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EXTENDED REPORT

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Background/aim: The technique of photoretinoscopy is unique in being able to measure the dynamics of the oculomotor system (ocular accommodation, vergence, and pupil size) remotely (working distance typically 1 metre) and objectively in both eyes simultaneously. The aim of this study was to evaluate clinically the measurement of refractive error by a recent commercial photoretinoscopic device, the PowerRefractor (PlusOptiX, Germany).

Method: The validity and repeatability of the PowerRefractor was compared to: subjective (non-cycloplegic) refraction on 100 adult subjects (mean age 23.8 (SD 5.7) years) and objective autorefraction (Shin-Nippon SRW-5000, Japan) on 150 subjects (20.1 (4.2) years). Repeatability was assessed by examining the differences between autorefractor readings taken from each eye and by re-measuring the objective prescription of 100 eyes at a subsequent session.

Results: On average the PowerRefractor prescription was not significantly different from the subjective refraction, although quite variable (difference +0.05 (0.63) D, $p=0.41$) and more negative than the SRW-5000 prescription (by -0.20 (0.72) D, $p<0.001$). There was no significant bias in the accuracy of the instrument with regard to the type or magnitude of refractive error. The PowerRefractor was found to be repeatable over the prescription range of -8.75 D to $+4.00$ D (mean spherical equivalent) examined.

Conclusion: The PowerRefractor is a useful objective screening instrument and because of its remote and rapid measurement of both eyes simultaneously is able to assess the oculomotor response in a variety of unrestricted viewing conditions and patient types.

The oculomotor triad comprising ocular accommodation, vergence, and pupil size is essential to seeing a clear, single, luminance intensity controlled image of the outside world. Continuous measurement of the oculomotor system is needed to understand further conditions such as ocular neurological effects and their progression, the potential of multifocal intraocular lenses, and the efficacy of orthoptic training. Although many techniques have been devised to measure accommodation continuously over the past two decades, photoretinoscopy is unique in enabling the measurement of accommodation, vergence, and pupil size in both eyes simultaneously, objectively, remotely (typically the camera is placed 1 metre from the eyes) and continuously.¹ The PowerRefractor is the first commercially available instrument to use photoretinoscopy and allow continuous measurement of the oculomotor triad. The instrument is marketed principally as a vision screener, for the objective measurement of refractive error.

Choi and colleagues² attempted to validate the PowerRefractor, but there were several limitations to their study: the PowerRefractor measures were compared in only 15 subjects with the patient's previous spectacle prescription and not in a current full subjective refraction; subjective refraction was performed on 40 patients, but details of the refraction were not given and the subjects had a variety of ocular pathologies; the authors' kindergarten study only compared the results with the Canon R-1 open field autorefractor; the intrasession repeatability was not assessed and intersession repeatability was only measured in the kindergarten group.

Three different techniques of photorefraction have been described: orthogonal,³ isotropic,⁴ and eccentric,^{5,6} but all work on the principal of analysing the vergence of reflected

light rays returning to a camera after illuminating a point on the retina. The PowerRefractor uses the latter technique, with an infrared light source located on the edge of a mask, eccentric to the optical axis of the camera. If the eye is accurately focused at the camera distance, the infrared light reflected from the fundus is imaged in the camera plane as an even luminance over the entire pupil. However, if the eye is defocused myopically with respect to the camera, the light reflected from the fundus is focused in a plane between the eye and the camera and subsequently spread out in a cone, the angle of which depends on the amount of defocus. Because the mask covers part of the camera lens, only rays emanating from same part of the pupil are imaged. Conversely, for an eye focused hyperopically in respect of the camera, only rays emanating from the opposite part of the pupil will be illuminated. The resulting light gradient across the pupil is measured by the PowerRefractor in six meridians separated by 30° simultaneous to a pulse of infrared light emitting diodes (LEDs) mounted on a knife edge perpendicular to each meridian in turn. The gradient of each pair of opposite meridians is averaged to remove the effect of asymmetrical meridians and the spherocylindrical refraction calculated.^{7,8}

The aim of this study was to assess the validity and repeatability of the PowerRefractor to measure refractive error in non-cycloplegic adults to both subjective refraction and to a recently validated open field autorefractor, the Shin-Nippon SRW-5000.

PATIENTS AND METHODS

In all, 100 subjects (40 male and 60 female), with a mean age of 23.8 (SD 5.7) years (range from 18 to 45 years, median 22.0 years) participated in the study. Subjects with ocular

pathologies and abnormal binocular vision were excluded from the study. Standard subjective refraction, using an end point criterion of maximum plus consistent with best vision, was performed on 200 eyes after the purpose of the study was explained and informed consent given. The study had previous approval by the institutional human science ethics committee. All refractions were performed by a UK trained and registered optometrist, who was masked as to the patient's habitual prescription and the results of the autorefractor. Retinoscopy was performed initially on all subjects followed by cross cylinder to locate the axis of the cylinder (in 2.5° increments) and its power (in 0.25D increments). Best sphere, duochrome and binocular balancing (Humphris technique) was used to refine the spherical component power (in 0.25D increments).

Autorefractor was carried out with the PowerRefractor (located 1 metre from the subject) in full refraction mode by a second optometrist. Subjects were seated such that both eyes were visible in the instrument monitor and viewed the camera lens (as specified in the manufacturer's instructions). A series of 50 readings were taken in quick succession (taking on average 10–12 seconds) from each eye and the final autorefractor prescription calculated from the average of the last five valid (identified by green coloration) results (power in increments of 0.25D, cylindrical component axis to <0.1°). The PowerRefractor readings were taken under an ambient illumination of 39.6 lux, which ensured that no readings were rejected because the pupil size was too small. Measurements of repeatability were obtained by examining the differences between the five readings taken from each eye and by remeasuring the prescription of 100 eyes at a subsequent session at the same time of day, 7–10 days after the first readings were taken. The validity of autorefractors is traditionally assessed by comparing their results with that of subjective refraction.⁹ This is because they are principally designed to assist ophthalmologists and optometrists to reach the end point of subjective refraction as quickly as possible, in a manner similar to that of retinoscopy.

The PowerRefractor was also compared to another commercially available autorefractor, the Shin-Nippon SRW-5000 in a separate cohort of 150 subjects aged 18–37 years (average 20.1 (SD 4.2) years, median 19.0 years), 45% of whom were male. The Shin-Nippon SRW-5000 is an infrared open view autorefractor found to be valid and repeatable compared to subjective refraction in both adults and children.^{10–11} Subjects were positioned such that the eye under test viewed a Maltese cross at 5 metres, so that the instrument was directly aligned with the visual axis of the eye. Five readings were taken in quick succession (power in increments of 0.125 D, cylindrical component axis to 1°). PowerRefractor measures were taken by another optometrist, as described above.

Statistical analysis

As the refractive error of the two eyes are related, only data from the right eye were analysed. The bias between measures

(the mean difference, standard deviation, and 95% confidence limits) were calculated and presented graphically.¹² Comparison between measures were performed using paired two tailed *t* tests. Assessing the variance in the astigmatic component poses a problem in the conventional clinical notation.⁹ Therefore the sphere, cylinder, and axis component were converted into a vector representation for analysis¹³: a spherical lens of power MSE (the mean spherical equivalent = sphere+[cylinder/2]); Jackson cross cylinder at axis 0° with power J_0 (= -[cylinder/2] cos[2×axis]); Jackson cross-cylinder at axis 45° with power J_{45} (= -[cylinder/2] sin[2×axis]).

RESULTS

The refractive error of the sample, as represented by the subjective refraction, ranged from -8.75 to +4.00D mean spherical equivalent (MSE mean = -1.44 (SD 2.44) D). The maximum amount of measured astigmatism was -4.50DC.

Prescription component differences between the PowerRefractor and subjective and objective SRW-5000 refraction are shown in Table 1. The mean difference in components measured by the PowerRefractor were in better agreement with non-cycloplegic subjective refraction than the SRW-5000 autorefractor, but were variable in both cases (Figs 1 and 2). The broken lines on the graphs (95% confidence interval) indicate the extent to which the PowerRefractor might over-read or under-read compared to the alternative methods examined (that is, the PowerRefractor might read as much as 1.28D above or 1.18D below subjective refraction for MSE).

There appears to be no bias in the accuracy of the PowerRefractor with the type or magnitude of refractive error (slope of regression line <0.05), although there are a few outlying values to the data, principally those with high myopia. Approximately 39% of PowerRefractor readings were within ±0.25D, and 67% within ±0.50D of the MSE as found by subjective refraction and 31% were within ±0.25D, and 57% within ±0.50D of the MSE as found by the SRW-5000 autorefractor (Fig 1B).

Figure 2 shows the difference in the J_0 and J_{45} component of patients' refractions between subjective refraction, SRW-5000 autorefractor and PowerRefractor compared to the mean value. Approximately 50% of PowerRefractor measures were within ±0.25D and 74% within ±0.50D of the cylindrical component of the prescription found by subjective refraction and 49% were within ±0.25D and 81% within ±0.50D of the cylindrical component found by SRW-5000 autorefractor. The axis of the cylindrical component was less reliable than the spherical and cylindrical power components (Table 2). However, if only cylindrical components ≥0.75D are considered (as these are likely to have more than a 0.1 logMAR affect on distance visual acuity if significantly off axis), the accuracy of cylindrical axis calculated by the PowerRefractor is found to be improved.

Intersession repeatability (that is, the standard deviation of differences between five measures taken on one occasion)

Table 1 Mean difference (SD) in refractive components between the PowerRefractor and non-cycloplegic subjective or SRW-5000 autorefractor objective refraction

Refractive component	PowerRefractor v subjective refraction		PowerRefractor v Shin-Nippon SRW-5000	
	Mean difference (D)	Significance	Mean difference (D)	Significance
MSE	+0.05 (0.63)	0.41	-0.20 (0.72)	<0.001
Sphere	+0.17 (0.56)	<0.01	-0.14 (0.77)	<0.05
J_0	+0.09 (0.28)	<0.01	+0.11 (0.31)	<0.001
J_{45}	-0.02 (0.15)	0.15	-0.02 (0.18)	0.23
Cylinder	-0.24 (0.52)	<0.001	-0.11 (0.58)	<0.05

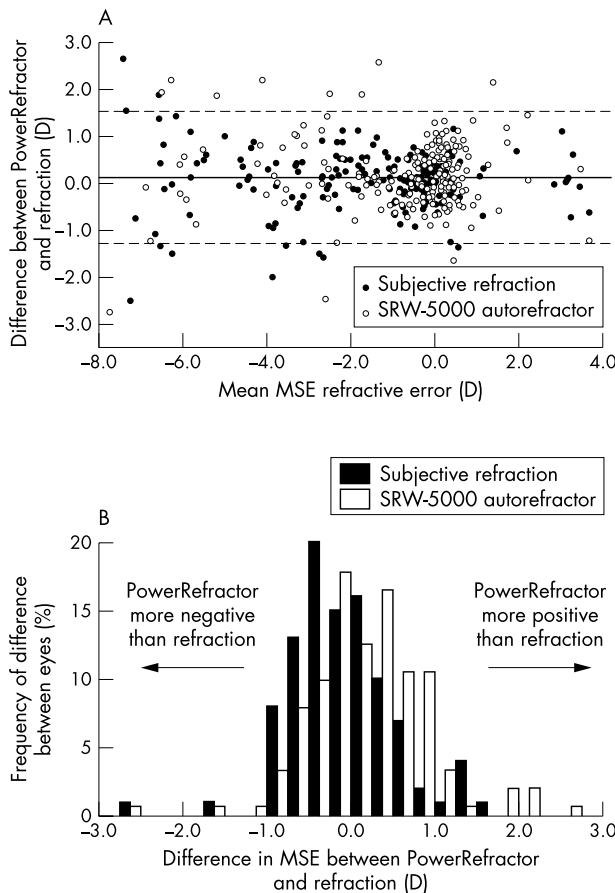


Figure 1 Difference between PhotoRefractor measures and subjective or SRW-5000 autorefractor objective MSE refraction. N=100/150 eyes.

was 0.050D for the spherical component, 0.062D for the cylindrical component 0.062D for the mean spherical equivalent, 0.036 for the J_0 and 0.029 for the J_{45} component. Table 3 presents the mean intrasession differences between the prescription components. These were found to be small, with the majority of the second visit prescriptions falling within plus or minus 0.50D of the initial measurement.

DISCUSSION

The ability of the PowerRefractor to measure continuously from a remote location, binocular parameters of the complete oculomotor triad, will prove to be of great value in optometric and ophthalmological research. Commercial photorefractive devices have been available for a number of years, but only for static measure of refractive error. For example the MTI

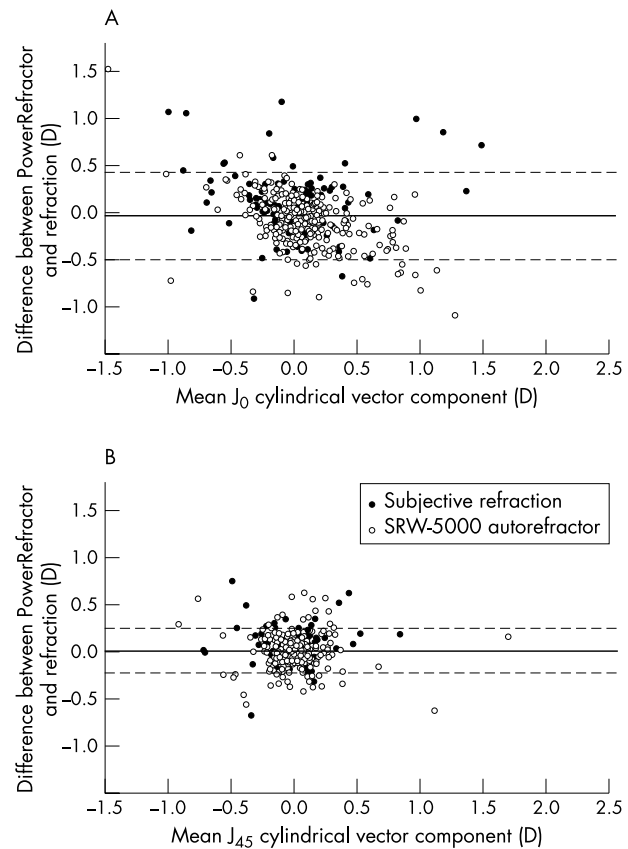


Figure 2 Difference between PhotoRefractor measures and subjective or SRW-5000 autorefractor objective J_0 and J_{45} vector components of refraction. N=100/150 eyes.

photoscreener is used in preschool screening in the United States, but requires the Polaroid of the imaged pupil crescents to be measured individually by a trained observer.¹⁴ Schaeffel and Howland¹⁵ tried to digitise this process, but were limited by the processor speed at the time, the dead zone obscuring low prescriptions and the non-linearity of the brightness across the pupil. The TOMEY ViVA and PR2000 were found to have only reasonable accuracy up to ± 3.00 D,^{16, 17} which may be the result of using a single light source, resulting in a large dead zone and a non-linear intensity gradient versus refractive error.¹ Linearity is improved by using LEDs at more than one eccentricity below the knife edge¹⁸ and by measuring the slope of the brightness profile across the pupil rather than the height of the pupil crescents.¹⁹

Although on average the PowerRefractor prescription was similar to that of subjective refraction, the range of differences was large (up to 3.5D), with 95% of readings

Table 2 Comparison of the axis of the cylindrical component measured by the PowerRefractor with both non-cycloplegic subjective and SRW-5000 autorefractor objective refraction

PowerRefractor ν	All prescriptions with a cylindrical component (%)		Prescriptions with a cylindrical component (subjective) ≥ 0.75 D (%)	
	Subjective	SRW-5000	Subjective	SRW-5000
No of subjects	74	124	30	37
Within $\pm 5^\circ$	32	23	40	41
Within $\pm 10^\circ$	54	37	67	59
Within $\pm 15^\circ$	65	50	80	73
Within $\pm 20^\circ$	70	56	87	76

Table 3 Difference in refractive component of the PowerRefractor found between different sessions

	MSE	J ₀	J ₄₅	Sphere	Cylinder
Mean difference	0.06	-0.001	0.003	0.07	-0.01
SD of differences	0.36	0.11	0.05	0.36	0.12
Within ±0.25D (%)	84	-	-	86	92
Within ±0.50D (%)	96	-	-	96	100
Within ±0.75D (%)	98	-	-	98	100

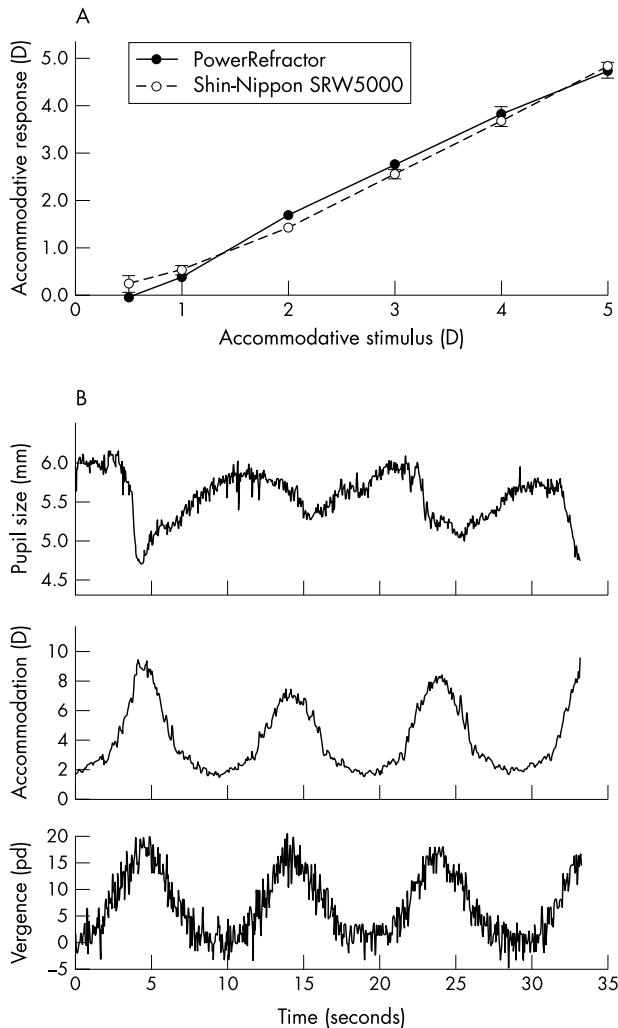


Figure 3 (A) Accommodative stimulus response curve for an emmetropic subject measured with the PowerRefractor and SRW-5000; (B) changes in the oculomotor response triad for the same subject binocularly viewing a target oscillating at 0.1 Hz between 10 and 50 cm.

within ±1.12D (Fig 2). This was particularly the case with myopic prescriptions over -4.0D, confirming the stated accuracy range of the PowerRefractor by Choi and colleagues.² However, the discrepancy between the PowerRefractor prescription and subjective refraction within this range could still be up to 2.5D. Undercorrecting myopia by such a degree would severely reduce a patient’s visual acuity and in young children could lead to impaired visual development. Two subjects with a prescription of greater than -10.0D were assessed outside of the study, for whom the PowerRefractor

indicated a prescription of only -3.0 to -4.0D. Compared to the Shin-Nippon SRW-5000 autorefractor, the PowerRefractor prescription was more negative and again had a wide range of differences. Both autorefractors measure refractive error using image analysis techniques of infrared light reflected from the fundus, although the PowerRefractor measures the light gradient and the SRW-5000 the reflected image size. Compared to previously validated open field autorefractors (for example, the Canon R-1 and Shin-Nippon SRW5000) the PowerRefractor is, on average, just as accurate, but approximately 24–42% more variable.^{10 20}

Inter-session and intra-session repeatability of the PowerRefractor was found to be small and was similar to previously validated open field autorefractors.^{10 20} This would indicate that the variability is due to the lack of individual calibration, the poor accommodative stimulus of the camera head LEDs, and perhaps the linear range of the change in light gradient across the pupil with refractive error,¹⁹ rather than stability of the imaging technique. An emmetrope focusing accurately at the camera distance should have a uniformly illuminated pupil. However, chromatic aberration, lead of accommodation, and in children small eye artefacts, all combine to produce focusing error and hence a light gradient across the pupil. As a slope change of +0.50 translates to approximately 1.0D, small changes in slope can have a significant effect of apparent refraction. In addition, as the camera head is closer than optical infinity, a ≤-1.0D myope, emmetrope and pre-presbyopic hypermetrope could all appear to have the same refractive error when focusing on the camera head LEDs at 1 metre. A more suitable target would be a non-accommodative distant target (such as a spot of light) with +1.0DS added to the internally generated prescription.

Figure 3 demonstrates the accommodative stimulus response curve for an emmetropic subject measured with the PowerRefractor and SRW-5000 and changes in the oculomotor triad when binocularly viewing a target oscillating sinusoidally at 0.1Hz between 10 cm (10D) and 50 cm (2D) from the subject. The stimulus response curve shows the accuracy of the technique compared to a well validated instrument and the trace to an oscillating target, the potential for the PowerRefractor to be a valuable tool in ophthalmological research.

In conclusion, the PowerRefractor is a practical and effective autorefractor over the range of refractive error (-8.75 to +4.00D) and age (18–45 years) assessed. It is likely to have a particular use in the screening of children and patients unable to give a subjective response. The variability, particularly with high myopia is, however, of some concern, with potential under correction of over 1D in ~7% of cases. The instrument will also be useful in research as it is able to measure remotely accommodation, pupil size, and gaze direction in both eyes simultaneously at 25 Hz, providing objective measures of the oculomotor system while subjects binocularly view a natural scene in an unenclosed and unrestricted environment.

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