Ophthal. Physiol. Opt., Vol. 2, No. 1, pp. 57-74, 1982.
Printed in Great Britain.

0275 - 5408/81/010057 - 18 $03.00/0
Pergamon Press Ltd.

THE DIOPTRON IPS VALIDITY AND RELIABILITY AS A FUNCTION OF ITS THREE ACCURACY INDICES

CHRIS N. FRENCH and IVAN C. J. WOOD*

Ophthalmic Optics Department, UMIST, PO Box 88, Manchester M60 1QD, U.K.

(Received 1 *June* 1981, *in revised form* 10 *July* 1981)

Abstract—Confidence factor, missed scans and relation junction were confirmed as indices of the Dioptron II's validity. Consequently, a classification of the instrument's measurements was recommended. This gave three classes of finding, first, second and third, and it was subsequently verified that instrument test - retest reliability also related to class of result. Repetition of measurements which were not first-class improved instrument validity but only to a limited degree. The link between confidence factor, and astigmatism and cylinder angle discovered with the Dioptron I was corroborated with this version.

INTRODUCTION

The Dioptron was introduced by Coherent in the early 1970s. It is an automatic i.r. optometer and was one of the first to take advantage of computer technology. An improved version, the Dioptron II, was subsequently developed and today there are perhaps 2000 in use worldwide. The machine and its operation are described in detail in Wood and French (1981). As well as a refraction, the instrument returns three indices which may be used to assess the value of its results. The purpose of this study was primarily to investigate the relationship between these indices and the Dioptron's validity and reliability.

The Dioptron I was first evaluated by Sloan and Poise (1974). Poise and Kerr (1975) examined the instrument in more detail with particular reference to its "confidence factor". They concluded that this information was of limited value to the clinician in predicting the accuracy of the Dioptron's measurements. In the early instrument, the confidence factor returned a value between one and zero. Measurements with larger values than 0.50 were more accurate than those with values less than 0.50. Poise and Kerr's (1975) results suggested to them that the confidence values related only to the cylinder power and axis validities, and did not predict the validity of the sphere-equivalent and sphere component of the eyes.

The Dioptron II has two further accuracy indices. These are referred to as "relation junction" and "missed scans". According to Coherent's operating instructions, the latter should also be born in mind when assessing the confidence which can be placed in the instrument's findings, while the former represents "engineering data that is coded for service analysis only".

In the Dioptron II, the confidence factor appears to vary from 0 to 100, depending upon the scatter of intermediate dioptric measurements about a sine-squared fitting function. In general, it would appear from the operating instructions that, with the exception of zero, smaller numbers indicate better measurements with less probability of pathology.

*Fellow of the British College of Ophthalmic Opticians (Optometrists).

There are three single-digit, missed-scan figures which indicate the number of times the instrument has had to discard a set of intermediate measurements at each of three phases of the instrument's operation. The first two digits represent missed focusing and axis scans which the manual dismisses as engineering/service information numbers which should not be bigger than four, while the third indicates missed measurement or "verification" scans.

The third parameter which can be used as an index of instrument accuracy is the relation junction, a three-digit number between —90 and 1000. This gives the number of degrees through which the optical sensing head has rotated in order to find a peak signal in its search for the optical axes. Numbers larger than 180 appear to indicate that the sensing head has had to rotate more than is usual. Numbers larger than 360 are thought to indicate that it rotated twice more than might be expected [see Wood and French (1981)].

In the 1979 operating instructions, confidence values of 0.01 - 1.00 were described as indicating a "normal reading with excellent accuracy", 1.01-10.00 "acceptable data but doctor should be alerted to possible pathology as the number increases", and 0.00, blank, greater than 10.00 "high possibility of pathology". The 1975 instructions had described data with confidence factors greater than 20.00 as "highly suspect". The 1979 manual describes 1 -3 missed measurement scans as "generally acceptable" while it says of 4-6 that they should be used with judgement and the eye should be carefully examined for pathology. The 1975 manual says of the latter measurements that they indicate that the Dioptron has "guessed" at the answer with little or no data.

Thus formally, Coherent do not advise readings to be repeated if confidence factor or missed scan values are poor, and simply view them both as indices of the likelihood of pathology. They make no comment on the seventh line of data, the "relation junction". We found it a little disturbing when we examined the reports of people who had used Dioptrons that there was often no reference at all to these indices [e.g. Mailer (1978)] which might have provided an important check on the type of eyes and how the instrument had been used. French and Wood (1981) have reported on the instrument's reliability and validity (Anastasi, 1976) using an ad hoc set of criteria. We, therefore, decided to investigate systematically how the confidence factor, missed scans and relation junction relate to the instrument's empirical accuracy.

METHOD

We used the Dioptron II in three distinct settings. Our main results come from the Open Clinic, in the Ophthalmic Optics Department of the University of Manchester Institute of Science and Technology. This clinic is open to staff and students of UMIST who are seen by final-year undergraduates supervised by full-time members of staff or local optometrists who undertake part-time teaching. One or two sets of Dioptron readings were obtained for each patient. The first was taken before they had been examined and, if time permitted, a second was taken before they left the clinic. For this part of the study the operators were final-year students who had been instructed briefly on the instrument's operation by Coherent. In addition to the Dioptron findings, the results of a retinoscopy and a final subjective were also available. These were executed without knowledge of the Dioptron results, but not independently of each other. Student retinoscopies were not always corrected by the supervisors because of their intermediate status, but particular care was taken on the final subjective findings as spectacle prescriptions were based on these.

The second set of data came from an Open Day at UMIST. Members of the general public were shown around the Institute and invited to have their sight screened by the Dioptron and by one or two optometrists from the Manchester Royal Eye Hospital (MREH). On this occasion the instrument was operated by an employee of Coherent and the results were compared with a retinoscopy.

The third and last set of data came from a small study carried out in the Outpatients Clinic of the MREH. The instrument was again operated by a Coherent employee, but this time the results were compared with the final subjective prescription obtained by a hospital optometrist. In the main, patients had been referred to the MREH by their general practitioners, sometimes after having been seen by an ophthalmic optician in general practice.

The data of our Open Clinic and Open Day groups of patients were both negatively skewed, tending towards myopia with average prescriptions of around - 1 DS, and SDs of 3 and 2 DS respectively. The outpatients sample had a wider spread with an SD of 5 DS, and tended towards hypermetropia with a mean of + 2 DS, due in part to the number of aphakic patients.

RESULTS

Open Clinic patient data

Our Open Clinic provided us with 687 eyes on which we could assess the Dioptron IPs validity. The majority of these eyes had been tested twice on the instrument, providing us with 1247 comparisons with the final subjective refractions.

Our first analyses sought to establish whether our three indices were related to the subjective validity of the Dioptron IPs findings. To ascertain this we collated the differences between the instrument and subjective sphere-equivalent, sphere component and cylinder component as a function of confidence factor, missed scans and relation junction by considering the variation of each index on its own. The absolute size of each difference was found and the proportions less than a -J-, *j* and 1 diopter calculated.

Missed scans. Table 1 shows the results for missed scans. For the Open Clinic data *61%* of the readings showed zero missed scans, 34% one missed focusing scan only, and the remaining *5%* of the observations were virtually all missed measurement scans, with values from one to six. We never experienced more than one missed focusing scan and only once a non-zero missed axis scan. From the subjective sphere-equivalent differences it is apparent that we have no evidence that results where one focusing scan has been missed differ from those where there have been no missed scans at all. Therefore, in order to simplify matters, we combined these two categories when we came to consider sphere and cylinder components. As can be seen from Table 1, missed scans are very definitely related to both sphere and cylinder component subjective validity, with *5%* of the clinic findings inferior to the rest.

Confidence factor. We divided the confidence factor values into the three categories suggested by Coherent's manual—between 0.01 and 1, between 1 and 10, and over 10 or 0. We chose not to reject out of hand results with a confidence factor of zero because on occasions they showed reasonable agreement with other results and because when operated in j- or j-D rounding mode the Dioptron's program does not itself disown such findings. The first category covered almost 70% of the Dioptron comparisons, the second

Table 1. Subjective validity as a function of the number of missed scans

pattern of missed scans	sphere-equivalent differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
"000"	46%	75%	95%	61%
"100"	45%	75%	93%	34%
not("000"or"100")	28%	47%	72%	5%
all	45%	74%	93%	100%(n=1 247)

pattern of missed scans	sphere component differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
"000"or"100"	48%	76%	95%	95%
not("000"or"100")	29%	53%	71%	5%
all	47%	75%	94%	100%(n=1 247)

pattern of missed scans	cylinder component differences			
	≤0.25 DC	≤0.50 DC	≤1.00 DC	all
"000"or"100"	59%	85%	97%	95%
not("000"or"100")	34%	57%	76%	5%
all	58%	84%	96%	100%(n=1 247)

Validity here is expressed as the difference between the subjective refraction and the Dioptron's findings. Patients are from UMIST's Open Clinic. Refractionists and Dioptron operators are supervised final-year undergraduates. Results are based upon 1247 comparisons on 687 eyes. Some eyes were run twice on the Dioptron. The table gives the proportions of differences falling within the indicated intervals. Because the top part of the table shows that there is essentially no difference between "000" and "100" categories for sphere-equivalent data, these have been combined for sphere and cylinder components in the lower part of the table.

almost a quarter, and the third just 7%. The distribution of confidence factors is positively skewed but, in order to facilitate more valid statistics and permit easier scrutiny, it may be made more symmetrical and normal by taking the logarithm of the non-zero values. If we do this by taking the log to base 10 we obtain the frequency histogram shown in Fig. 1. Table 2 shows how the subjective validity varies as a function of these three categories of confidence factor for sphere-equivalent, sphere component and cylinder component. Once again there is clear evidence that the index, this time confidence factor, is an important correlate of subjective validity; unlike with the Dioptron I (Poise and Kerr, 1975) it would appear to vary with sphere-equivalent and sphere component differences.

Relation junction. We divided up the relation junction index three ways as well. The first category we took as all values between -90 and + 180; this accounted for almost three-quarters of our Dioptron measurements. The second, for absolute values between 180 and 360, accounted for 17%, and the third, for values over 360, accounted for the final 10%. The distribution of relation junction values is also positively skewed, but there is no appropriate transformation to achieve normalization. Fig. 2 is a frequency histogram of the distribution. There were small secondary peaks with disproportionate numbers of values near the 90° points (270, 360, 450, and 540°) and at -35 and +35°. We do not know the reasons for this except to note that 89% of the - 35° values were for right eyes.

Table 2. Subjective validity as a function of confidence factor

confidence factor	sphere-equivalent differences			
	⩽0.25 DS	⩽0.50 DS	⩽1.00 DS	all
0.01 to 1.00	46%	76%	95%	69%
1.01 to 10.00	41%	69%	92%	24%
10.01 plus & zero	42%	67%	81%	7%
all	45%	74%	93%	100% (n=1 246)

confidence factor	sphere component differences			
	⩽0.25 DS	⩽0.50 DS	⩽1.00 DS	all
0.01 to 1.00	50%	77%	96%	69%
1.01 to 10.00	41%	72%	92%	24%
10.01 plus & zero	35%	68%	80%	7%
all	47%	75%	94%	100% (n=1 246)

confidence factor	cylinder component differences			
	⩽0.25 DC	⩽0.50 DC	⩽1.00 DC	all
0.01 to 1.00	63%	89%	98%	69%
1.01 to 10.00	50%	77%	94%	24%
10.01 plus & zero	41%	61%	80%	7%
all	58%	84%	96%	100% (n=1 246)

Validity here is expressed as the difference between the subjective refraction and the Dioptron's findings. Patients are from UMIST's Open Clinic. Refractionists and Dioptron operators are supervised final-year undergraduates. Results are based upon 1246 comparisons on 687 eyes. Some eyes were run twice on the Dioptron. The table gives the proportions of differences falling within the indicated intervals according to the size of confidence factor.

From Table 3 it is clear that relation junction is linked to the subjective validity. Although the effect with respect to sphere components appears slight, it is still statistically significant (i^2 = 13.3, df - 6, $P < 0.05$).

Classification of measurement. Having established empirically the relevance of all three accuracy indices on their own accounts it remains for us to examine how they act in concert and to set up overall criteria for the selection of Dioptron measurements according to their excellence. This can be achieved by seeing how the simultaneous variation of all three indices affects the distribution of subjective-Dioptron differences. With three categories for both confidence factor and relation junction, and two for missed scans, we might expect it to be useful to look at 18 (3 x 3 x 2) resulting categories of findings, but some of these contain very few comparisons. It therefore makes sense to combine categories and examine the 10 shown in Table 4. Even then some categories contain too few observations for a meaningful consideration and this reduces the prime sets of differences shown to eight. This is partly a consequence of the Dioptron's programming, which prevents results being printed out when the confidence factor is more than 20 and there are two or more missed scans.

The ^first-class" measurements, defined as having zero or one missed focusing scan only, a relation junction of less than 180 and a non-zero confidence factor of less than one, account for just over half the findings, returning the best subjective-validity results.

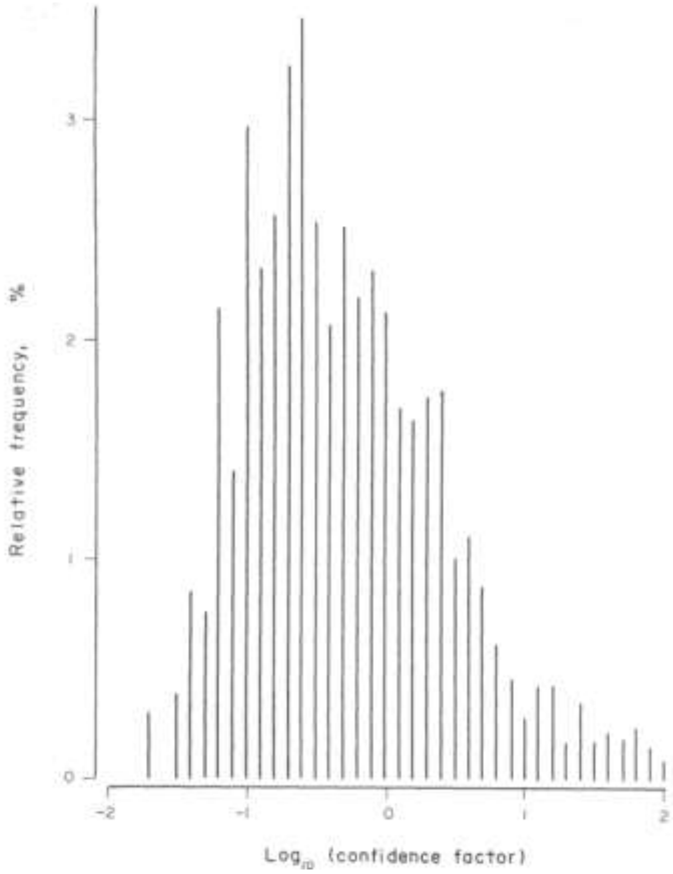

Fig. 1 Relative frequency distribution of logarithm to base 10 of non-zero confidence factor values for all Dioptron II measurements in study (*n* = 1627). Log values have been rounded to the nearest tenth.

If we group together those other validities with over 90% of their differences being less than 1 diopter, they will account for a further 30% of the Dioptron measurements. These, "second-class", measurements have similar proportions of differences less than a | and | diopter. The remaining measurements and their associated differences we have classified as "third-class". These have too many missed scans and/or a confidence factor of more than 10 (or 0) and/or a relation junction of more than 360, and account for 19% of our findings.

Table 5 recapitulates on the subjective validity of the sphere-equivalent as a function of class of findings as well as reporting the subjective validity for sphere component, cylinder component and also cylinder axis. In the case of the last we only report the results for cylinders larger than j diopter. The table, then, summarizes the importance of the "class" of readings for all four refractive parameters.

Comparison with retinoscopy. Up to now, we have only been concerned with subjective validity. But we also have the intermediate retinoscopy findings from the Open Clinic. It will be remembered that these had not been exhaustively verified by the supervisors, but despite this they can serve a useful role as a further validity check. Table 6 shows that the results corresponding to those already discussed are slightly poorer in their agreement with Dioptron findings, as might be expected.

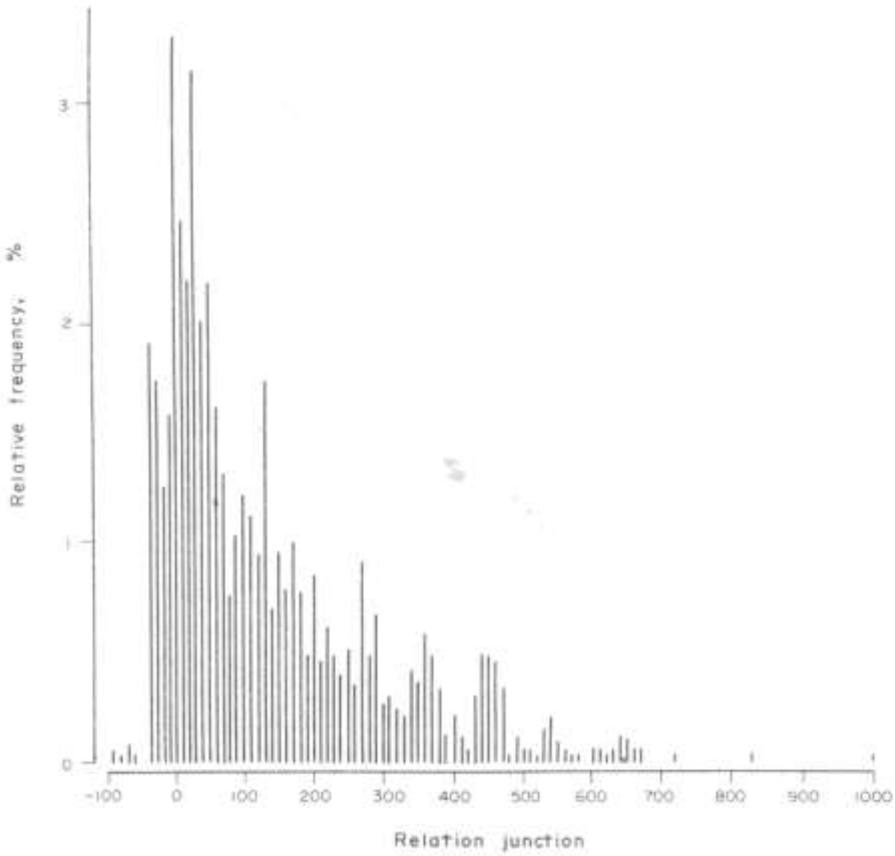

Fig. 2. Relative frequency distribution of relation junction values for all Dioptron II measurements in study *(n* = 1627). Relation junction values have been rounded to the nearest 10.

Test-retest reliability. The Open Clinic data are the only ones in our survey permitting an evaluation of the test-retest reliability of the Dioptron II findings. We have already shown that the instrument's reliability can be high (French and Wood, 1981), but we have not previously examined it as a function of the class of measurements. Each member of a pair of test - retest findings can be first-, second- or third-class. Thus, there are 9 (3 x 3) possible combinations of which only 6 are distinct. We are only here concerned with first - first, second - second and third - third pairs and the reliabilities of these expressed as the proportions of differences less than a |, 7 and 1 diopter are given in Table 7. As can be seen, the class of readings has a distinct influence on reliability as well as validity with 99- 100% of all differences being less than 1 diopter or 20° for first-class measurements and successively smaller proportions for second- and third-class. Caution must be observed in interpreting this table as some of the proportions are based on rather small samples. For first-class findings, the SEs of measurement are 0.16 DS, 0.17 DS, 0.13 DC and 5°.

Other data and its validity

We wondered how consistent the validity of first-class measurements would be when the type of patient and Dioptron operator are varied. Table 8 contrasts the subjective validities of the Open Clinic and Outpatients Clinic data. Naturally, the hospital patients

Table 3. Subjective validity as a function of relation junction

relation junction	sphere-equivalent differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
-90 to 180	46%	76%	95%	73%
181 to 360	42%	70%	90%	17%
361 plus	37%	63%	88%	10%
all	45%	74%	93%	100% (n=1 246)

relation junction	sphere component differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
-90 to 180	46%	77%	95%	73%
181 to 360	49%	71%	91%	17%
361 plus	45%	72%	91%	10%
all	47%	75%	94%	100% (n=1 246)

relation junction	cylinder component differences			
	≤0.25 DC	≤0.50 DC	≤1.00 DC	all
-90 to 180	62%	87%	97%	73%
181 to 360	49%	80%	95%	17%
360 plus	47%	68%	89%	10%
all	58%	84%	96%	100% (n=1 246)

Validity here is expressed as the difference between the subjective refraction and the Dioptron's findings. Patients are from UMIST's Open Clinic. Refractionists and Dioptron operators are supervised final-year undergraduates. Results are based upon 1247 comparisons on 686 eyes. Some eyes were run twice on the Dioptron. The table gives the proportions of differences falling within the indicated intervals according to the magnitude of the relation junction. Despite the similarity in the percentage figures for sphere component differences, an appropriate 3 x 4 chi-square test reveals a significant variation in validity ($x^2 = 13.3$, df = 6, $P < 0.05$).

have a high proportion of pathology, and high-class measurements are more difficult to obtain, but it is apparent that even for first-class measurements the validity is not as good. This certainly does not necessarily mean that either the optometrist or Dioptron is doing a worse job. Obviously some eyes are more tolerant of prescription variation than others, and this is particularly true of hospital patients.

Table 9 shows the comparison between the retinoscopic validities of the Open Clinic and Open Day data. Here there may have been a slight shift in the type of patient seen and operator used, but perhaps the most important difference lies in the quality of retinoscopic findings used as a validity criteria. For some of these validity estimates the numbers are small, but it would still seem apparent that the hospital retinoscopist was able to achieve results only a couple of per cent higher than the students, although there remains the probability that there was significant improvement in the axis validity. There appears little scope for accounting for the differences in terms of the calibre of Dioptron operator.

The frequencies with which measurements of different class could be achieved are given in Table 10. There were fewer first-class and more third-class measurements in the Open Clinic sample than the Open Day, and this was possibly due to the operator being a Coherent employee on the latter occasion. As expected, the Outpatients Clinic contained

Table 4. Subjective sphere-equivalent validity as a function of missed scans, confidence factor and relation junction

missed scan pattern	rel. junc.	conf. factor	sphere-equivalent differences				classification
			≤ 0.25 DS	≤ 0.50 DS	≤ 1.00 DS	all	
"000"&"100"	-90→180	0.01→1.00	49%	79%	97%	52%	first class
"000"&"100"	-90→180	1.01→10.0	42%	71%	94%	14%	second class
"000"&"100"	-90→180	10.01→∞	43%	70%	82%	4%	third class
"000"&"100"	-90→180	all	47%	77%	**96%**	70%	
"000"&"100"	181→360	0.01→1.00	43%	76%	92%	10%	second class
"000"&"100"	181→360	1.01→10.0	48%	72%	92%	5%	second class
"000"&"100"	181→360	10.01→∞	-	-	-	0%	third class
"000"&"100"	181→360	all	44%	74%	91%	**15%**	
"000"&"100"	361+	0.01→1.00	38%	57%	88%	6%	third class
"000"&"100"	361+	1.01→10.0	32%	65%	88%	3%	third class
"000"&"100"	361+	10.01→∞	-	-	-	1%	third class
"000"&"100"	361+	all	37%	63%	89%	10%	third class
not("000" "100")	all	all	26%	46%	72%	5%	third class
all	all	all	45%	74%	**93%**	100% (n=1246)	

Validity here is expressed as the difference between the subjective refraction and the Dioptron's findings. Patients are from UMIST's Open Clinic. Refractionists and Dioptron operators are supervised final-year undergraduates. Results are based upon 1246 comparisons on 687 eyes. Some eyes were run twice on the Dioptron. The table gives the proportion of differences falling within the indicated intervals and broken down according to the pattern of missed scans, and size of confidence factor and relation junction. A complete breakdown is not given because the numbers are too small for certain combinations to reveal reliable proportions. The Dioptron, itself, rejects measurements when the confidence factor is bigger than 20 at the same time as there are two or more missed scans.

the fewest first-class and most third-class findings because of the high proportion of pathology amongst the eyes. And, of course, as mentioned before we would expect fewer high-quality retinoscopies and subjective refractions.

Repetition and class of Dioptron findings

When we used the Dioptron we only took one set of measurements at a time. In normal practice one might examine the three indices for each eye and, depending upon the assessment of these, decide whether to obtain a second or even a third print out. In this way one is able to achieve a higher proportion of first- and second-class print outs than would otherwise be possible. By examining the indices for our pairs of Open Clinic findings we can assess what the chances are for improving the class of results for the average eye. For the Open Clinic data, *52%* were first-class. On the assumption that the class of measurements was totally independent of the eye under consideration then it would be expected that if two sets of readings were taken both would be first-class on *21%* of occasions; one would be first-class and one not, 50% of the time; and neither first-class, 23% of the time. We found empirically that the respective proportions were 33, 40 and 28%. Thus the class of measurement is to some extent tied to the eye being refracted.

In practical terms this means that a first-class measurement was found among Open Clinic data the first time of asking 52% of the time. Repeating the 48 non-first-class readings led to a further 20% of first-class readings. Amongst the pairs of readings, 94% would contain at least a second-class finding. Put another way (see Table 11) to achieve about a three-quarter probability of a first-class result and a 95% probability of a second

Table 5.

Subjective validity as a function of the class of measurements

class	sphere-equivalent differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
first	49%	79%	97%	52%
second	43%	73%	93%	29%
third	36%	60%	83%	19%
all	45%	74%	93%	100% (n=1 246)

class	sphere component differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
first	50%	79%	98%	52%
second	46%	74%	93%	29%
third	39%	67%	84%	19%
all	47%	75%	94%	100% (n=1 246)

class	cylinder component differences			
	≤0.25 DC	≤0.50 DC	≤1.00 DC	all
first	65%	91%	99%	52%
second	54%	83%	97%	29%
third	44%	66%	86%	19%
all	58%	84%	96%	100% (n=1 246)

class	axis differences			
	≤5°	≤10°	≤20°	all
first	37%	60%	86%	42%
second	34%	57%	82%	32%
third	35%	56%	77%	26%
all	35%	58%	82%	100% (n=620)

Validity here is expressed as the difference between subjective refraction and the Dioptron's findings. Patients are from UMIST's Open Clinic. Refractionists and Dioptron operators are supervised final-year undergraduates. Results are based upon 1246 comparisons on 686 eyes. Some eyes were run twice on the Dioptron. The table gives the proportions of differences falling within the indicated intervals and broken down according to whether relation junction, missed scans and confidence factor indicate they are first-, second- or third-class. For the axis validity figures, only cylinders larger than 0.50 DC have been included.

it would be necessary to repeat half the Dioptron measurements on eyes in a normal sample. The repeat proportion might not need to be so high for a skilled Dioptron operator.

Confidence factor and cylindrical component

Poise and Kerr (1975) argued that confidence factor for the early Dioptron was related to the cylinder axis and size. They discovered that the instrument had less confidence in those eyes with substantial amounts of astigmatism than in those with near spherical ametropias. Despite the change in the way confidence factor is now calculated, it is still true that the Dioptron II expresses less confidence in larger cylinders. We only had 32 measurements on cylinders larger than 4 DC, but amongst these only two had associated confidence factors smaller then 1.0 while 22 would be expected on the null hypothesis that

Table 6. Retinoscopic validity as a function of class of measurements

class	sphere-equivalent differences			
	⩽0.25 DS	⩽0.50 DS	⩽1.00 DS	all
first	46%	74%	96%	51%
second	34%	64%	92%	30%
third	36%	55%	79%	19%
all	40%	68%	92%	100% (n=1 238)

class	sphere component differences			
	⩽0.25 DS	⩽0.50 DS	⩽1.00 DS	all
first	45%	74%	95%	51%
second	34%	61%	93%	30%
third	38%	60%	81%	19%
all	41%	67%	92%	100% (n=1 238)

class	cylinder component differences			
	⩽0.25 DC	⩽0.50 DC	⩽1.00 DC	all
first	54%	84%	98%	51%
second	45%	73%	93%	30%
third	41%	63%	83%	19%
all	49%	77%	94%	100% (n=1 238)

class	axis differences			
	⩽5°	⩽10°	⩽20°	all
first	30%	52%	75%	42%
second	30%	48%	70%	31%
third	31%	50%	71%	27%
all	30%	50%	72%	100% (n=567)

Validity here is expressed as the difference between a retinoscopy and the Dioptron's findings. Patients are from UMIST's Open Clinic. Retinoscopists and Dioptron operators are final-year undergraduates. The retinoscopies were not always corrected by the supervisors as for the purposes of the clinic they were only intermediate. The differences, therefore, will be bigger than one would expect in practice. Results are based upon 1238 comparisons on 636 eyes. Some eyes were run twice on the Dioptron. The table gives the proportions of differences falling within the indicated intervals and broken down according to whether relation junction, missed scans and confidence factor indicate that they are first-, second- or third-class. For the axis validity figures, only cylinders larger than 0.50 DC have been included.

astigmatism was not relevant. This suggests that if we choose to repeat a measurement on an eye with high astigmatism we might find it impossible to obtain confidence factors compatible with our definition of "first-class" results. It is important to note that this does not necessarily mean that such measurements are less reliable or valid. It may simply be that high cylinder values "inflate" the confidence factor and make it a less useful statistic in such circumstances. The test-retest correlation coefficient for the log of the confidence factors is only 0.27. In other words, less than *10%* of the variation in the values can be accounted for by the eyes themselves. Thus, in most cases, the repetition of the Dioptron II measurements remains a sensible strategy to achieve an improved confidence factor.

Table 7. Reliability as a function of class of measurement

class	sphere-equivalent differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
first	78%	96%	100%	(n=165)
second	72%	87%	96%	(n=53)
third	57%	79%	82%	(n=28)
all†	71%	90%	95%	100% (n=506)

class	sphere component differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
first	77%	95%	99%	(n=165)
second	66%	89%	96%	(n=53)
third	64%	82%	89%	(n=28)
all†	69%	88%	95%	100% (n=506)

class	cylinder component differences			
	≤0.25 DC	≤0.50 DC	≤1.00 DC	all
first	84%	99%	100%	(n=165)
second	60%	83%	94%	(n=53)
third	43%	75%	86%	(n=28)
all†	66%	88%	95%	100% (n=506)

class	axis differences			
	≤5°	≤10°	≤20°	all
first	58%	84%	100%	(n=55)
second	36%	64%	82%	(n=28)
third	73%	82%	86%	(n=22)
all†	52%	73%	94%	100% (n=217)

Test - retest reliability here is expressed as the difference between two sets of Dioptron findings carried out before and after a retinoscopy and subjective routine. Patients are from UMIST's Open Clinic. Dioptron operators are final-year undergraduates. Results are based on comparisons on 506 eyes. The table gives the proportions of differences falling within the indicated intervals and broken down according to whether relation junction, missed scans and confidence factor indicate that the pairs of findings are both first-, both second- or both third-class. For the axis reliability figures, only cylinders larger than 0.50 DC have been included. "All" denotes the pairings of *all* classes of findings—first with second, third with first etc. Reliabilities for second- and third-class categories are based upon very small samples and must be regarded with caution.

The user must bear in mind, however, that the confidence factor tends to increase with the size of the cylinder—the problem perhaps becoming "obvious" with cylinders larger than 3.5 DC. With such eyes the clinician will be obliged to compromise his demands for a "good", i.e. low, confidence factor and accept higher figures.

Poise and Kerr (1975) also criticized the early Dioptron confidence factor after ascertaining that it was related to cylinder axis orientation. They found that for astigmatism greater than 1 diopter the instrument had most confidence in minus cylinder axes near the vertical meridian (against-the-rule astigmatism), followed by those axes near the horizontal meridian (with-the-rule astigmatism), than in the oblique axes. We used a parallel analysis of our own Dioptron II data and found that the instrument still has less

Table 8. Subjective validity of first-class measurements as a function of the group of patients

group of patients	sphere-equivalent differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
Open Clinic	49%	79%	97%	(n=642)
Outpatients Clinic	41%	71%	95%	(n=41)

group of patients	sphere component differences			
	≤0.25 DS	≤0.50 DS	≤1.00 DS	all
Open Clinic	50%	79%	98%	(n=642)
Outpatients Clinic	33%	71%	93%	(n=42)

group of patients	cylinder component differences			
	≤0.25 DC	≤0.50 DC	≤1.00 DC	all
Open Clinic	65%	91%	99%	(n=642)
Outpatients Clinic	49%	83%	95%	(n=41)

group of patients	axis differences			
	≤ 5°	≤10°	≤20°	all
Open Clinic	37%	60%	86%	(n=260)
Outpatients Clinic	32%	53%	68%	(n=19)

Validity here is expressed as the difference between the subjective refraction and the Dioptron's findings. Patients are from UMIST's Open Clinic or MREH's Outpatients Clinic. Refractionists and Dioptron operators are supervised final-year undergraduates in the former, while in the latter refractionists are hospital optometrists and the operator an employee of Coherent. For the axis validity figures, only cylinders larger than 0.50 DC have been included. Note the small numbers in some cases. The table gives the proportions of differences falling within the intervals indicated.

confidence in the oblique axes (x^2 = 14.8, df = 4, $P < 0.01$) on a 3 x 3 contingency table analysis, but were unable to confirm their observation of a difference between with- and against-the-rule axes.

It is conceivable that the Dioptron would have less confidence in oblique axes if these corresponded with a disproportionate number of large cylinders. An analysis with this in mind found that there was no excess of cylinders larger than 3.5 DC for oblique axes. However, the analysis of the Dioptron data did reveal a relationship between size of cylinder and whether or not the angle was oblique (x^2 = 38, df = 4, $P<0.01$; and $\%^2$ = 39, df = 4, $P<0.01$). Fifty-nine per cent of the oblique cylinders were found to be 0.50 DC or smaller as opposed to only 39% of the non-oblique cylinders. Parallel analyses for our retinoscopy and subjective data failed to reveal any similar significant differences (31 vs *29%* and 32 vs *26%).*

Poise and Kerr (1975) concluded, because of the two problems with larger cylinders, that the confidence factor had limited predictive value to the clinician. We feel that this overstates the position, particularly with respect to the Dioptron II, but certainly the clinician should bear it in mind when he is assessing the value of the instrument's measurements.

We found no major relationship between sphere component and confidence factor, missed scans or relation junction, nor between astigmatism and missed scans or relation junction to compare with that between astigmatism and confidence factor.

Table 9. Retinoscopic validity of first-class measurements as a function of calibre of retinoscopist and group of patients

group of patients	sphere-equivalent differences			
	≤ 0.25 DS	≤ 0.50 DS	≤ 1.00 DS	all
Open Clinic	46%	74%	96%	(n=636)
Open Day	49%	76%	97%	(n=136)

group of patients	sphere component differences			
	≤ 0.25 DS	≤ 0.50 DS	≤ 1.00 DS	all
Open Clinic	45%	74%	95%	(n=636)
Open Day	42%	79%	97%	(n=136)

group of patients	cylinder component differences			
	≤ 0.25 DC	≤ 0.50 DC	≤ 1.00 DC	all
Open Clinic	54%	84%	98%	(n=636)
Open Day	60%	87%	99%	(n=136)

group of patients	axis differences			
	≤ 5°	≤ 10°	≤ 20°	all
Open Clinic	30%	52%	75%	(n=237)
Open Day	34%	66%	87%	(n=47)

Validity here is expressed as the difference between a retinoscopy and the Dioptron's findings. Patients are from UMIST's Open Clinic or an Open Day at UMIST. The retinoscopies for the former were carried out by third-year undergraduates whose results were not always corrected, while those for the latter group were carried out by an hospital optometrist. Operators for the first group were the students, while for the second group a Coherent employee. For the axis validity figures, only cylinders larger than 0.50 DC have been included. The table gives the proportions of differences falling within the intervals indicated.

Table 10. Relative frequency of class of Dioptron measurements as a function of group of patients and/or calibre of operator

class	Open Clinic	Open Day	Outpatients Clinic
first	52%	61%	29%
second	29%	27%	25%
third	19%	12%	46%
all	100% (n=1253)	100% (n=290)	100% (n=148)

Relation junction, missed scans and confidence factor determined the class of measurement. Operators for the Open Clinic study were final-year undergraduates, while for the other groups a Coherent employee was used. The Outpatients group included eyes with a high proportion of pathology.

Table 11. Probability when two sets of readings are taken on a single eye of getting the following, according to our Open Clinic data

both readings first class	33%
at least one reading first class	72%
at least one reading second class or better	94%

Influence of pathology on accuracy indices

Coherent's manual stresses the roles of missed scans and confidence factor as indices of pathology, perhaps because it may be orientated towards the ophthalmologist. In our Open Clinic sample we therefore examined the frequency of various abnormalities as a function of the three indices and the class of result. For our largely "normal" subjects we recorded the presence of amblyopia, cataracts, glaucoma, small pupils, poor fixation, floaters, keratitis, oedema, tropias, phorias, diabetic retinopathy and nystagmus. While there may have been an increased proportion of pathology in second- and third-class results, it was not sufficiently obvious for us to see the accuracy indices as important indicators of pathology for the practitioner dealing with the ordinary spectrum of patients. On occasions we were unable to obtain a print out from the Dioptron because the confidence factor returned was 20 or over at the same time as there were two or more missed scans, and this position was not resolved by repeating the measurement. This occurred very rarely with Open Day and Open Clinic patients, but quite a few times with those from the hospital Outpatients Clinic—perhaps one in six patients.

Repetition and validity

Given that it is possible to improve the confidence factor, missed scans, and relation junction, and consequently the class of measurements by repetition, it is still arguable that this need not lead to any significant improvement in the validity of the measurements because of the admitted association of the accuracy indices with the type of eyes assessed. We were able to answer this by examining the consequent subjective validities of measurements which have been repeated in the Open Clinic sample. Eyes were grouped according to the class of each element of the pairs of Dioptron readings—both first-class, one first and one not, and both not first-class. The subjective validities are given in Table 12. As can be seen, the best results are for eyes which returned two first-class sets of measurements and these exceed those for first-class results in general (compare with values given in Table 5). First-class results where the other paired finding was not first-class were not as good as would be expected and less than the values given in Table 5. Thus it is possible to improve the validity of the results (as well as the accuracy indices) by repeating non-first-class results, but the amount of improvement is limited and the validity achieved by new first-class results will not equal that of those results which did not need repetition.

Table 12. Subjective sphere-equivalent validity for Open Clinic eyes grouped according to the classes of each member in the pairs of Dioptron findings

group of eyes	first class measure differences			non first class measure differences		
	≤0.25 DS	≤0.50 DS	≤1.00 DS	≤0.25 DS	≤0.50 DS	≤1.00 DS
both measures first class (n=328)	52%	84%	99%	-	-	-
one first class, one not (n=202)	48%	73%	95%	40%	65%	89%
both measures not first class (n=278)	-	-	-	42%	69%	90%

The table gives the proportions of differences falling within the indicated intervals.

Visual acuity (VA)

Mention needs to be made of an important criterion by which the practitioner might wish to judge the Dioptron's findings, VA. Unfortunately, we must be equivocal on this aspect of our results. We found that VAs associated with first-class Dioptron findings were better than second which were better than third (F = 16.6, df = 2, 616, P < 0.001; F' - 4.3, df - 2, 151, P < 0.05), but it is interesting to note that this difference was to a slight degree repeated in the retinoscopic and subjective VAs. This is not surprising as, has already been shown by our Clinic comparisons and the discussion on confidence factor, the type of eye will affect the class of Dioptron results. No comparison could be made between the subjective or retinoscopy, and the Dioptron VAs as they were carried out in different rooms on different charts under different conditions of illumination. Also, it should be mentioned that averaging decimal VAs in this manner is itself a little dubious on account of the non-normal distribution of the VA scores.

Bias

In connection with subjective validity, it should be noted that a Dioptron "bias" has been reported [e.g. Turnbull (1981)] with the instrument's results tending to be more negative than for a subjective. We rejected our non-first-class Dioptron measures before carrying out a parallel analysis. This was essential as otherwise the differences under consideration would have included those diverging substantially from a normal distribution. For sphere-equivalent, sphere component and cylinder component we found that on average the Dioptron gave results which were more negative than our retinoscopies (-0.05, -0.02 and -0.05 D) but that these differences did not reach statistical significance. The Dioptron also gave more negative results than for the subjectives (-0.1, -0.05 and -0.09 D) but this time the differences for sphere equivalent and cylinder component were both significant (P < 0.01 and < 0.001). Our results for these were compatible with the findings of Turnbull (1981) (-0.09 and — 0.07 D). Thus it would appear that the Dioptron returns results which are on average of the order of 0.05-0.10 D more negative than for a subjective; a difference which is unlikely to be of any clinical significance.

DISCUSSION AND CONCLUSIONS

If practitioners wish to achieve the best results from the Dioptron II, they should be willing to repeat those findings which do not appear satisfactory. The criteria they adopt should depend upon their aspirations and the use to which they wish to put the instrument's results, as well as the time and personnel available. Upwards of 50 — *60%* of their results may be expected to reach our definition of first-class and, by repeating the remainder once, the clinician should be able to achieve over three-quarters first-class and over *95%* second-class results. An hospital optometrist will have to be satisfied with a lower proportion of high-class results, and clinicians will be obliged to accept lower-class results for patients with over 4 diopters of astigmatism.

If we only consider first-class measurements, then we obtain SEs of measurement figures which are better than appear to be achieved by retinoscopists (French and Wood, 1981; Woodruff, 1979). However, this comparison unfairly favours the instrument. If retinoscopists, too, were allowed to offload that proportion of their results which they were less happy with, then it is possible that they might do as well. On the other hand, if we retain all the data and recalculate the SEs of measurement we obtain figures which are no longer legitimate, due to the non-normal distribution of Dioptron errors amongst low-class findings. What is required is a non-parametric comparison, but we do not possess retinoscopic reliability figures equivalent to those given in Table 7.

The best test of reliability and validity would be one where Dioptron findings were repeated where appropriate and only the best class retained, but with a record kept of the number of repetitions used to obtain the final result. Such a procedure would give results intermediate in quality to those already reported, and perhaps more equivalent to the task faced by a retinoscopist with whose results they should be compared. Evaluation studies of automatic refractors have tended to neglect the very important aspect of reliability (French and Wood, 1981).

It needs to be added that comparison of our results here with those found by other studies, with the results of other instruments, and even with claims made by Coherent is problematic. In each case the type of patient will vary, and, as we have demonstrated for very disparate groups, the accuracy of just one instrument and the proportion of first-class results will also change. All techniques produce some results that are so unreliable that the clinician will discard them. With traditional methods this is a matter of clinical judgement, but with the Dioptron the procedure can be formalized and this has been one of our aims. Thus, in making a comparison, one is not just comparing a set of validity and reliability figures, one also has to take into account the difficulty of the sample of eyes and the small proportion of eyes disregarded.

Even though the Dioptron comes with a performance guarantee in writing, "When you compare the Dioptron refractor with your subjective, Coherent guarantee you will get the following minimum results" (see Table 13), it still does not permit the user to make precise comparisons with the figures. Thus the guarantee cannot mean for all eyes as for example, such figures would not be achievable with hospital patients as our study (Table 8) makes clear. Obviously, it is not meant to refer to values derived from the improper use of the instrument, and it barely seems conceivable that it should refer to *all* classes of measurement. Presumably it refers only to high-class measurements on "relatively normal" people where measurements have been repeated in order to attain quality results and where a few eyes may have been disregarded because of abnormalities? A comparison of our first-class subjective validity figures for normal patients (Table 8) reveals figures *similar* to those claimed by Dioptron but with a slightly smaller percentage of differences within { D and somewhat poorer axes figures. Why this should be we do not know. Perhaps we should have used even stricter criteria for definitely first-class measurements. Perhaps it is due to our use of student operators. To some extent we discount the latter suggestion, however, as Table 9 appears to show that there is little scope for this consideration contributing more than the odd per cent improvement in validity figures which are similar in essence, except perhaps for the axis differences.

Table 13. The Dioptron "Written Performance Guarantee" for a comparison between the instrument and subjective results

eye parameter	differences		
	≤0.25D|5°	≤0.50D|10°	≤1.00D|20°
sphere component	55%	80%	95%
cylinder component	70%	85%	97%
axis	55%	76%	-

The table gives the proportions of differences falling within the intervals indicated. Figures pertaining to | D and 15° have been omitted to aid comparisons with our results. Coherent's axis specifications are based on subjective cylinders greater than j D.

Acknowledgements—We thank Alan Bunting and Teun Bos of Coherent, and John Bullock, Eleanor Parks and John Storey of the MREH for their kind help.

REFERENCES

Anastasi, A. (1976) *Psychological Testing.* Collier Macmillan, London.
Coherent Inc. (1975) *Dioptron Operating Instructions,* Coherent Medical Division, Palo Alto.
Coherent Inc. (1979) *Dioptron Operating Instructions.* Coherent Medical Division, Palo Alto.
French, C. and Wood, I. (1981) The Dioptron II—in practice. *The Optician* **181,** 14 August, 7-11.
Mailer, C. M. (1978) Automatic refraction and the private ophthalmologist: Dioptron II compared with subjective refraction. *Can. J. Ophthal.* **13,** 252-257.
Poise, K. A. and Kerr, K. E. (1975) An automatic objective optometer. *Archs Ophthal., N.Y.* **93,** 225-231.
Sloan, P. G. and Poise, K. A. (1974) Preliminary evaluation of the Dioptron. *Am. J. Optom. Physiol. Opt.* **51,** 189-197.
Turnbull, D. J. (1981) The Dioptron II automated objective refractor versus static retinoscopy: a clinical comparison. *Can. J. Optom.* **43,** 13-20.
Woodruff, M. E. (1979) A comparison of automated refractors and retinoscopic findings in a school screening program. *Can. J. Optom.* 41, 194-199.
Wood, I. and French, C. (1981) The Dioptron II—in theory. *The Optician* 181, 4 September, 18-24, 30.