Comparison of the Adaptive Optics Vision Analyzer and the KR-1W for measuring ocular wave aberrations

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Title:

Comparison of the Adaptive Optics Vision Analyzer and the KR-1W for measuring ocular wave aberrations.

Running title:

Comparison of two wavefront aberrometers.

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Background: To assess the agreement in the measurement of ocular aberrations between a new Adaptive Optics Vision Analyser (AOVA, Voptica S.L., Spain) and a commercial aberrometer (KR-1W, Topcon Corp., Japan), both based on the Hartmann-Shack technique.

Methods: One experienced examiner measured 29 healthy right eyes 9 consecutive times with the two instruments. The individual Zernike coefficients and the Root Mean Square (RMS) of each order from the second to the fifth order, the higher order RMS (RMS_{HOA}), the total RMS (RMS_{TOT}) and the values of the spherical equivalent (M) and Jackson cross-cylinder (J_0 and J_{45}) ~~in Dioptres (D)~~ were compared. All aberrations were computed for a 4.0 mm pupil diameter.

Results: ~~The~~ Bland and Altman analysis showed good agreement between instruments and most of the parameters showed no statistically significant differences. Although that the largest mean differences were obtained for the defocus coefficient C(2,0) and the spherical equivalent (M), with a mean difference (±SD) of 0.190 μ~~(mu)~~m (±0.099) and -0.150 D (±0.188), respectively, they were clinically acceptable and significant correlations were found between the AOVA and KR-1 W for the major refractive components such as M (r=0.995, p<0.001), J_0 (r=0.964, p<0.001), J_{45} (r=0.901, p<0.001) and C(4,0) (r=0.575, p~~<~~=0.001).

Conclusion: The results suggest~~ed a~~ good agreement between ~~both~~ instruments. However, accommodation and misalignments of the measurements ~~are likely~~may play~~ing~~ a~~n~~ ~~important~~ role in some of the statistically significant differences that were obtained, specifically ~~in the~~for defocus C(2,0), ~~the~~ vertical coma C(3,-1) and ~~the~~ spherical aberration C(4,0) coefficients, ~~. In any case~~however these differences ~~found~~ were clinically irrelevant.

Keywords: Ocular aberrations, refraction, wavefront aberrometers, agreement.

Wavefront sensing has become part of daily clinical practice, specifically for refractive and cataract surgery and for screening and assessing ocular diseases that modify the ocular aberrometric pattern such as keratoconus. Many instruments have been developed to assess ocular aberrations, the factor that most affects retinal image quality together with intraocular scattering.[1] The aberrometers based on the Hartmann-Shack technique [2,3] are the most widely used.

Thanks to new optical techniques such as adaptive optics technology,[4] it is now possible to measure refraction and higher order aberrations and to correct and modify them in a non-invasive manner. A new clinical device, the AOVA (Adaptive Optics Vision Analyser, Voptica S.L., Spain~~, the new version is currently marketed as AOnEye~~), ~~that~~ includes a Hartmann-Shack aberrometer and an adaptive optics spatial light modulator~~ is now commercially available~~. Spatial Light Modulators (SLM) are active optical devices that work either in transmission or reflective modes and can change the amplitude, phase or polarization of light waves in space and time. For wavefront manipulation purposes (e.g., wavefront correction) control over the phase is required. Deformable mirrors can also be used for similar wavefront manipulations.

The AOVA can perform visual simulations such as correcting and/or inducing certain aberrations, measure visual acuity, contrast sensitivity and glare, simulate different optics (lenses and refractive profiles), and combine optical and visual testing at any distance.

It is common practice to assess the accuracy of every new ophthalmic commercial instrument for repeatability, reproducibility, precision and reliability.[5-14] According to international standards,[15] precision and trueness describe the accuracy of a measurement method. Trueness refers to the closeness of agreement between a measurement and the true or accepted reference value; precision refers to the closeness of agreement between test results. The latter involves the concepts of repeatability and reproducibility. Note that in order to study trueness, the measurement method is assumed to be precise.

When an ophthalmic instrument becomes commercially available it is essential to compare its precision and agreement with other existing instruments. Accordingly, the aim of this study is to ~~analyse~~ compare ~~the~~ aberrometric data measured with the AOVA ~~and to compare them~~ with the KR-1W (Topcon Corp., Japan), an e~~well-~~stablished commercial wavefront analyser also based on the Hartmann-Shack technique ~~and which also includes a Placido disk topographer~~. ~~To our knowledge, no study has reported the agreement of AOVA measurements.~~ The repeatability (precision) of both the AOVA [16] and the KR-1W [12,13] have already been analysed. ~~Authors have reported~~The Root Mean Square of higher order aberrations (RMS$_{HOA}$) in AOVA and KR-1W of 0.078 and 0.014 μ~~(mu)~~m, respectively, suggesting that both devices provide reliable measurements. ~~It must be noted that the topography functions from the KR-1W and the visual simulations from the AOVA were not used in this study.~~ To our knowledge, no study has reported the agreement of the AOVA~~-~~ with another instrument~~measurements.~~

METHODS

Subjects

This cross-sectional study was conducted on healthy subjects recruited from the staff and students of the Faculty of Optics and Optometry of the Technical University of Catalonia (UPC, Terrassa, Spain). Only subjects with best spectacle-corrected visual acuity of at least ~~20~~6/~~20~~6, spherical correction between ± 5.00 D and astigmatic cylinder correction ~~smaller~~ less than or equal to 3.00 D were invited to participate. Participants ~~have~~ had no history of ocular disease, surgery ~~and~~ or pharmacological treatment. ~~In addition, c~~Contact lens wearers were instructed ~~not~~ to cease lens wear ~~them~~ for a complete day ~~just before~~prior to the examination when using soft lenses and ~~the previous~~for three days when using rigid lenses in order to avoid irregular changes in ~~the~~ corneal shape. ~~Furthermore, O~~Only subjects with a pupil diameter of 4 mm or more in mesopic conditions (room illumination was 1 lux) were included in the study because a 4-mm pupil was later used to compute ocular aberrations. The study followed the tenets of the Declaration of Helsinki. All subjects ~~were asked to give~~ gave ~~their~~ written informed consent after receiving a written and verbal explanation of the nature of the study.

Twenty nine right eyes of 29 participants were ~~finally~~ included in the study, with a mean ± standard deviation (SD) in age of 26.5±5.8 years (18 to 52 years). The mean manifest spherical refractive error was -1.26±1.93 D (-4.75 to +3.75 D) and the ~~cylinder~~ mean astigmatic refractive error was -0.76±0.74 D (-3.00 to 0.00 D).

Examination protocol

~~The s~~Subjects ~~who accepted to participate~~ underwent a standardized examination without cycloplegia to determine best visual acuity, manifest refractive error and natural pupil diameter. Next, a sequence of aberrometric measurements, in mesopic conditions, of the right eye of each participant was collected until 9 measurements were obtained using both instruments (in a randomized order). ~~All patients~~Participants were uncorrected ~~in terms of refraction~~ during the wavefront aberration measurement. ~~Moreover, t~~The automatic mode of ~~centring the eye included in~~ the KR-1W instrument which enables centring, focusing and measuring without the operator's input ~~help~~ was used.

Aberration data

Twenty seven parameters, computed using a 4 mm pupil diameter, were used for the analysis: the individual Zernike coefficients from the second (C(2,m)) to the fifth order (C(5,m)), ~~being~~ m being the angular frequency; the Root Mean Square (RMS) of each order from the second ($RMS_{n=2}$) to the fifth order ($RMS_{n=5}$); the RMS of higher order aberrations computed from the third to the fifth order (RMS_{HOA}); the total RMS computed from the second to the fifth order (RMS_{TOT}); and the objective refraction in the form of spherical equivalent (M) and Jackson cross-cylinder (J_0 and J_{45}). Aberrometric data were expressed in micrometres (μ~~(mu)~~m) and ~~computed using a 4-mm pupil. R~~refraction terms were expressed in Dioptres (D).

Statistical analysis

The statistical analysis was performed using SPSS ~~Statistics v~~version 20 (IBM Corp., USA) ~~for Windows~~ and Microsoft Office Excel 2007 (Microsoft Corp. USA). In all cases a 95% confidence interval was used, i.e., a p-value of less than 0.05 was considered to be statistically significant.

The Kolmogorov-Smirnov test was used to evaluate the normality ~~distribution~~ of all variables analysed ~~(p > 0.05)~~. ~~Next, the~~ Bland and Altman analysis was used to study the agreement between the 27 parameters obtained from the two instruments~~data~~.[17] ~~These authors suggested that the mean of the differences between pairs of equivalent measurements should be close to zero and defined t~~The 95% Limits of Agreement (LoA) were calculated as 1.96 times the standard deviation of the mean difference, and confidence limits were calculated for each LoA using Carkeet's exact method[18] considering the LoA's as a pair. ~~within which 95% of the differences between measurements are expected to lie. Finally, a~~A repeated measures MANOVA (Multivariate ANalysis Of VAriance), using the power vector terms (M, J_0 and J_{45}) as the dependent variables, was used to assess whether instrument type (i.e., AOVA and KR-1W) had statistically different refraction terms on average. Analogously, a repeated measures MANOVA using the 15 higher order aberration terms, i.e., the individual Zernike coefficients from the third to the fifth order, as the dependent variables was also performed. ~~In addition, i~~In order to examine each of the dependent variables individually, a paired sample t-test was used to determine statistically significant differences between the values provided by both aberrometers.

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To determine the correlation between measurements of the two devices, bivariate correlations ~~with the Pearson's correlation coefficient (r)~~ were also carried out and quantified using Pearson's correlation coefficient (r).

RESULTS

Firstly, the achieved power was calculated using the G*Power software (v3.0.10) for statistical power analysis~~.~~ ~~[18]~~-[19] ~~Previously to the power computation,~~using the mean of the differences and the mean standard deviation of the differences ~~was calculated~~ for all the Zernike coefficients. These ~~two~~ values ~~were introduced as input parameters~~ ~~al~~together with the significance level of 0.05; the two tailed~~s~~ comparison and the sample size of 29 ~~. The outcome resulted in an achieved~~gave a power of 0.88, which is fairly good for the purpose of the study.

The Kolmogorov-Smirnov test showed that all data were normally distributed ($p > 0.05$). The descriptive data (mean, SD) are shown in table 1. The mean Zernike coefficients and RMS parameters provided by both devices are shown in figure 1. As expected, the largest Zernike coefficient mean value was obtained for the defocus term C(2,0) since all patients were uncorrected during examination~~; defocus is typically the largest aberration in human eyes~~.

Figure 2 shows the Bland and Altman plots for the objective refraction power vectors (M, J_0 and J_{45}) and the Zernike coefficients C(4,0), C(3,-1), C(3,1). Very few outliers in the data sets can be observed and the plots do not show any recognizable pattern, i.e., differences do not systematically vary over the range of measurements, which indicates a good agreement between devices for these terms. Figure 3 illustrates some correlations obtained ~~also~~ for the objective refraction (M, J_0 and J_{45}) and the Zernike coefficients C(4,0), C(3,-1), C(3,1).

The repeated measures MANOVA using the power vector (M, J_0 and J_{45}) terms as the dependent variables showed a statistically significant difference ($F_{3, 26} = 8.18$, $p < 0.01$, Wilk's Lambda = 0.52). Similarly, the repeated measures MANOVA showed also a significant difference between instruments when considering ~~together~~ the HOA coefficients together ($F_{15, 14} = 3.93$, $p < 0.01$, Wilk's Lambda = 0.19).

The examination of each of the dependent variables ~~individually through~~using a paired sample t-test ~~between the values measured with~~to compare both aberrometers is shown in table ~~2~~1. ~~As it can be seen,~~ N~~n~~o significant differences between instruments were found for the majority of parameters linked to individual Zernike coefficients. However, statistically significant differences were obtained ~~in~~ for coefficients C(2,0), C(3,-1) and C(4,0), ~~the spherical equival~~power vectors M and ~~ent (M),~~ J_{45}~~,~~ and ~~the~~ all RMS values. In addition to the paired sample t-test, table ~~2~~ 1 shows Pearson's correlation coefficients for both instruments. Statistically significant correlations ($p < 0.05$) ~~could be established~~were observed for most variables analysed ~~. In this case,~~ eexcept~~ions were found~~ for the following parameters: C(4,-2), C(5,-5), C(5,1), C(5,5) and RMS$_{n=5}$. ~~Nevertheless, it should be remarked that~~However, the mean differences between the AOVA and the KR-1W for these coefficients ~~are~~ were very small (table ~~3~~2), and ~~thus not relevant from a~~ clinically insignificant~~ point of view~~. Additionally, in general the Pearson correlation coefficients decreased as the order of the Zernike coefficient increased. The same tendency ~~could be~~was observed when analysing the RMS values, for which higher Pearson coefficients were obtained for lower order values whereas no correlation was observed ~~in~~ for the fifth order RMS.

Table ~~3~~ 2 shows the mean differences (Mean$_d$), the SD of the mean differences and the corresponding 95% LoA and exact LoA confidence limits between measurements from both instruments according to the Bland and Altman analysis. ~~Confidence limits (CL) have been calculated for each LoA using Carkeet's exact method.[19] They were computed considering both LoA as a pair. It can be seen that t~~The mean differences obtained were very close to zero in all cases. The largest mean difference in absolute terms were found for the defocus coefficient C(2,0) (0.190 μ~~(mu)~~m). ~~Notice that t~~This Zernike coefficient is the main contributor to the spherical refractive error expressed in Dioptres and since the mean difference in spherical equivalent ~~difference~~ between devices ~~turned out to be~~was ~~of~~ -0.15 D (below 0.25 D), it can be considered of ~~no~~ limited clinical significance. Although, as shown in the Bland and Altman plot (figure 2A), ~~.~~ the spherical equivalent difference~~,~~ can be greater than 0.25 D in some individuals.

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DISCUSSION

This study explored the agreement of several ~~aberrometric~~ parameters provided by two commercial ~~instruments,~~aberrometers, the AOVA and the KR-1W, both based on the Hartmann-Shack technique. Our results showed good agreement between measurements from both instruments. However, no inferences regarding the trueness of the aberrometric measurements obtained can be drawn since there is no gold standard.

In general, ~~we obtained~~ better ~~results for the~~agreement was observed for individual Zernike coefficients than for ~~the~~ RMS values. The calculation of the RMS involves a non-linear transformation of the raw Zernike coefficients that makes them ~~not~~ independ~~a~~ent ~~on~~ of the sign of the ~~Zernike's~~ coefficient~~ sign~~. As a consequence of the loss of information, the RMS might overestimate or underestimate the differences between measurements. ~~Indeed, s~~Similar results were obtained by Rozema *et al.*[7] when performing a comparison among several aberrometers.

~~Nonetheless, the RMS is a useful metric of how far, on average, the readings of both instruments are. According to this, t~~The mean difference (Mean$_d$) between the RMS$_{HOA}$ obtained with the AOVA and the RMS$_{HOA}$ obtained with the KR-1W provides an overall estimation of the error present when comparing both devices. In our study this value (±SD) was 0.065 (±0.063) μ~~(mu)~~m as it can be seen in table ~~3~~2. It was computed as

$diffRMS_{HOA} = RMS_{HOA\,AOVA} - RMS_{HOA\,KR-1W}$ (equation 1),

in which the RMS$_{HOA}$ of each device was calculated as

$RMS_{HOA} = \sqrt{\sum_{n=3}^{n}\sum_{-m}^{m}(C(n,m)\cancel{(n,m)_{AOVA}})^2}$ (equation 2).

~~Notice that this~~This estimation does not consider the individual HOA coefficient differences between both devices. ~~For this purpose~~Therefore, ~~it is interesting~~the following equation was used to take into account the mean RMS of the differences of each HOA coefficient (RMS$_{diffHOA}$). ~~That is,~~

$RMS_{diffHOA} = \sqrt{\sum_{n=3}^{n}\sum_{-m}^{m}(C(n,m)_{AOVA} - C(n,m)_{KR-1W})^2}$ (equation 3).

~~In our study, T~~The mean RMS$_{diffHOA}$ (±SD) ~~turned out to be~~was 0.077 (±0.029) μ~~(mu)~~m. In both cases the mean value and SD are fairly similar. When comparing these results with the magnitude of the measured RMS$_{HOA}$ for each instrument, which is 0.171 and 0.106 μ~~(mu)~~m for the AOVA and KR-1W, respectively, it can be seen that both the diffRMS$_{HOA}$ and the RMS$_{diffHOA}$ are smaller. ~~Despite the fact that T~~The differences between wavefront measurements in both devices differed by less than the magnitude of the measured wavefronts, 0.077 is about 73% and 45% of the RMS$_{HOA}$ for KR-1W and AOVA respectively. This suggests that for small wavefront errors (i.e., eyes with ~~small amount~~low levels of aberrations, which ~~is in~~was ~~general~~ the case for most of the participants enrolled in this study) the overall agreement when measuring HOA between devices might not be as good as expected.

In contrast, statistically significant differences in the defocus ~~coefficient~~ C(2,0), ~~the~~ vertical coma C(3,-1) and ~~the~~ spherical aberration C(4,0) coefficients were also obtained. These results seem to reflect a general trend observed when assessing the agreement between ocular aberrometric devices.~~, since similar reports have been published.~~[5,7,8,11]

~~The measurements obtained for the s~~Spherical aberration and defocus ~~act as accommodation indicators [5,9] and~~ are of particular interest since their variability is linked to the change in the accommodative state of the eye.[5,9] ~~If we take into account~~Given that all patients underwent the examination without cycloplegia, ~~even~~ although both instruments presented a target ~~to the~~imaged at infinity, small changes ~~of~~ in accommodation ~~could still have~~may play a role in the observed differences since the instruments~~as they~~ were placed very close to the participants' eyes. Proximal~~Instrumental~~ accommodation ~~for~~ induced by both devices could not be exactly the same.

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In addition to changes in accommodation, some authors have suggested that an optical system with spherical aberration generates third-order coma as a linear function of pupil decentration.[11,20,21] Although in our study ~~the~~ illumination was ~~always~~ kept constant, differences in the targets of the analysed instruments could have induced small pupil displacements which could ~~slightly~~ contribute to the ~~increase of higher order aberrations~~differences observed in coma.

On the other hand, ~~other~~ factors related to the patients' variability can also affect ~~the~~ agreement between devices. For instance, López-Miguel et al.[13] suggested that saccadic eye movements and tear-film instability can significantly reduce the reliability of higher order aberration measurements. ~~Regarding instrument's variability, i~~It has also been ~~previously~~ reported that ~~the~~ instrument alignment ~~procedure~~ can affect ~~the~~ measurement~~accuracy of a measurement~~.[7,13] Related to this, we must take into account that the KR-1W has an automatic mode of centring that was used in all patients whereas a manual alignment was used for the AOVA.

Even though manufacturers make adjustments to minimize its influence, the wavelength of the light source included in each instrument might have also had an impact on the results. ~~The paper of~~ Rodriguez *et al.*[14] suggests that the main difference found between aberrometers (they compared the Zywave, the Tracey and one experimental prototype) is due to ~~the~~ longitudinal chromatic aberration caused by the use of different wavelengths. In particular, the authors found the sphere to differ by ~~a maximum of~~up to 0.7 D between infrared and green wavelengths.[6] ~~In our case, the~~ The AOVA operates at 808 nm and the KR-1W in a range from 820 to 840 nm according to their specifications,~~.~~ which~~This~~ suggests that the difference in wavelength might have had only a small influence in this study.

In conclusion, this study shows that the agreement (analysed ~~considering~~ over a 4 mm pupil~~ size~~) between the AOVA and KR-1W instruments is ~~overall~~ good, although small but statistically significant differences in some Zernike coefficients and RMS parameters were found. Due to the lack of a gold standard or a universal calibrated test eye, it is important to highlight that deviations in measurements between aberrometers do not ~~mean~~ necessarily mean that they are unreliable. On the other hand, ~~the~~ patient~~s'~~ and ~~the~~ instrument~~s'~~ variability ~~effects can~~could be reduced by increasing the number of measurements for each eye, as most instrument's companies advise~~ to do~~. Future studies should compare wavefront analysers in different population samples such as in patients undergoing refractive surgery and in patients with corneal disorders such as keratoconus to determine the agreement between devices in eyes with ~~more~~ higher levels of aberrations. In addition, comparison ~~between~~ of devices under cycloplegic conditions would provide data free from the potential influence of accommodation and over larger pupil diameters.

DISCLOSURE OF FUNDING SOURCES

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DISCLOSURE OF POTENTIAL CONFLICT OF INTEREST

The authors have no proprietary or commercial interest in the materials presented.

TABLE LEGENDS

Table 1. Mean value and standard deviation (SD) obtained with the AOVA and the KR-1W aberrometers for: the Zernike coefficients, the Root Mean Square (RMS) of each order and the objective refraction (~~spherical equivalent (~~M, ~~) and Jackson cross-cylinder (~~J_0 and J_{45}~~)~~). p-values of the paired sample t-test and Pearson's correlation coefficients (r) and corresponding significance (p-values) between measurements of the AOVA and KR-1W aberrometers are also shown (*: statistically significant correlations, D: Diopters, µ~~(mu)~~m: micrometers).

	AOVA		KR-1W		Paired t-test	Pearson correlation	
	Mean	**SD**	**Mean**	**SD**	**p**	**r**	**p**
Zernike Coefficients (µ~~(mu)~~m)							
C(2,-2)	0.050	0.150	0.074	0.151	0.060	0.941	<0.001*
C(2,0)	0.965	1.079	0.775	1.016	<0.001*	0.993	<0.001*
C(2,2)	-0.018	0.233	-0.033	0.228	0.104	0.972	<0.001*
C(3,-3)	-0.023	0.048	-0.036	0.043	0.139	0.825	<0.001*
C(3,-1)	0.006	0.042	-0.010	0.048	0.004*	0.834	<0.001*
C(3,1)	0.001	0.048	-0.004	0.047	0.734	0.874	<0.001*
C(3,3)	0.008	0.031	0.006	0.030	0.551	0.764	<0.001*
C(4,-4)	0.002	0.021	0.002	0.012	0.493	0.541	0.002*
C(4,-2)	0.001	0.011	-0.002	0.001	0.253	0.263	0.167
C(4,0)	0.033	0.026	0.013	0.025	0.001*	0.575	0.001*
C(4,2)	0.008	0.033	0.000	0.015	0.249	0.600	0.001*
C(4,4)	0.002	0.025	0.002	0.017	0.458	0.562	0.001*
C(5,-5)	0.003	0.017	-0.000	0.008	0.191	0.183	0.341
C(5,-3)	0.009	0.016	0.005	0.008	0.182	0.584	0.001*
C(5,-1)	-0.002	0.013	0.001	0.001	0.869	0.430	0.020*

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C(5,1)	0.001	0.014	0.002	0.006	0.417	0.364	0.053
C(5,3)	-0.001	0.013	-0.002	0.006	0.847	0.573	<.001*
C(5,5)	-0.002	0.017	-0.001	0.007	0.988	0.254	0.184
Root Mean Squares (μ~~(mu)~~m)							
$RMS_{n=2}$	1.185	0.876	1.024	0.808	<0.001*	0.993	<0.001*
$RMS_{n=3}$	0.120	0.043	0.092	0.033	0.001*	0.492	0.005*
$RMS_{n=4}$	0.089	0.034	0.039	0.019	<0.001*	0.408	0.023*
$RMS_{n=5}$	0.068	0.033	0.025	0.007	<0.001*	0.057	0.761
RMS_{TOT}	1.205	0.871	1.035	0.803	<0.001*	0.993	<0.001*
RMS_{HOA}	0.171	0.060	0.106	0.036	<0.001*	0.379	0.035*
Objective Refraction (D)							
M	-1.570	1.865	-1.419	1.850	<0.001*	0.995	<0.001*
J_0	0.047	0.305	0.041	0.293	0.671	0.964	<0.001*
J_{45}	-0.058	0.192	-0.092	0.192	0.042	0.901	<0.001*

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~~**Table 2.** p-values of the paired sample t-test and Pearson's correlation coefficients (r) and corresponding significance (p-values) between measurements of the AOVA and KR-1W aberrometers (*: statistically significant correlations).~~

	~~**Paired sample t-test (p)**~~	~~**Pearson correlation (r, p)**~~	
~~**Zernike Coefficients (μ(mu)m)**~~			
~~C(2,-2)~~	~~0.060~~	~~0.941~~	~~<0.001*~~
~~C(2,0)~~	~~<0.001*~~	~~0.993~~	~~<0.001*~~
~~C(2,2)~~	~~0.104~~	~~0.972~~	~~<0.001*~~
~~C(3,-3)~~	~~0.139~~	~~0.825~~	~~<0.001*~~
~~C(3,-1)~~	~~0.004*~~	~~0.834~~	~~<0.001*~~
~~C(3,1)~~	~~0.734~~	~~0.874~~	~~<0.001*~~
~~C(3,3)~~	~~0.551~~	~~0.764~~	~~<0.001*~~
~~C(4,-4)~~	~~0.493~~	~~0.541~~	~~0.002*~~
~~C(4,-2)~~	~~0.253~~	~~0.263~~	~~0.167~~

~~C(4,0)~~	~~0.001*~~	~~0.575~~	~~0.001*~~
~~C(4,2)~~	~~0.249~~	~~0.600~~	~~0.001*~~
~~C(4,4)~~	~~0.458~~	~~0.562~~	~~0.001*~~
~~C(5,-5)~~	~~0.191~~	~~0.183~~	~~0.341~~
~~C(5,-3)~~	~~0.182~~	~~0.584~~	~~0.001*~~
~~C(5,-1)~~	~~0.869~~	~~0.430~~	~~0.020*~~
~~C(5,1)~~	~~0.417~~	~~0.364~~	~~0.053~~
~~C(5,3)~~	~~0.847~~	~~0.573~~	~~<.001*~~
~~C(5,5)~~	~~0.988~~	~~0.254~~	~~0.184~~
~~Root Mean Squares (μ(mu)m)~~			
~~RMS$_{n=2}$~~	~~<0.001*~~	~~0.993~~	~~<0.001*~~
~~RMS$_{n=3}$~~	~~0.001*~~	~~0.492~~	~~0.005*~~
~~RMS$_{n=4}$~~	~~<0.001*~~	~~0.408~~	~~0.023*~~
~~RMS$_{n=5}$~~	~~<0.001*~~	~~0.057~~	~~0.761~~
~~RMS$_{TOT}$~~	~~<0.001*~~	~~0.993~~	~~<0.001*~~
~~RMS$_{HOA}$~~	~~<0.001*~~	~~0.379~~	~~0.035*~~
~~Objective Refraction (D)~~			
~~M~~	~~<0.001*~~	~~0.995~~	~~<0.001*~~
~~J$_0$~~	~~0.671~~	~~0.964~~	~~<0.001*~~
~~J$_{45}$~~	~~0.042~~	~~0.901~~	~~<0.001*~~

Table ~~3~~2. Mean differences (Mean$_d$), mean standard deviation of the differences (SD) and 95% Limits of Agreement (LoA) between measurements of the AOVA and KR-1W aberrometers. The 95% Confidence Limit [CL] for each LoA is also shown.

	Mean$_d$	**SD**	**Lower LoA [CL]**	**Upper LoA [CL]**
Zernike Coefficients (μ~~(mu)~~m)				
C(2,-2)	-0.024	0.050	-0.122 [-0.158;-0.103]	0.074 [0.055; 0.110]
C(2,0)	0.190	0.099	-0.004 [-0.076;-0.034]	0.384 [0.346; 0.456]
C(2,2)	0.015	0.055	-0.093 [-0.133;-0.072]	0.123 [0.102; 0.163]

C(3,-3)	0.012	0.028	-0.043 [-0.063;-0.032]	0.067 [0.056; 0.087]
C(3,-1)	0.017	0.026	-0.034 [-0.053;-0.024]	0.068 [0.058; 0.087]
C(3,1)	0.005	0.024	-0.042 [-0.059;-0.033]	0.052 [0.043; 0.069]
C(3,3)	0.002	0.021	-0.039 [-0.054;-0.031]	0.043 [0.035; 0.058]
C(4,-4)	0.001	0.018	-0.034 [-0.047;-0.027]	0.036 [0.029; 0.049]
C(4,-2)	0.002	0.013	-0.023 [-0.033;-0.019]	0.027 [0.023; 0.037]
C(4,0)	0.019	0.024	-0.028 [-0.045;-0.019]	0.066 [0.057; 0.083]
C(4,2)	0.008	0.027	-0.045 [-0.065;-0.035]	0.061 [0.019; 0.081]
C(4,4)	0.000	0.021	-0.041 [-0.056;-0.033]	0.041 [0.033; 0.056]
C(5,-5)	0.003	0.017	-0.030 [-0.043;-0.024]	0.036 [0.030; 0.049]
C(5,-3)	0.004	0.013	-0.021 [-0.031;-0.017]	0.029 [0.025; 0.039]
C(5,-1)	-0.003	0.012	-0.027 [-0.035;-0.022]	0.021 [0.016; 0.029]
C(5,1)	-0.001	0.013	-0.026 [-0.036;-0.022]	0.024 [0.020; 0.034]
C(5,3)	0.001	0.011	-0.021 [-0.029;-0.016]	0.023 [0.018; 0.031]
C(5,5)	0.000	0.017	-0.033 [-0.046;-0.027]	0.033 [0.027; 0.046]
Root Mean Squares (μ~~(mu)~~m)				
$RMS_{n=2}$	0.161	0.124	-0.082 [-0.172;-0.035]	0.404 [0.357; 0.494]
$RMS_{n=3}$	0.028	0.043	-0.056 [-0.087;-0.040]	0.112 [0.096; 0.143]
$RMS_{n=4}$	0.050	0.035	-0.019 [-0.044;-0.005]	0.119 [0.105; 0.144]
$RMS_{n=5}$	0.044	0.034	-0.023 [-0.047;-0.010]	0.111 [0.098; 0.135]
RMS_{TOT}	0.170	0.123	-0.071 [-0.160;-0.024]	0.411 [0.364; 0.500]
RMS_{HOA}	0.065	0.063	-0.058 [-0.104;-0.035]	0.188 [0.165; 0.234]
Objective Refraction (D)				
M	-0.150	0.188	-0.520 [-0.660;-0.447]	0.219 [0.147;0.359]
J_0	0.006	0.081	-0.152 [-0.212;-0.121]	0.165 [0.134;0.225]
J_{45}	0.034	0.085	-0.133 [-0.197;-0.101]	0.201 [0.168;0.264]

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FIGURE CAPTIONS

Figure 1. Mean value for the individual LOA Zernike coefficients (plot A), individual HOA Zernike coefficients (plot B) and RMS values (plot C) obtained with the AOVA and the KR-1W aberrometers (μm: micrometres). Error bars represent the 95% confidence intervals.

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Figure 2. Bland and Altman plots showing the mean of the differences (mean_d) and the corresponding 95% limits of agreement (LoA) between the values obtained with the AOVA and KR-1W aberrometers for the objective refraction M, J_0 and J_{45} (plots A, B, C, respectively) and for the individual Zernike coefficients C(4,0), C(3,-1), C(3,1) (plots D, E, F, respectively) (D: Dioptres, μ~~(mu)~~m: micrometres).

Figure 3. Correlation plots and regression coefficients between the AOVA and KR-1W for the objective refraction M, J_0 and J_{45} (plots A, B, C, respectively) and the Zernike coefficients C(4,0), C(3,-1), C(3,1) (plots D, E, F, respectively). All correlations were significant ($p < 0.01$). (D: Dioptres, μ~~(mu)~~m: micrometres).

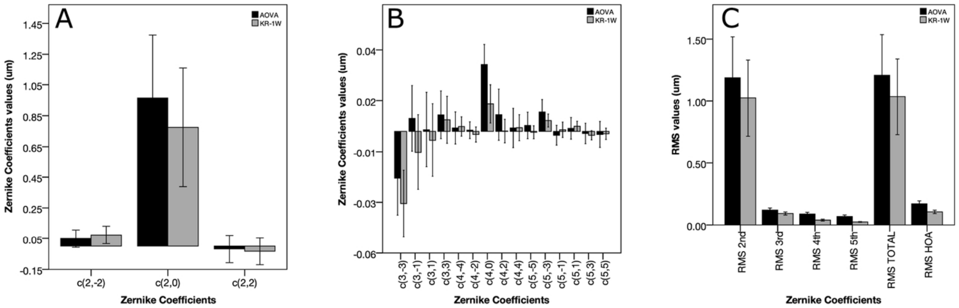

Figure 1. Mean value for the individual LOA Zernike coefficients (plot A), individual HOA Zernike coefficients (plot B) and RMS values (plot C) obtained with the AOVA and the KR-1W aberrometers (µm: micrometres). Error bars represent the 95% confidence intervals.
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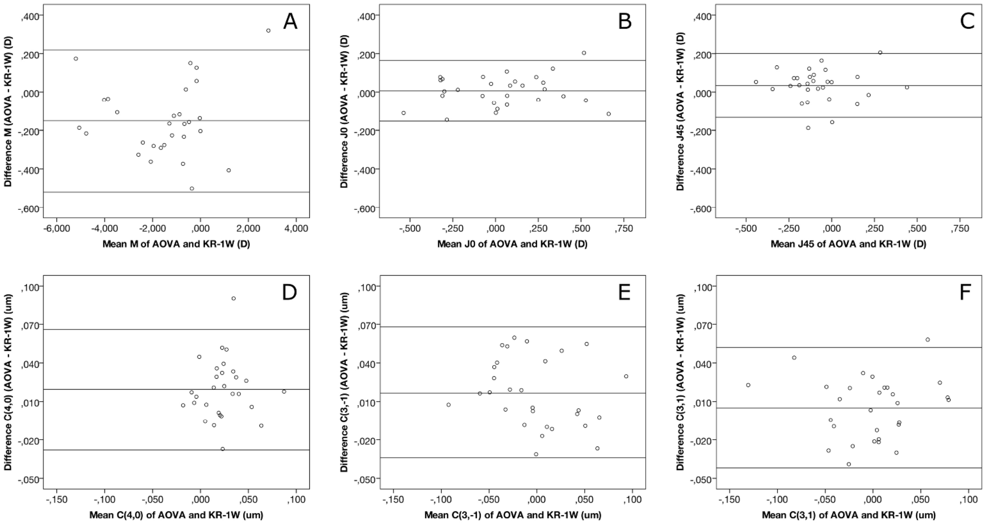

Figure 2. Bland and Altman plots showing the mean of the differences (meand) and the corresponding 95% limits of agreement (LoA) between the values obtained with the AOVA and KR-1W aberrometers for the objective refraction M, J0 and J45 (plots A, B, C, respectively) and for the individual Zernike coefficients C(4,0), C(3,-1), C(3,1) (plots D, E, F, respectively) (D: Dioptres, μm: micrometres).
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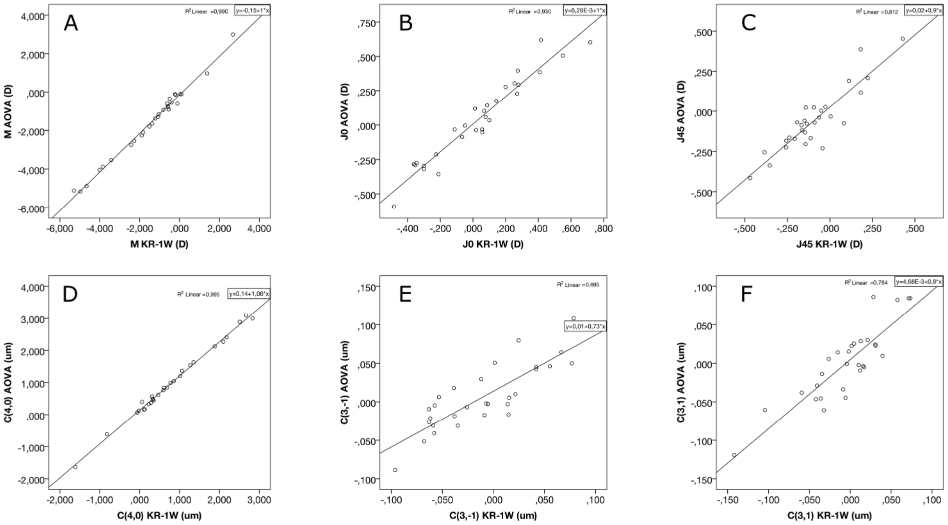

Figure 3. Correlation plots and regression coefficients between the AOVA and KR-1W for the objective refraction M, J0 and J45 (plots A, B, C, respectively) and the Zernike coefficients C(4,0), C(3,-1), C(3,1) (plots D, E, F, respectively). All correlations were significant ($p < 0.01$). (D: Dioptres, µm: micrometres).
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