ERRORS IN SUBJECTIVE REFRACTION — an exploratory study*

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The data which form the basis of this article come from the subjective refractions which first year students at UMIST carry out on each other during the refraction course. First year students are taught basic statistics and the elements of computing, and it was thought that it would be a good idea to examine this rather large pool of data during these courses. The primary aim of the exercise was educational.

It was thought that carrying out analyses[1] on ophthalmic data would be the best way to help students understand statistical and computing concepts as well as provide each of them with feedback on the comparative precision of their practical work. The secondary aim was simply to assess how well they do their refractions. It was not expected that their performances would be up to the same standard as a qualified optician, but with the dearth of information available on the latter it was thought that the results might give some indication of the variability of subjective refraction.

A great deal of data could be collected from each student patient's refraction, but in order to keep it within practical bounds we limited our study to measurements of the best sphere, spherical and cylindrical components, minus cylinder axis, unaided vision, and visual acuity of both eyes. This information was written on computer coding forms in the place of the more usual clinical record cards and was later transferred to punch-

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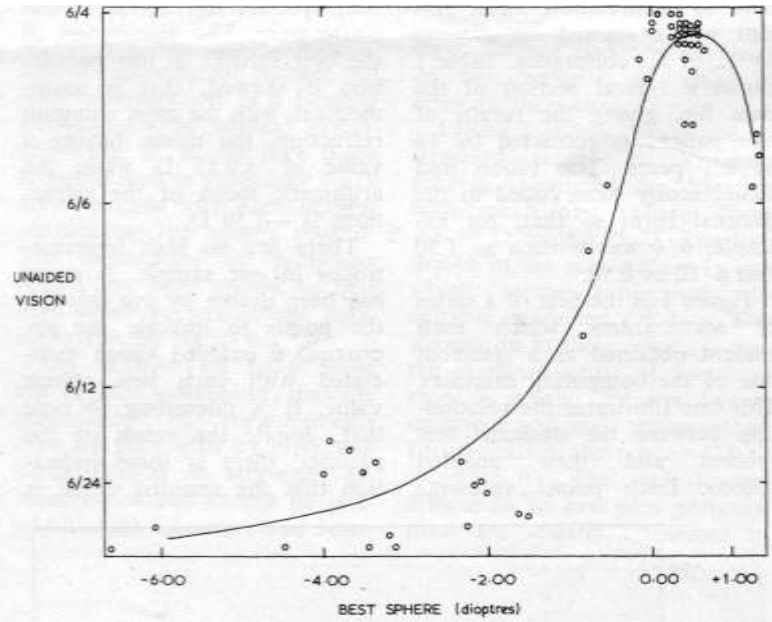

Figure 1. Scattergram of unaided vision against best sphere refraction for 54 eyes

Table 1. Patient number 21 as refracted by 14 of his colleagues. The information included in these columns is from left to right: examiner, patient, date, left best sphere, left sphere, left cylinder, left axis, right best sphere, right sphere, right cylinder, right axis, left vision^ right vision, left visual, acuity, right visual acuity. The figure 900t indicates to the computer programmes that data is missing or, in this case, that a cylinder axis for a cylinder power of zero dioptres would be inappropriate.

E04–P21	1	280174	−3.25	−3.00	−0.25	15	−3.00	−3.00	0.00	900†	0.01	0.01	1.50	1.50
E05–P21	1	310174	−3.50	−3.50	−0.25	120	−3.25	−3.25	−0.25	90	0.08	0.05	1.50	1.50
E07–P21	1	201173	−3.50	−3.50	−0.25	85	−3.25	−3.00	−0.25	70	0.05	0.05	1.50	1.50
E07–P21	1	280174	−3.50	−3.25	−0.25	70	−3.25	−3.00	−0.25	90	0.08	0.08	1.50	1.50
E11–P21	1	031273	−3.50	−3.00	−0.25	80	−3.25	−2.75	−0.25	85	0.08	0.08	1.50	1.50
E12–P21	1	270174	−3.50	−3.25	−0.25	130	−3.00	−3.00	−0.25	90	0.08	0.08	1.50	1.50
E17–P21	1	220174	−3.25	−3.00	−0.25	90	−3.00	−2.75	−0.25	110	0.10	0.10	1.50	1.50
E18–P21	1	220174	−3.50	−3.50	−0.75	70	−3.25	−2.75	−0.50	90	0.05	0.05	1.50	1.50
E23–P21	1	041273	−3.75	−3.50	−0.25	35	−2.75	−2.75	−0.25	90	0.05	0.05	1.50	1.50
E24–P21	1	041273	−3.50	−3.25	−0.50	60	−3.25	−3.00	−0.25	90	0.05	0.05	1.50	1.50
E25–P21	1	280174	−3.25	−3.25	−0.25	90	−3.00	−3.00	−0.25	90	0.06	0.06	1.50	1.50
E29–P21	1	280174	−3.25	−3.25	−0.25	73	−3.00	−3.00	−0.25	70	0.08	0.08	1.50	1.50
E30–P21	1	101273	−3.37	−3.25	−0.25	50	−3.00	−3.00	−0.25	75	0.08	0.08	1.50	1.50
E31–P21	1	061173	−3.75	−3.50	−0.25	90	−3.50	−3.25	−0.25	85	0.05	0.05	1.50	1.50
E32–P21	1	261173	−4.00	−3.25	−0.25	80	−3.50	−3.00	−0.25	105	0.05	0.05	1.50	1.50

TABLE 2
Average errors in refraction from our own and other studies UMIST students '73-74 data (17 students' subjective refractions)

	median reliability	standard error of measurement	per cent of measures within ±0.25 D
Best sphere	0.98	±0.23 D	73
Sphere	0.98	±0.25 D	68
Minus cylinder	0.60	±0.17 D	85
Unaided vision	0.93	±0.17	
Cylinder axis	0.91	±18°	

OTHER STUDIES

	standard error of measurement	per cent of measures within ±0.25 D
Jennings and Charman, 1973 (duochrome, simultan and laser)	±0.32 D	56
Hirsch, 1956 (retinoscopy)	±0.23/.25 D	
Safir et al, 1970 (retinoscopy)	±0.29/.39 D	

ed cards along with information on the patient, examiner and date of examination. Each patient was examined on average by 12 of his colleagues. Table 1 shows a typical section of the data file, giving the results of one patient as refracted by 14 of his peers. The vision and visual acuity were coded in the decimal form so that, for example, 6/4 was written as 1.50 and 6/12 as 0.50.

Figure 1 is the first of a series of scattergrams which each student obtained as a result of one of the computing exercises. This one illustrates the relationship between the students' best spheres and their unaided visions. Each point represents the average of about 12 separate refractions of a single eye. Fifty-four eyes are represented in this scattergram. The distribution of the best spheres in our population is skewed, that is asymmetrical, with the most common refraction, the mode, having a value of +0.25 D while the arithmetic mean of the refractions is — 1.56 D.

There are no high hypermetropes in our sample. A curve has been drawn by eye through the points to indicate the approximate unaided vision associated with each best sphere value. It is interesting to note that, despite the youth of the patients, there is some indication that the unaided vision is reduced for the few low hypermetropes, although this may be affected by uncorrected astigmatism.

A statistic frequently used to indicate the consistency of a measurement is the test-retest reliability coefficient[2,3]. The value of this coefficient varies between zero and unity, and indicates the degree of agreement between measurements made on two separate occasions. If a test or measurement is to be useful it must be reliable, and the higher the reliability coefficient the better. The typical consistencies (median reliability) of the student refractions for some of the measurements taken are given in Table 2. They vary from a high of 0.98 for the best spheres and sphere components to a lower 0.60 for the cylindrical components. Part of the reason for the low reliability of the cylinder component is the small spread of values for cylinder powers in the general population[4] compared with the unit of measurement used (0.25 D). In our sample, which is typical, the standard deviation is 0.32 D with a range of 1.0 D. It is important to note that the correlation coefficient is not the only form in which reliability may be reported. It may sometimes be misleading and other forms may be more appropriate or useful in certain circumstances.

To facilitate comparison with other studies, Table 2 gives both the median reliability coefficients and the standard errors of measurement[2]. The latter statistic is equivalent to the standard deviation of a single patient's measurements when they are independently taken by a number of examiners, and was directly calculated from those of a single patient. Figure 2 shows that these measurements approximate to a normal distribution and the standard error of mea-

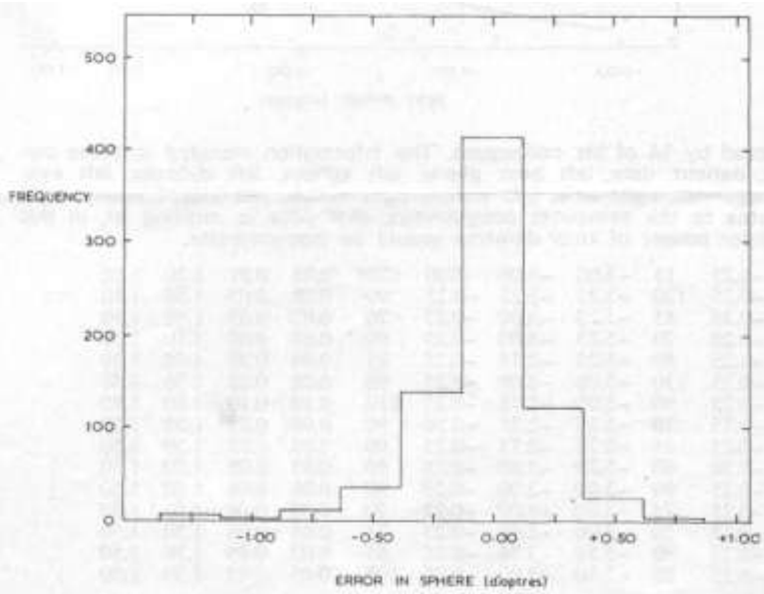

Figure 2. Frequency histogram of deviations from modal sphere measurements based on 738 observations on 29 patients

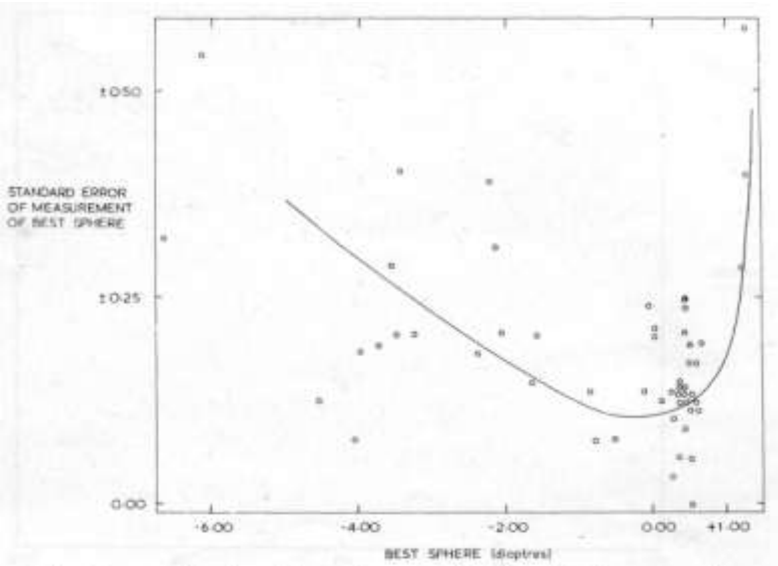

Figure 3. Scattergram of standard error of measurement of best sphere against best sphere for r 53 eyes

surement statistic may therefore be validly used. In our case it is not possible to derive this statistic from the test-retest reliability coefficient because the distributions of refractive states in our population under study is not Normally distributed.

The standard error of measurement is particularly useful in the interpretation of individual measurements. For example, if your 'true' best sphere is —0.50 D and the standard error of measurement is —0.23 D then, because of the normal distribution, 68 per cent of the refractions will lie between —0.27 D and —0.73 D. This variability in testing is due both to idiosyncrasies of patients and examiners, and to real variation in the patient's own refractive state. Table 2 also gives the equivalent percentage of refractions which will occur in the more conventional interval of ±0.25 D along with the comparable values for errors in retinoscopy[5,6] and specific refraction techniques[7] as found by other workers.

These standard error estimates of ±0.23 D to ±0.39 D are slightly larger than our own of ±0.17 D to ±0.25 D. The greater precision of our student refractions is due to the simple fact that in carrying out these refractions our students used a number of techniques repeated as desired while previous studies like those of Jennings and Char-man[7] have been concerned with the consistency of single techniques.

Another factor which may have influenced the results is the possibility that the students 'cheated' by asking the patients what their refractions were. Student examiners were told not to do this and had nothing to gain by ignoring the request, but such 'co-operation' is a familiar phenomenon in student practical work. If it did take place it would lead to artificially small error spreads with each student anticipating the other's results[8]. The expectancy of particular results has been shown to bias even objective retinoscopy measurements by up to 0.2 D[9].

Up to now we have made the implicit assumption that the consistency of measurements does not vary with the refractive state. This is an empirical assumption which should be tested although Charman and Jennings[7] did not find any evidence of heterogeneity of standard error in their study.

Figure 3 shows the individual standard errors in the best spheres calculated for 53 eyes with mean best spheres from —6.50 D to +1.25 D. The line drawn in the Scattergram is one which seems subjectively to suitably represent the data. The suggestion in these results is that the standard error of measurement is greater for low hypermetropes and high myopes than for patients in the range —2.0 D to +0.5 D. The well-known difficulties of low plus prescriptions are usually attributed to

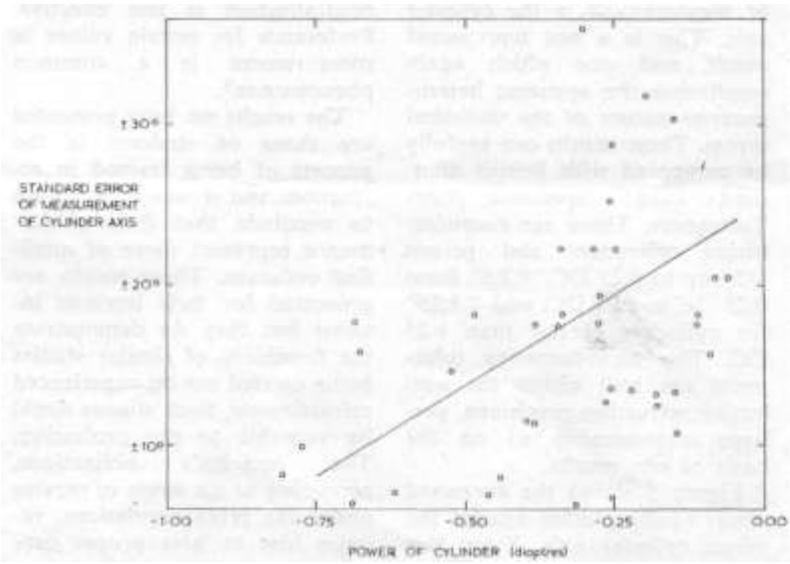

Figure 4. Scattergram of standard error of measurement of cylinder axis against cylinder power for 42 eyes

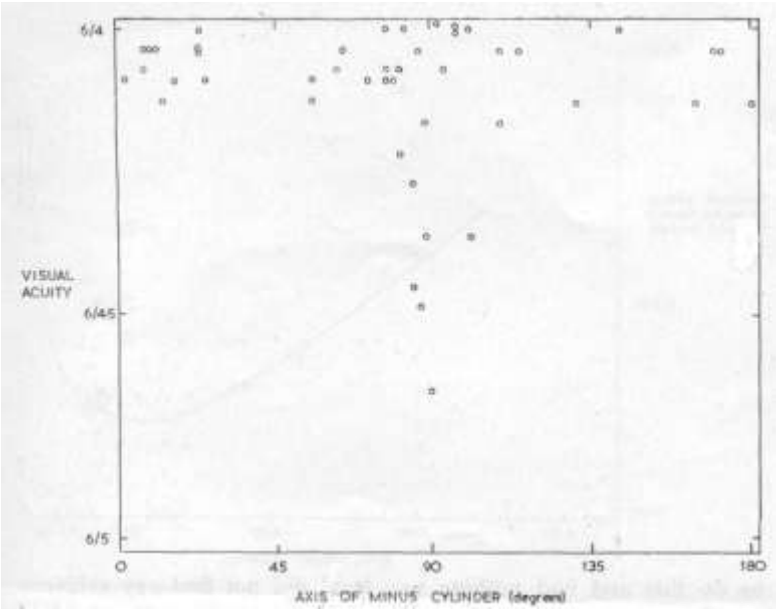

Figure 5. Scattergram of visual acuity against cylinder axis for 45 eyes

fluctuating accommodation. The cause of the increasing myopic variability is less obvious, although borne out by clinical experience. Thus, the standard error of the refraction is not constant and independent of the size of the refractive anomaly. In statistical terms, the errors are not homogeneous.

Cylinder axis standard errors are presented in Figure 4 as a function of cylinder power. Despite the variability in errors at each axis it is apparent that the larger the cylinder power, the smaller the standard error of measurement in the cylinder axis. This is a not unexpected result, and one which again emphasises the apparent heterogeneous nature of the statistical errors. These results can usefully be compared with British Standard 2738: Spectacle Lens Tolerances. These are manufacturing tolerances and permit ±5° up to 0.25 DC, ±2.5° from 0.25 DC to 1.25 DC, and ±1.25° for cylinders greater than 1.25 DC. The manufacturing tolerances are well within the subjective refraction precisions; perhaps unnecessarily so on the basis of our results.

Figure 5 shows the corrected visual acuity plotted against the minus cylinder axis. From this it appears that the visual acuity tends to be less for angles close to 90°. The effect is quite dramatic in this figure but two points should be born in mind: (i) the range of acuity represented in the scattergram is very small (6/4 to 6/5) and (ii)) it is an *a posteriori* phenomenon. It is, however, of interest in that one hypothesis suggests that student examiners have a fondness for 90° as a cylinder axis which is not strictly reflected in the true cylinder axes they are measuring, and because of this it can be argued that their neutralisation is less effective. Preference for certain values in measurement is a common phenomenon[8].

The results we have presented are those of students in the process of being trained in refraction, and it would be wrong to conclude that their performance represent those of qualified opticians. These results are presented for their intrinsic interest but they do demonstrate the feasibility of similar studies being carried out on experienced refractionists. Such studies could be valuable to the profession. The optician's obligations, according to his terms of service under the NHS regulations, require him to 'give proper care and attention in testing sight'[10].

As a final thought we sought to see whether the more precise student examiners were more highly rated by their teachers. A median reliability score was calculated for each examiner on each type of measurement, representing the average agreement of each examiner with his colleagues, and these scores were then correlated with the marks given by their teachers in the course of continuous assessment of refractive techniques.

As expected, there appeared to be a general trait of precision in that students with high reliability scores on one aspect of refraction also tended to have high reliability scores on the other aspects. However, there was no apparent association between the reliability scores and the marks given in assessment. That is, the best refractionists are not necessarily those who do the most precise refractions.

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subsequently found to be ascribable to sampling error --