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Ready-made readers vs CR-39: A study of refractive index, clarity, and scratch resistance

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Background: Columbia Resin 39 (CR-39) is a plastic polymer widely recognised in the ophthalmic industry for the production of spectacle lenses. This material is known for its superior optical qualities and higher scratch resistance compared to other materials. Ready-made reading spectacles (RMRS) offer a cost-effective and readily accessible option for vision correction.

Aim: This study aimed to compare lenses used in RMRS to CR-39 lenses, specifically in terms of refractive index, image quality and scratch resistance.

Setting: This study was conducted at the University of the Free State, Bloemfontein, South Africa.

Methods: In this comparative study, 12 RMRS lenses were evaluated against three CR-39 lenses. A spectrometer was used to determine the refractive index by quantifying the percentage of light transmission. Image quality was assessed using an optical tract that projected images of line pairs through the 15 lenses, utilising a monochromatic light filter. The scratch resistance was measured by counting the number of scratches on the lenses produced by an anti-scratch coating device.

Results: A statistically significant difference in the refractive indices was found. No statistically significant correlation was found in image quality. However, practically, CR-39 demonstrated superior image quality and exhibited less susceptibility to scratching.

Conclusion: When prioritising practical implications of image quality and scratch resistance, CR-39 lenses exhibit superior performance compared to RMRS lenses.

Contribution: This study offers the public community and the ophthalmic industry insights into the differences in optical and physical quality between RMRS and CR-39 materials.

Keywords: CR-39; ready-made spectacles; refractive index; image quality; scratch-resistance.

Introduction

In South Africa, the problem of inequality and limited healthcare access remains a significant concern, with affordability being the primary contributing factor preventing individuals from receiving adequate healthcare.[1] As the population ages, visual impairment is anticipated to become an increasingly significant problem.[2] In 2018, individuals aged 65 and older exceeded those aged 5 and under, and this demographic shift is projected to double by 2050.[2] Presbyopia, the irreversible loss of the accommodative ability of the eye because of ageing, will ultimately affect all individuals over the age of 50 years.[3] This condition arises from the natural ageing process of the ocular crystalline lens, wherein this lens loses its elasticity and becomes less spherical, resulting in a reduced ability to accommodate at near distances.[4]

It was also found that in 2015, the number of people with presbyopia, who had near vision impairment as a result of 'inadequate' or no refractive correction, was estimated to be 826 million.[2] Bourne et al. believed that the prevalence of mild, moderate and severe visual impairment will become more of a burden as the population continues to age.[2]

This underscores the importance of affordable refractive correction options, such as ready-made reading spectacles (RMRS), in addressing visual impairment in developing countries. Ready-made reading spectacles are often more cost-effective than custom-made spectacles and are therefore being explored as a viable alternative.[5] Ready-made reading spectacles typically consist of positive powered lenses, which provide additional converging power for the presbyopic individuals, aiding in the focusing of near objects. To address the high prevalence of uncorrected presbyopia, inexpensive, mass-produced and readily available corrections are necessary. Ready-made reading spectacles, designed with equal spherical dioptric power for both eyes and a fixed focal distance, has proven to be an effective solution when custom-made spectacles are unavailable. However, there are a vast number of varying manufacturers, and limited information regarding the types of lenses used in the production of these spectacles.[6]

Therefore, it is imperative to ensure that these RMRS are manufactured using lens material of acceptable quality, irrespective of affordability. To guarantee that RMRS meet acceptable quality standards, these lenses must be compared to established ophthalmic lens standards. The American National Standards Institute (ANSI) has outlined lens tolerances for optometrists, laboratories and manufacturers, specifically referencing the International Organization for Standardization (ISO) standards listed in ISO 16034-2002 for social lenses.[7] These standards encompass optical dioptric power ranges, power tolerances, reference points, prismatic tolerances as well as packaging requirements such as labelling, warnings and instructions.[8] According to the ISO, the materials used in the lenses for RMRS should be manufactured from hypoallergenic materials and must possess specific heat and impact resistance.[7]

In terms of optical quality, the ISO has established standards for lens transmittance.[9] In South Africa, the Health Professions Council of South Africa (HPCSA) outlined additional requirements for RMRS specifications. These requirements include the use of moulded lenses with dioptric powers ranging from +1.00 D to +3.00 D. Furthermore, a warning label must be affixed, indicating that these spectacles are intended for short-term use by individuals over 40 years of age and are not suitable for driving.[10]

By investigating the interaction between the optical qualities, lens specifications and frame durability of RMRS, it is essential to integrate various factors that will influence the overall performance of RMRS. Image quality is one of the technical standards governing optical quality, specifically focusing on the ISO standard for lens transmittance and the unique requirements outlined by the HPCSA for RMRS. These standards are critical for ensuring that the lenses provide adequate visual clarity. Image resolution and lens durability are key factors that influence the optical performance of RMRS.

By linking the above-mentioned factors, it becomes evident how the optical quality and physical characteristics of lenses and frames combined influence the effectiveness of RMRS, thereby underscoring the importance of adhering to both international standards and Pacific regional requirements.

The quality of an image is characterised primarily by its resolution, which is determined by the number of pixels composing the image.[11] Resolution is defined as the maximum spatial frequency of a grating consisting of black and white bars of equal width (Foucault pattern) at which the bars are resolved. The Foucault criterion is used to measure the image quality in optical systems.[11] Because resolution is limited by the wide spectral range of aperture pixel functions, a broader range of spatial aperture functions enhances resolution. However, a decrease in pixel size can lead to sensor sensitivity degradation and image distortion, whereas an increase in pixel size has the opposite effect.[11]

The durability of a lens can be significantly influenced by the choice of a spectacle frame. Frames are typically constructed from metal, plastic or a combination of both materials. They are available in various designs, including full frames, rimless and nylon-supra frames. For nylon-supra frames, the lens must be grooved to create an area for the cord to rest. This increases the risk of the lens chipping in that specific area.[12] Rimless frames attach the temples directly to the lenses by drilling holes into them. This process increases the potential for the lens to chip by creating weakened areas. Consequently, optometrists often prefer to use Trivex or polycarbonate lenses over Columbia Resin 39 (CR-39) lenses when fitting lenses into rimless and nylon-supra frames, as these lens materials offer greater durability and scratch resistance.[13] The durability of a lens also affects its impact resistance, particularly its scratch resistance. Because this study did not test impact resistance but instead compared the scratch resistance of lens materials used in RMRS with CR-39, the term ‘scratch resistance’ was used to describe this property.

When selecting a lens material for RMRS, it is crucial to consider not only transmittance, prism tolerances, and heat resistance of the material but also other factors, such as the Abbé value. A higher Abbé value corresponds to fewer chromatic aberrations, whereas a lower Abbé value results in noticeable colour fringes in the periphery of the lens, potentially decreasing visual acuity.[14] Chromatic aberrations relate to the refractive index of a lens material. When light passes through media, the speed of transmission is altered depending on the resistance offered by the medium. White light travels fastest in a vacuum; therefore, materials that are less transmission-resistant will allow white light to pass through faster. Resistance to the speed of white light is referred to as the refractive index.[15] Each wavelength in white light is refracted independently through lens materials; however, the standardised refractive index of a lens material is that of the value of the refractive index when yellow light passes through the material.[16] Materials that show similar refractive indices for different wavelengths in white light tend to exhibit less chromatic aberration; however, materials that have a larger range of refractive indices exhibit more chromatic aberration.[16] The refractive index of a lens material additionally impacts the thickness and weight of the finished lens; the higher the refractive index of the lens material, the thinner and lighter the lens will be.[17]

It is therefore essential to use a lens material that provides an acceptable proportion between refractive index and weight, like CR-39 lens material, which is a recognised and well-established ophthalmic lens material in the optical industry, known for its stable and consistent refractive index, power consistency and image quality.[17] With a refractive index typically around 1.498, it offers a balanced combination of optical performance and material properties.[14,17] However, in practical applications, the perceived benefit in terms of lens weight and thickness is dependent on the specific gravity of the material.[17] In the case of spectacle lenses where the prescription exceeds –7.00 D, a perceptible reduction in thickness and weight is observed due to the use of high refractive index materials.[17]

CR-39 provides an optimal balance between these characteristics, ensuring that lenses are both lightweight and efficient in correcting vision, which is entail for comfort and usability, particularly in RMRS.

Image perception, too, is affected by many aspects, one of which is the point through which the user sees through the lens. When the eyes are not perfectly aligned with the centre of a lens, known as the optical centre, several negative effects may arise, such as prismatic and chromatic aberrations. The visual consequences of these misalignments are more severe in high-index and aspheric lenses, which are common in higher prescriptions.[18] An important measurement to be taken into consideration is the distance between the eyes, known as pupillary distance (PD), which must be accurately measured to ensure the optical centres align with the line of sight as convergence takes place during near tasks.[18] Convergence refers to the inward movement of the eye when doing near tasks, such as reading. Failure to look through the optical centre becomes especially critical in near work. The measurements to assess the refractive index, image quality and preliminary powers of the lenses were at the centre of the lens, as this is the standardised reference point; additionally, the potential for chromatic aberrations at the periphery of the lens was avoided.

The standards established by the ANSI for RMRS fall under the category of dress lenses. These standards align with those set by the ISO, as specified in ISO 16034:2002.[8] A diverse range of RMRS is available in retail stores; however, detailed information relating to the lens characteristics remains limited. Despite the existence of optical quality standards and tolerances for dress lenses, not all contributing factors to optical quality are consistently adhered to.

Adherence to both international standards and regional requirements is critical to ensuring that RMRS provide optimal visual clarity and performance. This study investigated the properties of lenses used in RMRS, specifically focusing on their refractive index, image quality and scratch resistance compared to that of CR-39. It was hypothesised that CR-39 lenses would exhibit a more consistent refractive index and superior image quality and scratch resistance compared to RMRS lenses. The study aimed to compare the refractive index, image quality and scratch resistance of RMRS lenses to CR-39 lenses.

Research methods and design

Study design

This study employed a quantitative, comparative, descriptive design to examine the relative merits of various brands of lenses compared to CR-39 lenses.

Setting

This study was performed at the University of the Free State, Bloemfontein, South Africa.

Data collection

The data collection for the study was carried out at designated sites at the University of the Free State, Bloemfontein, South Africa. These sites included: the Clinical Skills Unit (CSU) of the School of Health and Rehabilitation Sciences, the Physics Department and the Centre for Universal Access and Disability Support's (CUADS).

Five retail stores within the Loch Logan Waterfront Mall were identified as sources for the RMRS used in the study. Convenience sampling was employed to acquire the necessary samples for both RMRS and CR-39. Within the mall, six distinct brands were identified. For each brand, two pairs of spectacles were obtained. One pair was designated for use in the study, while the second pair was retained as a backup resource in case of any damage to the primary pair. Consequently, the sample comprised six pairs of spectacles, resulting in a total of 12 RMRS lenses used in the study.

Additionally, three CR-39 lenses were also conveniently selected as these lenses were provided to the researchers at no cost by an undisclosed private optometry practice owner. Therefore, the final sample size comprised 15 lenses, of which 12 were RMRS lenses and three were CR-39 lenses.

Despite CR-39 being widely used in the optical industry, the impact resistance of the lens material is lower than Trivex and polycarbonate.[17] As such, CR-39 is not the ideal choice for rimless and nylon-supra spectacle frames. The impact resistance of the RMRS and CR-39 was outside the scope of this study; therefore, only full rimmed frames were included in the study, as these frames are ideal for fitting CR-39 lenses. Ready-made reading spectacles featuring uniform eye size and an optical power of +2.50 Dioptre Sphere were included in the study. Lenses with tints, coatings or blue light blocking filters were excluded from the study.

The spectacle lenses used in this study were de-identified. Each lens was assigned a label, such as 'A1-R' or 'A1-L', this was to ensure the brand or manufacturer was not identifiable. The letter on the label represents the lens pair of the spectacles. The letters 'L' and 'R' represent the left and right lens of the spectacles respectively. As the optic centre is a standardised point for optical measurements and the study population was single vision lenses without a complex design, the refractive index, image quality and power of the lenses were determined at this point. By using this standardised point, the results of this study will be consistent and comparable to other such studies. The lens power was verified by researchers using a vertometer. Each researcher independently assessed the dioptric power of every lens, and the findings were subsequently compared among the researchers. This preliminary test indicated that there were no discrepancies in the dioptric power of the lenses.

Measurements on the RMRS and CR-39 lenses were taken using the tests listed in the order of execution below.

Refractive index

To determine the refractive index, the Perkin Elmer Lambda 950 UV-Vis Spectrometer was used to measure the percentage of light transmitted through the lenses. By converting the transmittance (T) into fractions, as per Equation 1 developed by Swanepoel in 1983, the researchers derived the refractive index (n):[19]

$$n = \frac{1}{T} + \left(\frac{1}{T^3} - 1\right)^{\frac{1}{2}}. \qquad \text{[Eqn 1]}$$

For this study, the average percentage of light transmission across the wavelength range of 450 nm to 750 nm was used, as the spectrometer was able to accurately determine the percentages within this range of wavelengths of visible light.[16] The spectrometer measured the change in light direction to determine the amount of light passing through the lens surface. The computer software presented this information as the percentage of light transmission through the lens. By averaging the percentage transmittance across these wavelengths, the researchers obtained a fraction that was used in the above-mentioned formula to calculate the refractive index.[19] The measurement procedures were conducted at the University of the Free State Physics Department, with the assistance of an expert in the field of optics. This process was carried out on all 12 RMRS lenses and three CR-39 lenses.

Image quality

The image quality was determined in a dark room using a monochromatic light source placed at the end of an optical tract. The light was projected through a filter to manage the amount of light moving through the grate. This created an image through the lens that was captured on a camera. The optical tract projected images of varying numbers of line pairs through all 15 lenses. Alternating dark and light regions were created by the grid; the wider the transition between the dark and light regions, the greater the image blur (in terms of pixels), which indicated lower image quality.[20] A pixel cross-section was extracted from the captured image, and the collected data were then plotted on a line graph using the software. This created four wavelengths for each lens, respectively.

The width of the wavelengths from each lens was compared. The lens that provided the wavelength with the greatest width was the lens with the best image quality.[11] Optical performance variables, such as chromatic aberration and peripheral distortions, were not investigated using the chosen image formation apparatus; therefore, results should be interpreted as a comparative indicator, and not as an absolute measure of the quality of lenses.

Scratch resistance test

The lenses were then examined at the study cubicles at CUADS, which were windowless and maintained consistent LED lighting conditions throughout the examination to prevent any influence on the findings. Before intentionally scratching the lenses, the Max Closed-Circuit Television (MaxCCTV), a high-magnification device, was used to count the pre-existing scratches on the lenses in triplicate. The researchers used a HOYA marketing device that is used to test the anti-scratch coatings on the lenses. This device comprises two slots for uncut lenses and movable metal fibres designed to physically scratch the lenses. Each lens underwent 10 scratch cycles, with each cycle consisting of one pullover and one pushback, constituting two counts. Subsequently, the number of visible scratches was recounted three times using the MaxCCTV.

Data analysis

The data from each test were recorded on separate data sheets, followed by the creation of a composite sheet for comprehensive data analysis. Descriptive statistical measures, including frequency and percentage for categorical data, and median and percentile for numerical data, were calculated. The Wilcoxon Rank sum test was used to compare the RMRS lenses with the CR-39 lens. Given that the results were non-parametric, Spearman correlation coefficients were used to interpret and derive the data. These were used to analyse the results, particularly for non-parametric data, to determine the rank-based statistical dependence between two variables. Spearman correlation assesses the strength of a monotonic relationship between paired data points. This study specifically examined the correlation between the refractive index and image quality in CR-39 in relation to RMRS lenses. Spearman's correlation coefficient ranges from −1 to +1, where values closer to −1 and +1 indicate a stronger relationship between two variables. A P-value of < 0.05 was considered statistically significant.

Ethical considerations

Ethical approval to conduct the study was received from the Health Sciences Research Ethics Committee at the University of the Free State (reference number: UFS-HSD2023/0066/2802). Additional permissions were obtained from the Biostatistics and Physics departments, CUADS facility and Optometry department of the University of the Free State. To ensure confidentiality, the names of the brands and stores were de-identified and not disclosed. The study was conducted solely for research purposes, with no intent for marketing or advertising. Digital and hard copies are stored safely and will be destroyed after 5 years.

Results

This study was conducted on the RMS lenses labelled: A1-R, A1-L, B1-R, B1-L, C1-R, C1-L, D1-R, D1-L, E1-R, E1-L, F1-R, F1-L and compared to three CR-39 lenses labelled CR39-1, CR39-2 and CR39-3.

Three CR-39 lenses were conveniently chosen for this study. The results showed the refractive index of the CR-39 lenses in the study ranged from 1.44 to 1.58, which is similar to the reported refractive index of CR-39 (1.498). The CR-39 lenses also showed similar scratch resistance to each other, and none seemed to have outlying results. The results of these two variables showed the three lenses to be representative of the CR-39 lens material. However, image quality was determined using an optical tract, line pairs and pixel width of resultant wavelengths. As much as this method is scientifically sound, studies using this exact method to determine the image quality of CR-39 were not found; therefore, the image quality of the CR-39 lenses could not be verified against others.

The following results were obtained.

Refractive index

Spearman rank correlation analysis was conducted to investigate the relationship between the refractive indices ($N = 301$) of three CR-39 lenses (CR39-1, CR39-2, and CR39-3) and 12 RMRS lenses.

The *P*-values indicating the statistical significance and correlation coefficients (ρ) corresponding to each lens are presented in Figure 1 and Figure 2, respectively. All refractive index values for RMRS showed weak correlations to all CR-39 lenses, with all being positive correlations except for F1-R and F1-L, which demonstrated negative correlations to all CR-39 lenses. Statistically significant correlations ($P < 0.05$) were found for all comparisons besides C1-L and F1-R ($P > 0.05$), and the majority of the refractive index correlations were statistically significantly weak.

A1-R and A1-L exhibited weak correlation coefficients ranging from ρ = 0.306 to 0.390, with statistically significant *P*-values ($P < 0.001$) across all comparisons with the CR-39 lenses. Similarly, B1-L showed correlation coefficients in the range of ρ ≈ 0.384 to 0.391, also with statistical significance ($P < 0.001$). Lenses C1-R and C1-L showed weak correlations, with C1-L exhibiting correlation coefficients ranging from ρ = 0.028 to 0.038 and non-significant *P*-values ($P > 0.05$).

Other lenses demonstrated weaker but still statistically significant correlations. For example, B1-R showed weak correlation values (ρ ≈ 0.129 to 0.140), with corresponding *P*-values ranging from 0.015 to 0.025. D1-R exhibited significantly weak correlations ranging from ρ = 0.152 to 0.174 and *P*-values ranging from 0.003 to 0.008. D1-L exhibited significantly weak correlations ranging from ρ = 0.0341 to 0.326, but with all significant correlations ($P < 0.001$). E1-R and E1-L showed weak but statistically significant correlations, ranging from ρ = 0.235 to 0.274 ($P < 0.001$). Of particular interest were F1-R and F1-L, both of which recorded negative weak correlations ranging from −0.095 to −0.150, with only lens F1-L exhibiting statistically significant results ($P < 0.05$).

Image quality

The image quality of the lenses was determined using the width of 4 wavelengths for each lens. Table 1 shows the calculated width of the four wavelengths for each lens, with the RMRS width ranging from 2.00 to 3.00 pixels and that of CR-39 ranging from 2.20 to 3.38 pixels.

The correlation coefficients (ρ) (Figure 3) provide insight into the strength and direction of the relationship between the image quality of CR-39 lenses and RMRS lenses, with corresponding *P*-values indicating statistical significance (Figure 4). A1-R showed varying correlations with the CR-39 lenses; an average positive correlation with CR39-1 (ρ = 0.6) existed, a weak negative correlation with CR39-2 (ρ = −0.4),

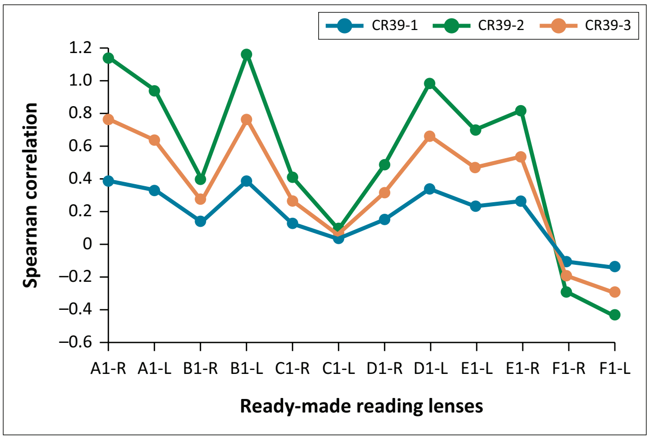

FIGURE 1: Spearman correlation between the refractive index of CR-39 and corresponding indices from ready-made reading spectacles lenses ($N = 301$).

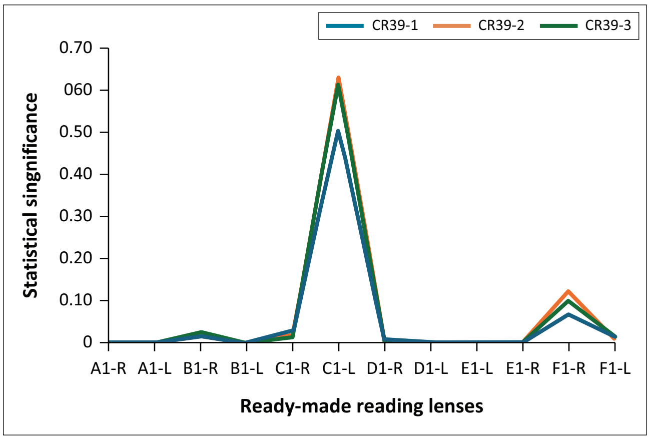

FIGURE 2: Statistical significance of the comparison between the refractive index of CR-39 and the refractive indices of ready-made reading spectacles lenses (0 = $P < 0.001$) ($N = 301$).

TABLE 1: Calculated width of the 4 wavelengths using the pixel cross-section of each image for each lens.

Wavelength width	Lens														
	A1-R	A1-L	B1-R	B1-L	C1-R	C1-L	D1-R	D1-L	E1-R	E1-L	F1-R	F1-L	CR39-1	CR39-2	CR39-3
Width 1	2.15	2.25	2.75	2.47	2.30	2.62	2.25	2.35	2.50	3.00	2.73	3.05	2.95	2.35	2.60
Width 2	2.25	2.00	2.50	2.65	2.20	2.40	2.20	2.35	2.35	2.40	2.70	2.45	2.45	2.30	2.50
Width 3	2.35	2.20	2.15	2.25	2.75	2.20	2.85	2.30	2.80	2.40	2.45	2.60	3.38	2.55	2.35
Width 4	2.80	2.40	2.30	2.30	2.37	2.35	2.15	2.65	2.40	2.73	2.20	2.50	3.18	2.20	2.50

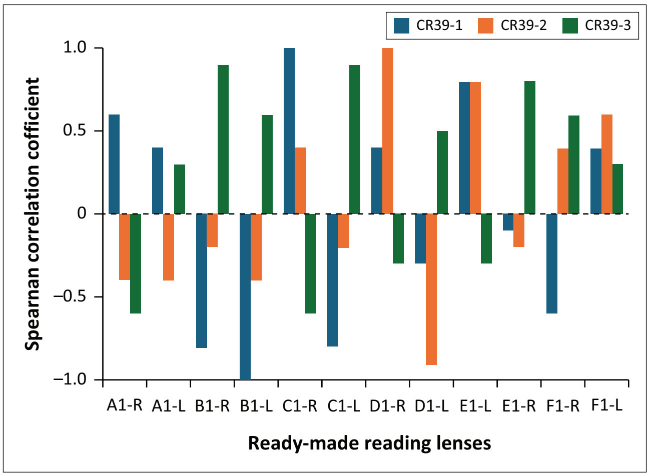

FIGURE 3: Statistical correlation between image quality of CR-39 and ready-made reading spectacles lenses ($N = 4$).

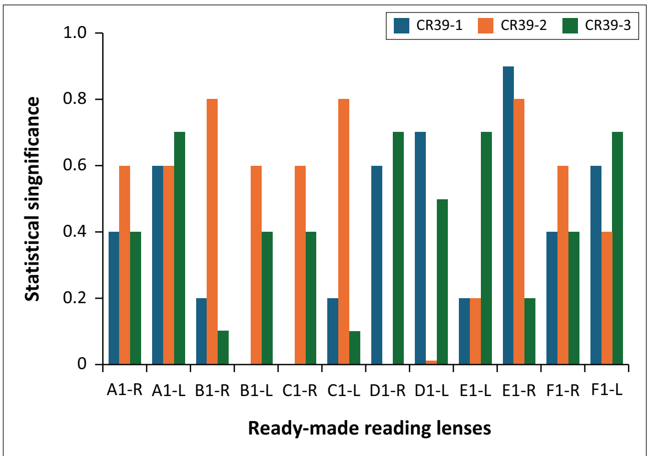

FIGURE 4: Statistical significance of the comparison between image quality of CR-39 and ready-made reading spectacles lenses, $N = 4$ ($0 = P < 0.001$).

and an average negative correlation with CR39-3 (ρ = −0.6), while A1-L displayed weak correlations ranging from 0.3 to −0.4. None of these correlations were statistically significant ($P > 0.05$). B1-R exhibited a strong negative correlation with CR39-1 (ρ = −0.8), a weak negative correlation with CR39-2 (ρ = −0.2), and a strong positive correlation with CR39-3 (ρ = 0.9). B1-L demonstrated a completely negative correlation with CR39-1 (ρ = −1), a weak negative correlation with CR39-2 (ρ = −0.4), and an average positive correlation with CR39-3 (ρ = 0.6) The *P*-value for B1-L with CR39-1 ($P = 0$) indicates a statistically significant relationship in contrast, B1-R showed a *P*-value of 0.2 for CR39-1.

Similarly, C1-R showed a significant complete positive correlation with CR39-1 (ρ = 1, $P = 0$), but weak and insignificant correlations with CR39-2 and CR39-3. C1-L displayed strong negative and positive correlations with CR39-1 and CR39-3, respectively, though all were statistically insignificant. D1-R had a significant, complete positive correlation with CR39-2 (ρ = 1, $P < 0.05$) and weaker, insignificant correlations with CR39-1 and CR39-3. D1-L showed a strong negative correlation with CR39-2 (ρ = −0.9) that was statistically significant, while other correlations were weaker and not significant.

E1-R demonstrated strong positive correlations with CR39-1 and CR39-2 (ρ = 0.8 for both), and a weak negative correlation with CR39-3 (ρ = −0.3), all statistically insignificant. E1-L exhibited weak negative correlations with CR39-1 and CR39-2 and a strong positive correlation with CR39-3 (ρ = 0.8), also without statistical significance. F1-R had average negative and positive correlations with CR39-1 (ρ = −0.6) and CR39-3 (ρ = 0.6), respectively, and a weak positive one with CR39-2 (ρ = 0.4), non-significant. Similarly, F1-L showed weak positive correlations with all CR-39 lenses, ranging from ρ = 0.3 to 0.6, with all corresponding *P*-values greater than 0.05.

Scratch resistance

Figure 5 shows a notable variation in scratch resistance among the lenses tested. Overall, the CR-39 lenses exhibited superior scratch resistance, with consistently low scratch counts ranging between 9.82 and 10.13. In contrast, the RMRS lenses displayed a broader range of surface scratches, ranging from 3.0 to 27.0, with E1-R, A1-L and F1-R, recording high scratch counts, peaking at 27 and B1-L and B1-R, exhibiting minimal surface scratches, indicating variability in scratch resistance across the RMRS series.

Discussion

In this study, researchers systematically investigated the refractive index, image quality and scratch resistance of ready-made reading spectacles lenses compared to CR-39 lenses, addressing the research gap in the ophthalmic industry in the understanding of affordable optical corrections in the context of near visual impairment in South Africa. Given the significant demographic shift towards an ageing population and the rising prevalence of presbyopia, it is essential to ensure that cost-effective solutions like RMRS maintain acceptable standards of quality to meet the increasing need for visual correction.

This study specifically compared the refractive index, image quality and scratch resistance of RMRS lenses to CR-39 lenses. The refractive index of the study lenses was

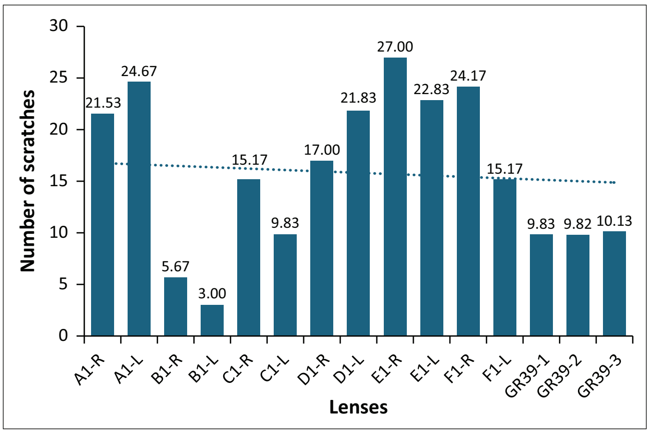

FIGURE 5: The number of scratches on CR-39 and ready-made reading spectacles lenses.

significantly different. Resultant wavelength widths of CR-39 practically showed a higher range, implying better image quality; however, correlations were statistically insignificant. CR-39 also showed superior scratch resistance to most RMRS.

Refractive index

It was determined that overall, a statistically significant weak positive monotonic correlation exists between the refractive index of RMRS and CR-39. A1-R, A1-L, and B1-L demonstrated the highest and most consistent correlation coefficients, which were statistically significant ($P < 0.001$). These results suggest strong and reliable refractive index properties with CR-39, therefore having the potential for these lenses to provide an individual with comparable refractive performance. E1-R and E1-L showed lower, but still statistically significant, correlations.

Notably, B1-R, D1-R, and D1-L exhibited the weakest yet still significant correlations. The lower coefficients for B1-R suggest limited correlation in refractive index, whereas D1-L, with stronger values than D1-R, may reflect manufacturing or material differences even within the same lens series.

The possibility of manufacturing differences is further supported by the results of C1-R and C1-L which showed despite lenses being from the same manufacturer, one lens (C1-R) yielded significant correlations (*P*-values: 0.013 to 0.028) with CR-39, while the second lens (C1-L) from the same manufacturer yielded insignificant correlations (*P*-values: 0.508 to 0.619).

The differences shown with RMRS lenses from the same manufacturer may point to inconsistencies in material composition, production methods and labelling, highlighting potential quality control issues.

A particularly intriguing observation was the behaviour of the F1 series. While both F1-R and F1-L showed negative correlation coefficients, only F1-L yielded statistically significant results ($P < 0.05$), suggesting a true but inverse relationship with the CR-39 lenses. The weak and non-significant correlations for F1-R ($P > 0.05$) contrast with the consistent significance seen in F1-L, warranting further investigation. This asymmetry raises questions about manufacturing precision or batch-specific variations in the refractive index, especially because negative correlations are unusual and may indicate underlying incompatibilities in optical performance.

The refractive indices of RMRS and CR-39 ranged from 1.39 to 1.69 and 1.44 to 1.58, respectively. The range of refractive indices for RMRS was wider than CR-39 and showed values lower and higher than those of CR-39. Because the refractive index of lens material affects light transmission, it is apparent from the results that the transmittance of white light through RMRS lenses differs notably compared to CR-39. Furthermore, the refractive index of a lens influences the Abbé value, which describes the degree of chromatic aberrations in a lens.[16] Therefore, the range of refractive indices present in RMRS implies a variation in the amount of chromatic aberration and possibly refractive power present of RMRS.

This study demonstrated a wide range of refractive indices present in RMRS, and a low correlation was found between the refractive indices of RMRS and CR-39. Ready-made reading spectacles could produce more chromatic aberrations, while some may present with less. It is, therefore, important for future studies to include a larger sample of RMRS with multiple manufacturers to ascertain the overall occurrence of chromatic aberrations in RMRS.

Collectively, these results underscore the importance of standardising the refractive properties of RMRS to ensure reliable visual outcomes. While most lenses show encouraging alignment with CR-39 standards, discrepancies, such as those found in the C1 and F1 series, highlight the need for rigorous quality control and further exploration into material behaviour and production variability.

Image quality

The image quality determined by the wavelength width showed RMRS had a lower range of widths compared to that of CR39 (2.00 to 3.00 pixels and 2.20 to 3.38 pixels, respectively), implying that CR-39 has better image quality than RMRS; however, image quality correlations were insignificant for most lenses. The analysis of Spearman rank correlations reveals a substantial degree of variability in the relationships between the image quality of the CR-39 lenses and RMRS. Most correlations were insignificant; only three RMRS showed statistically significant values with CR-39. Statistically significant values were shown by B1-L and C1-R with CR39-1 and D1-R with CR39-2.

B1-L and C1-R showed statistically significant complete correlations with CR39-1; however, D1-R showed the same with CR39-2, suggesting that their image formation properties are well-aligned with those of the CR-39 reference lenses. These findings are particularly noteworthy as they indicate that these spectacles may exhibit comparable optical performance to the CR-39 lenses.

Conversely, A1-R, A1-L, F1-R and F1-L exhibited weak to average correlations with the CR-39 lenses, with *P*-values indicating that these relationships are not statistically significant. This suggests that the image formation properties of these RMRS may not align closely with the CR-39 reference lenses, highlighting potential variability in the performance of commercially available RMRS and CR-39 lenses.

As shown by the results of the inconsistent refractive index of RMRS, the image quality of RMRS, too, was inconsistent across the brands and with each brand, as no pair of lenses from the same brand exhibited the same direction of correlation for all CR-39 lenses. Again, questioning the possible manufacturing process imperfections.

The current study showed the presence of variability of image quality in RMRS. The variability in image quality may be the reason for studies like that of Ebeigbe and Uwagboe[21] and Ekpenyong et al.[22] reporting contradicting findings. Ebeigbe and Uwagboe[21] found 41% of presbyopes were satisfied with the vision achieved with ready-made spectacles for correction of general refractive error; however, for a younger population of school-going age, Ekpenyong et al.,[22] found over 90% were satisfied with such ready-made spectacles

The results underscore the importance of validating the optical properties of RMRS to ensure consistent visual performance across different lenses. The variability observed in this study suggests that further research and quality control measures are necessary to ensure that commercially available RMRS meet the required optical standards.

Scratch resistance

All the CR-39 lenses exhibited fewer scratches compared to most of the RMRS lenses. The results indicate that CR-39 lenses are possibly more scratch-resistant than RMRS lenses. Notably, there is a variation in scratch-resistance between the two lenses of the same RMRS pair for all brands of RMRS used, potentially because of a manufacturing fault. Furthermore, the reduced scratch resistance of some RMRS may be a consequence of the materials used to achieve higher refractive indices.[17] As some RMRS lenses had higher refractive indices than CR-39, their lower scratch resistance may be attributed to the inherent properties of these high-index materials. Scratches impact the clarity of the image perceived by spectacle users, and are caused by many undesirable activities, such as cleaning lenses with rough abrasive materials, packing spectacles into a bag without a protective case, or even placing spectacles on a table with the lenses touching the surface of the table.[23] Geriatric patients are further at risk of experiencing the effects of scratched lenses, as one ages, the level of instability increases, which is one of the four most prevalent conditions of old age.[24] As RMRS are prescribed for presbyopic patients, an ageing population that uses RMRS has a higher probability of scratching RMRS because of physical instability, resulting in spectacles falling. Individuals with scratches on their spectacle lenses will consequently produce an unsatisfactory level of vision and will need to replace the damaged spectacles. Replacement of spectacles increases the overall cost of vision management for a user. This study proved that RMRS lenses are more prone to scratches compared to CR-39, and therefore, adequate training in the use and care of RMRS must be provided to users. Furthermore, practitioners prescribing RMRS and users of RMRS must consider the environment in which RMRS is used to avoid excessive scratches and the possibility of the long-term financial implications of replacing scratched RMRS.

Several lenses demonstrated statistically significant, but weak correlations. Although a relationship exists, this may not clinically translate into a perceivable difference in the visual performance for the user of the lenses. Weak correlations, even if significant, may have limited practical or clinical impact

The results are equally important for both manufacturers and consumers. For manufacturers in the ophthalmic industry, this study highlights the need to enhance the quality of RMRS lenses to ensure they meet acceptable ophthalmic standards. For consumers, especially those in developing countries with limited access to custom-made spectacles, the study suggests that RMRS provides a necessary refractive near correction. CR-39 lenses are still a preferable option where affordability is less of a constraint.

Study limitations and future recommendations

While the CR-39 lenses utilised in this study exhibited refractive indices within the expected range (1.44–1.58), closely aligning with the nominal value for CR-39 material ($n \approx 1.498$),[17] and demonstrated uniform surface durability across all samples, a few limitations should be acknowledged. Notably, the CR-39 lenses were procured from a single optical lens supplier, and the sample size was restricted to three lenses. In contrast, 12 RMRS lenses were included for comparative analysis. This discrepancy in sample size and supplier diversity may introduce sampling bias and limit the generalisability of the findings regarding the optical and mechanical comparability of CR-39 and RMRS lenses.

Future investigations should aim to incorporate a larger and more diverse sample of CR-39 lenses, sourced from multiple manufacturers, to enhance the robustness and external validity of the findings. Additionally, further research should be directed toward improving the manufacturing quality of RMRS lenses. It is recommended that future studies evaluate the impact resistance of RMRS lenses in rimless and nylon-supra frames, with direct comparisons to high-durability lens materials such as Trivex and polycarbonate.

Conclusion

This study has revealed a statistically significant difference in the refractive indices when comparing the optical characteristics of lenses used in RMRS to those of CR-39. There was no statistically significant difference between the image quality for RMRS and CR-39; however, optically, the CR-39 lens produced a clearer image. Finally, CR-39 exhibited higher scratch resistance than RMRS. These findings contribute to the understanding and evaluation of lens material quality. They provide valuable insights for potential manufacturers and spectacle users, suggesting that CR-39 should be considered the preferred choice because of its higher scratch resistance and optically superior image quality compared to RMRS lenses.

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Competing interests

The authors declare that they have no financial or personal relationships that may have inappropriately influenced them in writing this article.

Authors' contributions

M.V. conceived the initial idea for the study, led the research group, formatted the manuscript, collected data on scratch resistance, interpreted the data, wrote the article and continued to provide revisions during the editing process. G.R.A. contributed to the initial idea, formatted and edited the manuscript, collected data on refractive index and image quality testing and continued to provide revisions during the editing process. J.-A.O. contributed to the initial idea, formatted and edited the manuscript, collected data on refractive index and image quality testing and continued to provide revisions during the editing process. S.J. supervised the research, provided ongoing support and guidance and contributed to the writing and continued editing of the article.

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Data availability

Raw data were generated at the University of the Free State's Biostatistics Department. Derived data supporting the findings of this study are available from the corresponding author, M.V., upon reasonable request.

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