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OPTOMETRIC PARAMETER MEASUREMENT FOR PERSONALIZED PROGRESSIVE LENSES BY USING A MECHATRONIC POSITIONING SYSTEM

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Abstract: *This article presents tests performed with an optometric parameter measurement device incorporated into a mechatronic positioning system. During testing, it was considered that the correct positioning of the ocular centers of the pupil-centered customized progressive lenses was essential for clear perception of the visualized images. Customized measurements, which are a requirement for people with severe facial asymmetries, were performed using a tablet with special software to capture, process, and convert the pixels that make up the image into a unit of measurement in millimeters. The results obtained with the measuring device led to the high-precision measurements necessary for the construction, design, and manufacture of customized progressive lenses.*

Key words: *parameters optometrists, lenses progressive optimized, measuring devices, mechatronic system, embedded device*

1. INTRODUCTION

For measurement of optometric parameters in progressive lens wearers, special devices with dedicated software are used for their accurate determination according to facial asymmetries, functioning naturally for human use [1]. The more accurately these parameters are measured, the more precisely the progressive lenses can be constructed, providing maximum performance and good image clarity when used [2]. Mobile devices in the optical market are varied and constantly evolving. They can be further improved by adding them to various mechatronic systems for tablet positioning, and when placed at precise distances from the customer, measurements can be made more accurately [3].

To demonstrate the repeatability of optometric measurements using the optomechatronic tablet positioning device with dedicated software, we performed multiple measurements on several subjects, as detailed below.

1.1 The steps for measuring a patient's optometric parameters

Each optometric parameter of the patient is determined with the EYE FIT tablet, it is necessary to position it in a well-lit area, which is extremely important for capturing high-quality images. Determining the patient's parameters at "infinity" is easily achieved using the tablet positioning device. The patient is seated at 800 mm from it, in a stable position, looking towards the front camera of the tablet, then the frame with markers is attached to the frame of the glasses chosen by the patient.

The patient’s optometric parameters are determined by analyzing the images recorded and processed by the EYE FIT (E.F.) application (Fig. 1) on the tablet. The assessment consists of measuring distances between specific points in the image and comparing them with the established spacing of the markers, where the dimensional conversion factor corresponds to the ratio between the pixel count obtained and the marker’s known length.

Fig. 1. Mobile device for determination parameters individual [1]

To obtain correct measurement results a mobile device was fixed on eyeglass frame. A group of three markers were positioned on it, according to the distances that are needed to be measured for calculations. The handheld unit is light and made of carbon so that it does not modify the placement of the eyewear frame to which it is fixed and does not obstruct contact with the patient's nose or eye. The device's linear and angular values are predetermined and feed into the computation that yields the measurement data. Its precision relies chiefly on how accurately the marked frame is aligned with the spectacles selected by the patient. Alignment is achieved by ensuring the center mark lies exactly on the vertical axis that splits the face and the chosen frame equally (Fig. 2).

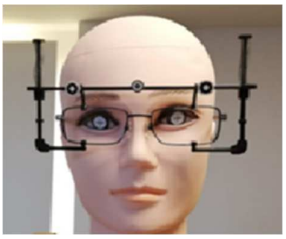

Fig. 2. Device frame with markers

A calibration marker tool is required to define an accurate coordinate system in which measurements are taken and to derive the needed image-correction parameters. Without such markers, valid coefficients for the transformation matrices that map pixels to spatial length units, mm, cannot be obtained. Once the markers are correctly fixed to the eyeglass frame, the patient can proceed with image acquisition.

First, a frontal image of the patient is taken, with their gaze aimed at the tablet's main camera, enabling the pupil distance to infinity to be computed for every distance step. This provides data for determining lens mounting height, eyeglass-frame dimensions, and nose-bridge width. (Fig. 3).

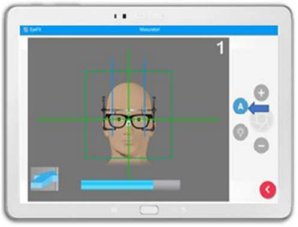

Fig. 3. Device frame with markers

The pair of photos is captured while the patient looks into the distance, allowing determination of the frame's pantoscopic tilt, its curvature, and the vertex distance corresponding to each eye. (Fig. 4).

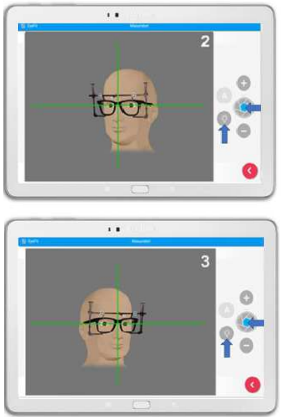

Fig. 4. Image acquisition of the patient in profile view [1]

In the existing workflow, the final image is captured while the patient fixes their gaze on the tablet's front camera, which enables evaluation of each eye's convergence and the reading position through the lens zone. It must be stressed that this image is taken with the tablet held at a reading distance set solely by the patient's arm, since the frame contains "demo lenses" (flat lenses) that do not permit real reading. This leads to an awkward and unrealistic posture. Furthermore, a second camera is involved, differing in resolution and mounted asymmetrically, positioned 20 mm off the tablet's vertical midline. Accurate alignment is critical because the E.F. software restricts how the tablet may be oriented, requiring its generated reticles to coincide exactly with the designated center indicators.

Once the patient images have been captured, the E. F. program processes the acquired data and displays the results for all measurement parameters related to the patient and the chosen frame, so that a progressive lens can be constructed. The result is presented in the form shown (fig. 5):

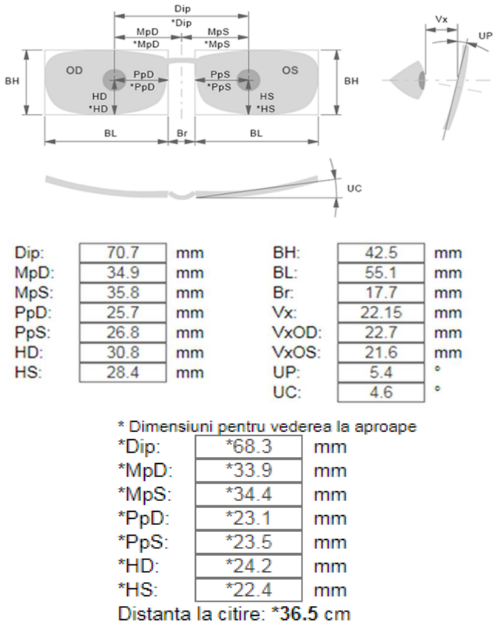

Fig. 5. The result measurement parameters individual optometrics [1]

In the Fig. 5. are presented the following parameters:

Dip= distance interpupillary distance;
MpD = interpupillary distance pupillary for EYE right;
MpS = distance pupillary for EYE left;
Vx = vertex distance (from cornea to lens);
HD, HS = mounting height;
BH = height frame;
BL = length frame;
Br = bridge nasal;
UP = angle pantoscopic;
UC = angle of curvature of the frame.

In Fig. 5, there's a difference between the patient's two eyes. Vertically, the difference between the pupil centers is two point four millimetres, and horizontally, it's one point one millimetres.

Furthermore, the patient's eyes do not align evenly, with a difference of 1.2 mm between them.

These results must be taken into account when positioning the optical center of the constructed lenses.

As illustrated in the figure, within the near zone there is a rightward angular shift of the patient's head relative to the tablet, and this lack of perpendicular alignment introduces errors in the obtained measurements.

For the reading distance, recorded at 365 mm, it becomes evident that the spacing between the two pupil centers does not stay stable because of ocular motion, producing vertical shifts of 2.2 mm and horizontal shifts of 2.1 mm.

Since the tablet is inclined to the patient's left side, the measured values may seem similar, yet differ by millimeters, potentially leading to discomfort or dissatisfaction for users of progressive lenses.

The construction of custom-made progressive lenses requires the optical centers to be positioned with tenths of a millimeter accuracy relative to the patient's pupil centers [4,5]. Additionally, the progression channel height must be calculated individually for each eye.

A patient with improper head positioning relative to the tablet will experience issues in the reading area due to inaccurate measurements [6,7]. It is possible that they may not see an entire line of text on a page and will have to move their head left and right to achieve clarity [8,9,10,11].

2. PARAMETER MEASUREMENTS WITH THE TABLET AND THE SYSTEM MECHATRONICS

The tablet used for imaging requires the patient's anthropometric parameters to be determined in order to be positioned with high precision and a high degree of repeatability. A mechatronic system has been designed and created to position the tablet in three directions relative to the patient.

This optomechanical system has three degrees of freedom, allowing the tablet to move vertically and horizontally, and rotate at angles between 0 and 90 degrees.

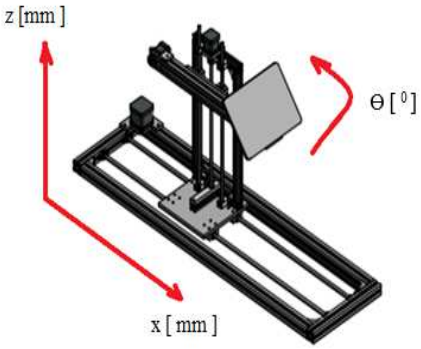

Fig. 6. System optomechatronic positioning with three degrees of freedom

This system uses Eye Fit software to analyze individualized parameters at defined working positions spanning near and mid-range tasks. Throughout the optometric session, the patient remains seated at a desk while three dedicated reference distances are applied (Fig. 6.).

In the reading mode, the device sets the tablet 350 mm from the patient's eyes and tilts it 50° from the vertical to capture the image employed to identify the pupil locations behind the lenses. In the laptop mode, the tablet is placed 450 mm from the eyes and angled 30° from the vertical, simulating a natural laptop posture (Fig. 7). Image acquisition and processing make it possible to compute the projected pupil coordinates at this distance. I

n the monitor mode, the tablet is positioned 650 mm from the eyes, raised to a height adapted to the patient, and inclined 15° from the vertical so the posture resembles viewing a screen, enabling projection of pupil positions for that range.

Both horizontal and vertical tablet adjustments at the prescribed angles are implemented through three stepper motors and linkages that convert rotational motion. According to the patient's main tasks, optical centers near the lenses can then be configured so the wearer maintains ergonomic working posture and obtains clear vision through the intended zones.

These operational details are included mainly for clarity and do not alter system behavior, but they help portray how the device is commonly applied in regular use.

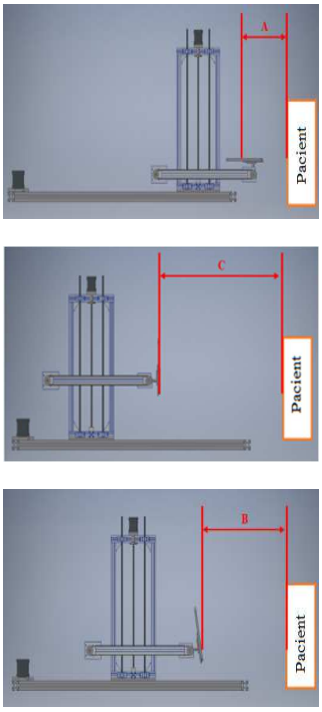

Fig. 7. Fixed working positions (A - reading, B - laptop, C - monitor) [2]

3. CALCULATION OF TABLET POSITIONING COORDINATES

To obtain the position required for determining the anthropometric parameters specific to the patient for both near vision and medium distance vision, a diagram was created with the most important parameters for characterizing the positioning of the device, as shown in Fig. 8.

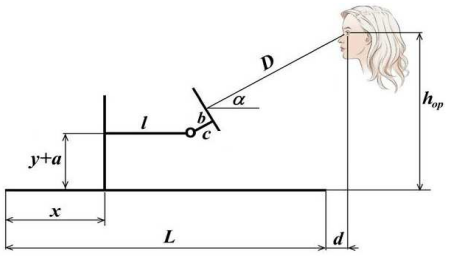

Fig. 8. Diagram for determination of the tablet positions

Referring to the diagram, the spatial coordinates used for positioning the tablet can be established for both the horizontal and vertical axes, noting that the angle α, or inclination A, is preset for ergonomic considerations. As illustrated in Fig. 8, the value L represents the distance from the initial x-coordinate reference

point to the right edge of the tablet holder, measuring 830 mm, while d refers to the offset between that edge and the plane carrying the reference frame, which is 200 mm. In the same horizontal layout, the supporting arm of the tablet, labeled l, has a length of 235 mm; the rotating segment, marked c, measures 45 mm; and b is the distance from the tablet's center to its attachment point, equal to 70 mm. The nominal operating distances for reading, laptop tasks, and monitor viewing are set at 350 mm, 450 mm, and 650 mm, respectively. Vertically, the height corresponding to the patient's eye level, h_opis, is taken from the tabletop on which the support assembly rests. The y-coordinate refers to the screw displacement needed to shift the tablet's center from its initial location to the required one, with a defined value a of 38 mm representing the distance between the table surface and the lower edge of the screw. Projecting the geometry in both x and y yields the subsequent equations:

$$x = L + d - l - (c + D)cos\alpha - bsin\alpha \quad (3.1)$$

$$y + a = h_{op} - (c + D)sin\alpha - bcos\alpha \quad (3.2)$$

or

$$x = 795 - (D + 45)cos\alpha - 70sin\alpha \quad (3.1^*)$$

$$y = h_{op} - (D + 45)sin\alpha - 70cos\alpha - 38 \quad (3.2^*)$$

It must be emphasized that horizontal motions occur in three preset positions linked to tasks such as reading, laptop use, and viewing a monitor, whereas movement in the y-axis demands an adjustment that corresponds to the vertical level of the patient's eyes.

Therefore:

Read position: angle $\alpha = 50°$, distance $D = 350\ mm$ and $x = 487.4\ mm$;

Laptop position: angle $\alpha = 30°$, distance $D = 450\ mm$ and $x = 331.3\ mm$;

Monitor position: angle $\alpha = 15°$, distance $D = 650\ mm$ and $x = 105.6\ mm$.

In number of steps of the motor, these distances are covered thus:

Read position: $n_1 = \frac{x_1}{\delta_p} = 2972\ steps$;

Laptop position: $n_2 = \frac{x_2}{\delta_p} = 2020\ steps$;

Monitor position: $n_3 = \frac{x_3}{\delta_p} = 644\ steps$.

Determination coordinate y with the relation (3.2*) implies evaluation the height at which it is located eyes the patient , being beneficial as this to be correlated with height saddle total . In the paper [3], is presented a diagram of the positions statistical preponderance of the various body segments human, defined as a percentage in height ratio people and which one is reproduced in Fig.9.

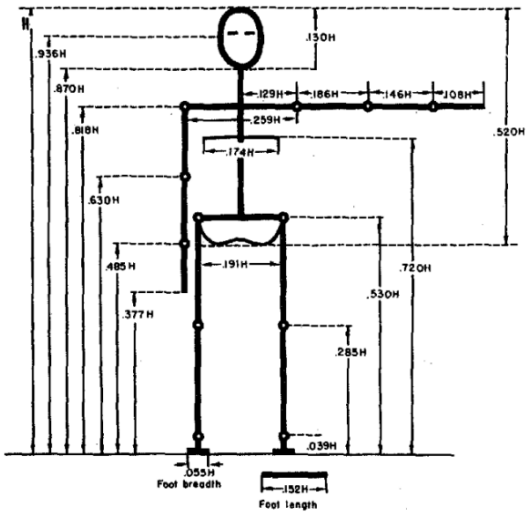

Fig. 9. Relative lengths of human body's segments according to Drillis and Contini [3]

Given that the intended working postures involve sitting upright with the forearms resting on the desk, it follows that h_op represents the value obtained by subtracting elbow height from the height of the eyes.:

$$h_{op} = 0{,}936H - 0{,}630H = 0{,}306H \quad (3.3)$$

where H is height patient. Equation (3.2*) becomes:

$$y = 0{,}306H - (D + 45)sin\alpha\text{-}70cos\alpha - 38 \quad (3.2^{**})$$

Based on equation (3.2**) the positions were evaluated required for subjects with a height of 1500 - 2000 mm, in the 3 test cases (read, laptop and monitor).

It is observed, from equation (3.2**), that change positions necessary, *y,* with height the patient, *H,* is linear and is calculated with:

$$\Delta y = 0{,}306 \cdot \Delta H \quad (3.4)$$

Table 1 presents an important coordinate *y*, in depending on height patient, calculated for $\Delta H = 10\ mm$, which corresponds to $\Delta y = 3{,}02\ mm$.

Table.1

Values coordinate *y*, positioning of the tablet, in activity function and height patient

	READ	LAPTOP	MONITOR
H [mm]		*y [mm]*	
1500	73.4	112.9	173.5
1510	76.42	115.92	176.52
1520	79.44	118.94	179.54
1530	82.46	121.96	182.56
1540	85.48	124.98	185.58
1550	88.5	128	188.6
1560	91.52	131.02	191.62
1570	94.54	134.04	194.64
1580	97.56	137.06	197.66
1590	100.58	140.08	200.68
1600	103.6	143.1	203.7
1610	106.62	146.12	206.72
1620	109.64	149.14	209.74
1630	112.66	152.16	212.76
1640	115.68	155.18	215.78
1650	118.7	158.2	218.8
1660	121.72	151.22	221.82
1670	124.74	164.24	223.84
1680	127.76	167.26	227.86
1690	130.78	170.28	230.88
1700	133.8	173.3	233.9
1710	136.82	176.32	236.92
1720	139.84	179.34	239.94
1730	142.86	182.36	242.96
1740	145.88	185.38	245.98
1750	148.9	188.4	249
1760	151.92	191.42	252.02
1770	154.94	194.44	255.04
1780	157.96	197.46	258.06
1790	160.98	200.48	261.08
1800	164	203.5	264.1
1810	167.02	206.52	267.12
1820	170.04	209.54	270.14
1830	173.06	212.56	273.16
1840	176.08	215.58	276.18
1850	179.1	218.6	279.2
1860	182.12	221.62	282.22
1870	185.14	224.64	285.24
1880	188.16	227.66	288.26
1890	191.18	230.68	291.28
1900	194.2	233.7	294.3
1910	197.22	236.72	297.32
1920	200.24	239.74	300.34
1930	203.26	242.76	303.36
1940	206.28	245.78	306.38
1950	209.3	248.8	309.4
1960	212.32	251.82	312.42
1970	215.34	243.84	315.44
1980	218.36	257.86	318.46
1990	221.38	260.88	321.48
2000	224.4	263.9	324.5

4. MEASUREMENTS RESULTS

In an effort to demonstrate the effectiveness of correctly positioning the power of the lenses when using the mechatronic device, a series of measurements were performed on two patients using E.F. software, in both measurement positions of the tablet: "in hand" and "mounted in the device." In the handheld position, the tablet was held by the optometrist for the distance image and by the patient for the near image, and the images had to be captured while standing. For the near position, this is not typical for activities associated with near vision, such as writing, reading, or working at a computer. It was therefore necessary to find a position that was typical for the patient's daily activities.

The E.F. tablet and software were used to capture a near image of the patient in the "standing with lenses in hand" position, as is currently done, and then, for the same patient, a near image was captured using the built-in mechatronic device in the "sitting" position (Fig. 10). Twenty measurements were taken for each method on the same wearer, and the results were analyzed. The customized progressive lens is constructed with power processed across more than 104,000 points on the inner surface. For clear near vision, the appropriate power placement at these distances must be constructed based on the patient's eye movement, both vertically and horizontally.

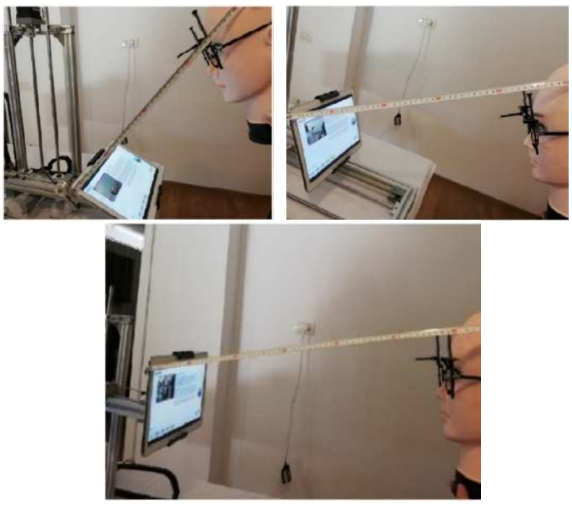

Fig. 10. Measuring with a tape measure of those three positions for close (350mm/450mm/650mm)

The trials performed on patients began with an evaluation comparing the way the tablet is positioned for reading or writing, whether it is handheld or fixed within the device. As illustrated in Tables 2 and 3, for both subjects the tablet's placement changes with respect to eye-to-tablet distance and tilt angle, influenced by the patient's posture, which leads to shifts in the progression-channel height and in each eye's convergence. When the device is used, the tablet is set according to coordinates derived from the patient's height, with the patient "seated" so that reading distance and eye alignment fluctuate less, producing more reliable measurements for that working setup. It should be emphasized that the stable posture adopted by the patient during device use is appropriate for lens utilization, and lens power distribution is designed in relation to ocular movements at these specific task distances. For comparison, 20 readings were collected for each patient for near-vision analysis, employing both the usual handheld-tablet method and the configuration where the tablet is placed in the device. The obtained measurement values are listed in Tables 2 and 3, as shown below.

Table 2

Results tablet measurements for first patient without device

No.	Reading Distance (mm)	Progressive Channel Height OD/OS (mm)	Convergence OD/OS (mm)
1	349	15.6/14.9	1.5/1.2
2	350	15.4/14.6	1.3/1.0
3	343	16.8/16.1	2.0/1.7
4	348	17.5/17.2	1.6/1.3
5	347	17.2/16.7	1.6/1.4
6	350	15.8/15.1	1.5/1.3
7	345	16.3/15.8	1.8/1.5
8	352	15.5/14.8	1.3/1.0
9	346	17.5/16.8	1.9/1.6
10	350	16.1/15.6	1.6/1.4
11	349	15.9/15.4	1.7/1.5
12	351	15.1/14.7	1.4/1.0
13	344	17.0/16.5	1.9/1.6
14	344	17.1/16.7	2.0/1.7
15	348	17.9/17.2	1.8/1.4
16	347	17.8/17.3	1.8/1.6
17	349	16.1/15.8	1.8/1.4
18	350	16.3/16.0	1.7/1.5
19	346	17.0/16.6	2.0/1.7
20	349	16.1/15.9	1.9/1.6

Table 3

Results tablet measurements for first patient with device

No.	Reading Distance (mm)	Progressive Channel Height OD/OS (mm)	Convergence OD/OS (mm)
1	342	15.9/15.2	1.9/1.5
2	348	15.3/14.7	1.5/1.2
3	346	15.5/15.0	1.7/1.4
4	340	16.0/15.4	2.0/1.6
5	346	15.5/15.0	1.7/1.4
6	348	15.3/14.7	1.5/1.2
7	342	15.9/15.2	1.9/1.5
8	346	15.5/15.0	1.7/1.4
9	348	15.3/14.7	1.5/1.2
10	346	15.5/15.0	1.7/1.4
11	350	15.1/14.3	1.4/1.1
12	348	15.3/14.7	1.5/1.2
13	348	15.3/14.7	1.5/1.2
14	346	15.5/15.0	1.7/1.4
15	348	15.3/14.7	1.5/1.2
16	342	15.9/15.2	1.9/1.5
17	348	15.3/14.7	1.5/1.2
18	346	15.5/15.0	1.7/1.4
19	350	15.1/14.3	1.4/1.1
20	348	15.3/14.7	1.5/1.2

The measurement conditions and outcomes indicate that the fluctuations may be considerably larger when the device is not used, in contrast to the more stable results obtained with it:

In the first patient, a deviation of 22 mm in the reading distance, a deviation of 1.6 mm in the progression channel height, and a deviation of 0.7 mm in the convergence difference were observed. On the other hand, the second patient results indicated an 8 mm variation in reading distance, 0.8 mm in progression channel height and 0.5 mm in convergence difference. What stands out is the lack of repeatability in case of the first patient, where the data obtained at 349 mm differ four times, while in the second case, all eight results at the 348 mm distance are identical.

Table 4

Results tablet measurements for the second patient without device

No.	Reading Distance (mm)	Progression Channel Height OD/OS (mm)	Convergence OD/OS (mm)
1	351	15.1/14.8	2.0/1.7
2	346	16.9/16.3	2.3/1.6

3	348	17.2/16.7	2.1/1.9
4	350	15.2/14.9	2.1/1.8
5	349	15.9/15.6	2.0/1.8
6	347	17.0/16.6	2.0/1.9
7	352	15.0/14.6	2.1/1.9
8	350	16.3/16.0	2.0/1.7
9	345	16.3/15.8	2.3/1.9
10	351	16.0/15.8	1.9/1.6
11	346	17.0/16.7	2.1/1.9
12	349	16.1/15.8	1.9/1.7
13	347	17.1/16.8	1.9/1.6
14	348	17.3/16.8	2.0/1.7
15	348	17.1/16.6	2.1/1.8
16	346	17.2/16.8	2.0/1.9
17	350	15.3/15.0	2.0/1.7
18	345	16.9/16.5	2.2/1.8
19	351	16.2/15.9	2.0/1.7
20	350	15.1/14.8	1.9/1.6

Similar to the first patient, the conditions and measurement results show that the variations may be greater in the non-device version than in the devices version:

The results for the first patient show a 14 mm variation in reading distance, 1.1 mm in progression channel height and 0.7 mm in convergence difference.

The second patient results in a 5 mm variation in reading distance, 0.4 mm in progression channel height and 0.3 mm in convergence difference. Also, there is no repeatability in case first case (table 4), where the data obtained at distances of 348 mm, 350 mm, and 351 mm differ three times, while in case described in table 5, all seven results at the 350 mm distance are identical.

Table 5

Results tablet measurements for the second patient without device

No.	Reading Distance (mm)	Progression Channel Height OD/OS (mm)	Convergence OD/OS (mm)
1	350	14.8/14.3	1.9/1.6
2	348	15.0/14.6	2.1/1.8
3	346	15.1/14.8	2.2/1.9
4	350	14.8/14.3	1.9/1.6
5	351	14.6/14.1	1.8/1.5
6	346	15.1/14.8	2.2/1.9
7	348	15.0/14.6	2.1/1.8
8	350	14.8/14.3	1.9/1.6
9	348	15.0/14.6	2.1/1.8
10	351	14.6/14.1	1.8/1.5
11	348	15.0/14.6	2.1/1.8
12	350	14.8/14.3	1.9/1.6
13	350	14.8/14.3	1.9/1.6
14	351	14.6/14.1	1.8/1.5
15	351	14.6/14.1	1.8/1.5
16	350	14.8/14.3	1.9/1.6
17	348	15.0/14.6	2.1/1.8
18	351	14.6/14.1	1.8/1.5
19	346	15.1/14.8	2.2/1.9
20	350	14.8/14.3	1.9/1.6

5. CONCLUSION

The "image capture" position, with the patient standing during near optometric measurements, introduces errors in both patient positioning and tablet positioning—vertically and horizontally. These incorrect positions, relative to the typical posture in which progressive lenses are worn, lead to calculation errors on the order of millimeters. As a result, the lenses are constructed with optical centers misaligned from the patient's visual axis. This misalignment causes discomfort with progressive lenses, or in some cases, unclear vision, leading to discomfort and headaches.

The tablet-type mobile device, which includes the Eye Fit software component for measuring optometric parameters, was initially tested in the laboratory using a mannequin, where all dimensions and working distances were known. After testing and software calibration, measurements were then performed on actual eyeglass wearers. However, testing for the near and intermediate zones is especially important for correctly positioning the optical center of progressive lenses, as many non-adaptation cases occur in these areas. Testing with the patient seated in the optomechatronic device, at fixed working distances, enables more accurate image capture, and thus more accurate determination of pupillary positions for correct progressive lens construction. Given that the tablet holder in the device eliminates the afore mentioned errors, particularly the potential

rotation of the tablet around the camera axis, a geometric model of the object-image correspondence was developed. This model incorporates the overall transverse magnification of the tablet, including its optical and electronic components. The model was validated by using software other than E.F., which confirmed its validity through the results obtained from the author's optometric measurements extracted from the images.

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Testarea măsurării parametrilor optometrici la purtătorii de lentile progresive personalizate realizată cu ajutorul unei tablete incorporate într-un sistem mecatronic de poziționare

Rezumat: *Acest articol prezintă testele efectuate cu dispozitivul de măsurare a parametrilor optometrici încorporat într-un sistem mecatronic de* poziționare*. În timpul testelor, s-a considerat că poziționarea corectă a centrelor optice ale lentilelor progresive personalizate pe proiecțiile pupilei pacientului era esențială pentru percepția clară a imaginilor vizualizate. Pentru a efectua măsurători personalizate, care sunt o cerință pentru persoanele cu asimetrii faciale majore, s-a*

utilizat o tabletă cu software special încorporat pentru a captura, procesa și converti pixelii care alcătuiesc imaginea într-o unitate de măsură în milimetri. Rezultatele obținute cu dispozitivul de măsurare au condus la măsurători de înaltă precizie necesare pentru construcția, proiectarea și fabricarea lentilelor progresive personalizate.

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