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Measurement of refractive error and accommodation with the photorefractor PowerRef II

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Abstract

The infrared photorefractor PowerRef II (PR II; PlusoptiX AG, Nürnberg, Germany) uses the principle of eccentric photorefraction. In eight subjects the mean non-cycloplegic refraction measured with the 'Full Scan' mode of the PR II at a far viewing distance (0.2 D) was significantly more hypermetropic by 0.6 D compared with subjective refraction. The mean accommodation differed by about this same amount between the PR II and the Canon R1 at three different viewing distances (3, 2 and 1 D). The PR II refraction at the 1 m reference distance was 0.25 D more hypermetropic compared with the subjective refraction at far (5 m); these measures were moderately correlated ($r = 0.7$). To determine temporal changes, the 'Dynamic Scan' mode was used over a 2-min period: the mean intraindividual standard deviation was 0.32 mm for pupil diameter and 0.29 D for accommodation, while the absolute measurement error of the 'Dynamic Scan' was found to be <0.12 D for the accommodation data. Interindividual reliabilities were satisfactory. However, the PR II did not provide a continuous stream of data and the specified sampling frequency of 25 Hz was rarely realized.

Keywords: accommodation, automated photorefraction, PowerRef II, PowerRefractor, pupil size

Introduction

Measuring accommodation in various visual environments is one aspect in the wide field of human factors research. Such applied vision studies require a measuring device that does not interfere with the actual visual condition. For this purpose, automated infrared photorefraction based on the principle of eccentric photorefraction (Bobier and Braddick, 1985; Howland, 1985; Wesemann *et al*., 1991; Schaeffel *et al*., 1993) is a potentially useful technique as it has a remote working distance and the refractive state is determined from a video image of the eyes. As the conventional measurement distance is 1 m from the eyes to the video camera (Schaeffel *et al*., 1993; Choi *et al*., 2000) the camera can easily be integrated into both experimental and field settings.

Some previous studies have reported on the performance of the PowerRefractor, that is no longer commercially available (Wolffsohn *et al*., 2002; Abrahamsson *et al*., 2003; Allen *et al*., 2003; Hunt *et al*., 2003; Suryakumar and Bobier, 2003). In the present study, the PowerRef II (PR II) of PlusoptiX AG (Nürnberg, Germany; Software 3.5) is used, which is technically based on its predecessor, the PowerRefractor. It has an infrared light source on the edge of a mask, eccentric to the optical axis of the camera. If the eye is accurately focused at the camera, the infrared light reflected from the fundus is imaged in the camera plane as an even luminance over the entire pupil. If the eye is defocused, the reflected light spreads out in a cone, the angle of which depends on the amount of defocus. Because the mask covers part of the camera lens, only light which is reflected from the same part of the pupil is imaged. In the case of defocus the resulting light gradient across the pupil is taken to calculate the refractive error.

The PR II provides three modes: the 'Gaze Scan' mode permits measurements and visualizations of the fixation angle and/or the strabismus angle; the 'Full Scan' mode allows binocular full refraction and measurement of pupil size, which is most interesting for

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measuring the static refractive status of the eye; the third mode, the 'Dynamic Scan' mode, allows measurements of temporal changes in pupil size and accommodation (with a simultaneous output of the fixation map). The latter is specified to operate at a temporal resolution of 25 Hz. It is the aim of the present study to determine whether the data of the 'Full Scan' mode match well with the subjective refraction, and with data from an autorefractor that is extensively used in human factor research – the Canon R1 (Canon Inc., Tokyo, Japan) (Matsumura *et al.*, 1983; McBrien and Millodot, 1985). In addition, the 'Dynamic Scan' data were used in order to check the possibility of continuously measuring accommodation during intervals of several minutes.

Three different measurement sessions were conducted to evaluate these properties of the 'Full Scan' and 'Dynamic Scan' modes. Details of each session are described below in three different sections, each followed by the results.

The general set up

For all three measurement sessions, the set up was the same. In order to keep the fixed 1 m distance from the eyes to the video camera and to present fixation targets at different viewing distances, we placed the camera above the subject's eye level and used two dichroic mirrors, which pass visible light and reflect infrared light (see *Figure 1*). According to Seidemann and Schaeffel (2003), the camera was placed in the mid-sagittal plane.

The subjects rested their head in a chinrest. The fixation target (1.5 deg diameter) contained black and white squares with a spatial frequency of 3 cycles/deg and was presented on paper cards or – for the 'Dynamic Scan' – on a TFT computer screen. All measurements were taken with a mean target luminance of 15 cd m^{-2}.

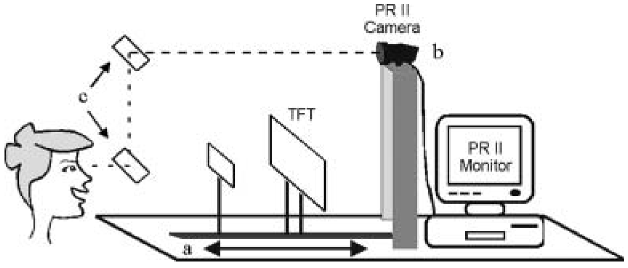

Figure 1. Schematic picture of the measurement set-up. The PowerRef II (PR II) was integrated in a workplace where the distance between the fixation targets and the eyes was variable (a). The camera of the PowerRef II was placed on the top of a tunnel, in the mid-sagittal plane, but above the horizontal eye level (b). To maintain the measurement distance of 1 m, the infrared light of the diodes surrounding the camera was reflected to the eyes through two infrared mirrors (c).

For each session two examiners completed all measures and none of the almost emmetropic subjects – with a minimal visual acuity of 0.8 (in decimal units) in each eye – wore glasses during the measurements.

Session 1

The '*Full Scan*' mode

It has been suggested that a photorefractor has to be calibrated individually to precisely measure the absolute amount of refraction or accommodation (Schaeffel *et al.*, 1993; Hunt *et al.*, 2003; Seidemann and Schaeffel, 2003). Unfortunately, the PR II does not provide the possibility for individual calibrations, which is a first obvious departure from its predecessor.

In the 'Full Scan' mode, as specified by PlusoptiX AG, the PR II determines the refraction sequentially in three pupil meridians and calculates the refractive state from 54 measurements. Best performance is achieved with gaze deviations smaller than 5° and pupil sizes ranging between 3 and 8 mm, with the best output at ≥4 mm.

The 'Full Scan' mode provides spherical and cylindrical refraction, as well as the spherical equivalent (SE) in dioptres. Being mainly interested in the accommodative state of the eye and as SEs describe the retinal image focus better than spheres, the SE was chosen as one dependent variable; however, mean spheres, cylinders and axes during the 'Full Scan' refraction are also reported. Eight subjects (mean age 24 years) participated.

Refraction was measured with the PR II and subjective refraction determined – both at a viewing distance of 0.2 D (5 m). Accommodation was measured binocularly at the three viewing distances of 3 D (0.33 m), 2 D (0.5 m), and 1 D (1 m) – both with the PR II and a Canon R-1 autorefractor. For the Canon R-1, the SE was taken as the median of 10 exposures per condition.

The accommodation data of the Canon R1 and the PR II were first separately regressed against the three viewing distances for the group of eight subjects. Secondly, the data of the PR II were regressed against the readings of the Canon R1 and finally the distance-dependent accommodation curve was calculated individually for each subject to account for the slope as a measure of the individual accommodative near response – although no individual calibration for the PR II could be made. To test for the repeatability of the data, all measurements were repeated on a second day.

Results

The accommodation data were analysed using four separate ANOVA for repeated measures with Greenhouse-Geisser adjusted error probabilities.

First, the refraction of the PR II was compared with the subjective refraction, while in each test the subjects viewed the fixation target at 0.2 D viewing distance. Mean spheres, cylinders and axis for both measurement days are listed in *Table 1a,b*. For further analysis the SE was used. At the 0.2 D distance, the SE of the PR II was significantly more hypermetropic by 0.63 D (S.D. = 0.43) than the subjective refraction ($F_{1,7} = 17.40$, $p < 0.01$), while the mean SE did not differ between the two measurement days (0.03 D: $F_{1,7} < 1$) or between the eyes (0.09 D: $F_{1,7} = 3.59$, $p = 0.10$).

The usual measurement distance of the PR II for describing a person's refractive status is 1 m (1 D), whereas 5 m (0.2 D) is used for subjective refraction. The correlation (averaged over the 2 days) between the SE (PR II) at 1 m and the SE (subjective refraction) at 5 m was $r = 0.77$ for the right eye and $r = 0.63$ for the left eye, respectively. Considering mean absolute differences, the PR II gave readings at the 1 m distance that were 0.25 D (S.D. = 0.18) more hypermetropic – compared with subjective refraction at far ($F_{1,7} = 5.94$, $p < 0.05$; see *Table 1*). The average SEs for all viewing distances are plotted in *Figure 2*.

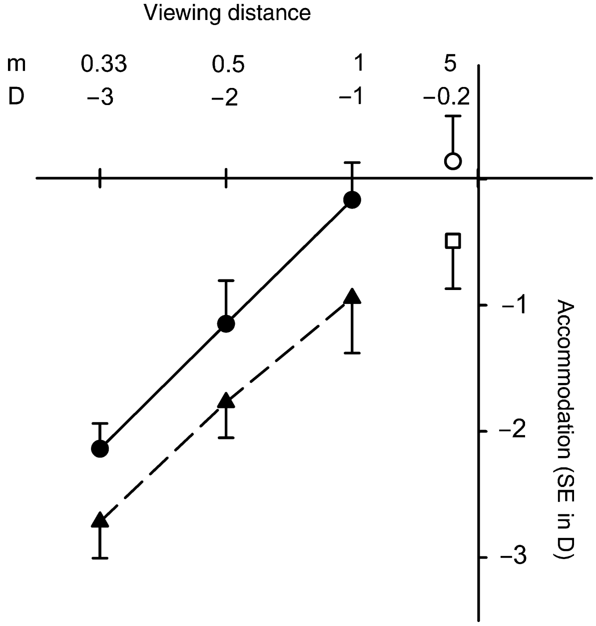

Figure 2. Average accommodation (SE in D; mean across eight subjects, two eyes and two sessions with error bars indicating the S.D.) for the three viewing distances (3, 2 and 1 D) and for the far distance of 0.2 D. Closed circles represent the data of the PowerRef II at viewing distances of 1–3 D, open circles correspond to the PowerRef II data at the viewing distance of 0.2 D, triangles show the data from the Canon R1 and the square represents the subjective refraction at the farpoint.

Accommodation measures (SE) as a function of viewing distance were regressed separately for the PR II and the Canon R1. For the PR II and Canon R1 the accommodation measures were regressed against the viewing distance, yielding an intercept of 0.76 D ($p < 0.01$) and a slope of 0.99 ($p < 0.01$; $R^2 = 0.91$) for the PR II and an intercept of −0.08 D (n.s.) and a slope of 0.88 ($p < 0.01$; $R^2 = 83$) for the Canon R1, respectively. The regression line for the PR II data as a function of the Canon R1 measurements is shown in *Figure 3*: the constant reflected that the PR II results were on average 0.59 D (S.D. = 0.42) more hypermetropic ($p < 0.01$).

Table 1. Mean refraction [sphere and cylinder in D, axis in degree; (S.D.)] measured with (a) the PowerRef II and (b) subjective refraction, with the eight subjects looking at a fixation target at the viewing distance of 0.2 D. Additionally, in (c) the mean refraction of the PowerRef II at 1 D is shown. The refraction data are separated for the two eyes and for the two measurement days

	Sphere	Cylinder	Axis
(a) PowerRef II (0.2 D)			
Day 1			
Right eye	0.23 (0.45)	−0.22 (0.16)	72.25 (78.80)
Left eye	0.19 (0.40)	−0.31 (0.12)	114.00 (52.02)
Day 2			
Right eye	0.41 (0.38)	−0.31 (0.18)	65.68 (85.09)
Left eye	0.16 (0.42)	−0.25 (0.13)	100.64 (69.15)
(b) Subjective refraction (0.2 D)			
Day 1			
Right eye	−0.34 (0.40)	−0.16 (0.27)	29.63 (52.47)
Left eye	−0.34 (0.30)	−0.25 (0.30)	53.75 (64.77)
Day 2			
Right eye	−0.41 (0.48)	−0.22 (0.28)	50.13 (68.56)
Left eye	−0.40 (0.42)	−0.31 (0.22)	90.38 (67.71)
(c) PowerRef II (1 D)			
Day 1			
Right eye	−0.03 (0.41)	−0.25 (0.13)	77.38 (74.23)
Left eye	−0.13 (0.38)	−0.28 (0.16)	68.88 (61.37)
Day 2			
Right eye	0.00 (0.42)	−0.22 (0.09)	57.75 (77.67)
Left eye	−0.19 (0.40)	−0.22 (0.11)	45.35 (56.50)

Additionally, the analysis of variance showed the same significance of the mean difference between the PR II and the Canon R1 ($F_{1,7} = 29.52$, $p < 0.01$), while the difference between the measurement days (0.02 D) and between the eyes (0.01 D) remained non-significant ($F_{1,7} < 1$, and $F_{1,7} < 1$, respectively). As expected, accommodation was affected by viewing distance for both techniques; the main effect of 1.88 D was highly significant ($F_{2,6} = 138.60$, $p < 0.01$). For all analyses, none of the higher order interactions were significant.

The mean individually calculated change in accommodation with changing viewing distance, i.e. the mean individual slope of the distance-dependent accommodation curve (see *Table 2*), was significantly higher (by the amount of 0.11) for the PR II compared with the Canon R1 ($F_{1,7} = 6.93$, $p = 0.04$).

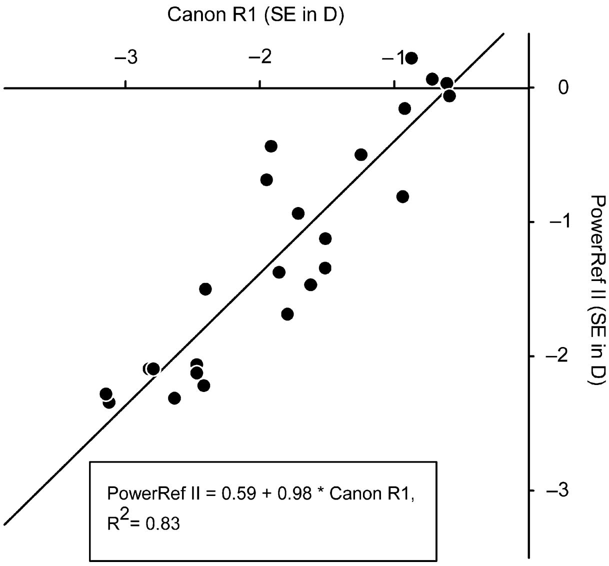

Figure 3. The accommodation response (SE in D) of the PowerRef II regressed against the readings (SE in D) of the Canon R1.

Table 2. Average slope [D (S.D.)] of the individual distance-dependent accommodation curve as a function of day, eye and technique

	Technique	
	PowerRef II	**Canon R1**
Day 1		
Right eye	1.05 (0.13)	0.87 (0.18)
Left eye	0.95 (0.22)	0.81 (0.28)
Day 2		
Right eye	1.05 (0.25)	0.93 (0.13)
Left eye	0.95 (0.21)	0.94 (0.16)

The mean test–retest correlation (averaged over the two eyes) for the individual slope was $r = 0.78$ for the PR II and $r = 0.86$ for the Canon R1, while the mean correlation (averaged over the 2 days and two eyes) between the calculated slopes of the PR II and the Canon R1 amounted to $r = 0.71$.

Discussion

Theoretically the PR II gives a zero reading when refraction corresponds to the camera distance of 1 m while, conventionally, refraction is calculated relative to infinity. In contrast to earlier studies describing the predecessor of the PR II, the PowerRefractor (Choi *et al*., 2000; Allen *et al*., 2003; Hunt *et al*., 2003), our data show a difference between subjective refraction and the PR II readings: the mean subjective refraction (tested at 0.2 D) of −0.5 D shows up as −0.2 D in the PR II (tested at 1 m). Additionally, comparing the accommodative response measurements at different viewing distances with the readings of the Canon R1 showed a significant deviation of the PR II data of 0.59 D – again in hypermetropic direction. A more hyperopic refraction result of the predecessor, the PowerRefractor, was also reported by Seidemann and Schaeffel (2003) relative to streak retinoscopy (1.08 D in SE), by Choi *et al.* (2000) relative to a Nidek AR800 autorefractor (Nidek, Aichi, Japan) (0.5 D in SE), while Hunt *et al.* (2003) observed a more myopic result (0.2 D in SE) relative to a Nippon SRW-5000 (Shin-Nippon, Japan); no difference between the PowerRefractor refraction and readings of the Nidek AR600-A was found by Allen *et al.* (2003).

It should be considered, however, that in contrast to the previous studies, only the mean SE of nearly emmetropic subjects was compared in our sample of eight subjects; the PR II was not tested in cases of large degrees of ametropia.

Our measurements of the accommodative response revealed that the slope of the distance-dependent accommodative function could be tested quite reliably – probably because these are measurements of relative changes. The individual slopes, calculated from the PR II data, were only slightly different from those of the Canon R1, at least within the range of subjects with normal vision.

Session 2

The 'Dynamic Scan' mode

The PR II is described as measuring sphere data and pupil size during the 'Dynamic Scan' with the camera working at a temporal resolution of 25 Hz. The original software package allows the user to record the measurements with a maximal duration of 2 min, but no export of this stream of data was available. The data analysis presented here was only possible after PlusoptiX AG provided a customer-centred software edition, which allows the storage of the 'Dynamic Scan' data, such as spheres and pupil diameters, for external calculations.

During the 'Dynamic Scan', as specified, refraction in the vertical meridian (accommodation) is calculated and best performance is again achieved with gaze deviations smaller than 5° and the range for pupil size measurement is set to 2–11 mm, but without evaluation of refraction.

Accommodation (sphere data) and pupil size were analysed for fixation intervals of 2 min at 3 and 1 D distance, for the right eye only. Spheres and cylinders of the 10 participants ranged from 0 to −0.25 D, measured by subjective refraction at far.

The subjects looked at the fixation target (as described above) while from time to time one of the black squares slowly disappeared and reappeared. The subjects were asked to count the disappearances. This visual task was included to ensure steady fixation over the whole 2 min data collection time. In order to test for repeatability, all measurements were repeated on a second day.

Results

For two of the 10 subjects the PR II gave no readings: for the first one, the pupils were too large (>8 mm) and for the second one too small (<3 mm). In a first data analysis the actual time interval between the subsequent single measurements was evaluated (the exact time of each measurement was printed in an additional variable in the output text file). Considering the specified frequency for data sampling of 25 Hz, theoretically 3000 data points (minus losses due to blinks and gaze drifts) should be measured during the 2 min recording period of the 'Dynamic Scan' mode. However, the inspection of our 32 measurement periods (8 subjects × 2 distances × 2 days) revealed that the best period comprised 1472 and the worst period 42 data points during the 2-min period. This suggests a lower and irregular sampling frequency. A distribution of all intermeasurement intervals (ms) showed a maximum between 70 and 90 ms, but intervals between 40 and 57 000 ms also occurred. Thus, data were not recorded at a fixed sampling rate; rather we found periods – ranging from a few milliseconds to several seconds – where no data were found and which were longer than those which could have been due to eye blinks or gaze drifts.

For the analysis of pupil diameter and accommodation all measurements corresponding to a pupil diameter ≤3.0 mm were excluded. Additionally, 10% of the data (5% at each end of the distribution) for each individual condition were deleted in order to correct for artefacts. In a corresponding ANOVA, the mean pupil diameter (averaged over 2 min) showed no difference between the two measurement days ($F_{1,7} = 2.29$, $p = 0.17$), whereas shortening the viewing distance caused an expected significant reduction in pupil size of 0.37 mm ($F_{1,7} = 14.19$, $p < 0.01$).

Table 3 shows the mean pupil diameter for the 2-min periods. Additionally, the mean S.D.s of the individual mean pupil diameter are shown as a measure of intraindividual stability of the data.

Table 3. Average pupil diameter [mm (S.D.)] and mean intraindividual SD (S.D.) from the 'Dynamic Scan' for the two distances and for the 2 days. Data were collected only for the right eye over a 2-min period

Distance	Pupil diameter	Mean intra-individual S.D.
Day 1		
1 D	5.51 (1.07)	0.28 (0.09)
3 D	4.72 (1.08)	0.29 (0.09)
Day 2		
1 D	4.72 (0.58)	0.37 (0.05)
3 D	4.45 (0.58)	0.34 (0.13)

The same analysis of the accommodation data showed no difference between the measurement days ($F_{1,7} < 1$) and again an expected significant difference between the two viewing distances of 1.23 D ($F_{1,7} = 55.74$, $p < 0.01$), when the accommodation data were averaged over the 2-min periods. *Figure 4* shows the accommodation data for all eight subjects. As a measure of intraindividual stability, the mean S.D. of the individual accommodation measurements was 0.29 D (S.D. = 0.20) – although the width of the subjects' data distribution differed noticeably between the subjects (see *Figure 4*). The average deviation of the accommodation data from the expected theoretical value for the two viewing distances was 1.27 D for the near (3 D) and 0.55 D for the far (1 D) distance. The test–retest reliabilities between days 1 and 2 (pooled across the distances) for pupil diameter and accommodation were $r = 0.78$ and 0.77, respectively.

Discussion

The 'Dynamic Scan' mode provides the researcher with a tool to measure the accommodative response with intraindividual S.D. ranging from 0.03 to 0.83 D and to measure the pupil sizes with intraindividual S.D.s ranging from 0.12 to 0.61 mm, respectively. For the accommodation data, four of eight subjects showed broader distributions with obvious outliers (see *Figure 4*), even though 10% of the raw data were already excluded. Maybe chromatic aberrations or artefacts due to small and/or variable pupil size produced light gradients across the pupil where no reliable focus error was established, with a remarkable effect of gradient slope changes on apparent refraction (see Hunt *et al.*, 2003). Nevertheless no constant sampling at a fixed frequency could be found; lack of data for up to several seconds occurred in addition to that missing due to eye blinks. Again the varying pupil diameter, the small pupils or a slight slow gaze drift during the fixation might have prevented accommodation measurements from being taken.

Session 3

The 'Dynamic Scan' mode: determining the measurement noise

Considering the data reported for the 2-min periods of 'Dynamic Scan', the question still remained, whether the great variations in the accommodative response of some subjects were due to real fluctuations or to the

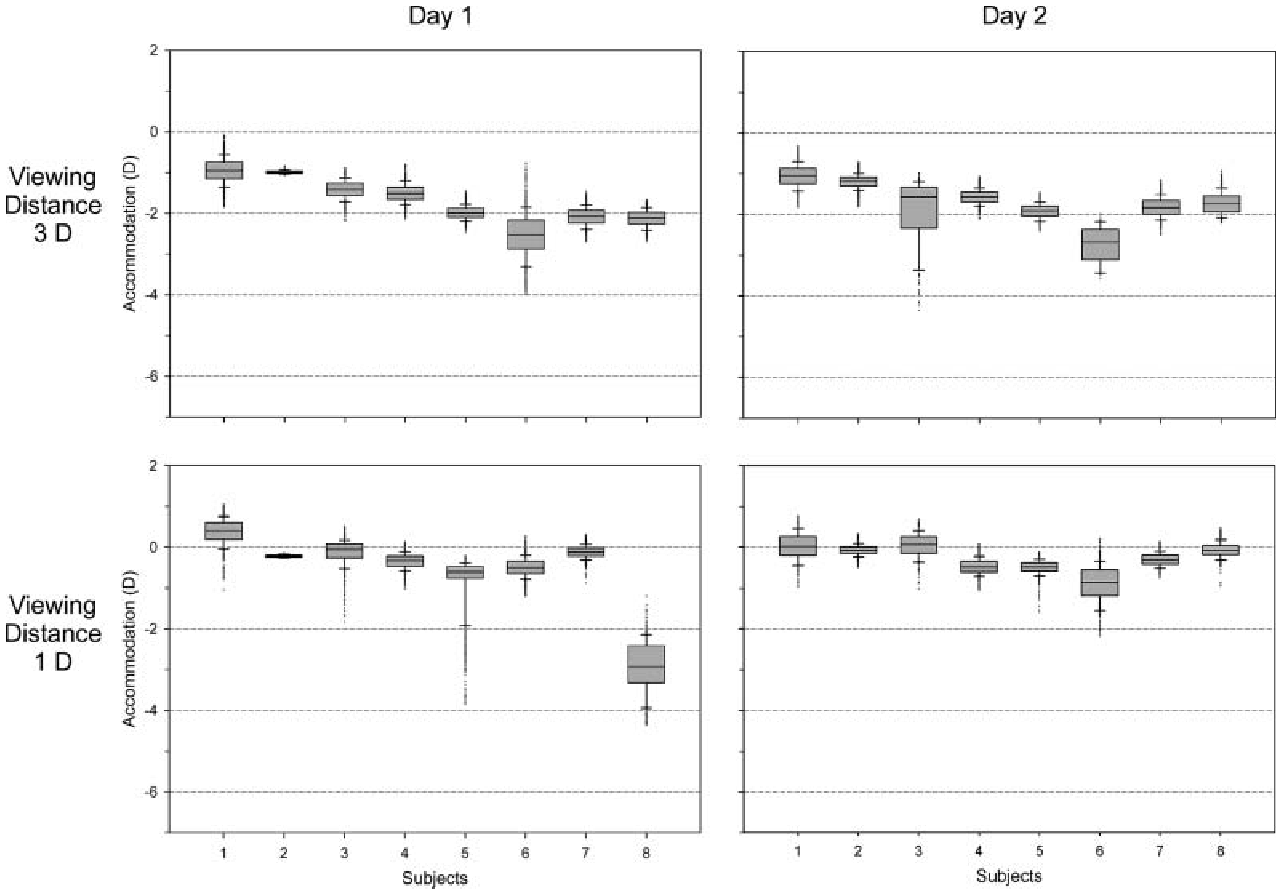

Figure 4. Box- and Whisker-Plots of the accommodation data, measured over the 2-min periods, for all eight subjects (right eyes) and for the two viewing distances (3 and 1 D), separated for each measurement day. Note that the subjects were sorted according to their mean accommodation during the first day at the viewing distance of 3 D.

measurement noise of the PR II system itself. To determine the noise of the system, the left eye of the subjects was occluded with an infrared light transmitting black filter and accommodation measured for both eyes for a 30-s period, while only the right eye fixated the target (described above) at the 1-m distance. In these conditions, any physiological fluctuations of accommodation (assumed to be synchronous in the two eyes) can be eliminated by calculating the difference between the eyes; the remaining measurement noise is assumed as independent in the eyes. Additionally, lenses with various powers (0.12, 0.25, 0.5, 1, 3 and 5 D) were placed in front of the left (occluded) eye, to see whether the PR II gives the same absolute amounts of response. For all lens powers four trials were measured: two without any lens and two trials with a lens in front of the left eye. For all trials the accommodative response was averaged over the 30 s and artefacts due to eye blinks (18.5%) [and extreme outliers (1.5%), for which it was not possible to identify a plausible source] were eliminated. Ten subjects participated, with ametropia (spheres and cylinders) ranging from −0.75 to 0.25 D, measured with subjective refraction at far.

Results

In order to extract the response of the PR II corresponding to each lens, we subtracted the left eye accommodation from the right eye accommodation data for all 24 trials of each subject, which resulted in: **(a)** the refractive difference between the eyes (plus noise) for trials without lenses; **(b)** the refractive difference between the eyes plus the lens response (plus noise) for trials with lenses in front of the left eye.

The S.D. of the left-right difference of trials without lenses (a) is a measure of the dynamic measurement noise. The first 2000 data points across the 12 trials without lenses for each subject were selected and it was found that the S.D.s of the left-right difference (a) ranged from 0.15 to 0.48 D between the subjects (with a mean of 0.25 D).

In a next step, we subtracted the left-right difference in accommodation data of the measurement trial without lenses (a) from those trials where lenses were used (b). The difference (a) − (b) gives the measured response to the lens power; the deviation of this observed lens power from the nominal lens power reflect an absolute measurement error of the PR II. These results for one trial combination (trial without lens minus trial with lens) are plotted in *Figure 5* (differences between the replications were negligible).

Obviously, the difference between expected and observed lens power changed with lens power (average deviation −0.03 D; S.D. = 0.34). Most of the deviations from the expected lens power were underestimations of the positive lenses. Additionally, the S.D. of the mean deviation for each lens ranged from 0.16 to 0.57 D indicating that for the PR II interindividual differences caused quite large deviations of the readings from the objective lens power for some lenses and some subjects (see *Figure 5*).

Nevertheless, for the 10 subjects the average absolute deviations of the PR II readings from the different objective lens powers were small (mostly < 0.12 D; ranging from −0.17 to 0.20 D) and even the trials with the smallest lens of 0.12 D differed significantly from those trials without a lens in front of the left (occluded) eye ($F_{1,8} = 35.57$, $p < 0.01$).

Discussion

In order to answer the question of whether the variation of the accommodation data in *Figure 4* is due to the PR II noise or individual fluctuations over the 2-min measurement periods the eye was measured with added objective lens powers. The readings of the PR II showed only small mean deviations from various lens powers, indicating that the variations in accommodation in *Figure 4* were mainly due to individual fluctuations of accommodation. But again the deviations of the PR II reading from the lens powers varied between the subjects, with some subjects having deviations of 0.5 D and more. (Note that *no* individual calibration for measuring accommodation is provided by the PR II system, as mentioned in Session 1).

General discussion

The PR II allows one to measure accommodation with a video camera installed at a 1 m distance from the eyes. This is an advantage for many test conditions (e.g. studies in visual ergonomics) compared with conventional autorefractors that require optical instrumentation installed close to the eyes. The prerequisite of successful measurements with the PR II is that a headrest is used to maintain stable test conditions and that the pupil size falls within the operating range. However, during the experiments, additional limitations of the PR II were found.

Unfortunately, the absolute mean value of refractive data provided by the PR II is 0.59 D more hypermetropic at different viewing distances compared with the refraction of the established Canon R1. Additionally, the PR II refraction at the system reference of 1 m is by 0.25 D more hypermetropic than subjective refraction at 5 m. This deviation questions the absolute calibration of the system as long as there is no possibility of individual

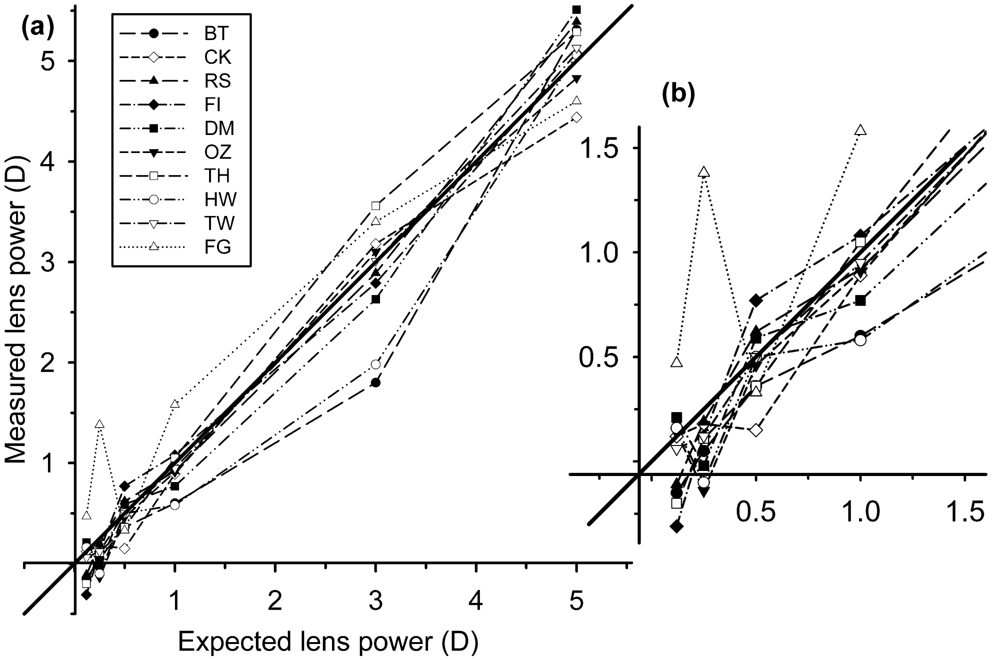

Figure 5. Individually measured lens powers (D) after calculating the difference between measurements with and without lenses in front of the (occluded) left eye as a function of objective lens powers (the different symbols reflect the eight subjects). In (a) all lenses (0.12, 0.25, 0.5, 1, 3 and 5 D) are shown, while (b) is a close-up of the low-powered lenses of 0.12, 0.25, 0.5 and 1 D.

calibration. However, the PR II refraction at the system reference of 1 m correlates moderately with the subjective refraction at far (5 m) – at least in the present range of small ametropia – and the relative changes of response accommodation with varying viewing distance fit quite well the data of a Canon R1 autorefractometer.

It was striking that the data measured via the 'Dynamic Scan' mode were not available for external calculation without specified software. Furthermore the accommodative and pupillary data were not measured as a continuous stream of data at the specified frequency of 25 Hz, nor of 12.5 Hz, respectively. Nevertheless, using the 'Dynamic Scan', pupil size and accommodation could be measured with quite good reliabilities and with a mean intraindividual S.D. of <0.5 mm for pupil diameter and <0.5 D for accommodation. Additionally, the mean deviation of the 'Dynamic Scan' reading from objective lens powers was small (<0.12 D) and S.D.s of the difference between the eyes ranged around 0.25 D – thus reflecting low absolute and moderate system specific measurement noise.

Although the present study refers only to a small sample of subjects with low ametropia, it shows the potential limitations of the PR II for measurements of accommodation in visual research. Its obvious shortcomings should be eliminated so that the PR II realizes the high performance of its predecessor, the PowerRefractor (see Choi *et al.*, 2000; Seidemann *et al.*, 2002; Seidemann and Schaeffel, 2003; Wolffsohn *et al.*, 2002; Abrahamsson *et al.*, 2003; Allen *et al.*, 2003).

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