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Non-prescription sun eyewear optical performance study

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Abstract

Non-prescription sun eyewear often has induced refractive power, prismatic deviations and variability in resolution within their lenses. The goal of current sun eyewear manufactures is to provide maximum optical quality in their lenses. In order to achieve superior optical quality in their lenses, manufactures attempt to have low refractive power, low prismatic power, and high resolution within and between their lenses. The purpose of this study was to assess various optical qualities including refractive power, prismatic deviation in primary and lateral gaze, and resolution of premium non-prescription eyewear available for over the counter purchase to consumers at local optical shops or stores. 48 pairs oflocally purchased sun eyewear from prominent national brands were purchased for this study. Two principal investigators measured both lenses in each pair of sun eyewear for refractive error and cylinder using a calibrated 8 power telescope. Prismatic deviation was measured on both lenses of each eyewear in primary gaze and 30 degrees dextroversional gaze. Resolution was also obtained for each individual lens by using the same calibrated 8 power telescope and the standard high contrast NBS Definition Pattern. All eyewear within the study produced measurable amounts of refractive power, with a majority oflenses measured producing a low minus power. Cylinder was also found in all lenses. Most lenses induced base-down and base-out prismatic deviations for primary gaze, and most lenses gave a base-out horizontal vergence effect in primary gaze. All but one lens produced base-out prism with temporal gaze and all lenses produced base-in prism in nasal gaze giving a yoked prismatic effect in lateral gazes. The majority of vertical deviations in lateral gaze were base-down. Resolution results showed large variability between lenses within the tested eyewear with over a third of the lenses not meeting current ANSI standards. It was concluded that refractive power and induced cylinder in all the lenses tested would have minimal perceptual effect based on the depth of focus innate in the human eye with variability and sensitivity most likely based on pupil size secondary to tint density. Prismatic deviations were felt to have a more detrimental effect on the viewer due to changes in perception of the viewer's environment. Resolution results were questionable based on variability in tint density and transmittance of individual lenses. Further investigation in areas of transmittance and tint are indicated in determining resolving capabilities of sun eyewear. Further testing in optical quality is also indicated and could include subjective responses to clarity and comfort in both recreational and professional athletes.

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NON-PRESCRIPTION SUN EYEWEAR OPTICAL PERFORMANCE STUDY

By

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Non-prescription Sun Eyewear Optical Performance Study

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Biographies

JARED GERVAIS:

Jared Gervais was born and raised on the Canadian Prairies in Regina, Saskatchewan. In 1997, he moved to the Rocky Mountains to attend the University of Calgary where he earned a Bachelor of Science degree in Kinesiology, with distinction. Jared was awarded the Denny Memorial Scholarship at Pacific University and was a member of the Beta Sigma Kappa Optometric Honor Society. He will receive his Doctor of Optometry from Pacific University in May 2006 and plans to return to Calgary to practice primary care optometry.

RYAN LARSEN:

Ryan Larsen grew up in Casper, Wyoming. He graduated from the University of Wyoming in 2001 with a Bachelor of Science degree in Zoology and Physiology, and received the Outstanding Undergraduate Award in Zoology and Physiology. Ryan will graduate with a Doctor of Optometry degree in May 2006. At Pacific University, he was a member of the Beta Sigma Kappa Honor Society and was awarded the Dean's Scholarship and the Wyoming Optometric Association Scholarship. Ryan plans to return to Casper and practice primary care optometry.

CHRIS FRAZIER:

Chris Frazier was born in Lander, Wyoming and grew up in Riverton, Wyoming. He was a graduate of Riverton High School in 1995. Chris graduated from the University of Wyoming with Bachelor of Science degree in 2000. Upon graduation he became an ABO-certified optical manager from 2000-2002. Chris was member of the Beta Sigma Kappa Optometric Honor Society and worked on several committees including the Faculty Developmental Committee and a search committee for the current clinical director's position during his tenure at Pacific University College of Optometry. Chris will graduate from Pacific University with a Doctor of Optometry degree in May 2006.

Abstract

Non-prescription sun eyewear often has induced refractive power, prismatic deviations and variability in resolution within their lenses. The goal of current sun eyewear manufactures is to provide maximum optical quality in their lenses. In order to achieve superior optical quality in their lenses, manufactures attempt to have low refractive power, low prismatic power, and high resolution within and between their lenses. The purpose of this study was to assess various optical qualities including refractive power, prismatic deviation in primary and lateral gaze, and resolution of premium non-prescription eyewear available for over the counter purchase to consumers at local optical shops or stores.

48 pairs of locally purchased sun eyewear from prominent national brands were purchased for this study. Two principal investigators measured both lenses in each pair of sun eyewear for refractive error and cylinder using a calibrated 8 power telescope. Prismatic deviation was measured on both lenses of each eyewear in primary gaze and 30 degrees dextroversional gaze. Resolution was also obtained for each individual lens by using the same calibrated 8 power telescope and the standard high contrast NBS Definition Pattern.

All eyewear within the study produced measurable amounts of refractive power, with a majority of lenses measured producing a low minus power. Cylinder was also found in all lenses. Most lenses induced base-down and base-out prismatic deviations for primary gaze, and most lenses gave a base-out horizontal vergence effect in primary gaze. All but one lens produced base-out prism with temporal gaze and all lenses produced base-in prism in nasal gaze giving a yoked prismatic effect in lateral gazes. The majority of vertical deviations in lateral gaze were base-down. Resolution results showed large variability between lenses within the tested eyewear with over a third of the lenses not meeting current ANSI standards.

It was concluded that refractive power and induced cylinder in all the lenses tested would have minimal perceptual effect based on the depth of focus innate in the human eye with variability and sensitivity most likely based on pupil size secondary to tint density. Prismatic deviations were felt to have a more detrimental effect on the viewer due to changes in perception of the viewer's environment. Resolution results were questionable based on variability in tint density and transmittance of individual lenses. Further investigation in areas of transmittance and tint are indicated in determining resolving capabilities of sun eyewear. Further testing in optical quality is also indicated and could include subjective responses to clarity and comfort in both recreational and professional athletes.

Acknowledgments

We would like to extend our thanks to Dr. John Smith and Dr. Scott Cooper for their help and guidance. We would also like to thank Nike for providing the eyewear used in this study.

Introduction

Non-prescription sun eyewear plays a significant role in many activities, including outdoor recreational and occupational tasks, sports, and driving. These activities require sun eyewear to provide adequate ocular protection and superior optical quality. Sun eyewear that provides adequate ocular protection will protect the wearer's eyes from wind, dust, debris, trauma, fatigue, squinting, and ultraviolet light. Superior optical quality is found in sun eyewear that has low refractive power, low prismatic effects, and high resolution. Today, wearer's of non-prescription sun eyewear are more aware of the need to protect their eyes from the outdoor environment and they want the best optical quality to go with this protection. As a result, manufacturers are striving to design sun eyewear that meets the demand of their customers.

Sun eyewear manufacturers must also meet the minimum, accepted standards of their industry, depending on where the eyewear is manufactured. The three most widely accepted standards are: The American National Standards Institute (ANSI) Z80.3-2001, *Nonprescription Sunglasses and Fashion Eyewear* which provides standards for the United States, Asia, and many other countries in the Western Hemisphere.[1] The European Standard (EN) 1836-1997, *Personal Eye Protection – Sunglasses and Sunglare Filters for General Use* is the standard required for European countries,[2] while Australian manufacturers must meet the newly revised Australian Standard (AS) 1067-2003, *Sunglasses and Fashion Spectacles.* [3]

This study assesses various optical qualities including refractive power, prismatic deviation in primary and lateral gaze, and resolution of premium non-prescription sun eyewear on the market.

While the optical quality of sun eyewear is the focus of this study, the ocular protection and health benefits sun eyewear provides should not be overlooked. Sun eyewear improves visual comfort by reducing eye fatigue and squinting, and provides protection from harmful ultraviolet light and ocular trauma.[4] High wrap sun eyewear also shields the eyes from wind, dust, and debris. A variety of ocular problems, including pinguecula, pterygium, keratopathy, and cataracts, are associated with prolonged exposure to the middle ultraviolet waveband (UVB).[5,6,7] Eye care professionals realize the importance of sun eyewear, and the American Optometric Association recommends sun eyewear provide 99-100% protection from near and middle ultraviolet (UVA, UVB) radiation.[8]

When evaluating the optical quality of non-prescription sun eyewear, one would assume, by definition it would have a refractive power of plano. This is not the case for many sun eyewear when the lens power is verified using a very sensitive optical telescope. Some lens designs intentionally incorporate very low amounts of minus power to help reduce prismatic effects. This is seen in a lens design by Reichow and Citek.[9] They demonstrated peripheral induced prism is decreased in spherical sun eyewear with steep base curves and high pantoscopic tilt while maintaining virtually zero prismatic deviation in primary gaze by using a slight amount of minus power, around -0.10 diopters (D), rotated just off the optical axis.

Very low amounts of minus or plus power would have little, if any, visual significance. Greater amounts of minus power, plus power, and differences between lenses may, however, cause a visually sensitive wearer to experience blurred vision, asthenopia, headache, decreased depth perception, and perceptual misjudgments of objects. These effects can additionally cause decreased reaction time and less than optimal performance for tasks that require quick decisions. ANSI Z80.3 limits the tolerance for refractive power of non-prescription sun eyewear to be 0.125 D to -0.25 D, and the difference between lenses to be no more than 0.1875 D.[1]

Non-prescription sun eyewear also has the potential of inducing cylinder, due to the horizontal wrap and pantoscopic tilts of the eyewear.[10] Again, very small differences between the powers of the two principal meridians would have no visual significance. Greater amounts of induced cylindrical power may cause a visually sensitive wearer to experience visual distortion, asthenopia, and headache. ANSI Z80.3 limits the cylinder power to 0.125 D.[1]

Sun eyewear also has the potential to induce prism in both primary and lateral gazes. Prism is induced in plano sun eyewear due to the steep base curves and the significant lens tilts used in the eyewear. Horizontal wrap will induce horizontal prism, and vertical pantoscopic tilts will induce unwanted vertical prism.[10] Lateral gaze can compound these effects because the viewer is no longer looking through the optical center where prismatic effects are minimized. Prism can result in an overall shift in the environment, alter the demands of the visual system and binocular vision, and lead to headaches and fatigue.[10] Adaptation to prism may occur, but deficits in visual perception occur in those that do not adapt. An induced prism of 1 prism diopter (pd) will produce an image jump of 1 cm at a distance of 1 meter. This example applies to a single lens, but similar effects occur when prisms with the base in the same direction, or yoked prisms, are placed before both eyes. With yoked horizontal prisms, the image will be displaced laterally. When the distance to the object is increased, the image jump proportionally increases. As a result, induced prism is even more detrimental to athletes viewing far away objects, such as golfers, judging the greens or baseball players catching a ball.

Prism can also induce a vergence effect, causing the eyes to converge or diverge. Each person can tolerate different amounts of combined prism, but in general vertical prism can cause more problems even with small amounts. If the prisms are oriented in opposing directions both the perceived size and distance of the object will appear to change.[11] Vergence effects can be potentially fatiguing and bothersome, and can affect depth perception. Looking with both eyes through base-in lenses makes an object appear larger and further away, and base-out lenses make an object appear smaller and closer than it actually is. Many people will adapt to prism, so if the eyewear are worn for a period of time, they may be able to make visual-motor adjustments to compensate for the prism. Since sun eyewear is not worn full time, but used intermittently, this may further complicate adaptation to the induced prism. There may be a learning curve and mistakes made along the way for athletes using lenses with high prismatic deviation. Eyewear with lower prismatic effects will provide better visual comfort and optical performance which can maximize visual perception. The ANSI Z80.3 standard for prismatic power allows for up to 0.25 pd of base-in or base-out prism per lens, with no more than 0.50 pd prismatic imbalance between the lenses.[1] EN 1836 allows for a maximum of 1.00 pd base-out and 0.25 pd base-in.[2]

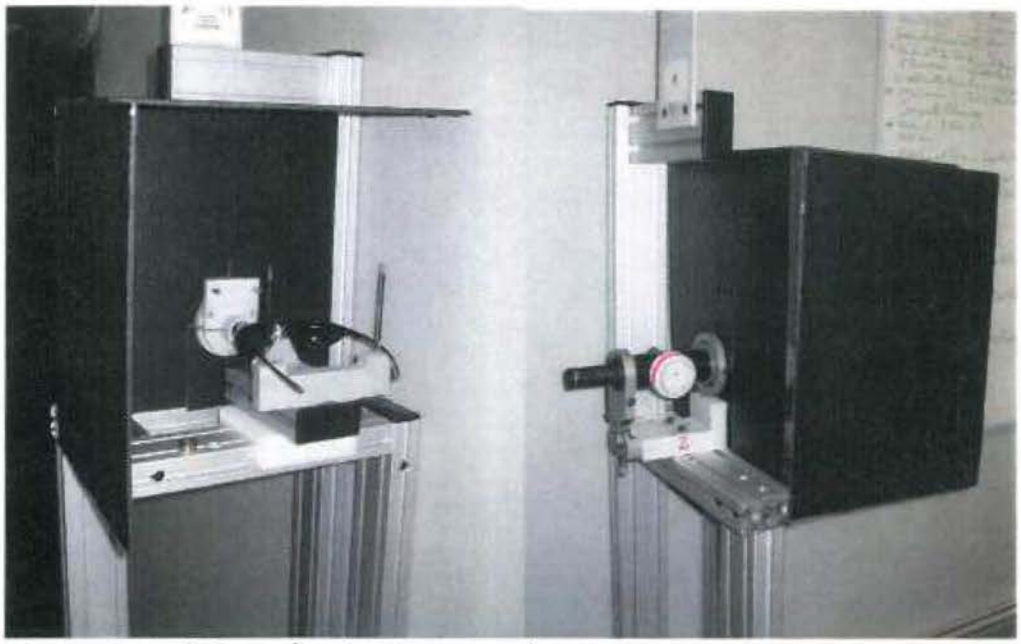
The overall ability for a lens to provide clear and distinct images is known as the resolving power or resolution of the lens. Crisp and clear vision is an important quality for non-prescription eyewear for elite athletes and average outdoor enthusiasts alike. Appreciation of the subtle detail of targets and terrain is a key component in many sports and outdoor pursuits. Eyewear with poor resolution may distort vision and peak performance may not be possible. Being able to see the subtle differences in the shaded areas on a bike trail may mean the difference between riding the proper line or sliding off the trail. The resolution of sun eyewear can be negatively affected by cylinder, warped lenses, aberrations, and tint.

Currently there are no standards for resolving power that are specific to sun eyewear. ANSI Z87.1, *Occupational and Educational Personal Eye and Face Protection Devices*, does, however, provide resolution standards for non-sun eyewear. According to this standard, all lines in both orientations of the NBS pattern of 20 cycles/degree need to be clearly resolved.[12] The NBS test pattern has multiple targets of varying spatial frequency from 10 to 40 cycles/degree. The smaller the pattern seen, the greater the resolution or clarity the lens provides. For a healthy young adult the high frequency cutoff is 40-60 cycles/degree.[13] For a given ambient illumination, tinted and polarized lenses will not have the same resolving capabilities as non-tinted eyewear because resolving power is affected by the amount of light transmitted through a lens. This testing is done under normal room illumination, so darkly tinted and polarized lenses may not transmit enough light to allow higher levels of resolution. As a result, these standards are used for comparative purposes only since tinted eyewear tends to fail this standard under normal indoor illumination. This was seen in PrivatePilot Sunglasses Shootout 2 (2003), where 73.8% of the 65 pairs of sun eyewear tested were not able to resolve the NBS pattern of 20 cycles/degree.[14]

Methods

Two principal investigators measured the refractive power, cylinder, horizontal and vertical prismatic deviations, and resolution in 48 pairs of non-prescription sun eyewear currently available to consumers. The eyewear used in the study was purchased from local distributors or directly from the open market by an assistant, and transported to the testing site. All testing was conducted at Pacific University's College of Optometry.

Masked testing protocol was used during the testing; each pair of sun eyewear was masked to the investigators by covering the head form mount with black foam core as seen in Figure 1a and 1b. In doing this, the primary investigators taking measurements were unable to see manufacture names, logos, or any other identifiable markings on any tested eyewear. An assistant placed the eyewear on the testing head mount apparatus and recorded the results found by the primary investigators.



Figures 1a and 1b: Refractive Power testing apparatus

Refractive power and cylinder were measured using a calibrated 8 power telescope. Each investigator adjusted the telescope to correct for their refractive error before measurements were obtained, reducing variations between investigators. Investigators could reliably measure lens powers to within 0.05 D. Testing procedures for refractive power measurements consisted of each investigator taking three separate measurements on each pair of eyewear in the two principle meridians. To take into account any variations caused by investigator fatigue, each of the three sample orders were randomized for each of the investigators

Based on the protocol outlined by Cooper et al., horizontal and vertical prismatic deviations were measured on both lenses of each eyewear at both primary gaze and 30 degrees dextroversional gaze.[10] The eyewear was mounted on a custom-built laser headform. The headform consisted of a triangular nose piece, and two flexible pins located 95mm from the nose piece to approximate the wearer's ears. The two pins were separated by 145mm horizontally to approximate the width between the wearer's ears. These parameters are based on the Canadian Standard Headform, the most current and accurate standardized headform used in eyewear design and testing.[15]

On the headform, two sets of lasers simulated the line of sight for primary gaze and 30 degrees dextroversional gaze. The lasers were placed in a position to simulate the center of rotation for each individual eye. They were separated from each other by

64mm, and located approximately 27mm from the back surface of the eyewear when placed properly on the triangular nose piece of the headform. See Figure 2a. Targets were placed at 5 meters primary gaze and 30 degrees dextroversion, where the lasers converged at point zero on the prismatic measurement grid. The target consisted of vertical and horizontal grids separated by 5mm, thus equal to a 0.1 pd separation for our 5m testing distance. Investigators could consistently measure both vertical and horizontal deviations to within 0.025 pd. Testing procedures for prismatic deviation consisted of one horizontal and vertical measurement from each investigator for each lens.

Figure 2a: Laser headform

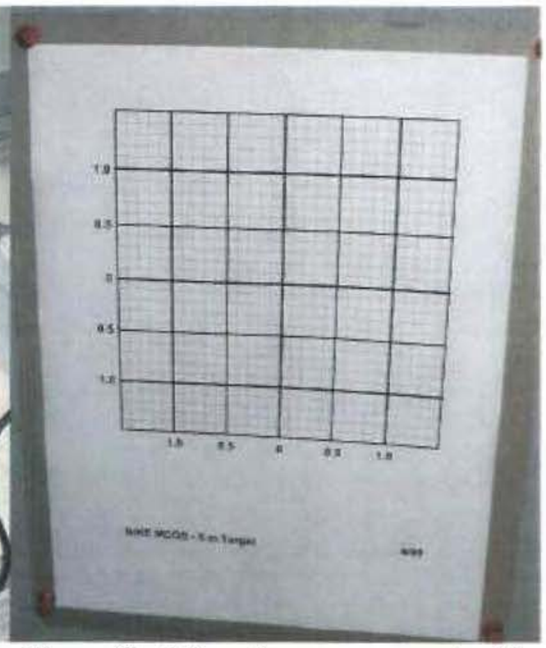


Figure 2b: Prismatic measurement grid

Resolution testing was obtained using the same calibrated 8 power telescope and the standard high contrast NBS Definition Pattern as seen in Figure 3. Testing was based on ANSI Z87.1 protocol. The NBS Pattern has bars representing 10-40 cycles/degree oriented both horizontally and vertically, and was located 10m from the investigators. As per ANSI Z87.1 standards, appropriate lighting was provided to allow for Pattern 40 to be resolved with no lens in front of the telescope. Most of the eyewear induced cylinder, so the best focus for the vertical and horizontal lines of the pattern did not usually correspond. The telescope was first focused until the highest resolution possible of the vertical lines was observed. This was repeated for the horizontal lines. Then the telescope was refocused until the best compromise or overall resolution was found, as per Z87.1 standards. This was the point where the vertical and horizontal lines on the pattern appeared equally sharp. The best resolution distinguishable between the two observers was then used in the results.

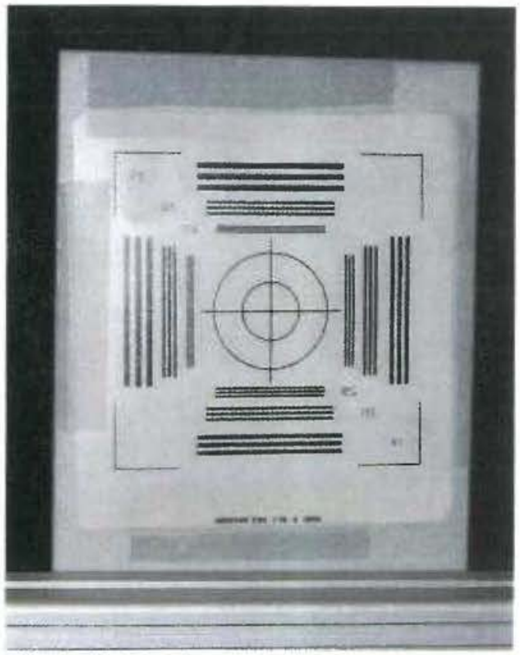


Figure 3: NBS test pattern

Results

Refractive power measures are shown in Table 1. The average spherical equivalent and cylinder for each lens tested, separated into polarized and non-polarized lenses, is listed. Also listed is the refractive power difference between the two lenses of each pair of eyewear. Average spherical equivalents ranged from 0.024 D to -0.221 D, with the majority having low minus power and all but one pair of tested eyewear met ANSI Z80.3 standards for refractive power within a given meridian. This outlying lens measured -0.275 D in one meridian, and the limit for ANSI is -0.250 D. All lenses had small amounts of cylinder that ranged from 0.002D to 0.122D and refractive power differences between lenses were all less than 0.10 D. All eyewear passed the ANSI Z80.3 standards for cylinder and refractive power differences between lenses. The top ten performers for cylindrical power measured below 0.010 D of cylinder. The top ten performers for refractive power differences between lenses measured below 0.005 D. Included in Table 1 is the overall mean and standard deviation for these measures.

Table 2 displays the average horizontal and vertical prismatic deviation at primary gaze for left and right lenses of all eyewear tested. Average horizontal deviations ranged from 0.125 pd base-in to 0.600 pd base-out, with the majority of lenses inducing a base-out effect. Average vertical deviations ranged from 0.413 pd base-up to 0.538 pd base-down, with the majority of the lenses inducing a base-down effect. Table 2 also shows the horizontal and vertical vergence demands. Most eyewear gave a base-out horizontal vergence effect that ranged from 1.100 pd base-out to 0.125 pd base-in, and vertical vergence that ranged from 0 pd to 0.225 pd. Out of the 48 pairs of eyewear tested, 11 (23.9%) failed to meet the ANSI Z80.3 standard for no more than 0.25 pd of induced prism in primary gaze. Ten pairs of the eyewear tested had at least one lens with zero induced prism, while only two pairs had both lenses that measured zero. All lenses met ANSI Z80.3 requirements for no more than 0.50 pd of prismatic imbalance between the lenses. Overall means and standard deviations for all eyewear tested are listed in Table 2.

Table 3 shows the average horizontal and vertical prismatic deviation at 30 degrees lateral right gaze for right and left lenses of all eyewear tested. Prism measurements were much higher in lateral gaze with average horizontal deviations ranging from 0.750 pd base-in to 0.045 pd base-out for right lenses and 0.225 pd to 1.400 pd base-out for left lenses. The top ten performers measured less than 0.300 pd base-in for the right lenses and less than 0.500 base-out for the left lenses. On lateral gaze, all but one of the right lenses induced a base-in effect and all left lenses induced a base-out effect, or in other words, a yoked prismatic effect. Yoked effects ranged from 1.000 pd to 0.198 pd base-left, and horizontal vergence demands ranged from 0 pd to 1.225 pd base-out. The top ten performers measured less than 0.450 pd for yoked prism and 0.100 pd for vergence. In lateral gaze the majority of the vertical deviations were a base-down effect, similar to primary gaze. Overall means and standard deviations for all eyewear tested are also listed in Table 3.

Resolution results are shown in Table 4 and depict the overall resolution of each lens, which was determined by observing the maximum frequency in which both horizontal and vertical meridians were in focus. If a lens had astigmatic power or cylinder, one or both meridians alone may have a high frequency of resolution, but the overall clarity would suffer resulting in a lower overall resolution and decreased clarity for that lens. Many lenses were able to achieve the 40 cycles/degree resolution in one meridian at a time but only a few were able to achieve 40 cycles/degree in overall resolution. Variability also was apparent between lenses with one lens having more clarity than its counterpart. Resolution ranged from 10 cycles/degree to the maximum measurement of 40 cycles/degree. Out of the 48 pairs tested, 18 (37.5%) did not meet the NBS 20 Pattern as outlined in ANSI Z87.1. Only two of the pairs of eyewear tested measured 40 cycles/degree in overall clarity in both lenses.

Table 1: Average spherical equivalent and cylinder measured for each lens for all eyewear.

Note 1: According to ANSI Z80.3, refractive power must be within +0.125 D to -0.25 D in a given meridian, the difference between lenses can be no more than 0.1875 D, and all cylinder must measure no more than 0.125 D between any two meridians.[6]

Note 2: All lenses met ANSI requirements for difference between lenses and cylinder.

NON-POLARIZED LENSES		RIGHT LENS		LEFT LENS			
MANUFACTURER	MODEL / LENS COLOR	SPH. EQUIV.	CYL.	SPH. EQUIV.	CYL.	DIFFERENCE BETWEEN LENSES	ANSI MET FOR REFRACTIVE POWER
Anarchy	Boomerang / Gray	0.024	0.083	-0.063	0.100	0.088	TRUE
Anarchy	Nexis 2 / Gray	0.022	0.019	-0.005	0.013	0.028	TRUE
Angel	Vixen / Brown	-0.002	0.017	-0.001	0.023	0.001	TRUE
Bolle	Downdraft 10014 / Gray	-0.055	0.048	-0.048	0.018	0.007	TRUE
Bolle	Turbulence / Amber	-0.016	0.015	-0.012	0.020	0.004	TRUE
Bolle	Sidney / Gray	-0.005	0.007	-0.004	0.038	0.001	TRUE
Calvin Klein	RL 3028 / Gray	-0.007	0.017	0.010	0.016	0.016	TRUE
DKNY	Laurel / Gray	-0.055	0.038	-0.062	0.023	0.007	TRUE
Electric	Digit GLS / Gray	-0.016	0.039	-0.023	0.036	0.007	TRUE
Guess	Xanadu / Gray	-0.037	0.020	-0.050	0.029	0.014	TRUE
Killer Loop	Shamble OKL 3116 / Gray Grad.	-0.015	0.027	-0.027	0.021	0.012	TRUE
Killer Loop	Bait OKL 3101 / Brown Gradient	-0.013	0.033	-0.015	0.021	0.002	TRUE
Nike	V3 ER0054 / Brown	-0.031	0.016	-0.034	0.008	0.003	TRUE
Nike	Tarj Classic / Brown	-0.058	0.021	-0.064	0.033	0.006	TRUE
Nike	Interchange S / Orange	-0.065	0.010	-0.075	0.059	0.010	TRUE
Nike	Skylon EXP / Gray	-0.063	0.025	-0.064	0.026	0.001	TRUE
Nike	V. Cadence / Brown	-0.063	0.020	-0.062	0.027	0.002	TRUE
Nike	Furi / Violet	-0.091	0.024	-0.074	0.045	0.017	TRUE
Nike	Skylon EXP RD / Orange	-0.064	0.015	-0.074	0.026	0.010	TRUE
Nike	Skylon EXP / Orange	-0.064	0.021	-0.079	0.028	0.015	TRUE
Nike	Skylon EXP RD / Gray	-0.058	0.028	-0.077	0.029	0.019	TRUE
Oakley	Fate / Gray	0.000	0.018	-0.001	0.028	0.000	TRUE
Oakley	Square Wire 2.0 / Gray	-0.023	0.014	-0.038	0.003	0.015	TRUE
Oakley	Splice / Gray	0.003	0.021	-0.017	0.013	0.020	TRUE
Ray Ban	ORB 3147 / Gray	-0.021	0.037	-0.029	0.013	0.008	TRUE
Ray Ban	ORB 4001 / Gray	-0.015	0.022	-0.008	0.011	0.007	TRUE
Rudy Project	Graal Fyol / Gray	-0.011	0.031	-0.005	0.028	0.007	TRUE
Rudy Project	Graal Fyol / Amber	-0.023	0.004	-0.040	0.025	0.017	TRUE
Rudy Project	Graal Fyol / Clear	-0.003	0.013	-0.020	0.026	0.017	TRUE
Serengeti	Bromo 6758 / Brown	0.005	0.006	-0.002	0.003	0.007	TRUE
Serengeti	Cascade 6760 / Rose	-0.017	0.006	-0.022	0.002	0.004	TRUE
Smith	Hudson / Gray	-0.047	0.019	-0.057	0.016	0.010	TRUE
Spy	Clint / Gray	-0.022	0.017	-0.024	0.017	0.003	TRUE
Von Zipper	Tribeca / Gray Gradient	-0.028	0.009	-0.034	0.008	0.006	TRUE
Vuarnet	Pouilloux PX3021NMA / Gray	-0.045	0.043	0.002	0.012	0.047	TRUE
	OVERALL MEAN	**-0.028**	**0.023**	**-0.034**	**0.024**	**0.012**	
	STANDARD DEVIATION	**0.027**	**0.015**	**0.027**	**0.018**	**0.016**	
POLARIZED LENSES							
Angel	Purr- 94BZ / Brown	-0.201	0.122	-0.221	0.108	0.020	FALSE
Arnette	AN 4034 / Gray	-0.003	0.007	-0.008	0.015	0.006	TRUE
Bolle	Turbulence / Violet	-0.024	0.004	-0.030	0.004	0.007	TRUE
Hobie	Anchor / Gray	-0.002	0.017	0.011	0.016	0.013	TRUE
Kaenon	Kore / Gray	-0.019	0.023	-0.008	0.013	0.010	TRUE
Maui Jim	MJ 126-02 / Gray	0.010	0.010	-0.009	0.007	0.019	TRUE
Nike	Skylon EXP.M / Gray	-0.106	0.022	-0.113	0.022	0.007	TRUE
Nike	Interchange S.P / Brown	-0.220	0.017	-0.187	0.004	0.033	TRUE
Ralph Lauren	7512/S / Brown	-0.107	0.040	-0.125	0.063	0.018	TRUE
Ray Ban	ORB 3155 / Gray	-0.002	0.014	0.007	0.018	0.009	TRUE
Revo	Revo 801/81 / Gray	-0.007	0.019	-0.006	0.028	0.002	TRUE
Smith	Hudson / Brown	-0.014	0.036	-0.003	0.005	0.010	TRUE
Vuarnet	Pouilloux PX13020BME / Gray	-0.006	0.008	0.003	0.005	0.010	TRUE
	OVERALL MEAN	**-0.054**	**0.026**	**-0.053**	**0.024**	**0.013**	
	STANDARD DEVIATION	**0.076**	**0.029**	**0.077**	**0.029**	**0.008**	

Table 2: Average horizontal and vertical prismatic deviation measured in primary gaze for each lens for all eyewear.

Note 1: According to ANSI Z80.3, a lens can have no more than 0.25 D of base-in or base-out prism, and no more than 0.50 D prismatic imbalance between the lenses.

Note 2: All lenses met ANSI requirements for prismatic imbalance.

Note 3: Horizontal positive values represent base-out shifts and negative values represent base-in shifts.

Note 4: Vertical positive values represent base-down whereas negative values represent base-up.

NON-POLARIZED LENSES		RIGHT LENS		LEFT LENS		VERGENCE		ANSI MET FOR HORIZONTAL PRISM
MANUFACTURER	MODEL / LENS COLOR	HORIZ.	VERT.	HORIZ.	VERT.	HORIZ.	VERT	
Anarchy	Boomerang / Gray	0.100	0.538	0.238	0.500	0.338	0.038	TRUE
Anarchy	Nexis 2 / Gray	0.125	0.125	0.075	0.025	0.200	0.100	TRUE
Angel	Vixen / Brown	0.000	0.175	0.000	0.250	0.000	0.075	TRUE
Bolle	Downdraft 10014 / Gray	0.200	0.338	0.000	0.375	0.200	0.038	TRUE
Bolle	Turbulence / Amber	0.100	0.238	0.500	0.175	0.600	0.063	FALSE
Bolle	Sidney / Gray	0.025	-0.175	0.025	-0.113	0.050	0.063	TRUE
Calvin Klein	RL 3028 / Gray	0.050	0.275	-0.050	0.200	0.000	0.075	TRUE
DKNY	Laurel / Gray	0.000	0.225	0.050	0.125	0.050	0.100	TRUE
Electric	Digit GLS / Gray	0.100	0.200	0.175	0.125	0.275	0.075	TRUE
Guess	Xanadu / Gray	0.088	0.275	0.100	0.200	0.188	0.075	TRUE
Killer Loop	Shamble OKL 3116 / Gray Grad.	0.200	0.250	0.150	0.225	0.350	0.025	TRUE
Killer Loop	Bait OKL 3101 / Brown Gradient	-0.025	0.400	-0.100	0.375	-0.125	0.025	TRUE
Nike	V3 ER0054 / Brown	0.025	-0.025	-0.050	-0.075	-0.025	0.050	TRUE
Nike	Tarj Classic / Brown	0.000	-0.100	-0.100	-0.100	-0.100	0.000	TRUE
Nike	Interchange S / Orange	-0.050	-0.050	0.075	-0.100	0.025	0.050	TRUE
Nike	Skylon EXP / Gray	-0.025	0.000	0.025	-0.025	0.000	0.025	TRUE
Nike	V. Cadence / Brown	0.000	-0.150	0.000	-0.150	0.000	0.000	TRUE
Nike	Furi / Violet	0.050	-0.050	-0.050	-0.050	0.000	0.000	TRUE
Nike	Skylon EXP RD / Orange	-0.075	-0.075	0.000	-0.100	-0.075	0.025	TRUE
Nike	Skylon EXP / Orange	-0.068	0.010	0.005	-0.025	-0.063	0.035	TRUE
Nike	Skylon EXP RD / Gray	-0.033	0.023	0.000	-0.035	-0.033	0.058	TRUE
Oakley	Fate / Gray	0.050	0.125	0.050	0.125	0.100	0.000	TRUE
Oakley	Square Wire 2.0 / Gray	0.150	0.175	0.025	0.175	0.175	0.000	TRUE
Oakley	Splice / Gray	0.000	0.000	0.050	-0.050	0.050	0.050	TRUE
Ray Ban	ORB 3147 / Gray	0.100	0.250	0.100	0.150	0.200	0.100	TRUE
Ray Ban	ORB 4001 / Gray	0.200	0.200	0.250	0.175	0.450	0.025	TRUE
Rudy Project	Graal Fyol / Gray	0.425	0.100	0.300	0.050	0.725	0.050	FALSE
Rudy Project	Graal Fyol / Amber	0.245	-0.050	0.173	-0.050	0.418	0.000	TRUE
Rudy Project	Graal Fyol / Clear	0.355	0.003	0.198	-0.063	0.553	0.065	FALSE
Serengeti	Bromo 6758 / Brown	0.075	0.075	0.100	0.075	0.175	0.000	TRUE
Serengeti	Cascade 6760 / Rose	0.250	0.125	0.175	0.200	0.425	0.075	TRUE
Smith	Hudson / Gray	-0.075	0.125	0.000	0.313	-0.075	0.188	TRUE
Spy	Clint / Gray	0.000	0.250	0.025	0.150	0.025	0.100	TRUE
Von Zipper	Tribeca / Gray Gradient	0.175	0.175	0.175	0.150	0.350	0.025	TRUE
Vuarnet	Pouilloux PX3021NMA / Gray	0.600	0.200	0.500	0.250	1.100	0.050	FALSE
	OVERALL MEAN	**0.095**	**0.120**	**0.091**	**0.099**	**0.186**	**0.049**	
	STANDARD DEVIATION	**0.146**	**0.158**	**0.139**	**0.159**	**0.265**	**0.039**	
POLARIZED LENSES								
Angel	Purr- 94BZ / Brown	0.225	0.350	0.275	0.325	0.500	0.025	FALSE
Arnette	AN 4034 / Gray	-0.025	0.200	0.150	0.150	0.125	0.050	TRUE
Bolle	Turbulence / Violet	0.355	-0.413	0.233	-0.413	0.588	0.000	FALSE
Hobie	Anchor / Gray	0.150	0.275	0.450	0.225	0.600	0.050	FALSE
Kaenon	Kore / Gray	0.350	0.225	0.325	0.125	0.675	0.100	FALSE
Maui Jim	MJ 126-02 / Gray	0.150	0.350	0.275	0.325	0.425	0.025	FALSE
Nike	Skylon EXP.M / Gray	0.075	-0.075	0.075	-0.050	0.150	0.025	TRUE
Nike	Interchange S.P / Brown	0.310	-0.253	0.295	-0.225	0.605	0.028	FALSE
Ralph Lauren	7512/S / Brown	0.025	0.100	0.075	0.100	0.100	0.000	TRUE
Ray Ban	ORB 3155 / Gray	-0.075	0.275	-0.050	0.150	-0.125	0.125	TRUE
Revo	Revo 801/81 / Gray	0.225	0.325	0.225	0.275	0.450	0.050	TRUE
Smith	Hudson / Brown	0.175	0.450	-0.125	0.225	0.050	0.225	TRUE
Vuarnet	Pouilloux PX13020BME / Gray	0.400	0.275	0.375	0.225	0.775	0.050	FALSE
	OVERALL MEAN	**0.180**	**0.160**	**0.198**	**0.111**	**0.378**	**0.058**	
	STANDARD DEVIATION	**0.145**	**0.246**	**0.160**	**0.210**	**0.273**	**0.059**	

Table 3: Average horizontal and vertical prismatic deviation measured at 30 degrees lateral right gaze for each lens for all eyewear.

Note 1: Horizontal positive values represent base-out shifts and negative values represent base-in shifts.

Note 2: Vertical positive values represent base-down whereas negative values represent base-up.

NON-POLARIZED LENSES		RIGHT LENS		LEFT LENS		VERGENCE	YOKED
MANUFACTURER	**MODEL / LENS COLOR**	**HORIZ.**	**VERT.**	**HORIZ.**	**VERT.**	**HORIZ.**	**HORIZ.**
Anarchy	Boomerang / Gray	-0.750	0.513	1.250	0.638	0.500	-1.000
Anarchy	Nexis 2 / Gray	-0.575	0.150	0.775	0.150	0.200	-0.675
Angel	Vixen / Brown	-0.600	0.150	0.725	0.300	0.125	-0.663
Bolle	Downdraft 10014 / Gray	-0.700	0.313	0.950	0.500	0.250	-0.825
Bolle	Turbulence / Amber	-0.525	0.250	0.775	0.275	0.250	-0.650
Bolle	Sidney / Gray	-0.550	-0.125	0.800	0.075	0.250	-0.675
Calvin Klein	RL 3028 / Gray	-0.550	0.250	0.700	0.225	0.150	-0.625
DKNY	Laurel / Gray	-0.325	0.225	0.375	0.175	0.050	-0.350
Electric	Digit GLS / Gray	-0.475	0.175	1.050	0.325	0.575	-0.763
Guess	Xanadu / Gray	-0.388	0.200	0.500	0.225	0.113	-0.444
Killer Loop	Shamble OKL 3116 / Gray Grad.	-0.400	0.200	0.875	0.275	0.475	-0.638
Killer Loop	Bait OKL 3101 / Brown Gradient	-0.625	0.425	0.675	0.525	0.050	-0.650
Nike	V3 ER0054 / Brown	-0.300	0.000	0.300	0.050	0.000	-0.300
Nike	Tarj Classic / Brown	-0.350	-0.100	0.425	-0.075	0.075	-0.388
Nike	Interchange S / Orange	-0.500	0.000	0.575	0.000	0.075	-0.538
Nike	Skylon EXP / Gray	-0.400	-0.025	0.525	0.050	0.125	-0.463
Nike	V. Cadence / Brown	-0.350	-0.125	0.375	-0.075	0.025	-0.363
Nike	Furi / Violet	-0.325	0.000	0.475	0.000	0.150	-0.400
Nike	Skylon EXP RD / Orange	-0.425	-0.075	0.450	0.025	0.025	-0.438
Nike	Skylon EXP / Orange	-0.423	0.015	0.513	-0.068	0.090	-0.468
Nike	Skylon EXP RD / Gray	-0.405	0.028	0.500	-0.055	0.095	-0.453
Oakley	Fate / Gray	-0.375	0.075	0.550	0.150	0.175	-0.463
Oakley	Square Wire 2.0 / Gray	-0.375	0.125	0.625	0.225	0.250	-0.500
Oakley	Splice / Gray	-0.500	-0.025	0.725	0.075	0.225	-0.613
Ray Ban	ORB 3147 / Gray	-0.450	0.250	0.775	0.275	0.325	-0.613
Ray Ban	ORB 4001 / Gray	-0.175	0.175	0.750	0.300	0.575	-0.463
Rudy Project	Graal Fyol / Gray	-0.225	0.075	1.150	0.100	0.925	-0.688
Rudy Project	Graal Fyol / Amber	-0.338	-0.050	0.913	-0.078	0.575	-0.625
Rudy Project	Graal Fyol / Clear	-0.270	0.018	0.958	-0.100	0.688	-0.614
Serengeti	Bromo 6758 / Brown	-0.450	0.100	0.775	0.200	0.325	-0.613
Serengeti	Cascade 6760 / Rose	-0.300	0.125	0.900	0.375	0.600	-0.600
Smith	Hudson / Gray	-0.575	0.138	0.650	0.488	0.075	-0.613
Spy	Clint / Gray	-0.475	0.225	0.600	0.175	0.125	-0.538
Von Zipper	Tribeca / Gray Gradient	-0.300	0.150	0.625	0.238	0.325	-0.463
Vuarnet	Pouilloux PX3021NMA / Gray	-0.125	0.125	1.350	0.350	1.225	-0.738
	OVERALL MEAN	**-0.425**	**0.113**	**0.712**	**0.180**	**0.287**	**-0.569**
	STANDARD DEVIATION	**0.138**	**0.145**	**0.245**	**0.187**	**0.272**	**0.144**
POLARIZED LENSES							
Angel	Purr- 94BZ / Brown	-0.100	0.300	0.625	0.425	0.525	-0.363
Arnette	AN 4034 / Gray	-0.650	0.225	1.025	0.325	0.375	-0.838
Bolle	Turbulence / Violet	-0.278	-0.350	0.963	-0.510	0.685	-0.620
Hobie	Anchor / Gray	-0.200	0.225	1.400	0.325	1.200	-0.800
Kaenon	Kore / Gray	-0.325	0.225	1.200	0.225	0.875	-0.763
Maui Jim	MJ 126-02 / Gray	-0.425	0.325	1.150	0.600	0.725	-0.788
Nike	Skylon EXP.M / Gray	-0.350	-0.075	0.675	-0.050	0.325	-0.513
Nike	Interchange S.P / Brown	0.045	-0.160	0.400	-0.228	0.405	-0.198
Ralph Lauren	7512/S / Brown	-0.175	0.100	0.225	0.200	0.050	-0.200
Ray Ban	ORB 3155 / Gray	-0.650	0.275	0.775	0.275	0.125	-0.713
Revo	Revo 801/81 / Gray	-0.500	0.300	1.125	0.450	0.625	-0.813
Smith	Hudson / Brown	-0.525	0.375	0.650	0.400	0.125	-0.588
Vuarnet	Pouilloux PX13020BME / Gray	-0.175	0.200	1.175	0.350	1.000	-0.675
	OVERALL MEAN	**-0.331**	**0.151**	**0.876**	**0.214**	**0.542**	**-0.605**
	STANDARD DEVIATION	**0.204**	**0.208**	**0.334**	**0.293**	**0.339**	**0.216**

Table 4: Average resolution measured for each lens for all eyewear.

Note 1: According to ANSI Z87.1, all lines in both orientations of NBS Pattern 20 need to be clearly resolved.

NON-POLARIZED LENSES		RIGHT LENS	LEFT LENS	ANSI Met for
MANUFACTURER	MODEL / LENS COLOR	OVERALL	OVERALL	Resolving Power
Anarchy	Boomerang / Gray	10	20	FALSE
Anarchy	Nexis 2 / Gray	20	28	TRUE
Angel	Vixen / Brown	20	20	TRUE
Bolle	Downdraft 10014 / Gray	20	20	TRUE
Bolle	Turbulence / Amber	28	28	TRUE
Bolle	Sidney / Gray	20	10	FALSE
Calvin Klein	RL 3028 / Gray	28	28	TRUE
DKNY	Laurel / Gray	28	20	TRUE
Electric	Digit GLS / Gray	14	14	FALSE
Guess	Xanadu / Gray	14	20	FALSE
Killer Loop	Shamble OKL 3116 / Gray Grad.	20	20	TRUE
Killer Loop	Bait OKL 3101 / Brown Gradient	20	20	TRUE
Nike	V3 ER0054 / Brown	20	40	TRUE
Nike	Tarj Classic / Brown	14	14	FALSE
Nike	Interchange S / Orange	20	10	FALSE
Nike	Skylon EXP / Gray	20	20	TRUE
Nike	V. Cadence / Brown	14	20	FALSE
Nike	Furi / Violet	20	10	FALSE
Nike	Skylon EXP RD / Orange	20	14	FALSE
Nike	Skylon EXP / Orange	14	28	FALSE
Nike	Skylon EXP RD / Gray	10	20	FALSE
Oakley	Fate / Gray	28	14	FALSE
Oakley	Square Wire 2.0 / Gray	20	40	TRUE
Oakley	Splice / Gray	20	20	TRUE
Ray Ban	ORB 3147 / Gray	10	28	FALSE
Ray Ban	ORB 4001 / Gray	28	28	TRUE
Rudy Project	Graal Fyol / Gray	10	20	FALSE
Rudy Project	Graal Fyol / Amber	40	28	TRUE
Rudy Project	Graal Fyol / Clear	40	28	TRUE
Serengeti	Bromo 6758 / Brown	40	40	TRUE
Serengeti	Cascade 6760 / Rose	40	40	TRUE
Smith	Hudson / Gray	20	20	TRUE
Spy	Clint / Gray	20	20	TRUE
Von Zipper	Tribeca / Gray Gradient	40	28	TRUE
Vuarnet	Pouilloux PX3021NMA / Gray	14	28	FALSE
	OVERALL MEAN	**22**	**23**	
	STANDARD DEVIATION	**9**	**8**	
POLARIZED LENSES				
Angel	Purr- 94BZ / Brown	10	10	FALSE
Arnette	AN 4034 / Gray	28	20	TRUE
Bolle	Turbulence / Violet	28	28	TRUE
Hobie	Anchor / Gray	20	28	TRUE
Kaenon	Kore / Gray	40	28	TRUE
Maui Jim	MJ 126-02 / Gray	28	28	TRUE
Nike	Skylon EXP.M / Gray	20	20	TRUE
Nike	Interchange S.P / Brown	14	20	FALSE
Ralph Lauren	7512/S / Brown	14	20	FALSE
Ray Ban	ORB 3155 / Gray	28	28	TRUE
Revo	Revo 801/81 / Gray	20	28	TRUE
Smith	Hudson / Brown	28	28	TRUE
Vuarnet	Pouilloux PX13020BME / Gray	28	28	TRUE
	OVERALL MEAN	**24**	**24**	
	STANDARD DEVIATION	**8**	**5**	

Discussion

48 pairs of non-prescription sun eyewear from 23 manufacturers were tested under three categories of optical accuracy: refractive power, vertical and horizontal prism in primary and 30 degrees lateral gaze, and resolution. 35 pairs from 17 manufacturers were non-polarized lenses and 13 pairs from 12 manufacturers were polarized lenses.

The manufacturers of sun eyewear designate their lenses as plano lenses, but ANSI Z80.3 allows a range of 0.125 D to -0.25 D. In this study, only one pair of eyewear failed to meet this standard. Since some manufacturers intentionally use small amounts of minus to minimize the amount of prismatic deviation, it makes it difficult to compare these to those that strive for plano as the goal. Most wearers will be able to see clearly through small amounts of minus power by using accommodation. And at distances greater than 1 meter, most viewers will have a lead of accommodation, which also aids in distance clarity. [15]

The minimum amount of power needed to stimulate accommodation is 0.15 D.[16] The majority of the lenses in this study were less than 0.10 D in spherical power and all lenses had less than 0.10 D of difference between lenses. This would not be enough power to elicit an accommodative response and is therefore, less likely to cause asthenopia.

Some of the lenses tested had minimal spherical equivalent power, but had unwanted cylinder. All lenses tested had less than 0.13 D in cylinder. Lenses that have less pantoscopic tilt and face wrap may benefit from inducing less cylinder, however, they may lack in coverage and protection.

Since most of these lenses have very low refractive powers and cylinder, the depth of focus in the human eye may be high enough for these differences to go unnoticed. On the other hand, since this eyewear is tinted, pupil size may actually increase and, therefore, decrease the depth of focus. As a result, some wearers may be sensitive to these low amounts of refractive power or cylinder. A 3-4mm pupil has a depth of focus of about +/-0.25 D, whereas a 6mm and 7mm pupil has a depth of focus of about +/-0.12 D and +/-0.06 D, respectively.[17]

Since the small refractive powers in these lenses may have minimal effect on the wearer, induced prism in eyewear could be argued to be more detrimental to the viewer. Prism can not only cause a lateral shift in the environment, it can cause an incorrect judgment of distance due to vergence effects. In sports, prism can cause an athlete to misjudge an object's location and depending on the task this may be the difference between 1st and 2nd place. As mentioned above, prism effects are magnified at longer distances, so activities such as driving, golfing, and hunting can be more affected. Drivers who have accurate distance perception are less likely to require last second corrections. Accurate lateral gaze through lenses, as well as peripheral vision, can be very important in some sports, so eyewear with less induced prism in lateral gaze will translate to more accurate image perception. Ability to judge distance is also crucial, so those lenses that have a minimal vergence demand will minimize distance errors.

Whether or not a viewer will adapt to prism varies from person to person and also depends on the length of time wearing the eyewear. For activities shorter in time, wearers may not adapt to the shift in the environment and therefore are more likely to make perceptual judgment errors.

The validity of the resolution results may be questioned since there are no standards that directly apply to tinted lenses. Factors that could contribute to a decrease in resolving capability are lens aberrations, warped lenses, cylinder, and tint. Each pair of eyewear has a different tint density; therefore, the ability to resolve 20 on the NBS pattern may not be related to the quality of the lens, but rather the transmittance of the lens. A darker tint will not allow enough light through the lens to distinguish the higher frequency bars. Polarized lenses will also decrease the amount of light transmitted and could negatively affect the resolving power. It is possible that some of the eyewear that failed to reach 20 cycles/degree could meet this level if the illumination was increased. Further investigation in areas of transmittance and tint would be beneficial in determining appropriate resolving capabilities of sun eyewear.

Putting equal weight on refractive power, prismatic power, and resolution may not be ideal for determining overall optical quality. The activities that the eyewear is used for and the tints available may determine which pair is ideal for certain users. Certain qualities in a lens may be more sought after, such as darkness of tint, eye protection, or optical quality. Those who wear the lenses for high performance sports may be more sensitive wearers and benefit more from lenses that cause less image jump and less visual asthenopia. Future testing in optical quality could include subjective responses of visual clarity and comfort with both recreational users and professional athletes.

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