Title: Assessment of optical quality of ready-made reading spectacles for presbyopic correction

Running title: Optical quality of ready readers

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Conflicts of interest

None of the authors have conflicts of interests to declare.

Abstract

Purpose: Several presbyopic patients in both developed and developing countries resort to ready-made reading spectacles for their near vision correction although the quality of these spectacles cannot always be assured. This study assessed the optical quality of ready-made reading spectacles for presbyopic correction in comparison with international standards.

Methods: A total of 105 ready-made reading spectacles with powers ranging from +1.50 to +3.50 dioptres in +0.50-dioptre steps, were randomly procured from open markets in Ghana and assessed for their optical quality, including induced prisms and safety markings, in line with standards by the International Organisation for Standardisation (ISO 16034:2002 [BS EN 14139:2010]) and low-resource countries.

Results: All lenses (100%) assessed had significant induced horizontal prisms outside the tolerance levels stipulated by the ISO standards while 30% had induced vertical prisms higher than the required tolerance levels, with +2.50 and +3.50-dioptre lenses recording the highest prevalence (48% and 43% respectively) of induced vertical prisms. When compared with less conservative standards suggested for use in low-resource countries, there was a reduction in the prevalence of induced horizontal and vertical prisms to 88% and 14% respectively. While only 15% of all spectacles had a labelled centration distance, none of the spectacles had any safety markings on them as per the ISO standards.

Conclusion: The high prevalence of ready-made reading spectacles in Ghana that fail to meet optical quality standards suggests the need for more robust, rigorous, and standardised protocols for assessing optical quality of these spectacles before they are sold on the market. This will alleviate unwanted side effects including asthenopia associated with their use. There is also the need to intensify public health awareness on the use of ready-made reading spectacles especially, by patients with significant refractive errors and ocular pathologies.

Keywords: Ready-made reading spectacles, optical quality, standards, tolerance, presbyopia

Key points

- None of the reading spectacles assessed met all the optical quality standards recommended by the International Organisation for Standardisation.
- It is advisable that all individuals needing reading spectacles are examined by qualified optometrists before they purchase reading spectacles.
- Stringent measures regarding the procurement and sale of reading spectacles need to be put in place and enforced so that only optically viable reading spectacles are sold on the market.

Introduction

Presbyopia develops when the "near point of accommodation has receded to the point that it is difficult or impossible to accommodate sufficiently for reading or other close work".[1] Globally, presbyopia is estimated to affect 1.8 billion people of which 826 million are visually impaired at near due to inadequate or no vision correction.[2] Uncorrected presbyopia is disproportionately more prevalent in developing and low income parts of the world. For instance, while the unmet need for presbyopia correction is estimated to be 1% in North America, it is reported to be 86.4% in Western Sub-Saharan Africa.[2] Uncorrected presbyopia leads to significant reductions in quality of life, productivity, and imposes marked individual and societal economic burden,[3–5] making it an important public health concern. Given that presbyopia develops in the prime working years of individuals who suffer from it, negative impacts associated with it are usually enormous and worrying.

In Ghana, the unmet need for presbyopia correction is reported to be 64%, with a substantial number of uncorrected presbyopes attributing their lack of near vision correction to high cost of spectacles and lack of access to eyecare facilities.[6] For instance, the average cost of a custom-made reading spectacles in Ghana is GHC 500.00 (45.00 USD) which is quite expensive, especially for most presbyopic individuals causing them to remain uncorrected. In addition, lack of equipment for the provision of effective refractive services to individuals with presbyopia has been reported as a significant barrier to near vision correction in Ghana.[7] Considering the fact that custom-made spectacles for presbyopia correction require financial and technical resources that may not be available in developing countries, low–cost spectacles such as ready-made reading spectacles (ready-readers) are usually considered appropriate alternatives.

Ready-made reading spectacles are typically single vision lenses with equal positive spherical powers in both eyes with fixed optical centration distance which are mass-produced for the correction of presbyopia. They are generally inexpensive, readily available in pharmacies, open markets and high street shops and are easy to obtain even in low resource countries. However, owing to their mass production and the lenses not being produced based on an individual's specific prescription, their testing and quality assurance may be compromised even though some manufacturers try to adhere to the required standards. Importantly, most of these spectacles are bought and used outside of a professional eyecare setting, thus, they may not go through any inspection and testing by a trained professional at all. For this reason, the International Organisation for Standardisation (ISO 16034:2002) guidelines[8] specify that manufacturers of ready-readers adhere to recommended tolerances including power, induced prism, and markings to ensure conformity, comfort, and enhance provision of optically good spectacles. Furthermore, other researchers have specified tolerances for use, especially in low-resource countries.[9]

Despite the specified standards, several studies in both developed and developing countries have found that a majority of commercially available ready-readers fail to meet required tolerances.[9–12] For instance, in a study by Elliot and Green in the United Kingdom,[10] it was reported that about half of all ready-readers assessed failed to meet the ISO 16034:2002 (BS EN 14139:2010) optical quality standards.[10] While the results from the study were quite surprising, it seems likely these findings will be worse in low-resource countries given that there are generally no regulations in the procurement and sale of these spectacles. Further to that, the majority of ready-made reading spectacles are mainly procured from varying sources by vendors based on price in an attempt to maximise profit with little attention to optical quality.

Although ready-made reading spectacles could significantly address the unmet need for presbyopic correction in developing countries, it is crucial that their optical quality align with required international standards as this will not only ensure optimum near vision, but also comfort for the patients who use them. As such, this study investigated how well commercially available ready-made reading spectacles in Ghana conform to international standards and tolerances recommended for use in low-resource countries.

Methods

The study was a descriptive cross-sectional study designed to assess the optical quality of commercially available ready-made reading spectacles in Ghana. A total of 105 reading spectacles were obtained from major wholesale and retail outlets within five regions across the country. These regions (Greater Accra, Ashanti, Northern, Upper East and Central) were chosen because they are the central hubs for the distribution and supply of ready-made reading spectacles to other parts of the country, thus, would be representative of reading spectacles sold across the entire country. Five spectacles each were purchased from 21 different vendors in the open markets, high street shops and pharmacies across the selected regions. These shops were randomly selected to ensure a mixed variety of frame design, brand, and cost of spectacles.

All spectacles purchased for the study ranged in optical power from +1.50 to +3.50 dioptres (D) in +0.50-dioptre steps as these were the commonly sold powers of ready-made spectacles on the market. Thus, for each power, 21 pairs of spectacles were procured. Even though +1.00 dioptre reading spectacles were also available on the market, for the purpose of this study and the minimal amount of prismatic effect that might be induced in these low-powered lenses, if any, they were excluded from the study.

Optical centres and dioptric power of the spectacles were measured and recorded by a qualified and experienced optical technician (optician) with the Huvitz HLM-7000 automatic focimeter (Huvitz Co. Ltd., https://medoff.net). The City Frame Rule (Sussex Vision International, https://www.sussex-vision.co.uk) was then used to measure any horizontal and vertical displacements of the optical centres in the lenses to compute the magnitude of any induced prisms using the Prentice's formula (Prism = Optical power of lens [D] x Amount of decentration [cm]). All other standard markings (name or trademark of manufacturer, warnings, and safety marks) on the frames, if any, were also recorded.

Back vertex power of each lens was compared with the ISO 16034:2002 (BS EN 14139:2010) standard which stipulates that the back vertex power of ready-made reading spectacles is expected to be ≤ 0.12D of the manufacturer's lens power specification with a cylindrical power of ≤ 0.09D, if any (Table 1). On prism tolerance, the induced prismatic effect resulting from decentration is also expected to be ≤ 0.33 prism dioptres (∆) vertically and horizontally (Table 1).[8] According to the ISO 16034:2002 (BS EN 14139:2010) standard, ready-made reading spectacles are expected to be fitted with a near centration distance which is to be indicated on either of the temples of the frames of the reading spectacles, on a hang tag or on a sticker. However, if this was not available on the frame, a centration distance of 62 mm was assumed as this has been found to be the most common and widely used near centration distance by manufacturers of ready-made reading spectacles. Based on this, any magnitude of horizontally induced prismatic effect was then calculated. Vertically induced prisms on the other hand, were calculated based on the amount of vertical displacement of the optical centre of the right eye lens when compared to the left eye.

In addition, all measurements were further checked against the specifications for ready-made spectacles suggested for use in low-resourced countries like Ghana, as reported by Ramke et al.[9] The specifications are that tolerance levels for measured back vertex power of ready-made readers should be ≤ 0.25D for both spherical and cylindrical powers with induced prism of ≤ 1.00 prism dioptre horizontally and ≤ 0.50 prism dioptre vertically (Table 1).

Table 1: Accepted spectacle power and prism tolerances specified by the ISO 16034:2002 standard[8] and for use in low resource countries[9]

Standards	Tolerances			
	Back vertex power (DS)	Cylinder power (DC)	Induced horizontal prism (Δ)	Induced vertical prism (Δ)
ISO 16034:2002 (BS EN 14139:2010)[8]	≤ 0.12	≤ 0.09	≤ 0.33	≤ 0.33
Low resource setting[9]	≤ 0.25	≤ 0.25	≤ 1.00	≤ 0.50

DS: Dioptre sphere, DC: Dioptre cylinder, Δ: Prism dioptre

Statistical analyses were conducted using IBM SPSS Statistics version 29 (IBM, Armonk, NY, USA). Point-biserial correlation was used to determine if there was a correlation between the cost of the ready-made spectacles and conformity to the ISO standard or the specifications for use in low-resource countries. The Cochran-Armitage Test was also used to test for a relationship between labelled spectacle power and the conformity to the ISO or low-resource country standards. A p-value < 0.05 was considered statistically significant. Data were presented in the form of tables and graphs.

Results

Twenty-one ready–made spectacles of each power ranging from +1.50D to +3.50D in +0.50D steps were measured to assess their optical quality in conformity with the ISO 16034:2002 (BS EN 14139:2010) standard[8] and standards suggested for use in low resource countries.[9]

The lenses ranged in cost from GHS 3.50 to 20.00 (0.30 – 2.00 USD), with a majority (77%) of spectacle prices ranging from GHS 5.00 to 8.00 (0.45 – 0.70 USD). None of the spectacles had any manufacturer's name or trademark, warnings or safety markings as required by ISO 16034:2002 (BS EN 14139:2010),[8] and only 16 (15%) spectacles had a labelled centration distance. The percentage of spectacles not conforming to ISO 16034:2002 (BS EN 14139:2010) optical standards are presented in Table 2. There were no significant correlations between either the cost of spectacles or the labelled spectacle power (optical power indicated on spectacles by manufacturer) and conformity to the ISO 16034:2002 optical tolerances (both $p > 0.05$).

Table 2: Distribution of spectacle power and induced prisms that are outside the tolerances specified by the ISO 16034:2002 standard[8] for all spectacles

	Power, n (%)	Horizontal Prism, n (%)	Vertical Prism, n (%)	Any optical tolerance, n (%)
+1.50	2 (10)	21 (100)	2 (10)	21 (100)
+2.00	1 (5)	21 (100)	7 (33)	21 (100)
+2.50	1 (5)	21 (100)	10 (48)	21 (100)
+3.00	0 (0)	21 (100)	4 (19)	21 (100)
+3.50	5 (24)	21 (100)	9 (43)	21 (100)
All†	9 (9)	105 (100)	32 (30)	105 (100)

Percentages were computed for, based on a total of 21 spectacles for each spectacle power

† Percentages were computed for, based on a total of 105 spectacles

Spectacles were also measured for conformity to optical standards recommended by Ramke et al.[9] for use in low resource countries such as Ghana. Table 3 shows the percentage of spectacles that fall outside of this standard. There was no correlation between the cost of ready-made spectacles and conformity to optical tolerances for low-resource countries ($p = 0.20$), but there was a statistically significant positive linear trend between labelled spectacle power and conformity to the low-resource country optical standards ($p < 0.001$). Higher labelled spectacle power was associated with a higher proportion of spectacles falling outside the optical standards.

Table 3: Distribution of spectacle power and induced prisms that are outside the power and prism tolerances recommended for use in low resource countries[9] for all spectacles

	Power, n (%)	Horizontal Prism, n (%)	Vertical Prism, n (%)	Any optical tolerance, n (%)
+1.50	0 (0)	14 (67)	1 (5)	14 (67)
+2.00	0 (0)	16 (76)	1 (5)	16 (76)
+2.50	0 (0)	21 (100)	4 (19)	21 (100)
+3.00	0 (0)	20 (95)	3 (14)	20 (95)
+3.50	2 (10)	21 (100)	6 (29)	21 (100)
All†	2 (2)	92 (88)	15 (14)	92 (88)

Percentages were computed for, based on a total of 21 spectacles for each spectacle power
† Percentages were computed for, based on a total of 105 spectacles

Measured centration distance for the ready-made spectacles ranged from 65 to 72 mm, with a mean (SD) of 69.1 (1.7) mm. This centration distance range was larger than the recommended near centration distance of 62 mm for ready-made reading spectacles (Figure 1), leading to considerable induced horizontal prism (mean (SD): 1.83 (0.69) Δ, range: 0.45 Δ to 3.62 Δ). This is illustrated in Figure 2.

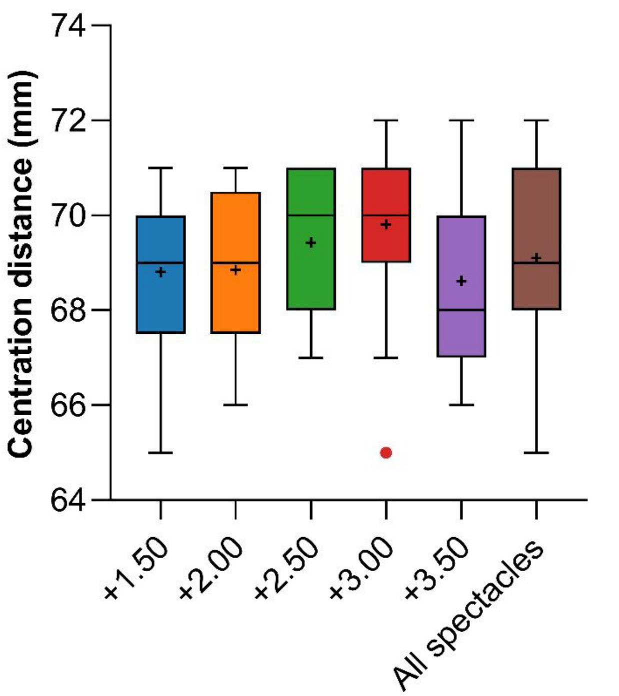

Figure 1: Centration distance of the spectacles measured. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. Dots represent outliers. + symbol represents the mean. Data are presented for each spectacle power and for all spectacles combined.

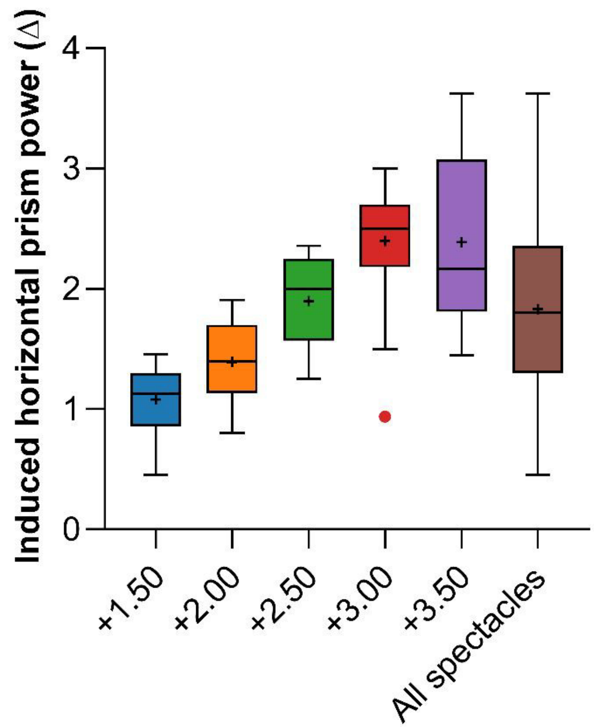

Figure 2: Horizontal prism measured on the spectacles assuming a 62 mm interpupillary distance. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. + symbol represents the mean. Dots represent outliers. Data are presented for each spectacle power and for all spectacles combined.

The mean (SD) vertical prism measured on the spectacles was 0.25 (0.24) Δ, ranging from 0.00 to 0.91 Δ (Figure 3). In addition, the mean differences between the labelled and measured lens powers for the left and right eyes are shown in Figure 4.

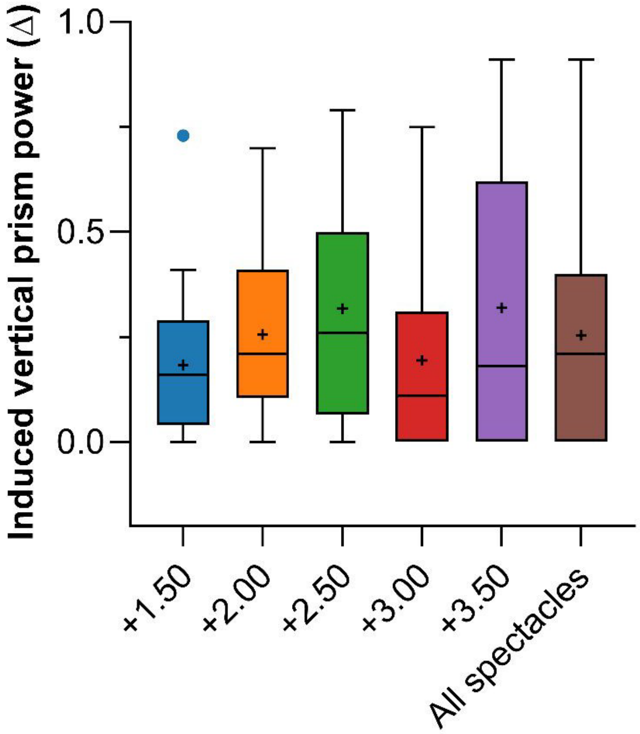

Figure 3: Vertical prism measured on the spectacles. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. Dots represent outliers. + symbol represents the mean. Data are presented for each spectacle power and for all spectacles combined.

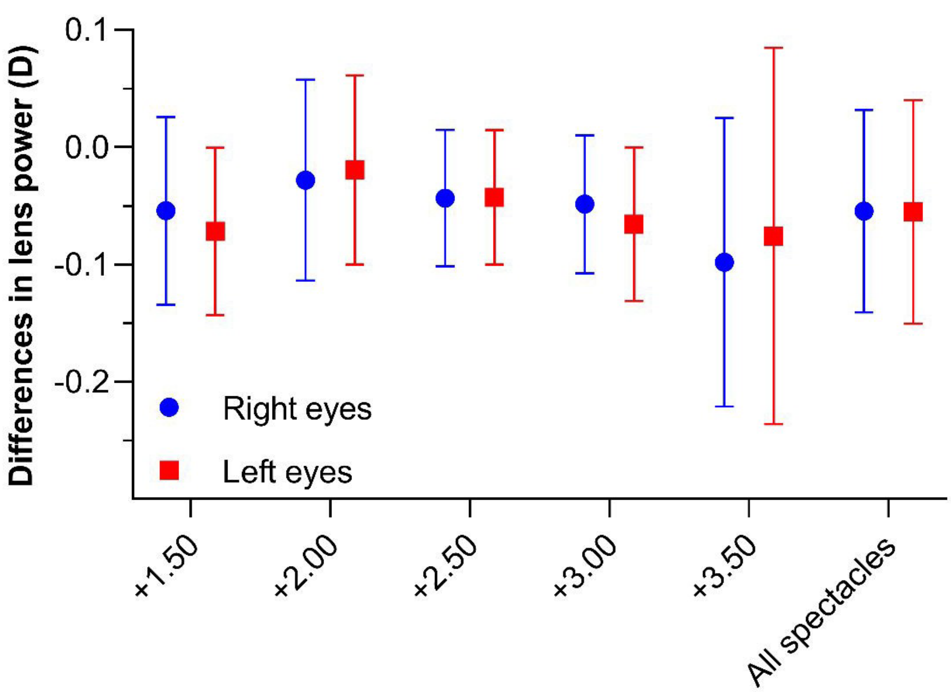

Figure 4: Mean difference (Labelled lens power - Measured lens power) for left and right lenses. Error bars represent the standard deviation. Data are presented for each spectacle power and for all spectacles combined.

Discussion

None of the ready-made reading glasses sampled in this study conformed to all the optical standards stipulated by the ISO 16034:2002 (BS EN 14139:2010) guidelines (Table 2). All the lenses failed to meet the ISO standard for horizontal prism assuming a 62 mm near interpupillary distance, and nearly a third of the lenses fell outside the tolerance levels for induced vertical prisms. The +2.50DS and +3.50DS ready-made reading spectacles had the highest number (48% and 43% respectively) of induced vertical prisms outside the tolerance levels stipulated by the ISO standard. When comparing the dioptric power of the spectacles against the ISO required tolerance levels, almost a quarter (24%) of the +3.50D of the ready-made reading spectacles failed to meet this standard. However, the price of the ready-made reading spectacles in this study did not correspond with conformity to ISO required standards and these findings are consistent with the findings of Ramke et al.[9] and Elliot and Green.[10]

Applying these ISO standards to developing countries like Ghana might seem unsuitable because such standards are stricter and might cause a majority of ready-made reading spectacles in low income countries to be rejected, likely making ready-made reading spectacles too expensive.[9,10,13] When a more compromising and conservative standard that is reported to be appropriate for use in low-resource countries is applied (Table 3),[13,14] virtually all ready readers with labelled lens power of +2.50DS, or higher failed to reach the recommended tolerance levels for induced horizontal prism. Despite these less-conservative standards proposed for use in low resource countries, there were still high failure rates of 67% and 76% for the low powered ready-made reading spectacles (+1.50DS and +2.50DS respectively) for horizontal prisms. However, the prevalence of vertical prisms outside tolerance levels for the spectacles reduced to 14%, with the +2.50DS, +3.00DS and +3.50DS ready-made reading spectacles making up the bulk of these unacceptable tolerances when the standards for low resource countries were applied. When these standards were applied to the dioptric power, all ready-made reading glasses were in conformity to the standard, except for the +3.50DS which had a failure rate of 10%.

Ready-made reading glasses are known to satisfactorily correct presbyopia, given that the wearers do not have significant refractive errors.[9,13] However, these may become unsatisfactory and wearers may experience discomfort if their interpupillary distance is significantly different to the optical centre distance of the lenses in the frame.[14] The surprisingly larger centration distance (69.1 [1.7] mm) found in this study may be because these lenses are manufactured to be used for distance vision and not as reading glasses. However, since 85% of the lenses do not have a labelled centration distance, it is impossible to determine if the larger centration distances are due to manufacturing error or that the spectacles are made to be used for distance vision. These larger centration distances are responsible for the surprisingly high failure rates for induced horizontal prism when both the ISO and low-resource country standards are applied. Elliot and Green[10] argued that manufacturers mostly use distance interpupillary distance as their guideline when manufacturing ready-made reading spectacles, when, in reality, they are supposed to be manufactured based on near interpupillary distances. Given that a near centration distance of 62 mm (centration distance for ready-made reading spectacles) was used to assess the magnitude of induced prisms in this study due to the lack of any published data on the average interpupillary distance for the presbyopic Ghanaian population, it is worth pointing out that the number of ready readers in this study that will fail the standard will be exaggerated should the average near interpupillary distance of presbyopic Ghanaians be smaller than 62 mm. It is, thus, unclear how appropriate these spectacles are for the presbyopic Ghanaian population.

A considerably higher induced base-out horizontal prismatic effect was observed in this study due to the larger mean (SD) centration distance of 1.83 (0.69) Δ recorded. This value is almost twice the maximum base out prism value, tolerable for near work.[14] The detrimental effects of horizontal induced prismatic effects have been documented and these depend on the power of the lens and the distance between the centration distance as defined by the Prentice rule.[12] Base-out prisms for near work particularly cause dizziness and eye strain. In a trial to assess the tolerability and comfort of a 2 Δ base-out for near work for 8 hours, all participants removed the prism within 10 minutes and none of the participants could adapt to its habitual use.[14] Furthermore, the 2 Δ base-out had the worse comfort rating at near, on a 1-100-point scale. This reiterates the consequences of having such a magnitude of base out prisms induced in ready-made reading spectacles on sale in Ghana on a commercial basis. The mean vertically induced prism (0.25 [0.24] Δ) from the ready-made reading spectacle samples was well within the proposed tolerance levels (≤ 0.50 Δ).[14] du Toit et al., in their trial, found that all participants, but one, managed near work for 8 hours when wearing 0.5 Δ base-up spectacles. Vertically induced prisms in ready-made reading glasses are caused by manufacturing error and can be tolerated if small. More so, small vertical prisms can be corrected by adjusting the frame.[9,14]

Irrespective of the type of standards applied to ready-made reading spectacles sampled for this study, the reported failure rates are alarming and have implications on comfortable and tolerable vision for near work. There is a need to address these outcomes in ready-made reading spectacles effectively because presbyopia is a growing public health concern.[2] As anticipated, majority of the ready-made reading spectacles that failed the standards were medium-to-high powered spectacles. This is because the amount of prism induced is a product of the power of the spectacles in dioptres and the centration discrepancy in centimetres as defined by the Prentice's rule.[10] Since the medium-to-high powered ready-made reading spectacles sampled for this study had a higher probability of non-conformity to standards, the authors recommend that ready-made reading spectacles in Ghana from +2.00 dioptres and above should only be restricted to sale in eye clinics or optometric centres after an eye examination by a qualified eyecare practitioner. By this, the optometrist or dispensing optician can assess the conformity of these spectacles to standards before they are issued out on sale. Specifically, these eyecare practitioners can measure the interpupillary distance of patients to ensure they match up with those measured on the spectacles. Ghana needs to train enough optometrists to provide refractive services to patients. A study by Morny et al.[15] reported that the total number of ophthalmologists, optometrists, and ophthalmic nurses in Ghana as of 2019 was 91, 370 and 500 respectively. These numbers represented eyecare professional to population ratios of 1:311,080 for ophthalmologists, 1:76,508 for optometrists, and 1:56,616 for ophthalmic nurses. Both ophthalmologist and optometrist ratios failed to meet the International Agency for the Prevention of Blindness proposed ratios of 1:250,000 and 1:50,000 respectively.[16] This lack of ophthalmologists and optometrists is exacerbated by the uneven distribution of eyecare professionals in Ghana, with a majority of the ophthalmic workforce practicing in the urban areas. For instance, over 70% of optometrists and ophthalmologists in Ghana work in urban areas. In many low-resource settings, the purchase of ready-made reading spectacles remains the first point of contact for majority of individuals with presbyopia, even though most vendors of these spectacles are not eye care professionals. As such, it is imperative and reasonable to propose that proper standard testing, monitoring, and random unit testing of ready-made reading spectacles from batches by manufacturers are implemented to minimise the infiltration of ready-made reading spectacles of poor optical standard in the Ghanaian optical space. There is also the need to intensify public health awareness on the use of ready-made reading spectacles especially, by patients with significant refractive errors (astigmatism) and ocular pathologies (cataract, glaucoma, diabetic retinopathy). This is because, for them the wearing of these spectacles could provide seemingly good near vision and prevent them from seeking thorough eye examination from qualified eye care professionals until at a later stage when little can be done to salvage their deteriorating ocular conditions. It is, therefore, prudent that regulatory bodies including the Ghana Standards Authority, the Allied Health Professions Council of Ghana, and the Ghana Optometric Association work together to ensure that education on the use of ready-made reading spectacles and their implications on eye health are promoted.

While spectacles for this study were randomly selected from a wide range of wholesale and retail shops noted for the supply and sale of ready-made reading spectacles across the entire country, hence ensuring appropriate representativeness of the sample, there was no published data on the average near interpupillary distance for the presbyopic Ghanaian population for comparison. Thus, the prevalence of induced horizontal prismatic effect could either be higher if near interpupillary distance for the presbyopic Ghanaian population is smaller than the specified 62 mm centration distance for ready-made reading spectacles or low, if otherwise. It is, therefore, imperative that future studies are conducted to ascertain and report the average near interpupillary distance for the presbyopic Ghanaian population so that ready-made reading spectacles sold in the country will be manufactured in accordance with that average interpupillary distance.

Conclusion

The high prevalence of ready-made reading spectacles in Ghana that fail to meet optical quality standards suggests the need for a more robust, rigorous, and standardised protocols for assessing optical quality of these spectacles before they are sold on the market. This will alleviate any unwanted side effects including asthenopia (headaches, double vision, tiredness, eyestrain) associated with their use.

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Tables

Table 1: Accepted spectacle power and prism tolerances specified by the ISO 16034:2002 standard[8] and for use in low resource countries[9]

Standards	Tolerances			
	Back vertex power (DS)	Cylinder power (DC)	Induced horizontal prism (Δ)	Induced vertical prism (Δ)
ISO 16034:2002 (BS EN 14139:2010)	≤ 0.12	≤ 0.09	≤ 0.33	≤ 0.33
Low resource setting	≤ 0.25	≤ 0.25	≤ 1.00	≤ 0.50

DS: Dioptre sphere, DC: Dioptre cylinder, Δ: Prism dioptre

Table 2: Distribution of spectacle power and induced prisms that are outside the tolerances specified by the ISO 16034:2002 standard[8] for all spectacles

	Power, n (%)	Horizontal Prism, n (%)	Vertical Prism, n (%)	Any optical tolerance, n (%)
+1.50	2 (10)	21 (100)	2 (10)	21 (100)
+2.00	1 (5)	21 (100)	7 (33)	21 (100)
+2.50	1 (5)	21 (100)	10 (48)	21 (100)
+3.00	0 (0)	21 (100)	4 (19)	21 (100)
+3.50	5 (24)	21 (100)	9 (43)	21 (100)
All†	9 (9)	105 (100)	32 (30)	105 (100)

Percentages were computed for, based on a total of 21 spectacles for each spectacle power

† Percentages were computed for, based on a total of 105 spectacles

Table 3: Distribution of spectacle power and induced prisms that are outside the power and prism tolerances recommended for use in low resource countries[9] for all spectacles

	Power, n (%)	Horizontal Prism, n (%)	Vertical Prism, n (%)	Any optical tolerance, n (%)
+1.50	0 (0)	14 (67)	1 (5)	14 (67)
+2.00	0 (0)	16 (76)	1 (5)	16 (76)
+2.50	0 (0)	21 (100)	4 (19)	21 (100)
+3.00	0 (0)	20 (95)	3 (14)	20 (95)

+3.50	2 (10)	21 (100)	6 (29)	21 (100)
All†	2 (2)	92 (88)	15 (14)	92 (88)

Percentages were computed for, based on a total of 21 spectacles for each spectacle power

† Percentages were computed for, based on a total of 105 spectacles

Figure Legends

Figure 1: Centration distance of the spectacles measured. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. Dots represent outliers. + symbol represents the mean. Data are presented for each spectacle power and for all spectacles combined.

Figure 2: Horizontal prism measured on the spectacles assuming a 62 mm interpupillary distance. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. + symbol represents the mean. Dots represent outliers. Data are presented for each spectacle power and for all spectacles combined.

Figure 3: Vertical prism measured on the spectacles. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. Dots represent outliers. + symbol represents the mean. Data are presented for each spectacle power and for all spectacles combined.

Figure 4: Mean difference (Labelled lens power - Measured lens power) for left and right lenses. Error bars represent the standard deviation. Data are presented for each spectacle power and for all spectacles combined.

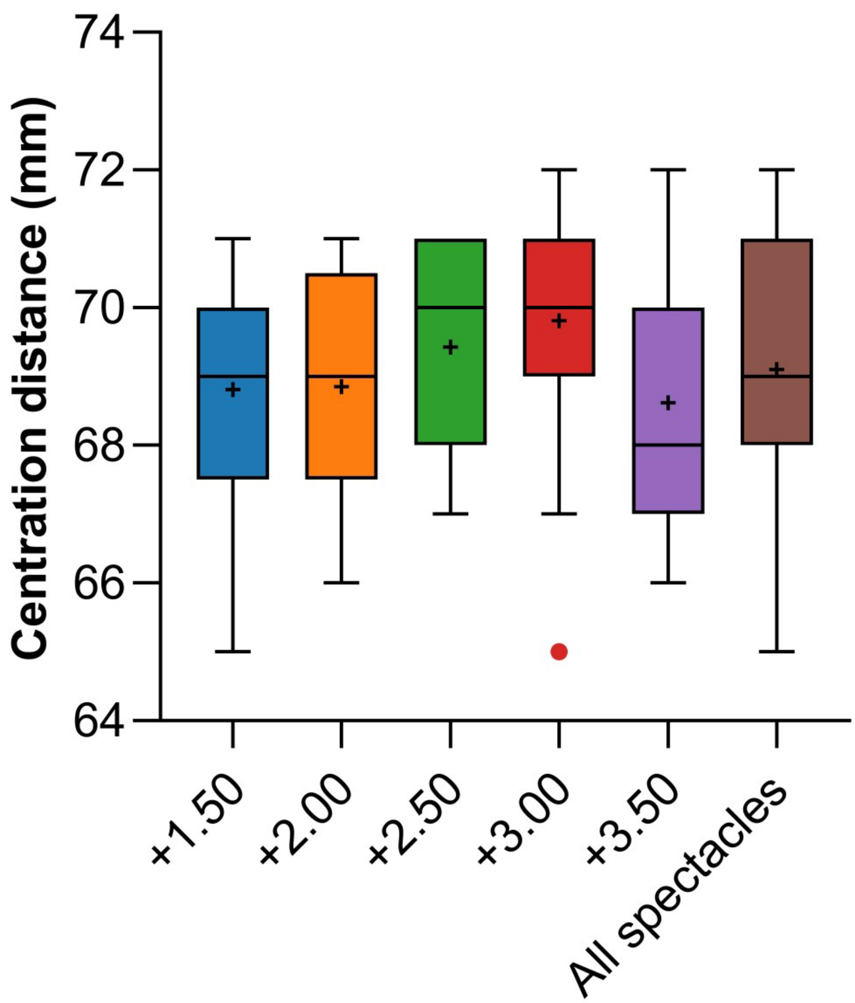

Figure 1: Centration distance of the spectacles measured. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. Dots represent outliers. + symbol represents the mean. Data are presented for each spectacle power and for all spectacles combined.

73x88mm (1200 x 1200 DPI)

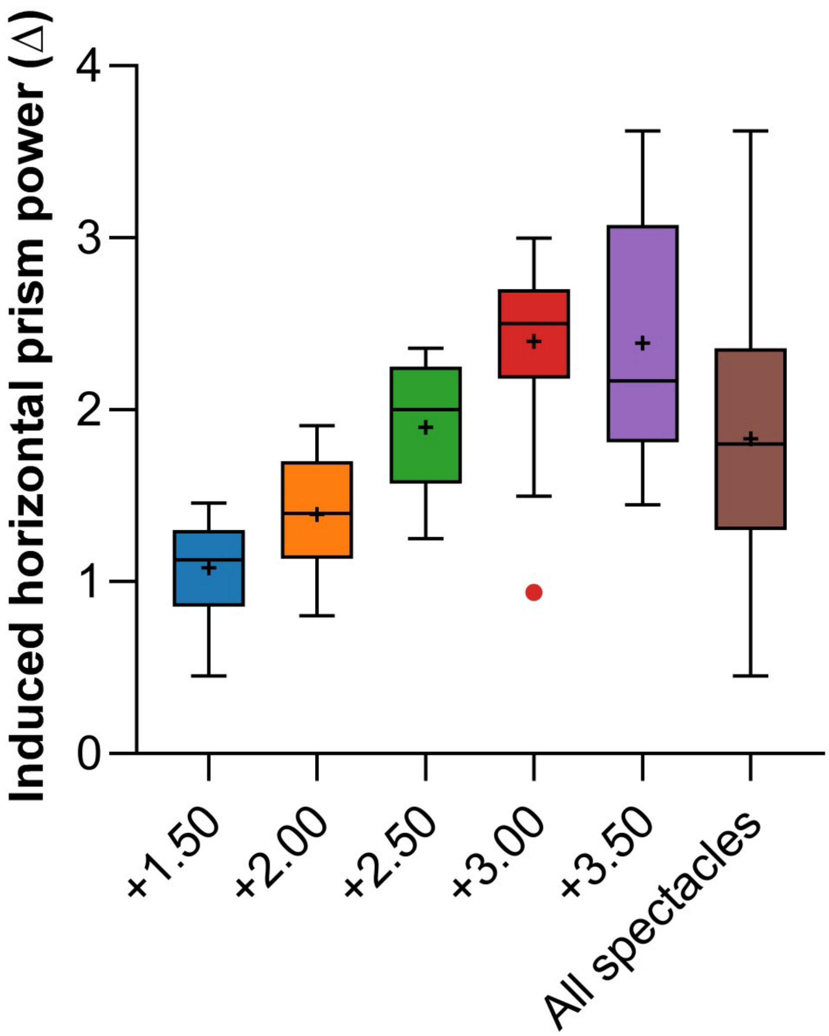

Figure 2: Horizontal prism measured on the spectacles assuming a 62 mm interpupillary distance. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. + symbol represents the mean. Dots represent outliers. Data are presented for each spectacle power and for all spectacles combined.

72x88mm (1200 x 1200 DPI)

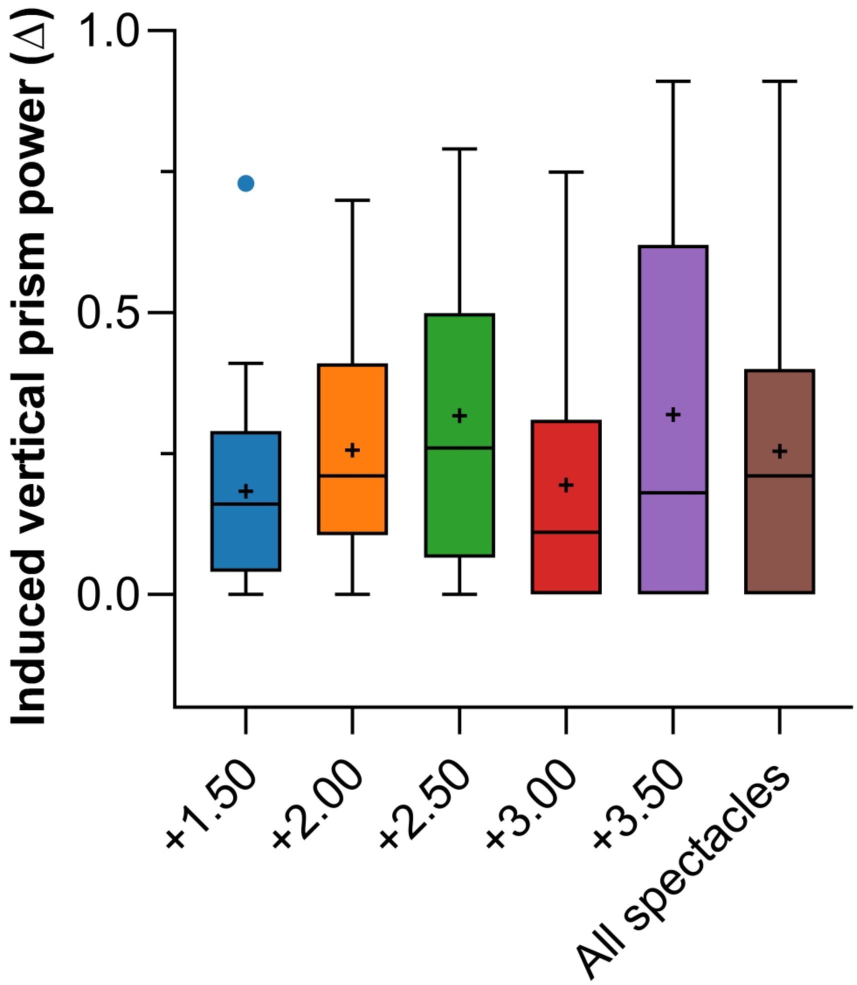

Figure 3: Vertical prism measured on the spectacles. Centre lines show the medians; box limits indicate the 25th and 75th percentiles; whiskers extend 1.5 times the interquartile range. Dots represent outliers. + symbol represents the mean. Data are presented for each spectacle power and for all spectacles combined.

75x88mm (1200 x 1200 DPI)

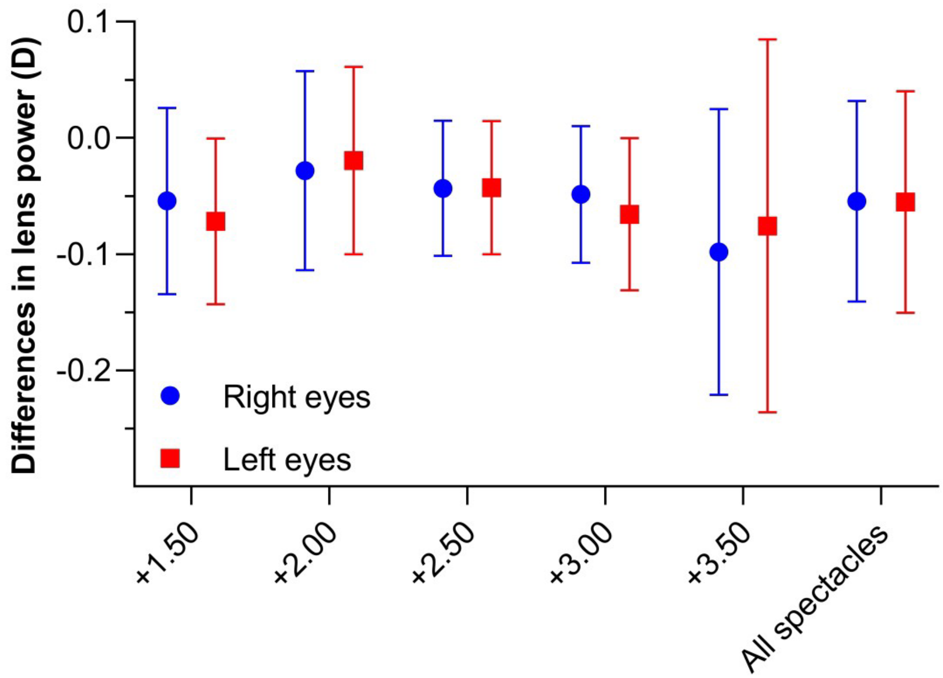

Figure 4: Mean difference (Labelled lens power - Measured lens power) for left and right lenses. Error bars represent the standard deviation. Data are presented for each spectacle power and for all spectacles combined.

109x88mm (1200 x 1200 DPI)