Predictions of postoperative visual outcome in subjects with cataract: a preoperative and postoperative study

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EXTENDED REPORT

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Aim: To assess the ability of critical flicker frequency (CFF) and optimal reading speed (ORS) to predict the potential vision in patients with cataract with and without ocular comorbidity.
Methods: The two novel tests were compared with two well established potential vision tests (PVTs), the potential acuity meter (PAM) and the laser interferometer (LI). Measurements were made preoperatively in 1 eye of 88 subjects using the battery of 4 PVTs. Postoperative measurements were made with the CFF and the ORS. The subjects studied were consecutive cases over a 12-month period who fulfilled the inclusion and exclusion criteria, and agreed to participate in this study.
Results: CFF was the PVT most resistant to the presence of cataract. Both CFF and ORS give a similar predictive precision in the presence of cataract and ocular comorbidity, although CFF seems more precise when the cataract is dense.
Conclusions: The PAM and the LI showed a limited clinical capability in predicting postoperative visual acuity, particularly with dense opacities. The CFF shows the most promise as a PVT, particularly with dense cataract. Further evaluation is required for both CFF and ORS.

A number of potential vision tests (PVTs) have been developed over the years to assess the visual outcome after cataract surgery, as shown in several reviews.[1 2] Little consensus exists as to which provides the best means of assessing retinal/neural function behind cataract.[3] The potential acuity meter (PAM; Marco Ophthalmics Inc, Jacksonville, Florida) and the laser interferometer (LI, Rodenstock, London, UK) have been used in a number of studies since their development. Both tests have proved unsatisfactory where dense opacities exist,[4 5] and this has lead the Agency for Health Care Policy and Research (AHCPR) to recommend that further studies should be conducted to evaluate the usefulness of a battery of PVTs as well as the development of new methods to predict visual outcome, particularly in eyes with advanced opacities.[3]

The critical flicker frequency (CFF) test has been proposed as a PVT, and has been found to produce results that are unaffected by the presence of dense cataract.[6 7] However, CFF seems to be sensitive to the presence of retinal/neural disease.[8–12]

Another novel PVT is the optimal reading speed (ORS), which is relatively unaffected by simulated cataract,[13 14] cataract[15] and media opacities,[16 17] but seems to be significantly reduced by macular and other neural diseases.[15 17–20]

The aim of this investigation is to prospectively investigate the performance of CFF and ORS as PVTs on a group of subjects before and after cataract removal, and to compare them with the performance of the PAM and the LI at the preoperative stage.

METHODS

Subjects

One hundred and eleven subjects with age-related cataract (68% women) were recruited from the cataract surgery waiting list at the Leeds General Infirmary, Leeds, UK.

Subjects were recruited as consecutive cases over a 12-month period who fulfilled the exclusion criteria and agreed to participate in this study. The exclusion criteria were as follows:

- Subjects with a preoperative logarithm of the minimum angle of resolution (logMAR) visual acuity (VA) of 0.18 (6/9) or better.
- Subjects unable to speak English.
- Subjects with any physical or mental disability that would make it arduous to perform the tests.
- Upper age limit 90 years.

Subjects were examined before and after the cataract surgery. The study and data accumulation gained approval from the hospital ethical committee and followed the Declaration of Helsinki for research involving human subjects. Informed consent was obtained from all subjects. Twenty-three subjects were lost to the study. Twelve were lost at the follow-up visit, nine developed postoperative complications and two did not undertake the surgical procedure leaving 88 subjects who completed the study.

Following the recommendations given by the AHCPR,[3] the 88 subjects were divided into two groups (table 1). Group A consisted of subjects with cataract and no other ocular disease, and group B consisted of subjects with cataract and ocular comorbidity. Groups A and B were further divided into two groups each, according to their cataract grading obtained using the Lens Opacity Classification System III (LOCS III): subgroup A1 consisted of 25 subjects with moderate cataract, subgroup A2 consisted of 21 subjects with advanced cataract, subgroup B1 consisted of 26 subjects with moderate cataract and comorbidity, and subgroup B2 consisted of 16 subjects with advanced cataract and comorbidity. Advanced cataract was defined as an LOCS III grading for nuclear opalescence, nuclear colour, cortical opacity $\geqslant$5.0 and/or a posterior subcapsular opacity $\geqslant$3. Similar grading subdivisions have been used in other recent studies.[21]

Procedures

In the preoperative visit, PVT measurements were obtained monocularly with the optimal refractive correction for the test

Abbreviations: AHCPR, Agency for Health Care Policy and Research; CFF, critical flicker frequency; LED, light emitting diode; LI, laser interferometer; LOCS III, Lens Opacity Classification System III; logMAR, logarithm of the minimum angle of resolution; ORS, optimal reading speed; PAM, potential acuity meter; PVT, potential vision test; wpm, words read per minute

Table 1 Demographic characteristics of 88 subjects assessed preoperatively and postoperatively

Group	Subgroup	n	Mean (SD) LOCS III cataract severity	Median (range) age (years)	Mean (SD) preoperative VA (logMAR)	Mean (SD) postoperative VA (logMAR)
A (Cataract only)	A1 (moderate cataract)	25	NO 3.2 (0.8) NC 3.2 (0.8) C 2.2 (1.6) P 0.9 (1)	75 (54–83)	0.31 (0.09)	–0.02 (0.07)
	A2 (advanced cataract)	21	NO 4.1 (1.2) NC 4.3 (1.4) C 1 (1.5) P 3.0 (2)	74 (56–85)	0.85 (0.47)	–0.03 (0.08)
B (Cataract and comorbidity)	B1 (moderate cataract and comorbidity)	26	NO 3.1 (0.8) NC 3.2 (0.8) C 2.5 (1.4) P 0.9 (0.9)	79 (63–90)	0.52 (0.29)	0.29 (0.37)
	B2 (advanced cataract and comorbidity)	16	NO 4.8 (1.2) NC 5.2 (1.1) C 1.2 (1.4) P 1.8 (2.1)	78 (66–89)	0.79 (0.51)	0.17 (0.21)

C, cortical opacity; LOCS, Lens Opacities Classification System; logMAR, logarithm of the minimum angle of resolution; NC, nuclear colour; NO, nuclear opalescence; P, posterior capsular opacity; VA, visual acuity.

distance in a random order for the two tests (CFF and ORS) before and the two tests (PAM and LI) after pupil dilatation by instillation of 1% tropicamide and 2.5% phenylephrine. The novel techniques of CFF and ORS were repeated at the postoperative visit to investigate the effect of cataract removal. Subjective refraction and measurement of the optimal VA occurred in the preoperative and postoperative visits.

Distance VA was measured monocularly using a Bailey–Lovie logMAR chart (mean luminance 200 cd/m^2) using a by-letter scoring system and a termination rule of no letters called correctly on a line.[22] The standard PAM procedure was used,[23] and VA was determined as the smallest line where the majority of letters were correctly identified. The Rodenstock Retinometer was the LI used following the standard procedure,[2] with the gratings presented at four random orientations: horizontal, vertical or oblique (45° to the right or the left). The highest spatial frequency at which the orientation of the fringe pattern could be correctly identified on two separate successive occasions gave a measure of the retinal/neural resolution. Oblique orientations were not used at threshold level, but subjects were not aware of this.[24]

The CFF stimulus consisted of a 1.5° (viewing distance 38 cm), 750 cd/m^2, light emitting diode (LED) of peak wavelength 625 nm, capable of emitting a frequency range from 1 to 86 Hz. The function generator produced a sine wave with an equal light/dark phase, and a modulation depth of 98%. The LED source was mounted at the centre of a matt white rectangular screen (50×50 cm) of luminance 94 cd/m^2. Two diagonal red lines, which crossed at the LED, were fixed to the screen and were used to help observers, particularly those with macular disease, maintain central fixation. All CFF thresholds were obtained using a 2 s fixed frequency presentation stimulus, to avoid local adaptation to the flicker.[25] A method of limits collecting three ascending and three descending presentations (with 2 Hz steps) in an alternating order was used to find the thresholds. The flicker/fusion threshold was recorded as the mean of six runs.

The ORS score for reading speed was determined with cards containing between two and four continuous-text Minnesota Low-Vision Reading Test sentences[26] of a fixed size. Charts of 1.2, 1.4, 1.6 and 1.8 logMAR were used. Each card was printed in reversed contrast polarity (white letters against black background) to minimise light scatter in the presence of media opacities. The room lighting produced a chart luminance of 100 cd/m^2 for a white test card. The test distance was 25 cm, and subjects were instructed to read each sentence aloud, as quickly and accurately as possible. Reading speed was recorded as the number of correct words read per minute (wpm). Previous work[15] suggests that reading speed measurements should be made with two charts that are 0.6 and 0.8 logMAR units above the distance VA. The faster of the two reading speeds was recorded as the optimal reading speed for that subject. If the calculated print sizes were both $\leqslant$1.2 logMAR or $\geqslant$1.8 logMAR compared with the distance VA, two measurements were taken with either the 1.2 or 1.8 logMAR charts and the average result was calculated.

Table 2 Mean (SD) for the preoperative predictions of visual acuity (VA) and the postoperative measurement of VA in the groups with moderate (A1) and advanced (A2) cataract only

	Mean (SD) preoperative VA predictions (logMAR)				Mean (SD) postoperative VA (logMAR)
	PAM	LI	CFF	ORS	
A1	0.18 (0.12)	0.17 (0.14)	0.14 (0.12)	0.17 (0.09)	–0.02 (0.07)
A2	0.36 (0.29)	0.47 (0.45)	0.12 (0.11)	0.35 (0.43)	–0.03 (0.08)
A1 and A2 combined	0.26 (0.22)	0.29 (0.34)	0.13 (0.12)	0.25 (0.3)	–0.02 (0.07)

CFF, critical flicker frequency; LI, laser interferometre; logMAR, logarithm of the minimum angle of resolution; ORS, optimal reading speed; PAM, potential acuity meter; VA, visual acuity.
The table indicates that all tests underpredict the postoperative VA by more than one logMAR line (the chart lines change by 0.1 units and each letter scores 0.02).

Finally, the cataract was graded using LOCS III.[27]

CFF (Hz) or ORS (wpm) were converted to VA (logMAR) by the application of linear regression. This was carried out in a separate study using 51 subjects with clear media consisting of 35 dry age-related macular degeneration, 8 wet age-related macular degeneration and 8 pseudophakes without comorbidity. The results from these subjects allow an assessment of CFF and ORS performance in the absence of cataract for a logMAR acuity range from –0.1 to 1.34. Scatterplots of log CFF and log ORS on the x axis were plotted against distance VA (logMAR) on the y axis. The regression equations obtained were then used to convert CFF and ORS results into VA predictions. The regression equations for the CFF and ORS were as follows:

VA (logMAR) = 5.44−3.33× CFF (log Hz)

VA (logMAR) = 3.44–1.48× ORS (log wpm)

The coefficient of determination (r^2) for CFF was 0.71 and for ORS was 0.69. If CFF and ORS are unaffected by the presence of cataract, then these conversions will allow a preoperative prediction of the VA likely to be achieved after cataract removal.

RESULTS

Table 2 details the effect of severity of cataract on the predictive ability of PVTs (A1 and A2).

Subjects with cataract and no other ocular disease obtained a mean (SD) postoperative VA of –0.02 (0.07) logMAR (∼20/19), suggesting normal neural performance.

A paired t test performed on groups A1 and A2 combined showed no statistically significant difference between CFF thresholds before (mean (SD) 39.4 (3.2) Hz) and after cataract surgery (39.1 (2.9) Hz; $p = 0.41$), suggesting that the CFF measurement is largely independent of the presence or absence of cataract. The ORS values, however, significantly improved after cataract surgery (153 (40.2) wpm before and 169.7 (26.2) wpm after surgery ($p = 0.003$). Thus, the ORS seems to be affected by the presence of cataract, which implies that the preoperative prediction will be an underprediction of post-operative performance.

The mean preoperative predictions were compared with the measured mean postoperative VAs for the cataract only groups in table 2, which indicated that all the PVTs underpredicted the postoperative VA. The predictive ability of the PVTs was further examined by using the analysis of Altman and Bland[28 29] for the comparison of two methods of measurement. This involves plotting the difference in VA (postoperative VA measurement−PVT prediction) against the mean VA ((post-operative VA measurement+PVT prediction)/2). Figure 1 shows the results, where the horizontal dotted lines indicate the limits of agreement (mean bias (2 SD)). Using this approach for groups A1 and A2 combined, the CFF test produced a mean bias of –0.159 logMAR (1½ lines of letters) with limits of agreement from –0.395 to 0.077. The other three PVT results were poorer, with the ORS achieving a bias of –0.273 with limits from –0.877 to 0.331. The PAM achieved a bias of –0.28, with limits from –0.734 to 0.174. Finally, the poorest result occurred with the LI where the bias was –0.312, with limits from –1 to 0.376.

Table 3 Distribution of the ocular comorbidities in the groups with moderate and advanced cataract (B1 and B2, respectively)

Moderate cataract and comorbidity (B1, n = 26)	Advanced cataract and comorbidity (B2, n = 16)
Dry AMD, n = 14	Dry AMD, n = 8
Glaucoma, n = 8	Glaucoma, n = 3
Wet AMD, n = 2	Amblyopia, n = 2
Epi-retinal membrane, n = 1	Epiretinal membrane, n = 2
Amblyopia, n = 1	Full-thickness macular hole, n = 1

AMD, age-related macular regeneration.

Effect of ocular comorbidity on the predictive ability of PVTs (B1 and B2)

Table 3 shows the distribution of the ocular comorbidities included in this analysis. The mean preoperative predictions are compared with the measured postoperative VAs in table 4, which suggests that the PVTs tend to underpredict the postoperative VA for the B2 group. There is little evidence of underprediction for the B1 group. Figure 2 shows the difference versus mean relationships between the measured postoperative logMAR VA and PVT prediction, which illustrates only small mean biases. Altman and Bland[28 29] analysis for groups B1 and B2 showed the CFF to give the smallest mean bias at –0.019 logMAR, with limits of agreement from –0.487 to 0.449. The ORS gave a small bias at –0.039 but larger limits from –0.713 to 0.635. The LI bias was –0.088, with limits from –0.584 to 0.408. Finally, the PAM gave the largest bias at –0.157, with limits from –0.771 to 0.457.

The predictive ability of the PVTs was further examined using Bland's one sample t method[29] for the comparison of two methods of measurement from a small sample. The mean (SE) of the differences allows for an estimation of the differences between the two methods with a 95% confidence interval (CI) for the bias. Table 5 summarises the results of this analysis. The logMAR scoring rates each letter at 0.02 units. The score can therefore be converted to an indication of the difference between the two methods of measurement expressed as the number of logMAR letters where five letters represent one line.

AHCPR[3] have recommended that studies should be conducted to evaluate the usefulness of PVTs to predict visual outcome, particularly in eyes with advanced opacities. With this in mind, groups A2 and B2 were combined and the Bland analysis[29] was repeated as above. This produced table 6, which quantifies the likely error in the PVT prediction, with a 95% confidence interval for the bias, expressed as the number of logMAR letters.

DISCUSSION

Cataract only groups (A1 and B2)

Figure 1 indicates that all the PVTs tend to underestimate the postoperative VA since most of the data points lie beneath the horizontal zero line. It also reveals a poor resistance to image degradation for the standard techniques of PAM, LI and ORS with advanced cataracts.

Paired t tests suggest that the CFF measurements were largely independent of the presence or absence of cataract. The relative bias and limits of agreement analysis indicates that, where only cataract is present, the CFF prediction gives the smallest bias with the smallest spread for the limits of agreement. Table 5 suggests that the best prediction of postoperative VA is achieved by the CFF technique (predicted error no more than two lines of letters).

Groups having cataract with comorbidity (B1 and B2)

Table 4 indicates that the performance of the four methods was similar for the group with moderate cataract with comorbidity (B1), where all PVTs show a mean similar to the postoperative measured VA. The group with advanced cataract (B2) showed a reduced predictive ability for all the PVTs, which is particularly noticeable for the PAM and the LI. Figure 2 illustrates a similar performance apparently to all the PVTs. However, the CFF gives the smallest mean bias with the smallest spread for the limits of agreement. The ORS gives a similar bias, but a larger spread for the limits of agreement. The bias of the LI is slightly larger, with a small spread for the limits of agreement. The PAM gives the

Table 4 Mean (SD) for the preoperative predictions of visual acuity (VA) and the postoperative measurement of VA in the groups with moderate cataract with comorbidity (B1) and advanced cataract with comorbidity (B2)

	Mean (SD) preoperative VA predictions (logMAR)				Mean (SD) postoperative VA (logMAR)
	PAM	LI	CFF	ORS	
B1	0.27 (0.15)	0.24 (0.16)	0.29 (0.31)	0.32 (0.37)	0.29 (0.37)
B2	0.50 (0.38)	0.36 (0.34)	0.23 (0.13)	0.27 (0.41)	0.17 (0.21)
B1 and B2 combined	0.35 (0.28)	0.28 (0.23)	0.26 (0.26)	0.30 (0.26)	0.25 (0.32)

CFF, critical flicker frequency; LI, laser interferometer; logMAR, logrithm of the minimum angle of resolution; ORS, optimal reading speed; PAM, potential acuity meter; VA, visual acuity.

largest bias with a broad spread for the limits of agreement, similar to those of the ORS.

Table 5 suggests that the best prediction of postoperative VA in the presence of comorbidity is achieved by the CFF technique.

Groups with advanced cataract (A2 and B2)

The AHCPR report[3] recommended that further studies should be conducted to evaluate the performance of new PVTs in the presence of well-developed cataract because current PVTs provide limited information. It therefore appears appropriate to concentrate on the results of the groups with advanced cataract (A2 and B2). Firstly, the increase in the prediction error with advanced cataract is observed for the PAM and the LI in tables 2 and 4, pointing to limited capability. This did not occur with the CFF measurement, where the prediction was slightly better in the presence of advanced cataract without comorbidity and only slightly worse in the presence of comorbidity. A repeated measures analysis of variance for groups A2 and B2 combined indicated a significant difference between the five methods ($F_{4,108} = 12.32$, $p = 0$) in the prediction/measurement of the postoperative VA. Post hoc comparisons indicated that predictions were significantly different from the measured postoperative VA with the PAM and the LI. However, the predictions were not significantly different from the postoperative VAs measured for the CFF ($p = 0.497$) and the ORS ($p = 0.411$).

Table 6 illustrates the extent of the prediction error in terms of the number of logMAR letters for advanced cataract with and without ocular comorbidity. The CFF underpredicts the postoperative performance by up to two logMAR lines of letters. The other three PVTs underpredict the postoperative performance by up to 4 or 5 lines of letters.

It is worth noting that contrast sensitivity or the evaluation of functional complaints could provide a more appropriate means of assessing visual and functional impairment in subjects with cataract.[30–34] However, VA was selected as the outcome measure since it seems to be the most common evaluation of visual success following cataract surgery.[3 35–37]

It must also be noted that the CFF and ORS conversion to a VA prediction relies on the derivation of a regression equation

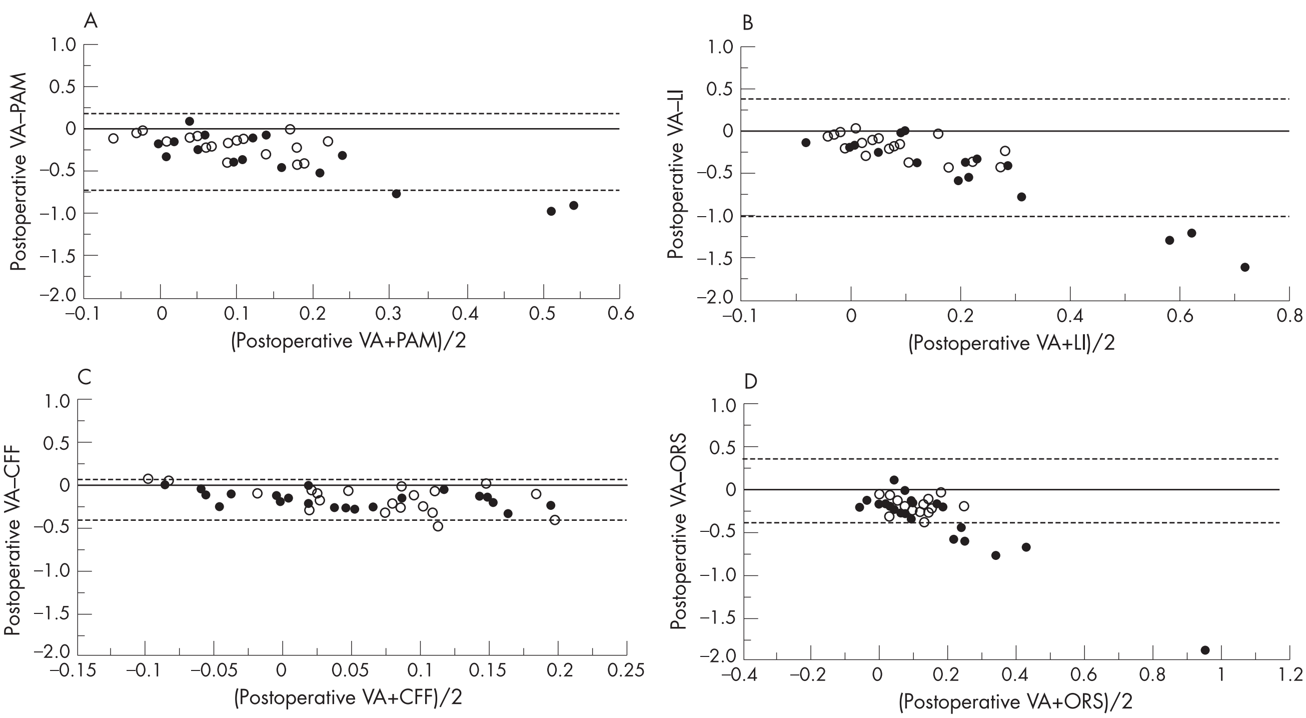

Figure 1 (A–D) Measured postoperative visual acuity (VA)−potential vision test VA prediction plotted against the mean of the two measurements using: (A) potential acuity meter (PAM), (B) laser interferometer (LI), (C) critical flicker frequency (CFF) and (D) optimal reading speed (ORS) for the groups with moderate (○) and advanced (●) cataract (A1 and A2, respectively). Points below the zero line indicate an underprediction of performance. The dotted horizontal lines indicate the limits of agreement.

Table 5 The PVT prediction error expressed in terms of logMAR letters based on the fact that each letter scores 0.02 and each five-letter line scores 0.10 units

	Prediction error expressed as the number of logMAR letters for groups A1 and A 2		Prediction error expressed as the number of logMAR letters for groups B1 and B2	
PAM	11 under	18 under	3 under	13 under
LI	10 under	21 under	1 under	9 under
CFF	7 under	10 under	3 over	5 under
ORS	9 under	18 under	3 over	7 under

CFF, critical flicker frequency; LI, laser interferometre; logMAR, log of minimum angle of resolution; ORS, optimal reading speed; PAM, potential acuity metre.
The word under indicates that the PVT has underpredicted the actual VA measured postoperatively. For example, the CFF underprediction will be between seven and ten letters for the cataract only group. CFF predicts between a five letters underprediction and a three letters overprediction, where cataract is combined with ocular comorbidity.

Table 6 PVT prediction error expressed in terms of logMAR letters for the advanced cataract groups A2 and B2

PAM	12 under	24 under
LI	10 under	22 under
CFF	3 under	9 under
ORS	9 under	21 under

CFF, critical flicker frequency; LI, laser interferometer; logMAR, logarithm of the minimum angle of resolution; ORS, optimal reading speed; PAM, potential acuity meter.
The word under indicates that the PVT has underpredicted the actual visual acuity measured postoperatively. The values have been derived from a 95% CI for the true mean logMAR bias.

from a small number of subjects being a representative method. It is inevitable that this conversion will introduce some error. Further studies should establish whether a regression equation based on a larger sample of subjects may minimise limitations.

Although different mechanisms mediate the appreciation of VA (spatial processing) and the detection of CFF (temporal processing),[38] a significant association between VA and CFF was obtained in this study. We acknowledge that it is perhaps unreasonable to measure temporal resolution by CFF and then use this to predict VA. However, where retinal/neural disease is present, it may well adversely affect both the spatial and temporal processing channels in a way that provides some association. Neurophysiological and behavioural studies in primates have shown that the magnocellular pathway is preferentially involved in the visual processing of flicker and motion.[38 39] In addition, Ikeda and Wright[40] reported that the magnocellular pathways continue to respond to image degradation such as defocused stimuli. This may provide an explanation for the CFF resistance to image degradation in the presence of dense opacities. Abnormalities in temporal processing (as measured by CFF) have previously been shown to be sensitive to disorders causing spatial impairment including optic neuropathies and maculopathies.[8–12]

In summary, there was a limited ability to bypass advanced cataracts when using the PAM and LI. This limits their use to mild or moderate levels of opacification. PVT assessments are less useful where opacification is not well developed. The CFF was the most robust measurement in the presence of cataract. The CFF measurement seemed to give the best prediction of postoperative VA in the presence of cataract, both with and without comorbidity, in this sample of subjects.

The preoperative ORS measurements may provide a better estimate of the likely postoperative reading performance. Thus, the possibility exists that ORS may be better at predicting other outcome variables that could be used to indicate successful surgery. Further investigations should address this possibility.

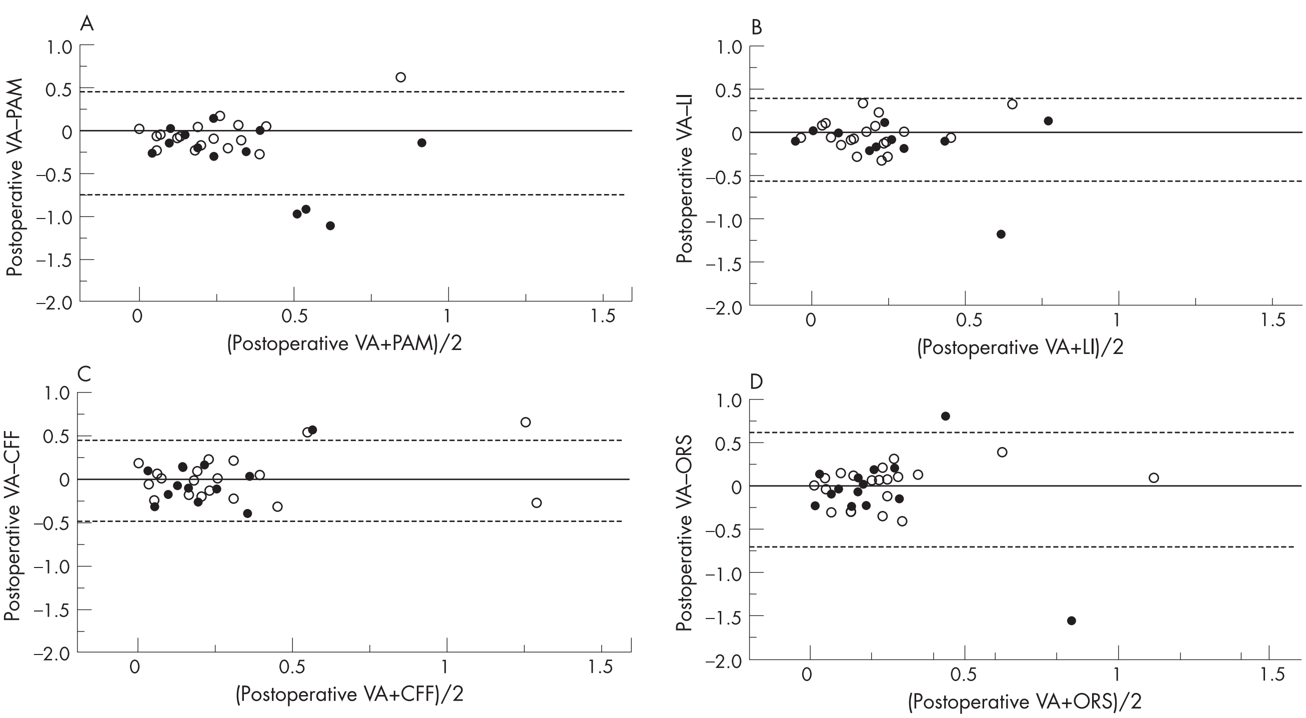

Figure 2 (A–D) Measured postoperative visual acuity (VA)−potential vision test VA prediction plotted against the mean of the two measurements using: (A) potential acuity meter (PAM), (B) laser interferometer (LI), (C) critical flicker frequency (CFF) and (D) optimal reading speed (ORS) for the groups with moderate (○) and advanced (●) cataract with ocular comorbidity (B1 and B2, respectively). Points below the zero line indicate an underprediction of performance. The dotted horizontal lines indicate the limits of agreement.

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Subjects were examined before and after cataract surgery. The study and data accumulation gained approval from the hospital ethical committee and followed the Declaration of Helsinki for research involving human subjects. Informed consent was obtained from all subjects.

Competing interests: None.

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