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# Subjective quasi-vector-based refraction with a conventional phoropter

**Jose Ricardo Albero Moreno**[1] | **Cesar Albarrán Diego**[2] | **Vicente Micó**[2]

[1]Clínica Baviera Castellón, Castelló de la Plana, Spain

[2]Departamento de Óptica y Optometría y Ciencias de la Visión, Universitat de València, Valencia, Spain

**Correspondence**
Cesar Albarrán Diego, Departamento de Óptica y Optometría y Ciencias de la Visión, Universitat de València, Valencia, Spain.
Email: cesar.albarran@uv.es

**Abstract**

**Purpose:** To introduce a novel methodology for subjective refraction based on power vectors with a conventional phoropter.

**Methods:** A conventional phoropter was used to measure power vector components of refraction ($M$, $J_0$ and $J_{45}$) directly by using the sphere power (for $M$ measurement) and the cylinder power combined with the Jackson cross-cylinders (for $J_0$ and $J_{45}$ measurements). Conventional subjective refraction was also performed, and this result was mathematically transformed into power vector notation for comparison purposes. Visual acuities with the conventional prescription and the quasi-vector-based prescription were compared.

**Results:** Refractive error from 40 healthy participants was measured by conventional and quasi-vector-based subjective refraction. No differences were found between methods for any of the power vector components of refraction ($p > 0.21$ in all cases). The visual acuity achieved with the prescriptions yielded similar values ($p = 0.85$).

**Conclusions:** Subjective refraction can be measured directly in power vector notation using a conventional phoropter without any additional adaptation and computation.

**KEYWORDS**
astigmatic decomposition, phoropter, power vectors, subjective refraction

## INTRODUCTION

Monocular subjective refraction refers to a clinical procedure consisting of a series of steps aimed at determining the combination of spherical and cylindrical lenses yielding the maximum visual acuity.[1] The goal of monocular subjective refraction is to obtain an optical prescription that reduces the size of the Sturm's interval to zero, thus achieving maximum visual acuity by placing a focused image of distant objects on the retina. This prescription has traditionally been expressed in sphero-cylinder notation, but there are other possible numerical expressions such as the power matrix or power vector notations.[2–7] The sphero-cylinder notation obtained after conventional or classical subjective refraction has the advantage of being easily interpreted clinically, but it is not the best formalism for statistical analysis or investigative purposes. A better option for these cases is the vector formalism as redefined by Thibos et al.,[3] which interprets refraction as a triplet of independent values ($M$, $J_0$ and $J_{45}$) in the form of a vector, known as the 'power vector'. The $M$ component represents the spherical equivalent (the spherical power that places the circle of least confusion on the retina), while the $J$ components define the astigmatism in the form of two Jackson crossed-cylinders (JCCs) with their axes at 0° and 90° ($J_0$) and 45° and 135° ($J_{45}$). These $J$ components represent a vector in an *antistigmatic* plane according to the definition by Harris.[8,9]

Traditionally, power vector notation is obtained by mathematical conversion of the sphero-cylinder notation

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obtained by a conventional subjective refractive procedure. However, previous works have demonstrated that power vector notation can be measured directly, both with trial lenses[10] or with a modified phoropter.[11] This latter option results in a more agile vector-based subjective refraction procedure which is less prone to alignment errors, but with the significant drawback of losing the phoropter's Risley prism, as its mount is used to build a continuously variable powered JCC.[12]

After developing a method for subjective vector-based refraction using both a hand-held JCC[10] and a modified phoropter without the Risley prism,[11] the next steps are directed towards developing a vector-based procedure using a conventional phoropter without the need for any modifications, thus retaining all measurement capabilities. Here, a quasi-vector-based subjective routine is presented, aimed at determining the refractive error in power vector notation directly.

The purpose of this work is to present this novel method, apply it to a population of healthy participants and compare the results with those from a conventional subjective refraction.

**Key points**

- A novel methodology is described for direct determination of the power vector components: spherical equivalent ($M$) and antistigmatic components ($J_0$ and $J_{45}$).
- The proposed methodology can be performed with standard refraction equipment without any additional modifications.
- The power vector refraction procedure yields similar results to conventional subjective refraction in healthy participants.

## METHODS

### Refractive examination procedure

All participants underwent a comprehensive ophthalmological and optometric examination, including subjective refraction and visual acuity (VA) testing using an Early Treatment of Diabetic Retinopathy Study (ETDRS) chart in LogMAR notation (Topcon CC-100, topconhealthcare.eu/en_EU). The ETDRS test features a random letter sequence presentation to prevent memorisation effects, as each participant was measured twice. Single-letter scoring was used. Ophthalmic examinations included corneal topography, slit-lamp and funduscopic examination and macular optical coherence tomography.

One experienced optometrist performed objective refraction (retinoscopy and autorefraction) followed by monocular subjective refraction using a conventional protocol, guided by the maximum plus lens to achieve maximum monocular VA (MPMVA), and using the standard ±0.25 dioptre (D) JCC in the phoropter to refine the axis and magnitude of the cylinder lens for astigmatism compensation. Refractive error and VA for each participant were recorded and anonymised.

A second experienced optometrist conducted power vector refractions, obtaining a set of power vector components ($M$, $J_0$ and $J_{45}$) convertible to sphero-cylinder notation. The conversion formulas can be found in the literature.[6,10]

The proposed quasi-vector refraction was performed using an EDTRS test with random letter sequence presentation, following this procedure:

Starting point:

1. Spherical equivalent obtained by autorefraction or retinoscopy is incorporated into the phoropter's spherical power wheel.

Obtaining the $M$ value by a conventional MPMVA procedure:

2. The initial spherical equivalent value is blurred by adding positive spherical lenses to control accommodation and avoid negative over-refraction, as in a traditional fogging procedure.
3. The initial amount of fogging is reduced in 0.25 D steps, checking for VA improvement at each step. No further steps are taken if VA does not improve.
4. A red–green filter is placed over the optotype for the final refinement with the bichrome test, aiming for equality or green best if equality is not achieved.[1]
5. The remaining spherical value on the phoropter's spherical power wheel is the final '$M$' value and is kept in the phoropter to start measuring $J_0$ and $J_{45}$.

Once $M$ is measured, the determination of $J_0$ and $J_{45}$ follows. Due to the orthogonality of the power vector components, each component is theoretically independent of the others, so $J_0/J_{45}$ can be measured without incorporating the $M$ component into the phoropter's spherical power wheel. However, it is common to add the $M$ value in the determination of $J_0/J_{45}$ components to achieve better VA. Due to the subjective nature of the methodology, reducing blur during refractive error measurements is recommended.

The procedure for $J_0$ and $J_{45}$ component determination involved positioning the phoropter's JCC with its axes in the same direction as the $J$ component to be measured (i.e., 0°/90° for $J_0$ and 45°/135° for $J_{45}$). This procedure is similar to the cylinder power refinement using the JCC in the regular subjective refraction protocol, without additional complexity. Additionally, axis refinement using the JCC in

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the conventional subjective refraction protocol is unnecessary here since the vector directions are fixed.

Obtaining the $J_0$ value:

6. With the *M* value obtained in step 5 incorporated into the phoropter's spherical wheel, the phoropter's ±0.25 D JCC is introduced with its negative axis (red dots) at 0° (see Figure 1 left).
7. Participants are informed that they will be shown two images, both blurred, and they should indicate which appears clearer or if both are equally blurred. For this step, an EDTRS visual acuity target, one line larger than that achieved with the *M* compensation in step 5, was used.
8. The JCC is flipped, and the participant is asked to compare both images (JCC negative axis at 0° vs. JCC negative axis at 90°), selecting the JCC position that minimises the perceived blur. Notice that when no astigmatism is present, or for those cases where astigmatism is pure oblique astigmatism oriented at 45°/135°, the participant should not prefer either of the two specified orientations (0° or 90°) and the $J_0$ component measurement is completed.
9. If one of the two positions is preferred, then a −0.25 D cylinder is introduced in the phoropter cylinder's wheel with its axis matching the negative JCC axis yielding the better image from the previous step (step 8). If the participant preferred the vision with the red dots along 180° (as in the left part of Figure 1), a −0.25 D cylinder ×180° is introduced in the phoropter's cylinder wheel. If they preferred axis 90°, then a −0.25 D cylinder ×90° is introduced in the phoropter's cylinder wheel.
10. Steps 8 and 9 are repeated, with additional cylinder power being added until no difference in image quality is perceived between the two JCC positions.
11. For every −0.50 D of cylinder power introduced into the phoropter, an additional +0.25 D sphere is added into the phoropter's spherical power wheel to maintain the circle of least confusion on the retina. That way, the value of the resulting spherical power is not the initially determined *M* value but rather the adjusted sphere after the cylinder power has been modified.
12. The final value of '$J_0$' is calculated from its theoretical definition of $J_0 = -0.5*C*\cos(2*\beta)$,[6,10] where C is the negative cylinder power from step 10 and β is the orientation from step 8 (β can be 0° or 90°). That is, $J_0$ is half the cylinder obtained in step 10; positive if it coincides with the horizontal axis and negative if it coincides with the vertical axis.

## Example showing how the $J_0$ value might be determined

Assume a value for *M* of −5.00 D has been obtained.

Step 5: This *M* value (−5.00 D) is dialled into the phoropter's sphere power wheel.

Step 6: Insert the ±0.25 JCC into the phoropter with its red dots at 90°/180°.

Steps 8 and 9: Flip the JCC. If the patient prefers the red dots at 180°, add −0.25 ×180° to the phoropter (now −5.00 −0.25 ×180°). If they prefer the red dots at 90°, then add a −0.25 D cylinder ×90° to the phoropter (now −5.00 −0.25 ×90°).

Steps 10 and 11: Flip the JCC again. If the patient maintains the same orientation preference (i.e., red dots at 180°), then more negative cylinder power is added until a position of no preference is reached, adjusting the sphere to maintain the spherical equivalent (e.g., −4.75 −0.50 ×180°). If the opposite orientation is chosen, the cylinder power in the phoropter would be reduced and flipped again, always maintaining the spherical equivalent.

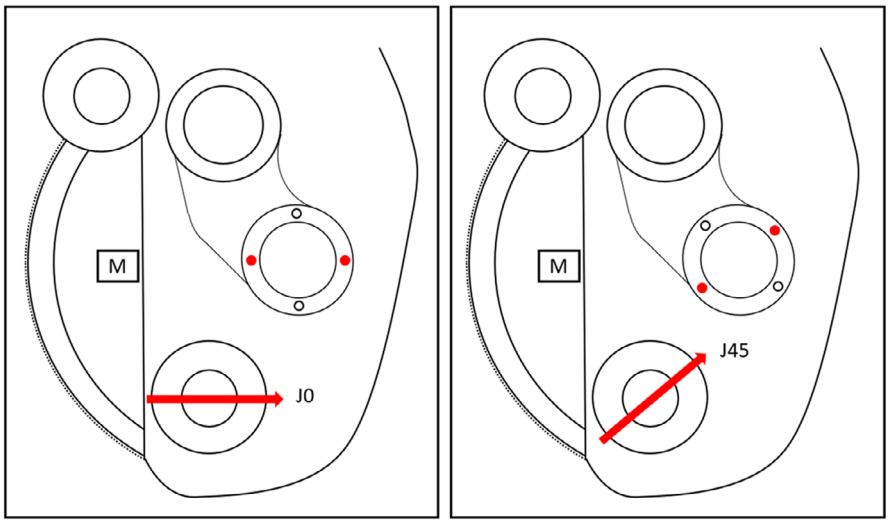


**FIGURE 1** Positioning of the phoropter's JCC for $J_0$ (left) and $J_{45}$ (right) measurements.

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Step 12: Calculate $J_0$ as half of the absolute cylinder value in the phoropter once no difference is perceived between the two JCC positions. If the final cylinder power when no difference is reported is −0.50 × 180°, then $J_o$ = +0.25. The sign of $J_0$ is indicated by the cylinder axis, with orientations of 180° and 90° indicating positive and negative values, respectively.

Obtaining the $J_{45}$ value (similar protocol to $J_0$):

13. The *M* value obtained in step 5 is reintroduced as the spherical power in the phoropter if it was changed during the measurement of the $J_0$ component.
14. The phoropter's ± 0.25 D JCC is introduced with its negative axis (red dots) at 45° (see Figure 1 right).
15. Participants are informed that they will be shown two images, both blurred. They should indicate which one appears clearer or if they are both equally blurred. At this step, an EDTRS visual acuity target, one line larger than that achieved with the *M* compensation after step 5 was used.
16. The JCC is flipped and the participant is asked to compare both images (JCC negative axis at 45° vs. JCC negative axis at 135°), selecting the JCC position that minimises blur. Notice that, when no astigmatism is present or for those cases where astigmatism is a pure ortho-astigmatism oriented at 0°/90°, the participant should not select either of the two specific orientations (45° nor 135°) and the $J_{45}$ component measurement is completed.
17. If one of the two positions is preferred, then a −0.25 D cylinder is introduced into the phoropter cylinder's wheel with its axis coinciding with the negative JCC axis yielding the better image in step 16. If the participant preferred the vision with the red dots along 45° (as in the right part of Figure 1), then a −0.25 D cylinder × 45° is introduced in the phoropter's cylinder wheel. If the participant preferred the vision with the red dots along 135°, a −0.25 D cylinder × 135° is introduced into the phoropter's cylinder wheel.
18. Flip the JCC. If the patient prefers the red dots at 45°, add −0.25 × 45° to the phoropter (now −5.00 −0.25 × 45°). If they prefer the red dots at 135°, then add a −0.25 D cylinder × 135° to the phoropter (now −5.00 −0.25 × 135°). These steps are repeated until no difference in image quality is perceived by the participant between the two positions of the JCC.
19. For every −0.50 D of cylinder power introduced into the phoropter, an additional +0.25 D sphere is added to the phoropter's spherical power wheel to maintain the circle of least confusion on the retina. That way, the value of the resulting spherical power is not the *M* value initially determined but the adjusted sphere for the added cylinder at this stage of the refractive error compensation routine.
20. The value of '$J_{45}$' is calculated from its theoretical definition of $J_{45} = -0.5*C*\sin(2*\beta)$,[6,10] where C is the negative cylinder power from step 18 and β its orientation from step 16 (β can be 45° or 135°). That is, $J_{45}$ is half the absolute cylinder obtained in step 18, being positive or negative if its axis is 45° or 135°, respectively.

## Example showing how the $J_{45}$ value might be determined

Assume a value for *M* of −5.00 D has been obtained.

Step 13: This *M* value (−5.00 D) is dialled into the phoropter's sphere power wheel.

Step 14: Insert the ±0.25 JCC into the phoropter with its red dots at 45°/135°.

Steps 16 and 17: Flip the JCC. If the patient prefers the negative axis at 45°, add −0.25 × 45° to the phoropter (now −5.00 −0.25 × 45°). If they prefer the negative axis at 135°, add −0.25 × 135°.

Steps 18 and 19: Flip the JCC again. If the patient maintains the same orientation preference (i.e., red dots at 45°), then more negative cylinder power is added until a position of no preference is reached, adjusting the sphere to keep the spherical equivalent (e.g., −4.75 −0.50 × 45°). If the opposite orientation is chosen, the cylinder power in the phoropter would be reduced and flipped again, always keeping the spherical equivalent.

Step 20: Calculate $J_{45}$ as half of the cylinder value in the phoropter once no difference is perceived between the two JCC flip positions. It is positive if the negative cylinder is at 45° ($J_{45}$ = +0.25). If the negative cylinder is at 135° (e.g., −4.75 −0.50 × 135°), $J_{45}$ would be negative ($J_{45}$ = −0.25).

Obtaining the sphero-cylindrical formula and measuring VA:

- Using a Microsoft Excel (Microsoft.com) spreadsheet, the sphero-cylindrical formula is calculated based on the values obtained for *M*, $J_0$ and $J_{45}$.[6]
- The resulting sphero-cylinder is placed in the phoropter to measure VA, rounding the sphere and cylinder power to the nearest 0.25 D and the cylinder axis to the nearest 5°.

Three detailed examples showing the entire procedure for three of the subjects measured in this study can be found in the Supporting Information section (Data S1).

It is important to note that participants with high astigmatism may have difficulty distinguishing the better image when the JCC is flipped during the $J_0$ (step 8) and $J_{45}$ (step 16) measurements, as visual acuity with only the spherical component (*M*) may be too poor to notice the differences between the two positions of a low-powered JCC (±0.25 D). Thus, the following decision tree is proposed after *M* measurement:

- If VA with the *M* correction in the phoropter is 0.40 LogMAR or better, the ±0.25 D crossed cylinders from the phoropter are used as explained above.
- If VA with the *M* correction is worse than 0.40 LogMAR, a ±0.50 D (for VA between 0.40 and 0.70 LogMAR) or a ±1.00 D (for VA worse than 0.70 LogMAR) hand-held JCC should

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be placed in front of the phoropter until 0.40 LogMAR VA (or better) is achieved, switching at this point to use the ±0.25 D JCC from the phoropter, as explained above.

In the proposed method, the astigmatic decomposition proposed by Gartner[13] is used, which is based on the optometric vector ($C_0$, $C_{45}$) for dealing with astigmatism, but this is complemented by the *M* component needed for refractive error determination. The values being managed are *M*, $C_0$ and $C_{45}$, which are conceptually different from the ones reported by Humphrey[14] and Thibos et al.[3]

We have termed this method 'quasi vector-based' to distinguish it from previous works where, once the *M* component is measured, its value is maintained during the $J_0$ and $J_{45}$ determinations. This is because both the handheld JCC[10] and the laboratory-made Stokes lens[11] do not alter the position of the circle of least confusion, as both are antistigmatic optical systems that neither introduce nor change the *M* component. However, in the method presented here, the spherical value on the phoropter's spherical power wheel is not maintained during the determination of the antistigmatic components. Here, each step of introducing negative cylinder power into the phoropter's cylinder power wheel displaces the circle of least confusion from the retina, since the phoropter's cylinder lenses are not antistigmatic but astigmatic,[8,9] and therefore have an *M* value different from zero that requires compensation. Consequently, a correction of +0.25 D sphere must be made for every −0.50 D change in cylinder power to keep the circle of least confusion on the retina. Due to this conceptual difference, the term 'quasi' is included in the title.

## Participants

Inclusion criteria were healthy participants over 18 years of age. Exclusion criteria included contact lens wear within 2 weeks of measurements, amblyopia, previous ocular surgery or a history of ocular disease.

Informed consent was obtained from the participants after a detailed explanation of the study. The protocol adhered to the principles of the Declaration of Helsinki and received institutional review board approval from the Clinica Baviera Medico-Legal Committee.

Before data recording and measurement, 10 participants were used to 'train' the optometrist in the clinical procedure until he was comfortable with the process of power vector refraction measurement and data anonymisation. These values were not included in the study. All data collected in this study can be found in the Excel file in the Supporting Information section (Data S1).

## Statistical analysis

Refractive findings from the conventional or standard monocular subjective refraction protocol with an MPMVA endpoint were obtained in the usual clinical sphero-cylindrical notation: sphere, negative cylinder and axis, while subjective power vector refractions were directly obtained in power vector components (*M*, $J_0$ and $J_{45}$). Sphero-cylinders were converted to power vector notation for statistical comparison.[6,10] VA was recorded in LogMAR notation.

Mean values ± standard deviations (SD) were used to describe results when normality could be assumed, or median values ± interquartile range (IQR) when the normality test failed.

Data from only one eye per participant were included to avoid bias.[15] Given the mirror symmetry of astigmatism between eyes, including both right and left eyes would require reversing the sign for left eyes to treat them as right eyes. A coin toss randomly determined that only left-eye data would be used in this work for all participants, thereby eliminating the need for sign reversal.

Statistical comparison between conventional and quasi-power vector outcomes was tested with a paired *t*-test, or a Wilcoxon rank-sum test if normality testing with the Shapiro–Wilk test failed.

Statistical analysis and graphics were performed using Rstudio version 4.3.1 (posit.co/download/rstudio-desktop) and the ggplot2 graphic package (ggplot2.tidyverse.org).[16] The significance level was set at 5% ($\alpha = 0.05$).

# RESULTS

Of the 50 initially enrolled healthy participants, data from only 40 subjects were considered for analysis, as the first 10 were used to train the optometrist in the quasi-vector-based refraction procedure. The mean age of the 40 participants was 45.7 ± 19.4 years (range 20–88 years).

## Differences in spherical component between methods

Data for the *M* component passed the Shapiro–Wilk normality test, both for the conventional refraction ($p = 0.76$) and the quasi-vector-based refraction ($p = 0.69$) findings. The variance of the *M* component in both groups was similar ($p = 0.98$), and a paired *t*-test revealed no statistically significant differences between the mean ± SD results for *M* obtained with the conventional (−1.61 ± 2.92 D) and quasi-vector-based (−1.61 ± 2.91 D) refraction procedures. Figure 2 shows a violin plot for the *M* component obtained with both the conventional and quasi-power vector refraction procedures, along with the result from the paired *t*-test.

## Differences in astigmatic components between methods

A non-parametric Wilcoxon rank-sum test (see result in Figure 3) was applied to examine the differences between median ± IQR values for $J_0$ obtained by conventional (0.00 ± 0.71 D) and quasi-vector-based (0.00 ± 0.75 D)

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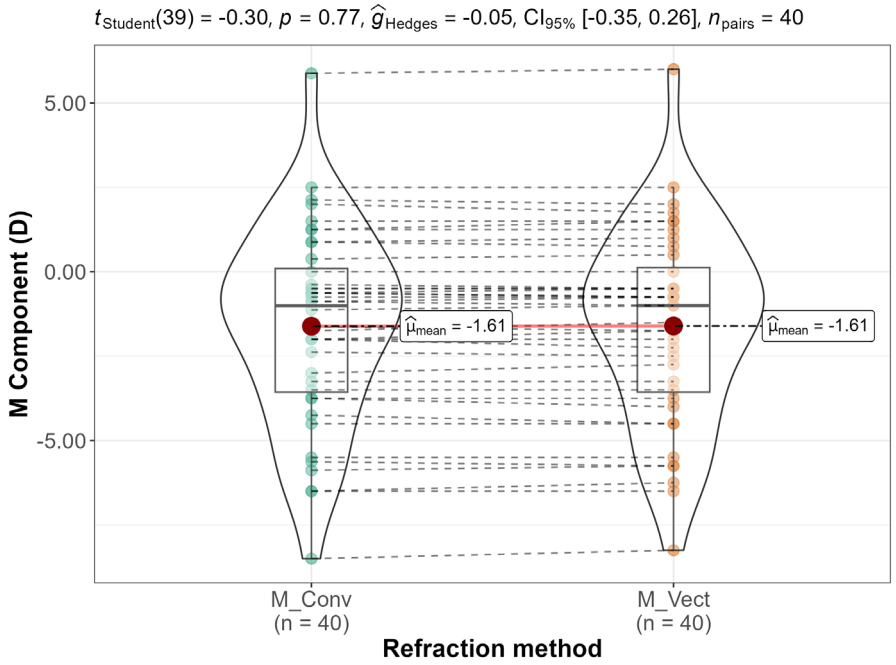


**FIGURE 2** Violin plot for *M* (spherical equivalent) values obtained with the two methods of measurement. Conv, conventional refraction procedure; vect, quasi-power vector refraction procedure.

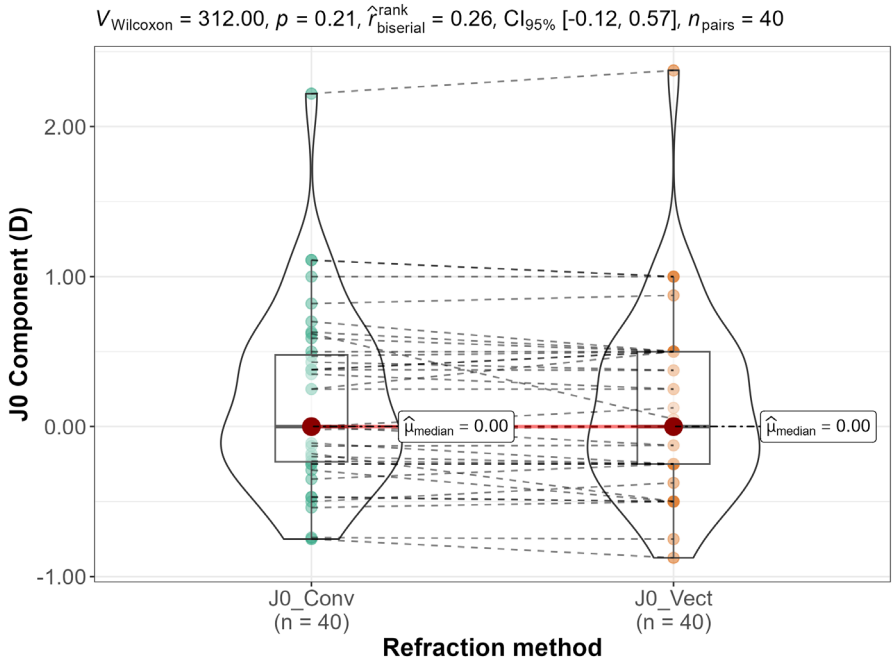


**FIGURE 3** Violin plot for $J_0$ values obtained with the two methods of measurement. Conv, conventional refraction procedure; Vect, quasi-power vector refraction procedure.

refraction procedures, as normality could not be assumed (Shapiro–Wilk, $p < 0.05$ in both cases). Figure 3 shows a violin plot for the $J_0$ component obtained with both the conventional and quasi-power vector refraction procedures, along with the statistical test result from the Wilcoxon test.

$J_{45}$ results also failed the normality test (Shapiro–Wilk, $p < 0.05$ in both groups), so the comparison for $J_{45}$ median ± IQR values using conventional refraction (0.00 ± 0.20 D) and quasi-vector-based refraction (0.00 ± 0.13 D) was also performed using a non-parametric Wilcoxon test. The result is shown in Figure 4.

## Differences in visual acuity between methods

The VA data did not pass the normality test (Shapiro–Wilk, $p < 0.001$ in both groups), so the non-parametric Wilcoxon rank-sum test was adopted to assess differences

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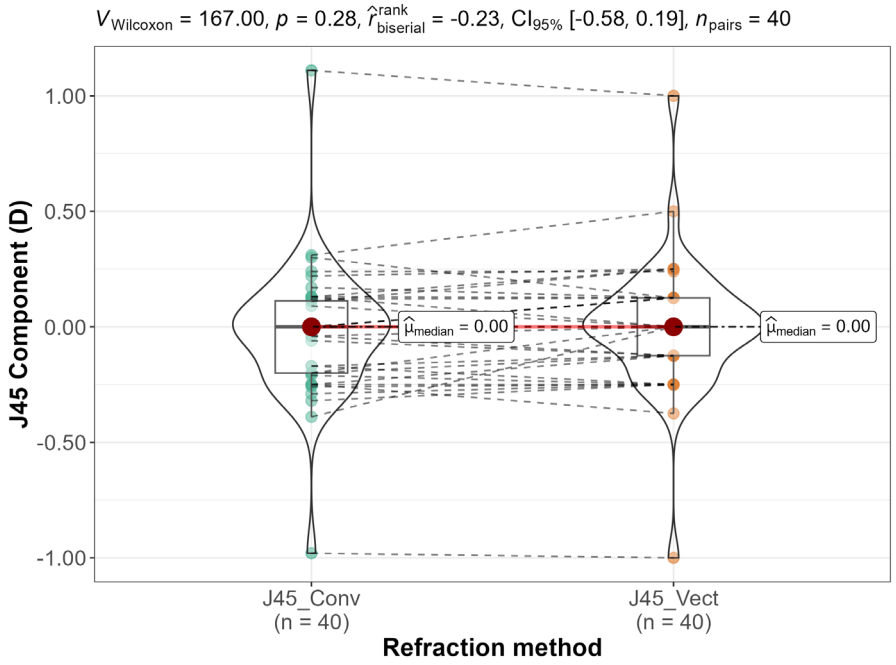


**FIGURE 4** Violin plot for $J_{45}$ values obtained with the two methods of measurement. Conv, conventional refraction procedure; Vect, quasi-power vector refraction procedure.

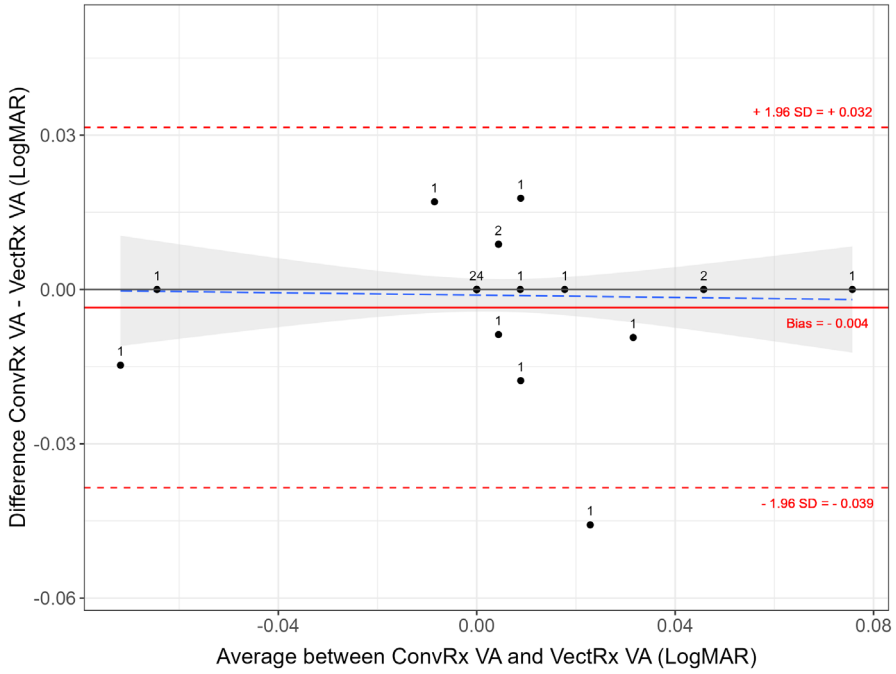


**FIGURE 5** Bland–Altman plot showing the difference between visual acuity (VA) values obtained after conventional and quasi-vector-based refraction methods. Horizontal dotted-red lines: ±1.96 * SD of the differences; horizontal solid black line: zero-difference line; horizontal solid red line: bias line; dashed blue line: linear data tendency; grey zone: 95% confidence interval around the tendency line. The number at each point indicates how many cases the point represents. ConvRx, conventional subjective refraction; VectRx, quasi-vector-based subjective refraction.

in the VA measured with the findings obtained using each refraction method. The result ($p = 0.85$) revealed no significant difference between the median ± IQR for the VA obtained with the conventional refraction method (−0.08 ± 0.08 logMAR) and that obtained with the proposed quasi-vector-based refraction method (−0.06 ± 0.10 logMAR).

Figure 5 shows differences in LogMAR VA values obtained with both refraction procedures by means of a Bland–Altman plot.

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As shown in Figure 5, 95% of the differences in VA between the two refraction methods lay within a range from −0.039 LogMAR to +0.032 LogMAR, with a bias close to zero (−0.004 LogMAR).

## DISCUSSION

A method is introduced for performing subjective refraction, directly obtaining a prescription in vector formalism using a conventional phoropter without any modifications.

Vector formalism applied to ocular refraction is not new. For example, Gartner published a study on astigmatism and optometric vectors in 1965,[13] and the Humphrey vision analyser (HVA) used this concept to measure refractive error in the mid-1970s.[14,17] More recently, Raasch revisited clinical refraction in three-dimensional dioptric space.[18] Thibos et al.[7] defined power vectors as an application of Fourier analysis, popularising vector formalism in vision science with applications in refractive surgery.

Traditionally, vector formalism has been used for statistical purposes after converting from the more clinically meaningful sphero-cylinder notation.[6] More recently, Revert et al.[10] demonstrated that power vector refraction can be measured directly with trial lenses and a set of hand-held JCCs, avoiding the conversion from sphero-cylinder notation. However, using hand-held JCCs introduced potential bias if the axis was not perfectly aligned, and the process was time-consuming.

To address these issues, Albero-Moreno et al.[11,12] developed a method for vector-based refraction using a modified phoropter, adapting a low-cost, self-made, continuously variable powered JCC lens (Stokes lens) to the phoropter's Risley mount. This method confirmed the feasibility of vector-based refraction but compromised some of the phoropter's capabilities by replacing the Risley prism with the orientable Stokes lens.

The current protocol aimed to perform vector-based refraction using a regular phoropter without modifications. Similar to previous work,[10,11] this method considered astigmatism as a Fourier analysis,[3] and measured the spherical equivalent (*M*) and the JCCs from which the antistigmatic $J_0$ and $J_{45}$ components were derived separately. *M* was obtained through a spherical MPMVA determination prior to obtaining the antistigmatic components, and these were extracted by positioning the phoropter JCC along fixed axes (0°–180° for the $J_0$ component and then 45°–135° for $J_{45}$), searching for those JCCs that matched the participant's perception.

Gartner proposed cylinder powers ($C_0$ and $C_{45}$) to characterise astigmatism,[13] while Humphrey did this with crossed-cylinder powers ($J_0$ and $J_{45}$).[3] Gartner's work neglected spherical components; only astigmatism was considered and treated as an optometric vector, although the spherical component S was calculated at the end using a classical ophthalmic formula. The current methodology lies between these approaches. It used the optometric vector defined by Gartner, setting the negative sign of the cylinders for refractive error compensation using subjective routines. This simplified that part of the visual analyser concerning the refractive correction assembly as reported by Humphrey.

Results from the new protocol were similar to those from conventional subjective refraction, both in terms of refractive error and visual acuity. Figures 2–4 show similar distributions for the two methods. This similarity is expected, particularly for the *M* component, which represents the spherical value that positions the circle of least confusion on the retina. However, the methodologies differed slightly: *M* is calculated from the sphere and cylinder values in conventional subjective refraction but is measured directly in quasi-vector-based refraction (being independent of the $J_0$ and $J_{45}$ values).

Regarding the possible limitations of this study, the repeatability of the proposed quasi-vector-based refraction procedure has not yet been tested. Nonetheless, this method is a variation of a vector-based refractive procedure presented previously,[11] in which repeatability was adequate with a sample of visually normal participants. Thus, similar repeatability with the proposed method can be expected with such participants, but this matter needs to be addressed in future studies. Two (or more) masked practitioners should perform this quasi-vector-based procedure on the same sample of participants to compare the findings.

Regarding the quasi-vector-based procedure, the corresponding sphero-cylinder notation was rounded to the nearest 0.25 D for sphere and cylinder powers and to the nearest 5° for the cylinder axis, based on the precision of the phoropter. For example, if a result of −2.00 D, −0.13 D and +0.25 D was obtained for *M*, $J_0$ and $J_{45}$, respectively, with the quasi-vector-based procedure, then the corresponding prescription of −1.72 DS and −0.56 DC × 58° was rounded to −1.75 DS and −0.50 DC × 60° for visual acuity measurement. A phoropter with greater precision (narrower lens intervals) might yield different results, especially for higher astigmatism.

The optometrist performing quasi-vector-based refractions in this work (JRAM) had prior experience with vector-based-refraction with the phoropter modification described elsewhere,[11,12] so this learning curve was short. For an inexperienced practitioner, some practice will be required.

From the patient's perspective, the method requires a subjective interpretation of blur during the procedure, with the participant never reaching the expected good vision achieved at the end of the refractive procedure by the conventional method. In other words, the proposed method does not directly provide a combination of refractive lenses providing maximum optimisation of VA. Additionally, the participant is required to distinguish between one lens position with blur and other lens position with less blur at each step. This may be a less intuitive protocol from a patient's perspective.

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During the antistigmatic components determination, the phoropter's JCC was flipped between two positions, and the cylinder power was adjusted until no difference in image quality was perceived, taking the first 'no difference' report as the corresponding cylinder value for *J* determination, rather than looking for a possible bracketing range of similarity between the two JCC positions followed by a reversal. An alternative approach could involve identifying a bracketing technique and taking the midpoint as the cylinder value for the corresponding *J* determination, which might produce different results. This requires further investigation.

Another point that could require further study is the necessity of rechecking *M* after determining $J_0$ and $J_{45}$. In the present protocol, *M*, $J_0$ and $J_{45}$ were determined consecutively, without subsequently rechecking *M*. Astigmatism in the current participants was <2.50 D, except for a sole case of 4.50 DC. It remains to be determined whether the *M* recheck is necessary in cases of high astigmatism. For a case of 4.50 D astigmatism, similar *M* values were obtained for the conventional refraction (*M* = −1.75 D) and the quasi-vector-based procedure (*M* = −1.50 D).

In the *J* determination, if a participant reported an initial 'equal' response between the two JCC positions, a result of 0.00 was reported. It might be advantageous in such a situation to add −0.25 DC to test for reversal to 0.00 DC.

A further limitation of the quasi-vector-based technique relates to the minimum discernible difference capability of some participants with the phoropter's ±0.25 D JCC. If the VA with the *M* component at the point of obtaining each of the *J* components was worse than 0.40 LogMAR, then these participants might experience difficulties in differentiating the blur produced by each of the two JCC positions. This is likely to occur in the presence of high astigmatism. Therefore, for those patients, it may be necessary to start the *J* determination procedure with a higher-powered JCC than found in the phoropter. This can be accomplished with a hand-held ±0.50 D or ±1.00 D JCC when starting the *J* determination to ensure the correct sign of each *J* component (i.e., the correct axis). In the current sample (including the 50 participants), the ±1.00 D hand-held JCC was only required on one occasion and the ±0.50 D hand-held JCC twice.

As stated previously regarding the clinical use of a vector-based procedure,[10,11] this protocol is not presented as a substitute for conventional refraction, but rather as an alternative that could have applications in certain situations, such as irregular corneas or an unreliable starting point (e.g., unreliable retinoscopy, keratometry or autorefractometry), and as an interesting new refraction method for motivated clinicians seeking to expand their knowledge and implement new routines in refractive determination.

## AUTHOR CONTRIBUTIONS

**Jose Ricardo Albero Moreno:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (lead); writing – review and editing (equal). **Cesar Albarrán Diego:** Conceptualization (equal); data curation (equal); formal analysis (equal); writing – review and editing (equal). **Vicente Micó:** Conceptualization (equal); methodology (lead); supervision (lead); writing – review and editing (equal).

## CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflicts of interest.

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## ORCID

*Jose Ricardo Albero Moreno* https://orcid.org/0000-0002-3575-9792
*Cesar Albarrán Diego* https://orcid.org/0000-0001-8972-1784
*Vicente Micó* https://orcid.org/0000-0001-9457-1960

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## SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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