, Dull, Defective	Totals
Normal.........	158	182	340
Ametropic ...	74	123	197
Totals......	232	305	537

TABLE LXVIII. *Keenness of Vision and Intelligence.* *Boys.*

Vision	Intelligence: Excellent	Good	Medium	Dull	Defective	Totals
Normal	44	192	168	68	8	480
6/9..	4	27	33	5	3	72
6/12	—	9	11	8	—	28
6/18	4	20	24	14	1	63
6/24 and under......	—	8	8	5	2	23
Totals......	52	256	244	100	14	666

TABLE LXIX. *Keenness of Vision and Intelligence.* *Girls.*

Vision	Intelligence: Excellent	Good	Medium	Dull	Defective	Totals
Normal	30	145	136	54	8	373
6/9......	3	27	28	13	2	73
6/12	1	12	20	6	—	39
6/18	—	16	25	8	4	53
6/24 and under......	1	6	7	5	1	20
Totals......	35	206	216	86	15	558

Fourfold Tables.

TABLE LXVIII *bis. Boys.* TABLE LXIX *bis. Girls.*

		Intelligence			Intelligence		
		Excellent, Good	Medium, Dull, Defective	Totals	Excellent, Good	Medium, Dull, Defective	Totals
Vision	Normal	236	244	480	175	198	373
	6/9 and under...	72	114	186	66	119	185
	Totals......	308	358	666	241	317	558

TABLE LXX. *Relation of Intelligence to Refraction and Keenness of Vision.*

Method	Refraction Class		Keenness of Vision		Mean
	Boys	Girls	Boys	Girls	
Contingency	·13	·19	·20	·18	·17
Fourfold Table	·12	·14	·16	·18	·15
Mean......	·13	·16	·18	·18	·16

the resemblance in defective vision. On the other hand the physical source of defective vision is probably not only indirectly related to the teacher's estimate of intelligence but also associated with the actual mental power. Defective vision will often be found coupled with a physical degeneracy, which directly influences the intelligence. Bad sight is seen to be sensibly, but not markedly, correlated with want of intelligence. Until, however, we know that there is no relationship between myopia and actual defective intelligence*, we must not assume that the improvement of the sight would much improve the estimate of intelligence.

Undoubtedly all resemblance in ability between children and parents is ultimately physical, and connected with the acuteness of sensation as well as the facility in mental processes. From this standpoint it is of interest to find that sight probably contributes its quotum to the measure of inheritance of ability.

(16) *General Conclusions.* This paper is admittedly only a *first* study of the eugenic side of vision. No one can recognise its defects more fully than the authors themselves do. These defects obviously arise from a double source. In the first place

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* A study of refraction and vision among imbecile and defective children would be of much value from this standpoint.

the specialists who have collected statistics of vision and have the requisite ophthalmological knowledge appear to have little or no statistical training, and hardly realise the nature of those statistical classifications and methods, which alone can lead to definite results. In the second place those who have training in statistical processes and a knowledge of the type of problems which arise in other branches of eugenic enquiry, are liable to slip in dealing with such specialised material as the present.

The topics, which the student of eugenics must ever keep before him, are:

(i) The influence of breeding on the good or bad grade of each human characteristic.

(ii) The intensity of the effect produced by nurture on the same characteristics.

In the case of the physical properties of the eye he needs (i) material showing for a random sample of the population the influence of parentage and ancestry on the eyes of the offspring. He further requires (ii) to know, as in the case of all human characters, the law of average growth, and (iii) to measure the relative intensity of the influence of home life, school life, and adult occupation on the characters of the eye.

There cannot be a doubt that the anthropometric school laboratory, which takes ophthalmological observations of the eyes of the same boys and girls for the whole period of their school life, will obtain much more valuable scientific material, than the laboratory which still further adds to the endless and mostly unutilised data for height, weight and chest measurements. Further, something of the same kind ought to be done for adults, commencing, say, with the undergraduate population and passing to sample occupations*. The urgent point at present is to obtain a standard population which is not ophthalmologically selected. The first object must be to measure for anthropometric purposes the eye-sight of each child, and for these purposes we ought to know the refraction and the astigmatism to at least $\frac{1}{4}$ dioptre, and replace the "keenness of vision" test by a more scientific continuous system than the type letters with their discrete sizes and consequent lumpings of frequency†. In a fixed anthropometric laboratory, it ought to be easy to alter continuously the size of the type letter, and thus obtain a continuous system of readings. This is not a criticism of the ophthalmologist's methods, but merely a statement of the fact that for the study of heredity it is not satisfactory to group 75 °/ₒ of brothers together as 6/6. Within this group lie many grades of keenness of vision, which undoubtedly we shall find are individually inherited. The results obtained by such a school laboratory—until centres of measurement are multiplied—will not be as numerous as those which deal by aid of a coarse sieve with tens of thousands of children but for our present purposes they will be of higher value. Again such splendid work as that of the Edinburgh Charity Organisation Society which follows

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* Many large firms employ hundreds of workpeople, whose physical fitness, including goodness of vision, is an asset of as great value as the efficiency of the machinery. A careful annual ophthalmological inspection would very soon repay its cost by enabling us not only to measure occupational influence, but to prescribe occupational hygiene.

† The evil effect of this is manifest in Tables XXXII—XXXIII.

each child into its home, if it must perforce deal with hundreds instead of thousands, is essential if we are to determine the influence of home environment. The like problem in adult life may be more difficult, and at present we may have to trust largely to ophthalmological selections like those of Steiger, but the urgency is as great as the difficulty and we insist on the random sample of the general adult population as the ultimate goal. No argument as to heredity from the ophthalmologist's sample is valid without allowance, often wide allowance, for this selection. When we turn to the influence of school environment, we long in vain to find a few hundred children of both sexes brought up without school and without reading as a standard population. Uncivilised races are probably too different from civilised races in other forms of environment than merely absence of school life, to be safe guides, although a thorough ophthalmological survey of one or two uncivilised races would undoubtedly be of value. Perhaps the best we can do at present is to compare town with country schools, schools having few with schools having many children, schools optically well with schools ill arranged, and the sight of those who remain students till adult life with the sight of those who go into rural occupations at 13 to 15. All these things will aid in throwing light on the influence of environment if they do not completely determine it.

As far as the admittedly slender data of this first study reach, there is:

(i) No evidence whatever that overcrowded, poverty stricken homes, or physically ill-conditioned, or immoral parentages are *markedly* detrimental to the children's eye-sight.

(ii) No sufficient or definite evidence that school environment has a deleterious effect on the eye-sight of children. Undoubtedly considerable changes of vision take place during school years, marked first by a decrease in the hypermetropic classes and an increase in the emmetropic class. This is followed between 10 and 14 by a decrease in the emmetropic class and an increase in the hypermetropic, astigmatic and myopic classes; the balance being still in favour of emmetropia when school is left. Is the first a growth law and the second an environmental effect, or are both but phases of one law of growth—a passage from hypermetropia to emmetropia and myopia of the eyes of "unstable stocks"? It is suggested that the latter is the truth, because so many hypermetropic individuals have myopic siblings, and in 60 °/₀ of cases the hypermetropic sibling is the younger. This is a suggestion; it is far from being definitely proved, but it serves to indicate that the charge against the school from the standpoint of vision has yet to be firmly established.

(iii) Ample evidence that refraction and keenness of vision are inherited characters, and that the degree of correlation between the eye-sight of pairs of relatives is of a wholly different order to the correlation of eye-sight with home environment.

(iv) Sufficient evidence to show that intelligence as judged by the teacher is correlated with vision in a moderate manner (·16). There is not enough evidence to prove that if the source of poor vision were removed the intelligence would reach a higher stage. Defective physique including defective powers of sensation are we know closely correlated with defective mentality, they are both signs of an ultimate physical degeneracy. In many cases, no doubt, helping the vision will aid the intelligence, but we cannot suppose that poor vision is the source of all the poor intelligence we find associated with it.

This is the first eugenic study which has endeavoured to compare the inheritance and the environment factors. We anticipated finding them to be far more comparable in magnitude. As far as the material developed in this memoir goes, it points, if not overwhelmingly at least strongly, to the moral: Pay attention to breeding, and the environmental element will not upset your projects. Improve to the utmost your environment, and breeding will lay low your schemes.

The first thing is good stock, and the second thing is good stock, and the third thing is good stock, and when you have paid attention to these three things, fit environment will keep your material in good condition. No environmental or educational grindstone is of service, unless the tool to be ground is of genuine steel—of tough race and tempered stock.

To bring home this fact in each department of human physique and mentality seems to be the urgent social problem of to-day.

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TREASURY OF HUMAN INHERITANCE

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