1040-5488/05/8204-0298/0 VOL. 82, NO. 4, PP. 298–306
OPTOMETRY AND VISION SCIENCE

ORIGINAL ARTICLE

Assessment of Objective and Subjective Eccentric Refraction

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ABSTRACT: *Purpose.* When performing perimetry, refracting subjects with central visual field loss, and in emmetropization studies, it is important to accurately measure peripheral refractive errors. Traditional methods for foveal refraction often give uncertain results in eccentric angles as a result of the large aberrations and the reduced retinal function. The aim of this study is therefore to compare and evaluate four methods for eccentric refraction. *Methods.* Four eccentric methods were tested on 50 healthy subjects: one novel subjective procedure, optimizing the detection contrast sensitivity with different trial lenses, and three objective ones: photorefraction with a PowerRefractor, wavefront measurements with a Hartmann-Shack sensor, and retinoscopy. The peripheral refractive error in the horizontal nasal visual field of the right eye was measured in 20° and 30°. *Results.* In general, the eccentric refraction methods compared reasonably well. However, the following differences were noted. Retinoscopy showed a significant difference from the other methods in the axis of astigmatism. In 30° eccentric angle, it was not possible to measure 15 of the subjects with the PowerRefractor and the instrument also tended to underestimate high myopia (<-6 D). The Hartmann-Shack sensor showed a myopic shift of approximately 0.5 D in both eccentricities. The subjective method had a relatively larger spread. *Conclusions.* This study indicates that it is possible to assess the eccentric refraction with all methods. However, the Hartmann-Shack technique was found to be the most useful method. The agreement between the objective methods and the subjective eccentric refraction shows that detection contrast sensitivity in the periphery is affected by relatively small amounts of defocus. (Optom Vis Sci 2005;82:298–306)

Key Words: peripheral vision, refractive errors, eccentric refraction, detection, contrast sensitivity, photorefraction, wavefront aberrations, retinoscopy

Eccentric correction is needed in different fields of vision research. It is often difficult to assess the peripheral refraction in large eccentric angles, and traditional refraction methods give uncertain results. The aim of this study is therefore to compare four different methods for eccentric refraction.

The human eye is by nature optimized for central vision and it is well known that oblique astigmatism, i.e., astigmatism induced by the oblique angle of the incident light, and other aberrations greatly increase with the off-axis angle in the periphery.[1, 2] In healthy eyes, the peripheral vision is mainly used for tasks with lower demands on retinal image quality such as orientation and motion detection. The peripheral optics of the eye can therefore have larger errors than foveal vision without being considered disturbing. However, the peripheral errors have attracted large interest in certain fields of vision research. It is, for example, important to correct the eccentric refractive errors to perform accurate psychophysical measurements of the peripheral retinal function such as perimetry and detection measurements.[3] The peripheral optics might also influence the process of emmetropization and is therefore investigated in myopia development research.[4, 5] In low vision, there are an increasing number of patients without foveal vision, i.e., with central visual field loss, and thus totally relying on their remaining peripheral vision.[6] This condition is often a consequence of age-related macula degeneration. A recent study has shown that the remaining vision for these people can be improved by correcting the eccentric defocus and astigmatism.[7, 8]

Measuring the peripheral optics and refractive errors with traditional methods is often difficult as a result of the reduced retinal function and the large aberrations. In the periphery, the lower sampling density of the retina can limit high contrast resolution,[3] which implies that a conventional subjective resolution test will be less sensitive to refractive errors. Another difficulty with traditional subjective refraction is the large aberrations, which lead to a less well-defined far point. The same problem arises for retinoscopy performed in eccentric angles; the aberrations make the point of neutralization more difficult to assess.[9] It is therefore a need to investigate and compare different techniques to perform eccentric refraction. In study mentioned here of people with macula degeneration, off-axis refractive errors were measured by photorefraction with the PowerRefractor instrument.[4, 10, 11] Other methods used to investigate peripheral refraction are: the Zeiss parallax optometer,[12–14] the Hartinger optometer,[15] retinoscopy,[9, 16] the double-pass method,[4, 17–22] the Hartmann-Shack (HS) wavefront sensor,[23, 24] and subjective detection measurements with trial lenses (Berkeley, CA).[25] However, most of these methods were originally developed for central vision, and their accuracy for eccentric refraction has not been well documented. The aim of this study is therefore to compare the eccentric refraction in 50 normal healthy subjects measured with three different objective methods and one novel subjective method.

METHODS

Four methods were used to assess the eccentric refractive error: subjective eccentric refraction, wavefront measurements with a HS sensor, streak retinoscopy, and photorefraction with a PowerRefractor. The methods are described in detail in the subsequent sections and can be seen in the photos in Figure 1. The eccentric refraction of the right eye of 50 subjects was measured with natural pupils. Every subject was measured in 20° and 30° from the visual axis in the horizontal nasal visual field. However, because of the long measurement time, the subjective eccentric refraction was only performed in 30°. The subjects were also foveally refracted with traditional subjective refraction and their binocular vision was assessed. The different eccentric measurements were performed under as similar conditions as possible. During all measurements, the left eye was corrected with the foveal prescription together with an additional +0.5 D to avoid accommodation. The subject's head was stabilized with a headrest oriented straight, which meant that the subject had to turn his or her eyes to view a fixation target with the left eye. The right eye was uncompensated and blocked so it could not see the fixation target, as shown in Figure 2. The apparent size (2.5°) and luminance (~120 cd/m^2) of the fixation target was kept constant and the background illumination in the room was <1 lux. The measurements were performed on two different occasions. The foveal refraction and the subjective eccentric refraction were assessed first, and on the next occasion, the three objective measurements were performed.

Twenty-nine male and 21 female subjects from 19 to 72 years old (mean = 34 years) participated in the study. All subjects had healthy eyes with normal binocular vision. The foveal refraction of the right eye ranged from +3.75 D to -7 D (mean = -0.75 D) in spherical value and the cylinders ranged from 0 D to -2.75 D (mean = -0.5 D). The subjects were instructed not to wear contact lenses on the days of measurement. The measurements followed the tenets of the Declaration of Helsinki and were approved by the local Research Ethics Committee. All subjects gave informed consent before participation.

Subjective Eccentric Refraction

As mentioned in the introduction, peripheral resolution acuity can be less sensitive to uncorrected refractive errors, and Wang et al. suggested that contrast detection acuity should instead be used.[25] Therefore, a novel subjective method was developed that optimized the peripheral detection contrast sensitivity with different trial lenses. A moving Gabor stimulus (spatial frequency 2 cycles/degree, window size 4°, velocity 1 cycles/s, and mean luminance 20 cd/m^2, created with WinVis software, Neurometrics Institute) with variable contrast was presented on a computer monitor. The subject's right eye viewed the stimulus through different trial lenses, whereas the left eye only viewed the fixation target at a distance of 3 m. The contrast of the stimulus was increased loga-

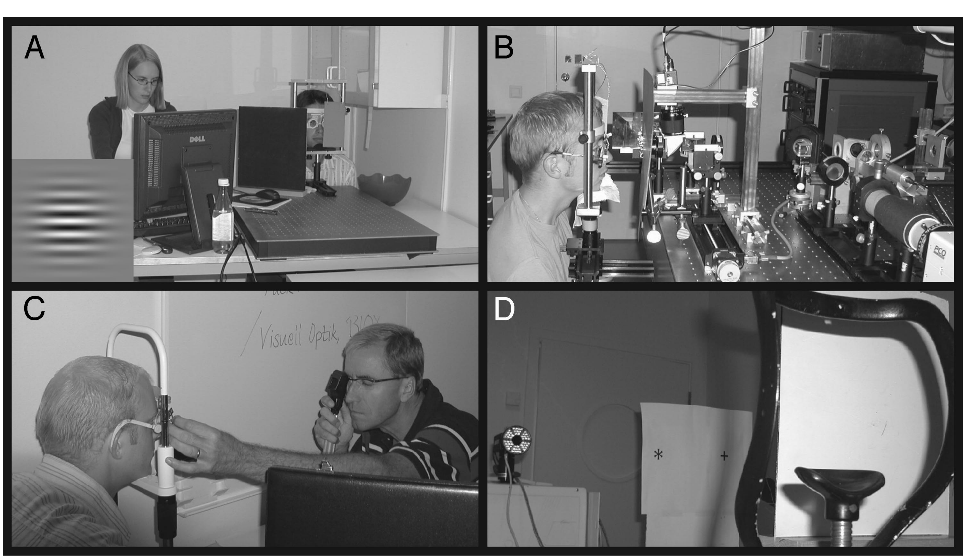

FIGURE 1.
The four methods to assess the eccentric refraction: A: the subjective eccentric refraction (inset: the Gabor stimuli); B: the Hartmann-Shack sensor; C: retinoscopy; and D: photorefraction.

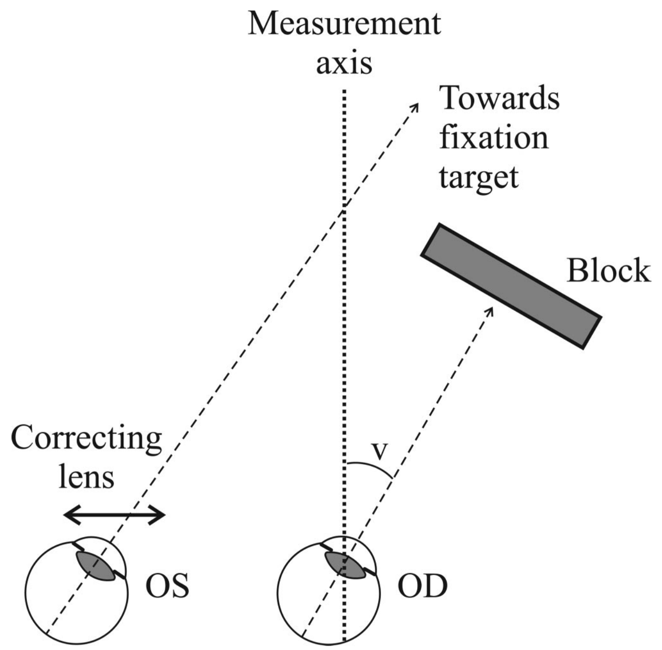

FIGURE 2.
The principle of the setup in all four methods. The right eye (OD) of each subject was measured in 20° and 30° (angle v) in the horizontal nasal visual field. The left eye (OS) was corrected and viewed the fixation target.

rithmically until it was detected by the subject, who should then push a button. This was practiced a couple of times before the actual measurement started. During the subjective eccentric refraction, the contrast sensitivity was measured at least twice for each lens. The lens that gave the highest contrast sensitivity was selected. The lenses were first evaluated in steps of 1 D and then refined in steps of 0.25 D. A zero-diopter lens was used to test ±0 D. The measurements were performed straight through the trial lenses to make sure that no astigmatism was induced.

The trial lenses were added in three steps with a spherical lens, a cylindrical lens with axis 90°, and a crosscylinder in 45°/135°, respectively. In the first step, the lines of the grating were oriented horizontally and an optimal spherical lens was found to correct the refractive error in the 90° meridian of the eye, i.e., it is not the spherical equivalent. With this spherical lens in place, a vertical grating was used to find the power of an additional cylindrical lens with axis 90°. This cylindrical power together with the spherical corrected the refractive error in the 180° meridian of the eye. With the optimal powers in the 90° and 180° meridians in place, the remaining error, according to the theory of astigmatic decomposition,[26] was a crosscylinder in meridian 45°/135° and the circle of least confusion was thus on the retina. Finally, the power of this remaining crosscylinder in 45°/135° was optimized with the lines of the grating oriented along the 45° meridian of the eye. Unfortunately, crosscylinders with a power larger than ±1 D were not available. Therefore, if the necessary crosscylinder power was too large, a cylinder with axis 45° was instead used, which generated a line focus instead of a point focus on the retina. However, this was accounted for when the subjective refraction was calculated (see "Results").

Hartmann-Shack Sensor

An HS sensor was used to measure the eccentric wavefront aberrations in each angle, as an average of three separate measurements. The subject viewed the fixation target, 3 m away, through a mirror. In this HS setup, the pupil of the eye was imaged (magnification ×0.85) on a lenslet array with 325 μm × 325 μm lenslets and a focal length of 18 mm.[24] The resulting spot pattern was unwrapped, i.e., for each lenslet, the corresponding spot was found, with a novel software algorithm.[27] Like in most HS systems, the wavefront was reconstructed from the displacements of the spots with Zernike polynomials.[28–31] When the refractive errors were calculated from the wavefront, the large off-axis aberrations must be taken into account. The reconstructed wavefront was therefore used to simulate the point-spread function of the eye together with a large number of different corrections. The refractive correction that gave the largest Strehl ratio, i.e., the highest peak of the point-spread function, was chosen.[24, 32]

Retinoscopy

Streak retinoscopy was performed eccentrically by an experienced low-vision optometrist (J.G.) without any prior knowledge about the refractive state of the eye or the results from the other methods. Traditional clinical with-and-against movement was used to estimate neutralization. During the measurements, the fixation target was located 3 m away.

Photorefraction

Infrared photorefraction was performed eccentrically with the PowerRefractor instrument[4, 10, 11] (Multi Channel Systems GmbH, Tübingen, Germany), originally designed for foveal refraction. The subject was sitting 1 m away from the instrument and the fixation target was placed at the same distance. The measurement in every angle was an average of three separate measurements.

RESULTS

The eccentric refractions found with the different methods are spectacle corrections, which have been adjusted to position the far point at infinity, i.e., the dioptric distance to the fixation target has been added. The refractions are expressed in terms of spherical equivalent, M, crosscylinder in 0°/90°, J0, and crosscylinder in 45°/135°, J45:

$$M = S + \frac{C}{2}$$

$$J0 = -\frac{C}{2}\cos(2\theta)$$

$$J45 = -\frac{C}{2}\sin(2\theta) \qquad (1)$$

where S is the sphere, C is the cylinder (negative cylinder convention was used) and θ is the cylinder axis from the HS sensor, retinoscopy, and PowerRefractor methods, respectively. The trial lens powers from the subjective method were recalculated in the following manner:

$$M = \text{Sph} + \frac{C90}{2} - \frac{1}{3}$$

$$J0 = \frac{C90}{2}$$

$$J45 = -C45 \quad (2)$$

where Sph is the power of the spherical lens found in the first step, C90 is the power of the cylindrical lens in step two, and C45 is the power of the crosscylinder in the last step. The additional minus one-third diopter in M is to adjust for the distance to the fixation target. Note that the values of J0 and J45 have to be combined to describe the cylinder, e.g., with a negative J0 value, J45 = 0 D means that the axis is 90° and J45 <0 D will change the axis in the direction toward 135°.

Figures 3 and 4 show the results of the different eccentric refraction methods in 20° and 30° in the horizontal nasal visual field. In the graphs, the horizontal axes represent the corrections found with the HS sensor and the vertical axes represent the data from the other methods. Ideally, if all methods gave exactly the same correction, all data points should lie on a straight line through zero with slope one. This line of equality is plotted for comparison. To find significant differences between the refraction methods, multiple Wilcoxon paired-sample signed-rank tests have been used for all combinations of the methods (three and six comparisons for 20° and 30°, respectively). The significant differences are given in Table 1 together with the individual mean differences and standard deviations found in each of the comparisons. The results from M, J0, and J45 and in the different angles were treated separately. To compensate for the increased risk of a type I error when multiple comparisons on the same sample were made, the principle of Bonferroni was used. This mean that each individual hypothesis test was made on the $\alpha = 0.001$ level, which resulted in a total experiment-wise error rate of <0.01. However, the risk of overlooking a true difference, i.e., a type II error, was larger. Pearson correlation coefficients were not used for the statistical analysis because they depend on the range of the true refractions of the subjects and because a high correlation does not necessarily imply a high agreement.[33] In 30°, the PowerRefractor could not measure 15 of the subjects as a result of the large oblique angle, which makes the

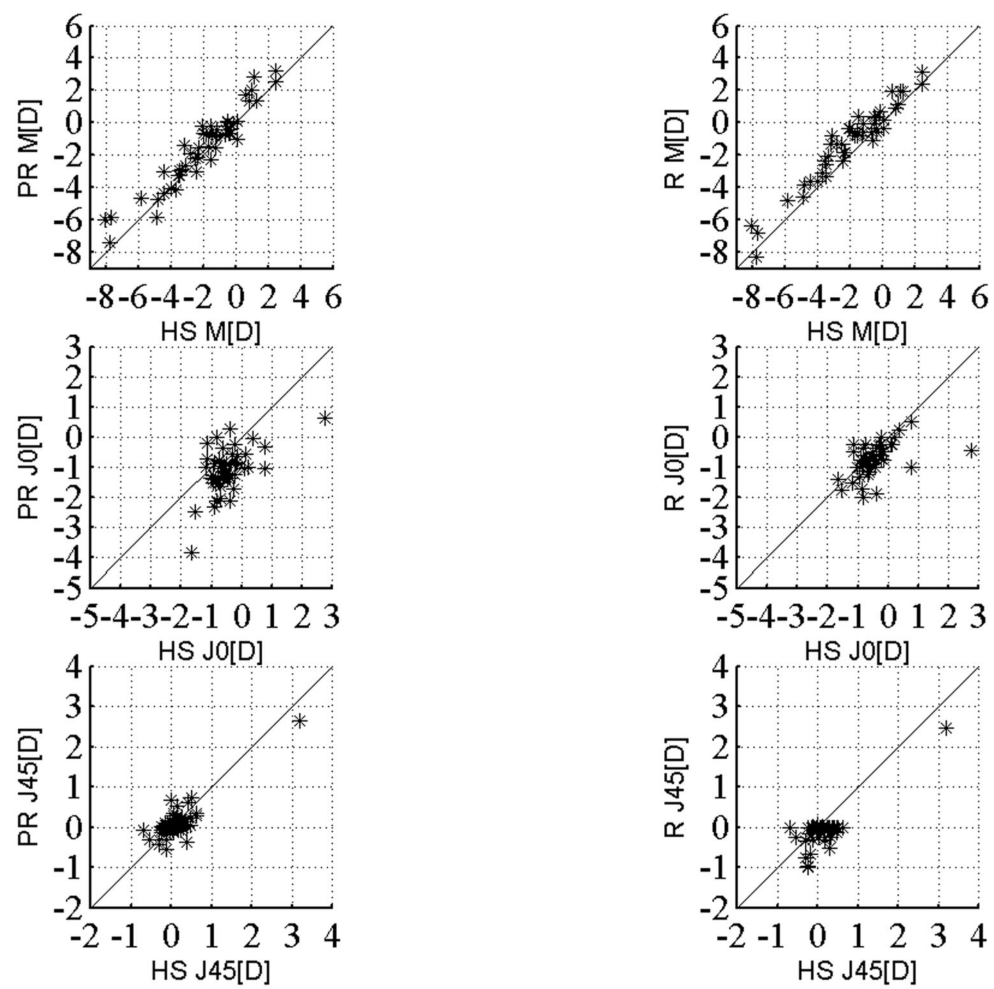

FIGURE 3.

The results from the eccentric refraction in 20° expressed in spherical equivalent (M) and crosscylinders in 0°/90° (J0) and 45°/135° (J45). The corrections found with photorefraction (PR) and retinoscopy (R) are plotted against the corrections found with the Hartmann-Shack sensor (HS).

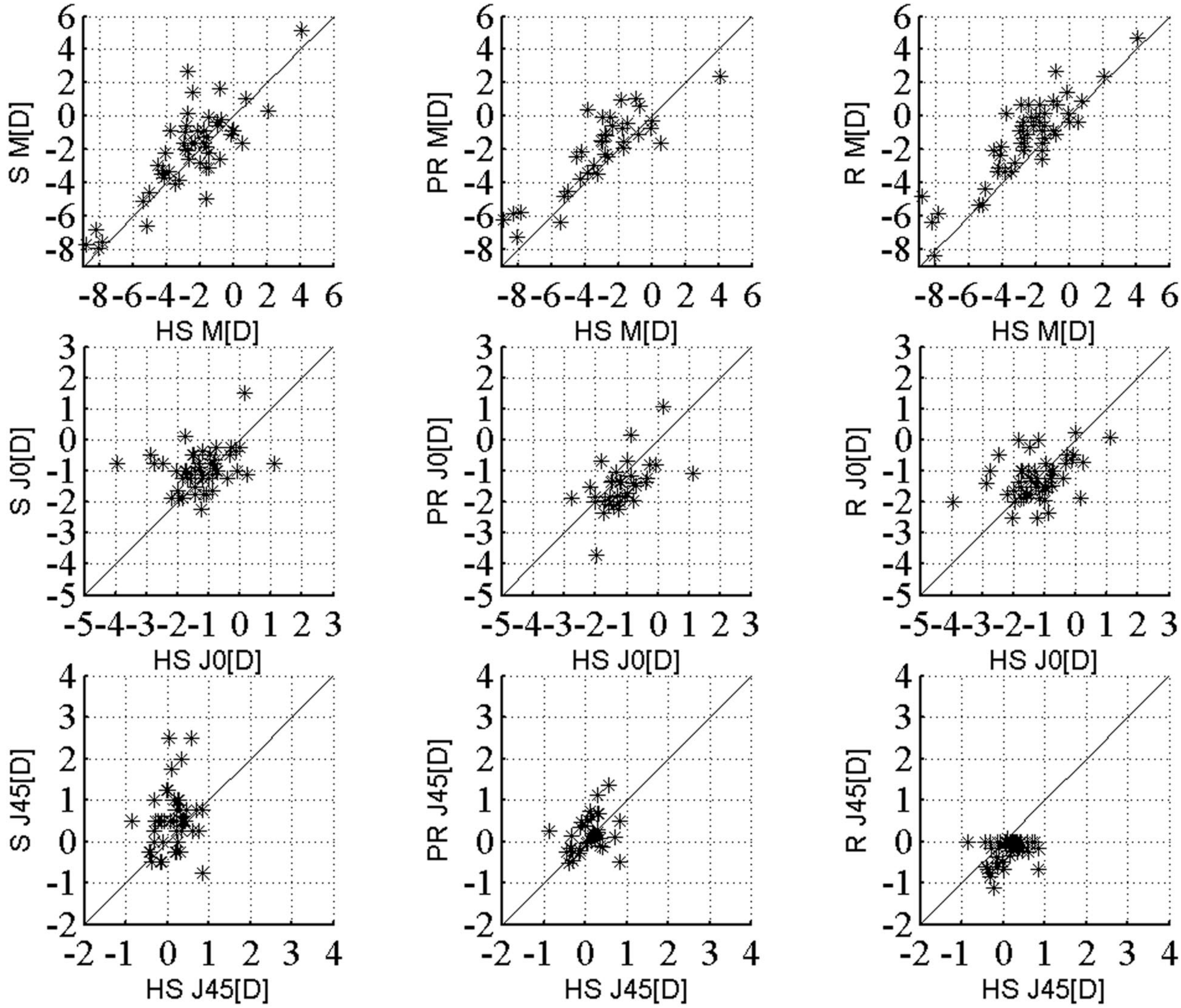

FIGURE 4.

The results from the eccentric refraction in 30° expressed in spherical equivalent (M) and crosscylinders in 0°/90° (J0) and 45°/135° (J45). The corrections found with subjective eccentric refraction (S), photorefraction (PR), and retinoscopy (R) are plotted against the corrections found with the Hartmann-Shack sensor (HS).

visible area of the pupil too small.[4] On one subject, the subjective measurement of J45 failed, i.e., no optimum C45 could be found; the J45 correction of that subject has therefore been removed from the analysis.

As can be seen in the graphs of Figures 3 and 4 and in Table 1, the different methods for eccentric refraction compared reasonably well and they all found cylinder axes close to 90°. One characteristic is the asymmetric distribution in J45 for retinoscopy vs. the HS sensor. Both in 20° and 30°, retinoscopy finds J45 equal to 0 D for a large number of subjects, whereas the other methods do not. This means that retinoscopy showed a smaller spread in J45 and found a cylinder axis of exactly 90° more often than the other methods. In M, the retinoscopy and the PowerRefractor measurements agree well in both 20° and 30°. However, at high myopic M values ($<$-6 D), they both show a tendency to underestimate the refraction compared with the HS sensor and the subjective method. This was confirmed when foveal measurements with the PowerRefractor were compared with traditional subjective refraction in this study (see Fig. 5). In M in 30°, retinoscopy is the only objective method that is significantly different from the subjective method ($p < 0.01$ two-tailed) and the same is true for the PowerRefractor in J0. Another characteristic is that the HS sensor constantly overestimates myopia with approximately 0.5 D, which was also seen in foveal measurements (see Fig. 5). A statistically significant difference of -0.25 D in M was found between foveal HS sensor measurements and traditional subjective refraction ($p < 0.01$ two-tailed). This difference was constant at high ametropia and showed no tendency to increase. The novel subjective eccentric refraction in 30° generally showed a larger spread compared with the other methods, especially for J45. Many subjects found the subjective method very tiresome, which might partly explain the spread. However, the mean differences in M and J0 between the HS and the subjective (-0.51 D and -0.30 D, respectively) and between the subjective and the PowerRefractor measurements (-0.49 D and 0.54 D) were of the same magnitude as those between the HS and the PowerRefractor methods (-0.99 D and 0.35 D).

TABLE 1.
Comparisons between the different methods for eccentric refraction in 20° and 30° expressed in spherical equivalent (M) and cross cylinders in 0°/90° (J0) and 45°/135° (J45)

		M			J0			J45		
		Sign diff from	Mean diff	SD	Sign diff from	Mean diff	SD	Sign diff from	Mean diff	SD
20°	(HS–PR)	0	−0.51	0.77	0.25	0.63	0.67	—	0.03	0.28
	(HS–R)	0.25	−0.77	0.72	0	0.27	0.62	0	0.23	0.31
	(PR–R)	—	−0.25	0.68	0	−0.36	0.70	0	0.19	0.28
30°	(HS–S)	—	−0.51	1.57	—	−0.30	0.95	—	−0.35	0.74
	(HS–PR)	0	−0.99	1.37	—	0.35	0.74	—	−0.06	0.48
	(HS–R)	0.5	−1.24	1.22	—	0.01	0.87	0	0.33	0.38
	(S–PR)	—	−0.49	1.38	0	0.54	0.80	0	0.43	0.59
	(PR–R)	—	−0.19	0.83	—	−0.23	0.90	0	0.36	0.39
	(S–R)	0.25	−0.73	1.18	—	0.31	0.74	0.25	0.68	0.71

HS, Hartmann-Shack sensor; PR, photorefractor; R, retinoscopy; S, subjective eccentric refraction.

All values are in diopters. The "sign diff from"—columns show whether there is a significant difference between two methods and, in that case, how large this difference is ($p < 0.01$ two-tailed). For example, a zero means that the difference between two methods is significant different from zero diopters. A minus sign means that no significant difference was found. The two other columns show the mean difference (mean diff) and the standard deviation (SD) when comparing the methods pair wise.

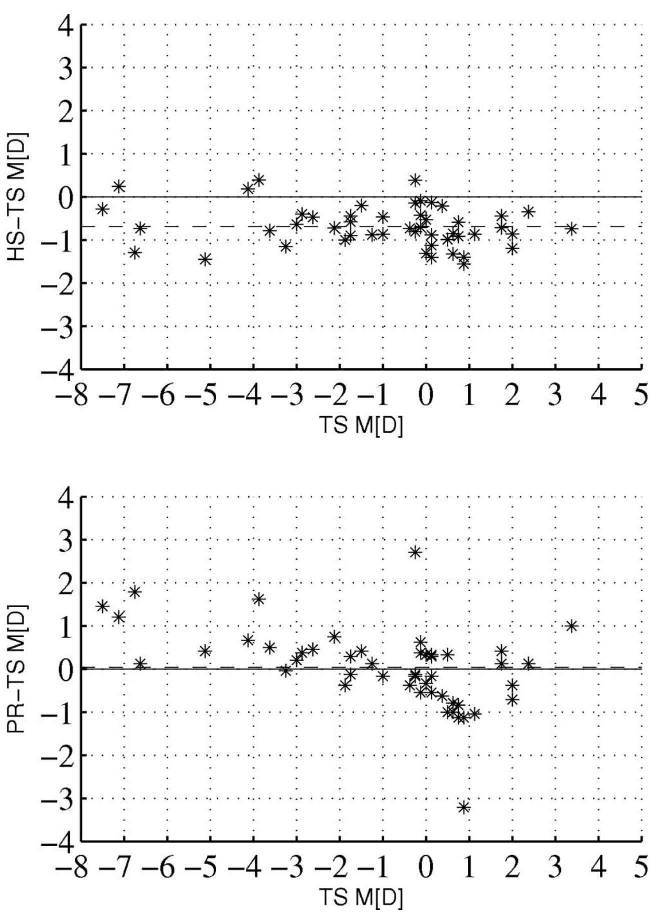

FIGURE 5.
Foveal measurements of the spherical equivalent (M) with the Hartmann-Shack (HS) sensor and the PowerRefractor (PR) compared with traditional subjective refraction (TS). In the upper/lower graph, the difference between HS/PR and TS are plotted as a function of the M values for TS. The dashed line indicates the mean difference and the solid line marks zero difference.

DISCUSSION

The reason to use a subjective method for eccentric refraction is to try to find "the gold standard," comparable to how conventional subjective refraction is used in central vision. As was mentioned earlier, the eccentric refraction is more difficult to assess as a result of the aberrated optics, which produce poor retinal image quality, and as a result of the low-resolution capacity of the retina, which might undersample the retinal image. The novel subjective eccentric refraction method has been designed to measure detection contrast sensitivity, because detection acuity in the periphery is considered to be limited by contrast rather than by the sampling density of the retina.[3, 34] In conformity with Wang et al.,[25] the subject views sinusoidal gratings through different trial lenses and the spread of the retinal image in the meridian perpendicular to the lines of the grating is minimized. However, instead of maximizing the detection acuity for a certain contrast, this novel method maximizes the contrast sensitivity for a spatial frequency of 2 cycles/degree. This frequency was chosen because it is lower than the spatial resolution of the retina, which Anderson et al. found to be about 6 cycles/degree in 30° of eccentricity,[34] and it should therefore be no risk of aliasing phenomena. A higher frequency will give a more distinct maximum in contrast sensitivity as a function of lens power, but at the same time the interval at which the object can be detected at all is smaller and thus more difficult to find. Wang et al. approximated the axis of astigmatism to be close to 90° or 180°. However, when the power of the astigmatism is large, a small difference in the axis of the correction will have a large influence on the retinal image quality. The current method therefore implements an idea of the Humphrey Vision Analyzer[26]: to minimize the retinal blur in three meridians and use astigmatic decomposition to find the axis of the astigmatism. The astigmatic decomposition is used because the investigated meridians might not coincide with the astigmatic meridians of the eye. This means that the lens powers have to be recalculated to correspond to the refractive error in the measured meridian.[35, 36] In this case, the lens powers are influenced by the elliptic shape of the oblique pupil. However, this effect is probably small as long as the axis of the elliptic pupil and the astigmatic meridians of the eye are nearly coaxial.

The main difficulty with the subjective eccentric measurements was to stabilize the attention and the bias, i.e., the criterion of seeing, of the subject. The subject was encouraged to push the button as soon as something was detectable on the screen, even if he or she could not see that it was a grating. However, the long measurement time of approximately 30 to 45 minutes was very tiresome, and many subjects found it hard to concentrate that long. A two-interval forced-choice paradigm with grating detection would have been a less demanding task for the subjects and might have lowered the spread of the subjective method. Despite this difficulty, it was possible to measure contrast sensitivity as a function of lens power with a clear maximum for all but a few subjects. This maximum indicates that relatively small amounts of defocus affect the contrast sensitivity. An example of the outcome of a successful measurement is shown in Figure 6. As can be seen in the graph, the contrast sensitivity is different for different orientations of the grating, a phenomena also noted by other authors.[37] This was also confirmed by some of the subjects, who found it more difficult to detect the vertical and oblique gratings.

The HS sensor accurately measures the total wavefront aberrations of the eye and can thus give a description of how the retinal image is affected by the aberrations. The difficulty is to find what is subjectively considered to be the optimal refraction. In this study, the selected refractive correction optimizes the Strehl value of the retinal image.[24] Guirao and Williams found that image plane metrics like this one correspond well to subjective impression.[32] The Strehl optimization corresponds to the SRX-method (Strehl ratio computed in spatial domain) in the comparison study by Thibos et al.[38] In that study, the SRX-method was ranked 11 in a comparison of 33 different metrics to predict the foveal refraction from wavefront measurements. However, although Thibos et al. could not find any significant difference between the SRX-method and 13 of the other top 15 metrics, the Strehl optimization might not be the best metric in the periphery, where the aberrations are large.[39] The fact that the HS sensor overestimates myopia might be partly explained by this choice of metric together with some proximal accommodation resulting from the small distance between the subject and the HS sensor. An advantage with optimization of image plane metrics is the trial and error process, which will not be misled by local maxima. A local maximum for a certain correction means that the retinal image quality is better here compared with what it is for other, slightly different corrections. However, if the correction is changed more radically, another minimum can be found with even better image quality. The trial and error technique avoids this by objectively comparing a wide range of corrections. There are commercially available HS sensors for foveal measurements, some of them with very high accuracy and dynamic range of refraction. With some changes in software, they should be possible to use for eccentric refraction as well.

Retinoscopy showed a more narrow distribution of J45 values with a high frequency of zero and almost no positive values, which means that it more often found cylinder axes between 90° and 110°. This difference in J45 either means that retinoscopy is reflecting the true variability of the subjects and that the other methods have a much larger measurement variation and uncertainty or that retinoscopy could not detect small deviations from the vertical axis. We are inclined to believe that retinoscopy was insensitive to small variations in the axis of the cylinder. The primary argument for this statement is the large amount of eccentric aberrations, which make the reflex distorted and very difficult to interpret compared with on-axis retinoscopy. The

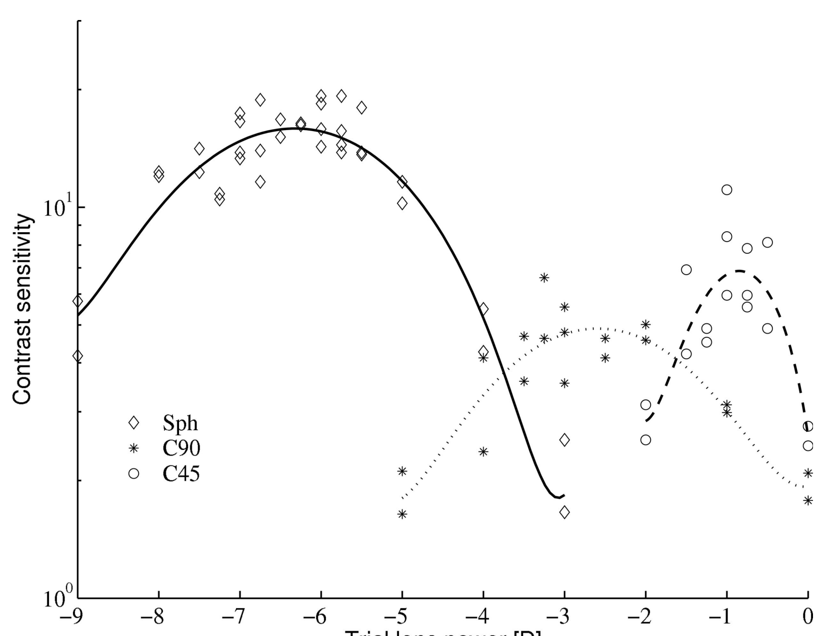

FIGURE 6.

An example of the outcome of the three steps in the subjective eccentric refraction. The contrast sensitivity is plotted as a function of trial lens power. The curves are fitted to the mean contrast sensitivity found with each trial lens. Sph, spherical lenses; C90, cylinder lenses with axis 90°; C45, crosscylinders in 45°/135°.

optometrist who performed the retinoscopy used traditional clinical with-and-against movement and not the sliding door effect mentioned by Rempt et al.[16] The optometrist had no prior knowledge of the refraction, but he was aware that theory predicted the axis of the astigmatism to be close to 90°. This knowledge might have produced a bias, especially when the reflex was difficult to interpret. The pupil sizes during retinoscopy were probably smaller than during the other measurements because of the bright lamp used. This miosis should lower the influence of spherical aberration, and this could be one explanation as to why retinoscopy underestimated the myopia compared with the subjective refraction. This hyperopic shift compared with subjective measurements has earlier been found in a study by Millodot and Lamont.[40] Our conclusion, that retinoscopy is unreliable in eccentric measurements in large angles, is not in agreement with studies by Wang et al.[25] and Millodot et al.[40] However, these studies only included three to four subjects and did not attempt to assess the axis of the astigmatism. Furthermore, a recent study of off-axis retinoscopy found that the eccentric refraction was more difficult to assess when the degree of eccentricity increased.[9]

The PowerRefractor was included in the study because it is a commercially available instrument, which has been used earlier to measure eccentric refraction.[4, 7] It is also one of the few autorefractors that can measure off-axis and it has the advantage of reporting the viewing angle. However, the instrument is not designed for off-axis measurements and had difficulties in large eccentric angles. The underestimation of high myopia found in this study was expected because the linear range of the PowerRefractor is from +4 D to -6 D according to Choi et al.[10]

CONCLUSIONS

This study has evaluated and compared four different methods for eccentric refraction: a novel subjective method, wavefront measurements with an HS sensor, streak retinoscopy, and photorefraction with a PowerRefractor instrument. It was possible to estimate the spherical and cylindrical eccentric errors with all methods. However, the PowerRefractor could not measure all subjects and had difficulties with large myopia. Retinoscopy was difficult to perform in large angles as a result of the large aberrations. The subjective method was very time-consuming and showed a relatively large variance. Therefore, wavefront measurements with the HS sensor appear to be the most useful method, although it showed a constant shift toward myopia. The PowerRefractor also proved to be useful in moderate angles up to 20° off-axis and for myopia <-6 D. This conclusion is in agreement with another resent study, which also found the HS sensor to be useful in eccentric measurements.[41] The HS sensor also has the advantage of providing the total wavefront aberrations of the eye. This information can be used to better interpret the influence of the aberrations on the retinal image quality and different image plane metrics can be evaluated. It can also be used to investigate whether the large aberrations influence the results of the eccentric refraction methods differently. An additional result is that the eccentric refraction is very individual and varies largely between subjects, which has also been noted in other studies.[1, 2, 12, 13, 16] In summary, this study shows that wavefront measurement is a useful tool to assess the eccentric refraction.

ACKNOWLEDGMENTS

The authors thank Professor Gunnar Englund and Professor Per Söderberg for valuable discussions. The authors are also grateful to all the subjects for volunteering to this study. The financial support for this research, provided by the Carl Trygger Foundation, the Göran Gustafsson Foundation, and the Carl-Johan and Berit Wettergren Foundation, is greatly appreciated.

Received June 20, 2004; accepted February 1, 2005.

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