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RESEARCH

Comparison of physiognomy and frame angle parameters using different devices to prescribe progressive addition lenses

Oscar Garcia-Espinilla[a,b,c], Ines Gallegos-Cocho[a], Irene Sanchez[a,b,c], Pilar Cañadas[b,c] and Raul Martin[a,b,c,d]

[a]Optometry Research Group, IOBA Eye Institute. School of Optometry, University of Valladolid, Valladolid, Spain; [b]Departamento De Física Teórica, Atómica Y Óptica, Universidad De Valladolid, Valladolid, Spain; [c]Optometry Department, Universidad De Valladolid, Instituto Universitario De Oftalmobiología Aplicada (IOBA), Valladolid, Spain; [d]School of Health Professions, Plymouth University, Plymouth, UK

ABSTRACT

Clinical relevance: Accurate measurement of several physiognomy parameters (interpupillary, nasopupillary and fitting height distances) and frame angles (pantoscopic and frame wrap angles) is essential for prescribing progressive addition lenses for presbyopic patients.

Background: Few reports have described the repeatability of different devices commonly used to conduct essential measurements for prescribing progressive addition lenses.

Methods: Interpupillary, nasopupillary (at far and near distances) and fitting point heights were measured three consecutive times in 21 healthy volunteers with four devices (traditional frame ruler, PD-5 interpupilometer, OptiCenter, and VisiOffice). Pantoscopic and wrap frame angles were also measured three times with Essilor standard pantoscopic ruler, Opticenter and VisiOffice.

Results: The frame ruler, PD-5 and Opticenter showed better repeatability for interpupillary and nasopupillary distance (co-efficient of variation close to 1%, within-subject standard deviation or Sw < 0.50 mm) measurements at far and near distances than Visioffice (co-efficient of variation > 2%, Sw > 0.50 mm). Fitting point heights measurements showed worse repeatability with all devices (frame ruler: co-efficient of variation close to 5%, Sw = 0.46 mm; Opticenter co-efficient of variation > 5%, Sw > 0.80 mm; Visioffice co-efficient of variation > 10%, Sw > 1.50 mm). Pantoscopic angle measurements showed very low repeatability with the ruler and Opticenter (co-efficient of variation > 25%, Sw > 1.90 mm). The frame wrap angle showed unacceptable repeatability values with the ruler (co-efficient of variation > 10%, Sw = 0.49º) and Visioffice (co-efficient of variation > 60%, Sw > 2.50º), but acceptable repeatability with Opticenter (co-efficient of variation < 1%, Sw = 0.05º).

Conclusions: Interpupillary and nasopupillary distance measurement showed acceptable repeatability with all the assessed methods; however, these measurements alone are no longer sufficient for free-form progressive addition lens prescription, which requires fitting point heights and pantoscopic and frame wrap angle measurement. Such measures display a lack of repeatability that could induce centration errors and could affect vision and/or adaptation of the user.

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Physiognomy parameters; presbyopia; Presbyopic correction; Progressive addition lenses

Introduction

Most of the worldwide population use spectacles to correct any refractive error (myopia, hyperopia and astigmatism) – affecting approximately 75% of the population[1] – or presbyopia, affecting over a billion people.[2] Presbyopia affects the population older than 45 years and is expected to affect more than 2.1 billion of the population of the world older than 60 years by 2050.[3] One essential procedure to avoid uncomfortable wear of glasses is an accurate measurement of the pupillary distance or interpupillary distance,[4] especially when progressive addition lenses are prescribed.

Although presbyopia can be corrected with different options[2] such as ophthalmic lenses,[5] contact lenses[6] or surgery,[7] progressive addition lenses are the favourite option for most users.[8,9] Progressive addition lenses require an adaptation process[8] with a variable duration between one and three weeks,[10,11] because progressive addition lens designs induce astigmatism. Single vision or segmented bifocal lenses do not induce astigmatism[12,13] (explained by the Minkwitz theorem).

Currently, free-form progressive addition lenses are popular because these designs minimise the impact of induced Minkwitz astigmatism (caused by asymmetrical refraction at a spherical surface[14,15]) on vision performance.[16,17] Customising lens design according to physiognomy characteristics of the future user, and the selected frame (use position), provides natural vision, satisfaction and an easier adaptation process.[18]

Interpupillary distance measurement is necessary when prescribing any lens correction, but especially progressive addition lenses.[10] In addition, measurement of the distance between the centre of the pupil to the bottom of the frame – referred to as the fitting height or fitting point height – and other measurements such as the pantoscopic and frame wrap angles, are required to minimise impact on vision.[19] Improper mounting of lenses into the frame has been described as one of the main reasons for the inability of wearers to adapt to progressive addition lenses.[18–20]

Traditionally, pupillary distance and fitting point height measurements required for dispensing progressive addition lenses to the frame are taken with a frame ruler.[4,21] These measurements have limited precision and are highly depend on the ability of the examiner.[21] Different devices and software applications have been developed to conduct pupillary distance, fitting point height, pantoscopic and frame wrap

CONTACT Irene Sanchez isanchezp@ioba.med.uva.es Optometry Research Group, IOBA Eye Institute. School of Optometry, University of Valladolid, Valladolid, Spain

angles and other facial physiognomy measurements, to help in the prescription process for progressive addition lenses. Pantoscopic and frame wrap angles are described as very critical aspects of the fitting procedure for free-form progressive addition lenses.[22] Unfortunately, no clinically validated and/or accepted gold-standard method exists to measure these angles.[9,10]

In some eye care disciplines, several repeatability studies can be found (e.g. in corneal topography[23] and ocular biometry,[24]) because knowledge about repeatability is essential for the introduction of any new device into clinical practice.[23,24] However, a lack of studies exists to assess the repeatability of proposed new devices to measure facial physiognomy distances or frame angles.

For these reasons, the purpose of the present study was to analyse the intrasession repeatability of measurement of facial physiognomy distances (pupillary distances and fitting point height) achieved using four devices – the PD-5 interpupilometer (Topcon®, Japan), OptiCenter (Prats Optical Barcelona, Spain), and VisiOffice (Essilor, France) and a frame ruler (gold-standard). Intrasession repeatability of frame pantoscopic and wrap angles measured with the four devices were also assessed and compared.

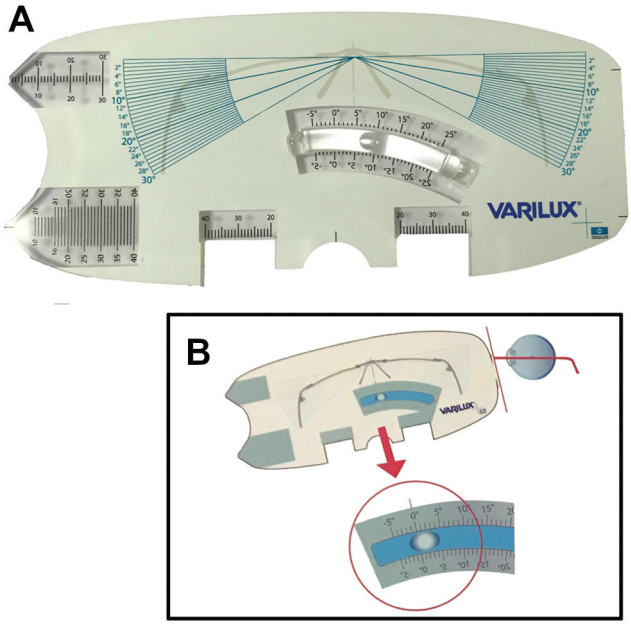

Figure 1. A: Essilor's ruler used to measure the pantoscopic and frame wrap angles and B: schematic representation of the correct procedure for pantoscopic measurement.

Methods

Subjects

This study involved 21 healthy volunteers aged between 19 and 24 years with a visual acuity better than 6/7.5 to allow accurate target fixation at far and near distances. Patients with previous ocular surgery, a history of ocular pathology, strabismus and eye pathology were excluded. The study followed the tenets of the Declaration of Helsinki and was approved by the Human Sciences Ethics Committee of the University of Valladolid.

Measurement procedure

Different devices were used to conduct three consecutive measurements of three different facial physiognomy parameters: interpupillary distance, nasopupillary distance at far and near distances, and fitting point heights, with a traditional frame ruler, PD-5 Interpupilometer, Opticenter and VisiOffice. Two different frame angles (pantoscopic and wrap) were measured using the Essilor standard pantoscopic ruler, Opticenter and VisiOffice. For the measurements, all the volunteers were wearing the same model of frame correctly adjusted (horizontal dimension of the frame: 51 mm; distance between nasal rims: 19 mm; frame height: 24 mm) in the same session. A different, masked and experienced operator performed each set of measurements with each device.

Frame ruler measurements of interpupillar and nasopupillar were conducted following a modified Viktorin's method[25] and fitting point heights[26] distance with the bottom (lower part of the inner side of the ring) of the frame at far (6 m) and near (40 cm) distance. A mark was placed at the centre of the pupils of the patient to guarantee correct measurement of nasopupillary distance when the frame was not symmetrically centred, for example, by nose asymmetry.

Pantoscopic and frame wrap angles were measured using a specific ruler designed by Essilor (Figure 1A) following the instructions of the manufacturer. To measure the pantoscopic angle, the upper and bottom parts of the frame (without lenses) are placed in contact with the flat surface of the ruler. The pantoscopic angle is determined by a bubble that marks a value in the ruler (Figure 1B). To measure the wrap angle, the frame is placed over the ruler by its upper part, the bridge is centred with the ruler, and the end of the frame will be over a line that determines the angle.

Interpupillary distance was also collected using the PD-5 Interpupilometer that uses the light reflex method. This device has three eyepieces – two of them for the patient and the third in the back, for the examiner – and a support for the forehead of the patient to avoid device movement during the measurement. To take the measurement, the patient looks at the fixation stimuli, and the examiner aligns two marks with the corneal reflexes of the patient moving a wheel. Measurements appear on a screen in the upper part of the interpupilometer.

Opticenter is an iPad application designed by Prats Optical (Figure 2A) with an accuracy of 0.1 mm to pupillary and fitting point heights and 0.1° to pantoscopic and frame wrap angles (according to manufacturer description). To determine interpupillary distance, nasopupillary distance and fitting point height measurements, the patients were positioned at approximately 1 m from the iPad and one image was taken in the primary gaze position. The patient placed a diadem over the frame using three square reference patterns (Figure 2B) that are detected by the application software and allow the capture of the picture when the reference square patterns are identified by the software.

The pantoscopic and frame wrap angles can also be measured using this application, taking two additional pictures – one lateral picture that allows alignment of the reference marks with the top and bottom of the frame in the correct head position of the user to measure pantoscopic angle, and another picture of the frame placed on a horizontal flat surface with the iPad parallel to the flat surface to measure wrap angle. The reference marks must be aligned with the nasal and temporal ends of the frame.

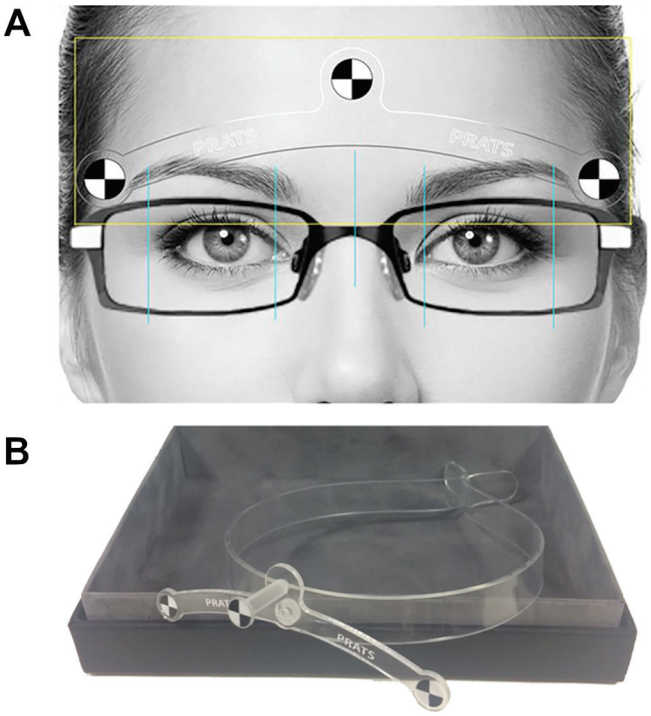

Figure 2. A: Screenshot of the Opticenter app and B: details of the Opticenter diadem complement.

VisiOffice is a device designed by Essilor (Figure 3A) comprising a column with a digital camera behind a semi-mirrored glass in the upper part of the column, that takes images of the patient. The patient needs to wear an accessory adapted to the frame that has three reference square patterns over the frame (two laterals and one central and upper) (Figure 3B). Visioffice software automatically detects the corneal reflexes of the patient and estimates the centres of rotation of the eyes to provide the distance between the centres of rotation and mounting distances, which are equivalent to the nasopupillary distance, interpupillary distance, fitting point height, pantoscopic angle and frame wrap angle.

To collect the measurements, the patient is positioned in front of the column looking at the bridge of the frame reflection in the mirror at a distance that is indicated by the device. When the patient is correctly positioned, the examiner commences taking measurements. When two yellow circles are manually aligned with the pupils of the patient, the measurements automatically appear on the screen.

Statistical analysis

Statistical analysis was performed using SPSS for Windows software (version 23.0; Chicago, USA). The non-parametric data distribution of variables were verified using the Kolmogorov–Smirnov test ($p < 0.05$ indicated that the data were not normally distributed). The description of the collected variables (far and near interpupillary distance and nasopupillary distance, fitting point heights, frame pantoscopic and wrap angles) was summarised as means, standard deviation and range.

The mean of the three measurements was calculated for each parameter collected by different devices. Differences between devices in respect of each measured parameter were compared using the Wilcoxon non-parametric paired test ($p < 0.05$ was considered statistically significant).

The present study followed the definitions of repeatability according to the British Standards Institute and International Organization for Standardisation.[27] The intrasession repeatability of the set of three consecutive measurements of each parameter was calculated using the following four parameters in the same session: within-subject standard deviation,[28] repeatability[28] (2.77× within-subject standard deviation, which defines the difference between two measurements of the same volunteer for 95% of the pairs of observation), co-efficient of variation[28] (percentage value of the variation of the measurement and defined as the ratio of the within-subject standard deviation (Sw) to the overall mean [co-efficient of variation = within-subject standard deviation/mean×100 (%)]) and the intraclass correlation co-efficient (ICC; classified as follows: less than 0.75 = poor agreement; 0.75 to less than 0.90 = moderate agreement; 0.90 or greater = high agreement.[29])

The limits of agreement was assessed following Bland and Altman recommendations, whereby 95% of the differences, or limits of agreement, lie between 1.96 standard deviation of the mean difference.[27] Exact 95% confidence intervals for repeatability limits of agreement was also calculated to provide robust results.[30]

Results

Table 1 summarises the mean, standard deviation and range of each device measurement as well as repeatability co-efficients. Non-statistical differences were found between the frame ruler interpupillary distance measurement and PD-5 (difference: 0.46 ± 1.39 mm; $p = 0.393$, $Z = -0.854$), Opticenter (difference: −0.08 ± 1.13 mm; $p = 0.572$, $Z = -0.565$) and Visioffice (difference: 0.41 ± 1.84 mm;

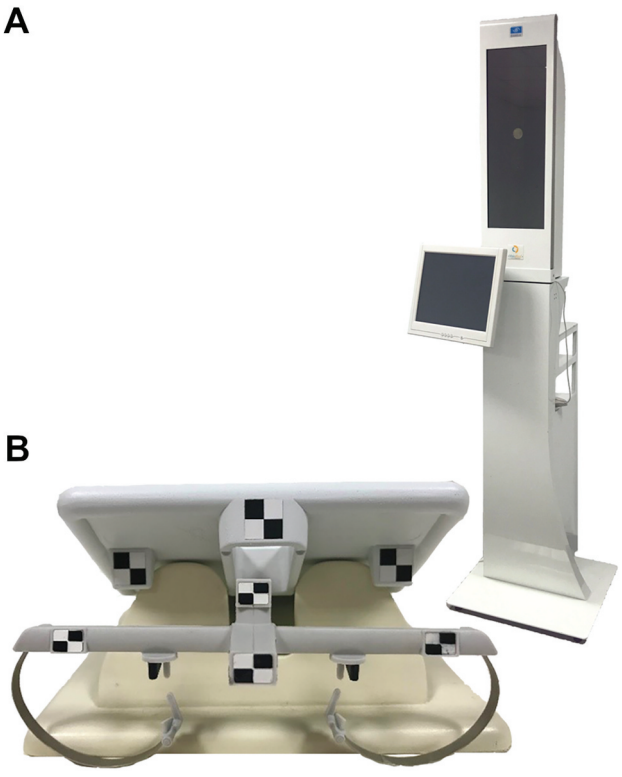

Figure 3. A: Visioffice (Essilor) device used in this study and image and B: detail of the Visioffice complement to fit in the frame to conduct the measurements.

Table 1. Summary of the measurements and intraobserver repeatability co-efficients (Sw, CV, ICC and LoA) for all the parameters measured using the frame ruler, Essilor's ruler, OptiCenter (Prats Optical Barcelona, Spain), VisiOffice (Essilor, Paris, France), and the PD-5 interpupilometer (Topcon, Japan).

Parameters	Mean ± SD	Sw	Rep	CV (%)	ICC	Lower LoA (95%CI)	Upper LoA (95%CI)
Frame ruler							
IPD Far Vision (mm)	60.24 ± 2.25	0.81 ± 0.51	2.28 ± 1.42	1.35 ± 0.85	0.94	−2.86 (−3.54 to −2.36)	2.38 (3.07 to 1.88)
NPD Far Vision RE (mm)	30.36 ± 1.11	0.46 ± 0.26	1.27 ± 0.73	1.51 ± 0.87	0.92	−1.56 (−1.94 to −1.28)	1.37 (1.75 to 1.09)
NPD Far Vision LE (mm)	29.88 ± 1.18	0.46 ± 0.34	1.27 ± 0.94	1.53 ± 1.15	0.93	−1.7 (−2.11 to −1.4)	1.42 (1.82 to 1.12)
IPD Near Vision (mm)	56.97 ± 2.28	0.61 ± 0.56	1.70 ± 1.55	1.07 ± 0.99	0.96	−1.99 (−2.57 to −1.56)	2.49 (3.08 to 2.06)
NPD Near Vision RE (mm)	28.65 ± 1.17	0.26 ± 0.30	0.72 ± 0.83	0.92 ± 1.05	0.97	−1.22 (−1.49 to −1.02)	0.87 (1.14 to 0.67)
NPD Near Vision LE (mm)	28.32 ± 1.16	0.39 ± 0.33	1.09 ± 0.91	1.39 ± 1.16	0.94	−1.33 (−1.7 to −1.06)	1.49 (1.86 to 1.22)
Fitting point Height RE (mm)	14.71 ± 1.49	0.70 ± 0.37	1.93 ± 1.03	4.76 ± 2.48	0.91	−2.06 (−2.63 to −1.64)	2.31 (2.88 to 1.89)
Fitting point Height LE (mm)	14.62 ± 1.54	0.72 ± 0.51	1.99 ± 1.41	5.00 ± 3.73	0.90	−2.22 (−2.85 to −1.76)	2.6 (3.23 to 2.14)
Pantoscopic (°)	3.27 ± 3.23	1.27 ± 0.62	3.53 ± 1.71	26.65 ± 47.73	0.93	−4.08 (−5.1 to −3.33)	3.76 (4.79 to 3.01)
Frame Wrap (°)	4.25 ± 0.50	0.49 ± 0.26	1.35 ± 0.72	11.45 ± 6.35	0.61	−1.68 (−2.07 to −1.39)	1.3 (1.68 to 1.01)
PD-5							
IPD Far Vision (mm)	59.78 ± 2.39	0.44 ± 0.26	1.23 ± 0.51	0.74 ± 0.42	0.99	−1.6 (−1.94 to −1.35)	1.03 (1.37 to 0.78)
NPD Far Vision RE (mm)	29.86 ± 1.35	0.26 ± 0.28	0.73 ± 0.76	0.88 ± 0.93	0.97	−1.06 (−1.33 to −0.85)	1.06 (1.33 to 0.85)
NPD Far Vision LE (mm)	29.92 ± 1.35	0.38 ± 0.22	1.06 ± 0.61	1.29 ± 0.76	0.97	−1.38 (−1.67 to −1.17)	0.81 (1.09 to 0.6)
Opticenter							
IPD Far Vision (mm)	60.20 ± 2.59	0.26 ± 0.13	0.72 ± 0.36	0.44 ± 0.22	0.99	−0.86 (−1.09 to −0.69)	0.75 (0.99 to 0.59)
NPD Far Vision RE (mm)	30.81 ± 1.50	0.35 ± 0.16	0.97 ± 0.45	1.14 ± 0.53	0.98	−1.13 (−1.44 to −0.9)	1.02 (1.33 to 0.8)
NPD Far Vision LE (mm)	29.39 ± 1.54	0.29 ± 1.16	0.81 ± 0.45	1.00 ± 0.59	0.98	−0.93 (−1.2 to −0.74)	0.93 (1.2 to 0.74)
Fitting point height RE (mm)	15.72 ± 2.01	0.89 ± 0.54	2.48 ± 1.51	5.78 ± 3.42	0.91	−3.17 (−3.99 to −2.59)	2.47 (3.29 to 1.89)
Fitting point height LE (mm)	15.39 ± 2.12	0.82 ± 0.52	2.27 ± 1.43	5.37 ± 3.26	0.93	−2.91 (−3.67 to −2.36)	2.35 (3.11 to 1.81)
Pantoscopic (°)	7.66 ± 3.58	1.97 ± 1.42	5.44 ± 3.94	29.11 ± 29.20	0.85	−6.04 (−7.96 to −4.67)	7.21 (9.13 to 5.84)
Frame Wrap (°)	5.41 ± 0.41	0.05 ± 0.05	0.15 ± 0.15	0.97 ± 0.94	0.99	−0.19 (−0.25 to −0.14)	0.23 (0.29 to 0.19)
Visioffice							
IPD (mm)	59.78 ± 2.84	1.22 ± 0.66	3.38 ± 1.84	2.05 ± 1.11	0.92	−3.95 (−4.95 to −3.21)	3.79 (4.79 to 3.05)
NPD RE (mm)	29.70 ± 1.43	0.67 ± 0.46	1.86 ± 1.28	2.29 ± 1.62	0.89	−2.28 (−2.87 to −1.85)	2.24 (2.83 to 1.81)
NPD LE (mm)	30.09 ± 1.97	1.00 ± 0.59	2.78 ± 1.65	3.32 ± 1.89	0.89	−3.3 (−4.14 to −2.68)	3.18 (4.02 to 2.56)
Fitting point height RE (mm)	20.37 ± 6.04	1.50 ± 0.87	4.15 ± 2.42	8.02 ± 5.39	0.97	−5.2 (−6.44 to −4.3)	4.26 (5.49 to 3.35)
Fitting point height LE (mm)	20.40 ± 5.88	1.54 ± 0.70	4.14 ± 1.95	7.90 ± 3.67	0.98	−5.13 (−6.24 to −4.31)	3.41 (4.53 to 2.59)
Pantoscopic (°)	9.30 ± 4.33	2.11 ± 2.16	4.24 ± 5.99	32.11 ± 37.81	0.84	−9.11 (−11.26 to −7.52)	7.44 (9.6 to 5.86)
Frame Wrap (°)	5.97 ± 3.34	2.74 ± 1.55	7.58 ± 4.30	67.21 ± 81.38	0.70	−8.59 (−10.87 to −6.92)	8.88 (11.16 to 7.21)

SD: standard deviation; Sw: within-subject standard deviation; Rep: Repeatability; CV: co-efficient of variation; ICC: intraclass correlation co-efficient; LoA: limit of agreement; CI: confidence interval; IPD: interpupillary distance; NPD: nasopupillary distance; RE: right eye; LE: left eye.

p = 0.39, Z = −0.859). The nasopupillary distance of left eye measured with the frame ruler showed a similar trend, without significant differences with PD-5 (difference: −0.04 ± 1.06 mm; p = 0.572, Z = −0.565), Opticenter (difference: 0.40 ± 1.13 mm; p = 0.191, Z = −1.307) and Visioffice (difference: −0.22 ± 1.58 mm; p = 0.263, Z = −1.120), as well as the nasopupillary distance of right eye measurements between the frame ruler and Opticenter (difference: −0.48 ± 0.88 mm; p = 0.055, Z = −1.917). However, statistically significant differences were found between the nasopupillary distance of right eye measured with the frame ruler and PD-5 (difference: 0.50 ± 0.80 mm; p = 0.013, Z = −2.491), and Visioffice (difference: 0.63 ± 0.94 mm; p = 0.011, Z = 2.558).

Regarding the fitting point height values, Visioffice showed statistically significant differences in both eye measurements (difference: −5.57 ± 6.29 mm; p = 0.001, Z = −3.211 in right eye and −5.68 ± 6.13 mm; p < 0.001, Z = −3.541 in left eye). However, Opticenter measurements were not statistically significant (difference: −0.87 ± 2.26 mm; p = 0.127, Z = −1.524 in right eye and −0.64 ± 2.66 mm; p = 0.486, Z = −0.697 in left eye) compared with the frame ruler outcomes. Differences between all measurements are summarised in Figure 4.

Both Opticenter (difference: −4.05° ± 3.75°; p = 0.002, Z = −3.070) and Visioffice (difference: −6.20° ± 3.32°; p < 0.001, Z = −3.846) showed statistically significant pantoscopic angle values compared with measurements achieved using the Essilor ruler. However, the wrap angle values were significantly lower using Opticenter (difference of −1.17° ± 0.77°; p < 0.001, Z = −3.682) but were not statistically significant compared with the measures achieved with Visioffice (difference: −1.74° ± 3.33°; p = 0.065, Z = −1.848).

Frame ruler repeatability

The frame ruler showed great repeatability in nasopupillary distance measurements at far and near distances with a co-efficient of variation <1.6% and within-subject standard deviation <0.46 mm in both eyes, and in interpupillary distance measurements with a co-efficient of variation <1.35% but with a within-subject standard deviation (Sw) between 0.8 mm and 0.6 mm at far and near distances, respectively. However, the fitting point height measurements showed worse repeatability but clinically acceptable values (co-efficient of variation close to 5% and Sw close to 0.70 mm) in both eyes. The pantoscopic and frame wrap angles showed low repeatability (co-efficient of variation = 26.65% and Sw = 1.27° and co-efficient of variation = 11.45% and Sw = 0.49°, respectively) measured with Essilor's ruler.

PD-5 interpupilometer repeatability

The PD-5 Interpupilometer only allows interpupillary distance or nasopupillary distance measurements and showed great repeatability with a co-efficient of variation of ~1% and a Sw closer than 0.5 mm in all the measured variables.

Opticenter repeatability

Opticenter showed great repeatability when the interpupillary distance, nasopupillary distance and frame wrap angles are measured (co-efficient of variation < 1.2%, Sw < 0.35 mm and 0.05°); nevertheless, the fitting point height measurements showed worst repeatability values with a co-efficient of variation higher than 5% and an Sw close to 0.9 mm in both

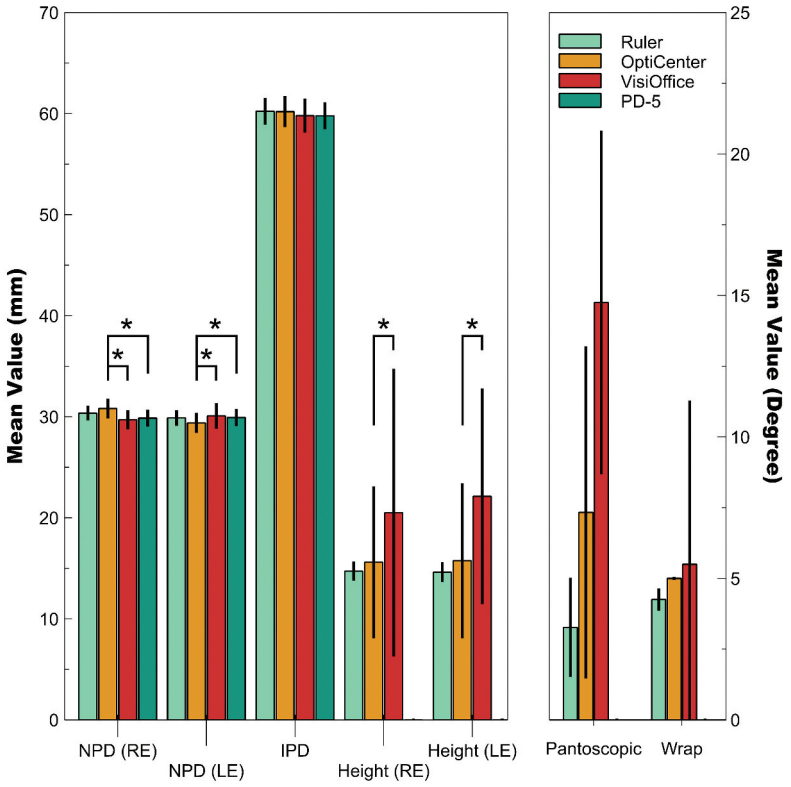

Figure 4. Bar graph representation of the mean and 95% confidence interval of distances (left) and angles (right) measured with every device. Statistically significant differences between devices are highlighted with the * symbol. IPD: interpupillary distance; NPD: nasopupillary distance; RE: right eye; LE: left eye; mm: millimetres. Opticenter showed statistically significant differences with Visioffice and PD-5 NPD RE (1.02 ± 0.78 mm, Z = −3.243, p = 0.001 and 0.91 ± 0.77 mm, Z = −3.463, p = 0.001, respectively) and NPD LE (−0.73 ± 1.16 mm, Z = −2.51, p = 0.01 and −0.74 ± 0.89 mm, Z = −2.789, p = 0.005, respectively). Additionally, the RE and LE height measurements between Opticenter and Visioffice were statistically significant (−4.70 ± 5.81 mm, Z = −2.675, p = 0.007, and −5.09 ± 5.84 mm, Z = 2.864, p = 0.004, respectively).

eyes. A similar trend was found with pantoscopic angle repeatability values, with a co-efficient of variation > 28% and Sw = 1.97º. The repeatability values of the fitting point height and pantoscopic angle measurements could exceed thresholds accepted for clinical use.

Visioffice repeatability

Visioffice measurements showed great variability in their outcomes; some measurements had great repeatability, but others showed very low repeatability. Most of the repeatable measurements were interpupillary distance (co-efficient of variation = 2.05% and Sw = 1.22 mm) and nasopupillary distance (co-efficient of variation < 3.32% and Sw < 1.00 mm in both eyes). However, height measurements (with co-efficient of variation > 10% and Sw = 1.46 mm in both eyes) and both the pantoscopic (with co-efficient of variation > 30% and Sw = 2.1º) and wrap (with co-efficient of variation > 65% and Sw close to 6º) angles showed unacceptable repeatability values.

Discussion

There appears to be no previous report describing and comparing repeatability outcomes of interpupillary distance, nasopupillary distance, fitting point height, pantoscopic angle and frame wrap angle measurements of current devices, as this study has assessed. However, facial measurements are essential to obtain a correct lens fitting in for optical prescriptions, especially when standard and customised progressive addition lenses are prescribed for presbyopia. Previous reports have analysed the repeatability of interpupillary distance using a standard ruler,[21] a pupilometer,[31] interpupillary distance measuring devices[32] and other devices such as the eye tracker,[33] without information about nasopupillary distance and limited reports about fitting point height measurements that are of prime importance in progressive addition lens prescription.[9]

Similar Sw was found for interpupillary distance to that previously reported by different authors. Mcmahon et al.[21] found interpupillary distance repeatability measured by an experienced examiner with a frame ruler Sw = 0.56 mm and with an interpupilometer Sw = 0.39 mm. Holland et al.[31] reported more repeatable measurements of interpupillary distance with an interpupilometer (Sw = 0.36 mm) than those achieved with a frame ruler (Sw = 0.69 mm). Wesemann[32] compared interpupillary distance achieved with eight interpupillary distance devices (Visioffice [Essilor], ImpressionIST [Rodenstock], Visureal [Ollendorf], RVT [Zeiss], PD-2 pupillometer [BON], Digital CRP pupillometer [Essilor], Pm-100 pupillometer [Rodenstock], and PD-5 Pupilometer [Topcon]), showing Sw values of 0.09 mm, 0.24 mm, 0.24 mm, 0.13 mm, 0.47 mm, 0.29 mm, 0.32 mm and 0.29 mm, respectively.

Murray et al.[33] reported similar repeatability values for interpupillary distance (Sw between 0.25 and 1.08 mm) using an eye-tracker device, but these results were not comparable due to differences in technology. However, high-resolution eye tracker measurements could provide accuracy measurements of these parameters but this technology is not used in clinical practice.

Walsh et al.[26] suggested that parallax errors are the main cause of errors with Viktorin's method for measuring interpupillary distance. Other reports have assessed interpupillary distance in different populations (Turkish[34] or non-Caucasian[35] subjects) but without interest in the requirements to successfully fit ophthalmic lenses as the present results highlight.

Precise facial measurements are of paramount importance for correct lens centration to achieve satisfactory vision because Minkwitz astigmatism limits clear zones and degrades the quality of stereoscopic vision.[16,17] Moreover, slight near zone decentration causes asthenopia and symptoms by the induced prism and the extra demand on fusional reserves (according to Prentice law), leading the user to cease wearing progressive addition lenses.[10,20,36]

Interpupillary distance and nasopupillary distance are considered essential measurements in prescribing lenses, but fitting point height measurements, which are not considered compulsory, are especially important in progressive addition lenses.[37] This is to allow an optimum visual field and correct position of the far and near viewing zones. The present results have shown that fitting point heights measurements have lower repeatability than interpupillary distance or nasopupillary distance using all the measurement methods used.

One possible explanation for this low repeatability might be related to frame position because incorrect fitting could cause slight differences in each measurement. Also, the head position of the patient could induce a greater impact in fitting point heights measurements than in horizontal pupillary distances. This is especially the case with automatic devices (Visioffice showed worse repeatability of fitting point heights with CV > 10%), or semiautomatic devices (Opticenter showed a CV slightly higher than 5%), compared with examiner measurement (with CV<5%) that is able to correct the head position of the patient to a more natural or correct position.

Practitioner error in the patient height position could also affect this measurement, with leading incorrect results (frame, patient or practitioner during each measure). The present results suggest that automatic or semiautomatic algorithms or software designed to conduct these measurements should be improved to provide more repeatable outcomes than measurements conducted by experienced practitioners.

Similar results have been found with pantoscopic angle measurement, which is one of the critical measurements required for customisation of progressive addition lenses prescription.[10] These results showed that the pantoscopic angle is the parameter with the lowest repeatability of all assessed methods. Because this measurement is highly dependent on the head position of the patient, and a little movement can change the outcome in several degrees, this measurement could be very difficult to standardise. Thus, it is necessary to improve or design new measurement methods to guarantee repeatable pantoscopic angle measurements.

The traditionally accepted device for conducting pupillary measurements in clinical practice is the frame ruler,[4] which has shown similar repeatability to PD-5, and better repeatability than the Opticenter and VisiOffice devices for naso- and interpupillary distance measurements. The frame ruler precision is usually limited to 1 mm, but this better repeatability does not mean better accuracy because there is no gold-standard method to determine the true interpupillary distance. Thus, in adapting progressive addition lenses in highly myopic or hyperopic patients, this lack of precision can generate errors that could induce a prismatic effect that may induce non-tolerable patient discomfort.

Moreover, the ruler measurement procedure is a manual method that could depend on the ability and experience of the examiner.[4] This suggests that an inexperienced examiner or any examiner error could explain the inability of patients to adapt to progressive addition lenses. Thus, development of measurement devices that are more precise and repeatable and less dependent on examiner ability are necessary to improve ophthalmic lens centration, especially in high ametropias or free-form progressive addition lenses.

Clinical implications

The current accepted method (frame ruler) to conduct compulsory facial measurements to prescribe and mount ophthalmic (monofocal and/or progressive addition lenses) lenses could have a lack of precision. According to ISO 21987:2017, the maximum horizontal and vertical (nasopupillary distance and fitting point height, respectively) tolerated error in ophthalmic lens centration is of 1.0 mm. This lack of precision and repeatability may not comply with this rule.

Traditional interpupillometer devices showed acceptable repeatability but cannot provide fitting height distances. New digital methods introduced in clinical practice require further developments to improve their repeatability, because these results suggest lower repeatability in fitting height distances and pantoscopic and wrap angles using the digital methods assessed. Thus, ophthalmic lens centring with these devices could not be performed exactly.[26]

The inability to adapt to a prescription occurs more frequently in progressive addition lenses because these lenses require precise lens centration due to far and reduced intermediate and near clear vision zones that must be correctly aligned with the vision gaze of the patient.[10] The introduction of free-form progressive addition lenses allows the prescription of patient-custom lenses that require highly accurate measurements of traditional facial (interpupillary distance, nasopupillary distance and fitting point height) and spectacle (pantoscopic and wrap angles) parameters. New parameters such as head position and movement, ocular rotation centre location have also been proposed to guarantee correct lens centration and facilitate patient adaptation.[9] The development of repeatable and accurate measurement methods for all these parameters (facial, spectacle and patient related) are essential to ensure an acceptable adaptation rate to these lenses because the life expectancy is increasing, and the population older than 45 years[38] with presbyopia is also rising.

Study limitations

The main study limitation could be related to the relatively small sample size conformed by healthy Caucasian young people. However, this sample size is sufficient to conduct well-designed repeatability studies according to previous recommendations for the conduct of repeatability studies and results presentation showing 95% confidence intervals for repeatability Bland-Altman limits of agreement.[27,31,39] Moreover, the age of the participants could have limited impact on study results, because non differences could be expected between collaboration of young versus presbyopic patients during facial physiognomy assessment and

frame angle parameters measurement in healthy subjects. Future reports assessing more patients with different ages (including presbyopic population), eye and refractive characteristics are necessary to assess whether differences across age, ethnicity, and refraction could affect the facial measurement procedure and/or the prescription of free-form progressive addition lenses.

Another study limitation is the difficulty of comparing the present results with previous reports due to two main issues: the relatively low number of scientific studies assessing this topic and the heterogeneous statistical analysis conducted in previous studies. Considering this, the co-efficient of variation is the only repeatability value expressed as a percentage (to compare more easily between the outcomes of different reports), because absolute values are not always comparable (depending on the assessed characteristics of patients). However, a small co-efficient of variation is too sensitive when the mean value is near zero, which limits its usefulness; the mean values could be close to zero, as occurs for the pantoscopic and frame wrap angles values measured in the present study.

Conclusion

Interpupillary distance and nasopupillary distance showed acceptable repeatability with all the assessed methods adopted in the present study. The fitting point heights and pantoscopic and frame wrap angles showed lower repeatability, which could affect lens mounting, thus inducing centration errors. Interpupillary distance measurement alone is no longer sufficient for prescribing free-form progressive addition lenses; it is therefore necessary to develop and clinically validate accurate and repeatable methods for measuring facial physiognomy parameters and frame angles. This would allow personalisation of real free-form progressive addition lenses, providing sound prescription for the correction of presbyopia and improvement in quality of life for the patients.

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ORCID

Oscar Garcia-Espinilla http://orcid.org/0000-0002-2060-240X
Irene Sanchez http://orcid.org/0000-0002-5970-4841
Pilar Cañadas http://orcid.org/0000-0002-3741-8318
Raul Martin http://orcid.org/0000-0001-7156-619X

References

[1] Wolfram C, Höhn R, Kottler U, et al. Prevalence of refractive errors in the European adult population: the Gutenberg health study (GHS). Br J Ophthalmol. 2014;98:857–861.
[2] Wolffsohn JS, Davies LN. Presbyopia: effectiveness of correction strategies. Prog Retin Eye Res. 2019;68:124–143.
[3] United Nations. World population ageing 2017 report; 2017. [Cited 2020 Feb 3]. Available from: http://www.un.org/en/development/desa/population/publications/pdf/ageing/WPA2017_Report.pdf .
[4] AlAnazi SA, AlAnazi MA, Osuagwu UL. Influence of age on measured anatomical and physiological interpupillary distance (far and near), and near heterophoria, in Arab Males. Clin Ophthalmol. 2013;7:711–724.
[5] Bell GR. Verifying and evaluating progressive addition lenses in clinical practice. Optometry. 2001;72:239–246.
[6] Fernandes PRB, Neves HIF, Lopes-Ferreira DP, et al. Adaptation to multifocal and monovision contact lens correction. Optom Vis Sci. 2013;90:228–235.
[7] Van Cauwenberge F, Rakic JM. Recent advances in the treatment of presbyopia. Rev Med Liege. 2014;69:361–365.
[8] Boroyan HJ, Cho MH, Fuller BC, et al. Lined multifocal wearers prefer progressive addition lenses. J Am Optom Assoc. 1995;66:296–300.
[9] Muždalo NV, Mihelčič M. Individually designed PALs vs. Power optimized PALs adaptation comparison. Coll Antropol. 2015;39:55–61.
[10] Han SC, Graham AD, Lin MC. Clinical assessment of a customized free-form progressive add lens spectacle. Optom Vis Sci. 2011;88:234–243.
[11] Jaschinski W, König M, Mekontso TM, et al. Comparison of progressive addition lenses for general purpose and for computer vision: an office field study. Clin Exp Optom. 2015;98:234–243.
[12] Sheedy JE. Progressive addition lenses -matching the specific lens to patient needs. Optometry. 2004;75:83–102.
[13] Sheedy JE, Hardy RF, Hayes JR. Progressive addition lenses - measurements and ratings. Optometry. 2006;77:23–39.
[14] Barbero S, Portilla J. The relationship between dioptric power and magnification in progressive addition lenses. Ophthalmic Physiol Opt. 2016;36:421–427.
[15] Meister DJ, Fisher SW. Progress in the spectacle correction of presbyopia. part 1: design and development of progressive lenses. Clin Exp Optom. 2008;91:240–250.
[16] Sheedy JE, Campbell C, King-Smith E, et al. Progressive powered lenses: the Minkwitz theorem. Optom Vis Sci. 2005;82:916–922.
[17] Esser G, Becken W, Altheimer H, et al. Generalization of the Minkwitz theorem to nonumbilical lines of symmetrical surfaces. J Opt Soc Am (A). 2017;34:441–448.
[18] Chamorro E. Lens design techniques to improve satisfaction in free-form progressive addition lens users. JOJ Ophthalmol. 2018;6:1–10.
[19] Selenow A, Bauer EA, Ali SR, et al. Assessing visual performance with progressive addition lenses. Optom Vis Sci. 2002;79:502–505.
[20] Odjimogho E, Odjimogho S. Survey on problems associated with the use of progressive addition lenses (Pal). J Niger Optom Assoc. 2011;11:16–19.
[21] McMahon TT, Irving EL, Accuracy Lee C. Repeatability of self-measurement of interpupillary distance. Optom Vis Sci. 2012;89:901–907.
[22] Keating MP. Oblique central refraction in spherocylindrical corrections with both faceform and pantoscopic tilt. Optom Vis Sci. 1995;72:258–265.
[23] Ortiz-Toquero S, Rodriguez G, De Juan V, et al. Repeatability of placido-based corneal topography in keratoconus. Optom Vis Sci. 2014;91:1467–1473.
[24] Garza-Leon M, Fuentes-de la Fuente HA, García-Treviño AV. Repeatability of ocular biometry with IOLMaster 700 in subjects with clear lens. Int Ophthalmol. 2017;37:1133–1138.
[25] Elliot DB. Refraction and prescribing. In: Clinical procedure in primary eye care. Vol. 71. Amsterdam (Netherlands): Sauders Elsevier; 2014. p. 74.
[26] Walsh G, Pearce EI. The difference between belief and reality for Viktorin's method of inter-pupillary distance measurement. Ophthalmic Physiol Opt. 2009;29:150–154.
[27] McAlinden C, Khadka J, Pesudovs K. Statistical methods for conducting agreement (comparison of clinical tests) and precision (repeatability or reproducibility) studies in optometry and ophthalmology. Ophthalmic Physiol Opt. 2011;31:330–338.
[28] Bland M. An introduction to medical statistics. 3rd ed. Oxford. United Kingdom: Oxford University Press;2000.

[29] McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. Psychol Methods. 1996;1:30–46.
[30] Exact Parametric Carkeet A. Confidence intervals for bland-altman limits of agreement. Optom Vis Sci. 2015;92:e71–80.
[31] Holland BJ, Siderov J. Repeatability of measurements of interpupillary distance. Ophthalmic Physiol Opt. 1999;19:74–78.
[32] Wesemann W. Comparison of PD measuring devices. Part 2. *Optician* [Serial on the internet] 2010 [Cited 2020 Feb 26]: 22–28. Available from: http://assets.markallengroup.com/article-images/image-library/147/uploads/importedimages/devices.pdf
[33] Murray NP, Hunfalvay M, Bolte T. The reliability, validity, and normative data of interpupillary distance and pupil diameter using eye-tracking technology. Transl Vis Sci Technol. 2017;6:2.
[34] Yildirim Y, Sahbaz I, Kar T, et al. Evaluation of interpupillary distance in the Turkish population. Clin Ophthalmol. 2015;9:1413–1416.
[35] Pivnick EK, Rivas ML, Tolley EA, et al. Interpupillary distance in a normal black population. Clin Genet. 1999;55:182–191.
[36] Tang CY. Spherical lens decentration errors by prentice's rule. Ophthalmic Physiol Opt. 1989;9:86–90.
[37] Forkel J, Reiniger JL, Muschielok A, et al. Personalized progressive addition lenses: correlation between performance and design. Optom Vis Sci. 2017;94:208–218.
[38] Lutz W, Sanderson W, Scherbov S. The coming acceleration of global population ageing. Nature. 2008;451:716–719.
[39] Hu AL, Qiao LY, Zhang Y, et al. Reproducibility of optical quality parameters measured at objective and subjective best focuses in a double-pass system. Int J Ophthalmol. 2015;8:1043–1050.