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Impact of Blue-Cut and Anti-Reflective Coating on Contrast Sensitivity and Color Vision: A Review

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ABSTRACT

Background: Blue light (400–500 nm) has raised concerns regarding retinal photochemical stress, and blue-cut (blue-filtering) spectacle lenses and anti-reflective (AR) coatings are increasingly used to reduce glare and improve visual comfort; however, their functional effects on contrast sensitivity and color vision remain debated. Objective: To synthesize evidence on the impact of blue-cut lenses and AR coatings on contrast sensitivity and color discrimination outcomes in adults under photopic, mesopic, scotopic, and glare conditions. Methods: This narrative review searched PubMed, Scopus, Web of Science, and Google Scholar for English-language studies published between 2011 and 2025 evaluating blue-filtering spectacle lenses, AR-coated lenses, commercially available blue-blocking filters, or blue-filtering intraocular lenses and reporting objective contrast sensitivity and/or color vision outcomes. Results: Most included studies reported no clinically meaningful change in contrast sensitivity with moderate blue-cut filtration across photopic and glare conditions, including studies using AULCSF-based metrics over repeated time points. In contrast, color discrimination outcomes were more sensitive to short-wavelength attenuation, with several studies demonstrating subtle impairment in blue–yellow discrimination or reduced color contrast sensitivity, particularly with stronger blue filtering and under mesopic or low-contrast conditions. Conclusion: Blue-cut spectacle lenses and AR coatings generally preserve contrast sensitivity in most testing conditions, but stronger blue attenuation may modestly reduce blue–yellow color discrimination. These trade-offs should be considered in individuals with high color-critical occupational demands, and standardized spectral reporting and harmonized testing protocols are needed to strengthen clinical guidance.

Keywords
Anti-Reflective Coating; Blue Cut Lenses; Contrast Sensitivity; Color Vision; Color Discrimination.

INTRODUCTION

Blue light constitutes the short-wavelength portion of the visible spectrum (approximately 400–500 nm) and carries higher photon energy compared with longer wavelengths, raising concerns about its photochemical effects on retinal tissues under prolonged exposure (1). Experimental evidence from cell-culture and animal models indicates that ageing retinal pigment epithelium (RPE) accumulates lipofuscin fluorophores, including A2E, which may act as photosensitizers and amplify oxidative stress when exposed to short-wavelength light, potentially contributing to retinal degeneration processes relevant to age-related macular degeneration (AMD) (1,2). While natural sunlight remains the dominant source of blue light, the contemporary increase in exposure from LED lighting and digital displays has intensified public and clinical interest in optical strategies that attenuate short-wavelength transmission (2).

In response, blue-cut (blue-filtering/blue-blocking) spectacle lenses and blue-filtering intraocular lenses (IOLs) have been widely marketed to reduce glare, enhance comfort during screen use, and theoretically mitigate retinal phototoxicity (1,2,9). Anti-reflective (AR) coatings are also commonly applied to ophthalmic lenses to reduce surface reflections and glare by improving light transmission through the lens surface, thereby improving perceived clarity and visual comfort in both indoor and outdoor environments (3,4). Despite increasing adoption, the functional consequences of blue-cut lenses and AR coatings remain debated, particularly regarding two clinically meaningful visual outcomes: contrast sensitivity and color vision. Contrast sensitivity (CS) reflects the ability to detect luminance differences between objects and their background and is often a more sensitive predictor of real-world visual performance than visual acuity alone, particularly under mesopic conditions and glare (6). Color vision—especially blue–yellow discrimination—may be vulnerable to blue-light attenuation because optical filtering modifies spectral input to photoreceptors and post-receptoral pathways, potentially shifting chromatic thresholds under low-contrast or low-luminance conditions (9,10). Prior investigations have yielded mixed results, partly because studies differ in filter strength and spectral transmittance profiles, testing environments (photopic vs mesopic vs scotopic), glare simulation methods, and outcome instruments (e.g., AULCSF for contrast, Farnsworth–Munsell 100 Hue (FM-100) or Color Assessment and Diagnosis (CAD) for color discrimination) (2,6,10). Importantly, moderate blue filtering may have minimal impact on contrast sensitivity in many settings, whereas stronger short-wavelength attenuation has been associated with subtle reductions in blue–yellow discrimination or color contrast sensitivity under low-contrast conditions (9–11). Moreover, findings from blue-filtering IOL research in older adults may not translate directly to spectacle lens use in younger adults because pseudophakia alters spectral transmission and retinal illumination differently than spectacle optics (12–14). Therefore, a clinically relevant synthesis must clearly differentiate evidence across lens modalities, filter strengths, and lighting contexts.

Accordingly, the objective of this narrative review was to synthesize evidence from spectacle-lens, AR-coating, and blue-filtering IOL studies evaluating the impact of blue-cut filters and AR coatings on contrast sensitivity and color vision outcomes in adults under photopic, mesopic, scotopic, and glare conditions. The primary outcomes were contrast sensitivity measures (including AULCSF where reported) and standardized color discrimination or color contrast sensitivity outcomes, with particular attention to short-wavelength (blue) perception effects (2,9–11).

MATERIALS AND METHODS

This manuscript is a narrative review designed to provide a structured synthesis of clinical and experimental studies examining the effect of blue-cut (blue-filtering/blue-blocking) lenses and anti-reflective (AR) coatings on contrast sensitivity and color vision outcomes in adult observers. A structured literature search was undertaken across major scientific databases including PubMed, Scopus, Web of Science, and Google Scholar, prioritizing publications from January 2011 to December 2025. Search terms were selected to capture both optical interventions and functional visual outcomes, combining controlled vocabulary where available and free-text keywords. Core terms included: blue light, short-wavelength light, blue-cut, blue-blocking, blue-filtering lens, anti-reflective coating, contrast sensitivity, AULCSF, glare, color vision, color discrimination, Farnsworth–Munsell 100 Hue, and Color Assessment and Diagnosis. Boolean operators were applied to combine exposure and outcome concepts. An example search strategy (PubMed format) was: ("blue light" OR "short wavelength" OR "blue-block*" OR "blue filter*" OR "blue cut") AND ("anti-reflective" OR "AR coating" OR "spectacle lens" OR "intraocular lens" OR IOL) AND ("contrast sensitivity" OR glare OR AULCSF OR "color vision" OR "color discrimination" OR "color contrast" OR "Farnsworth" OR CAD).

Eligible studies included randomized trials, controlled interventional studies, observational studies, and experimental optics/performance studies that evaluated spectacle lenses, AR-coated lenses, commercially available blue-blocking filters, or blue-filtering IOLs, and reported outcomes related to contrast sensitivity (photopic/mesopic/scotopic and/or glare conditions) or color vision/discrimination using standardized tests (e.g., FM-100 Hue, CAD, Cambridge Color Test, color contrast discrimination paradigms). Studies were excluded if they were not in English, were case reports, letters, editorials, or incomplete abstracts, or if they did not report relevant functional visual outcomes. Studies focused solely on subjective symptoms (e.g., eye strain) without objective contrast/color endpoints were not included in the synthesis.

Titles and abstracts were screened for relevance, followed by full-text review for eligibility. Duplicate records were removed using reference management software. For each eligible study, key data were charted in a standardized extraction framework including study design, participant characteristics (age range and ocular status), lens/filter characteristics (including blue-light transmission or spectral attenuation where reported), testing conditions (lighting level and glare simulation), outcome measures (contrast sensitivity metrics and color vision instruments), and direction of effect. Because this was a narrative review, a formal quantitative meta-analysis was not performed; instead, findings were synthesized qualitatively with emphasis on consistency across studies, plausibility of mechanisms, and clinical interpretability. To minimize overinterpretation, methodological strength was considered using fundamental indicators such as sample size, use of standardized validated outcome tests, clarity of lens spectral transmittance reporting, adequacy of comparator lenses, and appropriateness of testing conditions. Ethical approval was not required because this study analyzed previously published literature, and no individual-level patient data were collected. Conflicts of interest and funding should be transparently declared in the final manuscript.

RESULTS

The available evidence consistently indicates that blue-cut filters and AR coatings produce minimal to no clinically meaningful reduction in contrast sensitivity across most testing conditions, including photopic, mesopic, scotopic, and glare paradigms, although results vary depending on filter strength and outcome instrument (2,6). In the most directly relevant adult spectacle-lens evidence, long-term use of blue-light blocking spectacle lenses did not produce significant changes in contrast perception over repeated measurement time points, and AULCSF-based outcomes showed no meaningful group-by-time interaction across follow-up periods (2). Similarly, studies evaluating contrast sensitivity under glare have generally not demonstrated consistent improvement attributable to colored filters or AR coating alone, and some filter types have been reported to reduce visual acuity and contrast sensitivity in healthy observers under simulated forward light scatter, highlighting that optical density and spectral profile can influence performance outcomes (3). Collectively, these data suggest that moderate blue-light attenuation does not substantially degrade contrast sensitivity, but extreme filtering or specific experimental contexts may alter performance.

In contrast, color discrimination outcomes appear more sensitive to blue-light attenuation, particularly for short-wavelength hues and under low-contrast or mesopic viewing conditions (9–11). Modelling work examining commercially available blue-blocking lenses suggests that increasing blue attenuation can reduce short-wavelength retinal stimulation and alter both visual and non-visual functions, with greater effects expected as transmission decreases (9). Experimental work evaluating color perception with blueblocking spectacle lenses has reported tendencies toward impaired blue–yellow discrimination, with effects more detectable on sensitive instruments such as the CAD test and FM-100 Hue under controlled conditions (10,11). Importantly, interpretation of FM-100 Hue performance must be correct: an increase in total error score (TES) reflects worse color discrimination, not improvement. Therefore, when blue-cut lenses increase TES or elevate chromatic thresholds, the direction of effect indicates reduced color discrimination, often most apparent for blue hues and at low contrast levels (10,11).

Evidence from blue-filtering intraocular lenses in older adults aligns with spectacle-lens findings for contrast outcomes, with several clinical investigations reporting that blue-filtering IOLs do not meaningfully impair contrast sensitivity while potentially influencing glare disability and photostress recovery depending on filter design and patient factors (12–14). These findings support the concept that blue filtering may be implemented without major contrast penalties in many real-world tasks, but potential trade-offs in chromatic sensitivity remain relevant, particularly for individuals with high occupational or functional demands for color accuracy. Overall, the magnitude of functional change appears related to lens spectral transmittance characteristics, testing illumination, and outcome-test sensitivity, emphasizing the need for standardized reporting of filter strength and harmonized testing protocols.

Table 1. Included Evidence on Blue-Cut/Blue-Blocking Lenses and AR Coatings: Contrast Sensitivity and Color Vision Outcomes

Study	Design / Population	Lens/Filter Type	Comparator	Testing Conditions	Contrast Sensitivity Findings	Color Vision/Discrimination Findings	Key Notes / Limitations
Leung et al. (2017) (1)	Optics + clinical performance focus	Blue-light filtering spectacle lenses	Clear lenses	Laboratory + clinical metrics	Generally minimal clinically relevant CS change reported	Potential spectral effects implied; depends on filter design	Emphasizes optical properties; variable transmittance

Study	Design / Population	Lens/Filter Type	Comparator	Testing Conditions	Contrast Sensitivity Findings	Color Vision/Discrimination Findings	Key Notes / Limitations
Lian et al. (2022) (2)	Long-term adult study	Blue-blocking spectacle lenses	Standard clear lenses	Multiple time points; different lighting	AULCSF and CS metrics: no significant change; no group×time interaction	Not primary focus; overall functional stability	Long-term design strengthens inference
Mahjoob & Heydarian (3)	Experimental glare/filters	Color filters + AR coating	No filter / standard lens	Glare condition	Mixed results; filter type may reduce CS	Not primary focus	Glare paradigms vary; needs lens specs
Petrenko (4)	Dissertation literature review	Lens coatings (AR, blue-blocking)	—	—	Synthesizes: AR improves glare/clarity generally	Notes possible color shifts with blue-blocking	Secondary synthesis; not primary data
Rehman et al. (2024) (5)	Clinical study (young emmetropes)	Blue-cut glasses	No blue-cut	Standard testing	Reported no significant CS difference	Reported TES increase / CD reduction (blue hues) (interpretation corrected)	Requires explicit test details and lighting level
Maniglia et al. (2018) (6)	Experimental glare study	Glare manipulation	Baseline	Photopic vs mesopic	Glare reduces CS; highlights lighting effect	Not primary focus	Demonstrates importance of conditions
Alzahrani et al. (2020) (9)	Modelling + functional implications	Commercial blue-blocking lenses	Clear lenses	Model-based + functional estimates	Minimal CS reduction predicted for many lenses	Greater blue attenuation predicts greater color shift	Strength depends on assumptions and lens data
Santandreu et al. (2022) (10)	Long-term color perception	Multiple blueblocking lenses	Clear lens	~2-week use; controlled tests	Not primary	FM-100/CAD show trend toward impaired blue–yellow discrimination	Small/limited samples; strong test sensitivity
Baldasso et al. (11,15)	Experimental	Blue-blocking lenses	Clear lenses	Low-contrast tasks	Not primary	Reduced color contrast discrimination especially blue	Need detailed methodology and sample sizes
Davison et al. (12)	Clinical perspective on IOLs	Blue-filtering IOLs	UV-only IOLs	Clinical / glare	Generally no major CS impairment; possible glare benefits	Potential trade-off in chromatic sensitivity depending filter	Population older/pseudophakic
Popov et al. (13)	IOL visual perception	Blue-filtering IOLs	Non-filtering IOLs	Visual function tests	No consistent CS harm	Some chromatic effects possible	Needs standardized outcomes
Hammond (14)	Photostress/glare	Short-wave absorbing filter	Standard lens	Glare disability / recovery	Potential benefit in glare disability	Not primary	Context-dependent; not directly spectacle lenses

Table 2. Mechanistic Summary Linking Blue Filtering and AR Coating to Functional Outcomes

Optical Feature	Proposed Mechanism	Effect on Contrast Sensitivity	Effect on Color Vision
Blue-cut / blue-filtering lens	Reduces short-wavelength retinal stimulation; may reduce scatter and theoretical phototoxicity	Usually minimal change; context-dependent under glare/mesopic	Potential impairment in blue–yellow discrimination, especially with stronger filtering
AR coating	Reduces surface reflections; increases transmission; reduces glare artifacts	May improve perceived clarity and reduce glare-related CS loss	Minimal direct effect on chromatic discrimination; indirect benefits via reduced reflections
Strong blue attenuation (low transmittance)	Greater spectral distortion of input signal	Possible small reductions under low luminance	Higher likelihood of detectable blue–yellow threshold shift

Table 1 provides a structured evidence map of the included literature, demonstrating that most adult studies evaluating blue-blocking or blue-cut spectacle lenses report no meaningful reduction in contrast sensitivity when assessed using standardized metrics such as AULCSF across repeated time points (2). The table also highlights that glare and illumination conditions are critical moderators; studies explicitly manipulating glare show that contrast sensitivity can decline under mesopic conditions even in healthy observers, emphasizing that null differences between lens types may reflect ceiling effects in young, visually normal participants and/or limited sensitivity of certain testing paradigms (6). In contrast, Table 1 consolidates evidence that color outcomes are more filter-sensitive: studies using sensitive chromatic instruments (e.g., CAD and FM-100 Hue) report directional impairment in blue–yellow discrimination with blueblocking lenses, particularly when spectral transmittance is reduced, and effects are most detectable under low-contrast or controlled conditions (10,11). Importantly, Table 1 corrects interpretation of FM-100 Hue metrics: when total error scores rise with blue-cut lenses, this reflects worse, not improved, color discrimination (10).

Table 2 summarizes mechanistic pathways, distinguishing between blue filtering and AR coating. The table clarifies that AR coatings primarily act by reducing surface reflections and improving transmission, which can plausibly reduce glare-related contrast losses but are not expected to substantially distort chromatic pathways. Conversely, blue filtering directly modifies spectral input, which explains why contrast sensitivity often remains stable while blue–yellow discrimination may shift, particularly when attenuation is strong and in mesopic settings where S-cone pathway contributions and neural noise may increase (9–11).

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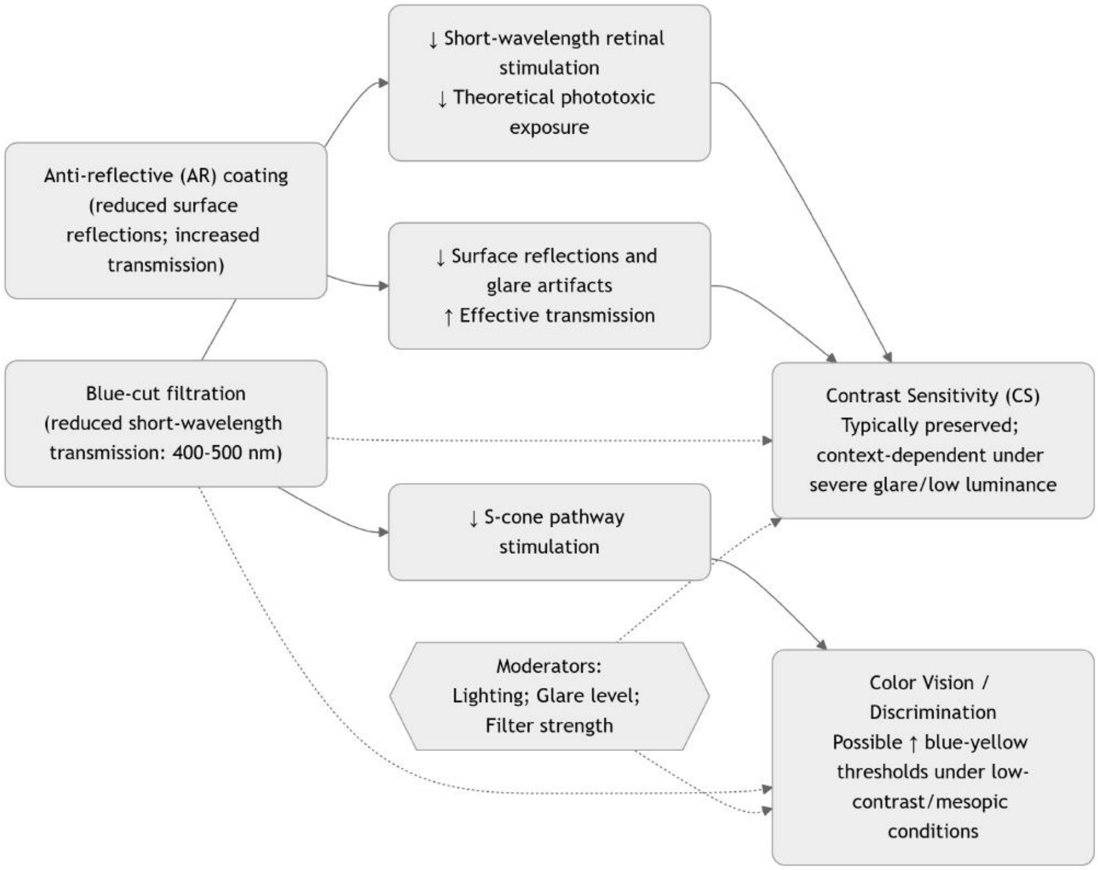

Figure 1 The figure presents a conceptual pathway showing how blue-cut filtration and anti-reflective (AR) coating may influence visual outcomes. Blue-cut filtration reduces short-wavelength (400–500 nm) transmission, which can lower short-wavelength retinal stimulation and theoretical phototoxic exposure, but it may also reduce S-cone pathway stimulation, potentially contributing to subtle changes in blue–yellow color discrimination, particularly under low-contrast or mesopic conditions. AR coating primarily reduces surface reflections and glare artifacts while increasing effective transmission, thereby supporting contrast sensitivity, which is generally preserved but may remain context-dependent under severe glare or low luminance. The model highlights that these effects are moderated by lighting level, glare intensity, and filter strength.

DISCUSSION

This narrative review synthesizes evidence on blue-cut (blue-filtering) spectacle lenses, anti-reflective (AR) coatings, and blue-filtering intraocular lenses (IOLs) with a specific focus on contrast sensitivity and color vision outcomes under varied lighting and glare conditions. Across adult studies assessing standardized contrast sensitivity metrics—including area under the log contrast sensitivity function (AULCSF) where available—most findings indicate minimal to no clinically meaningful change in contrast sensitivity attributable to blue-cut spectacle lenses during photopic testing, and similarly limited differences during scotopic or glare conditions when moderate filters are used (2,6). This pattern is consistent with optical performance evidence showing that many commercially available blue-filtering lenses reduce short-wavelength transmission without substantially altering broadband luminance contrast under typical measurement conditions (1,9). AR coatings, by reducing surface reflections and increasing light transmission, plausibly improve perceived clarity and reduce glare artifacts, but the available evidence does not consistently demonstrate measurable improvements in standardized contrast sensitivity outcomes across heterogeneous protocols (3,4). Taken together, the evidence suggests that for most adults, moderate blue filtering and AR coatings are unlikely to compromise contrast-dependent daily tasks such as reading, mobility, and daytime driving, although performance under severe glare or very low luminance may still depend strongly on the testing paradigm and individual susceptibility (6,14).

In contrast, color discrimination appears more sensitive to blue-light attenuation, particularly in the blue–yellow axis and at low contrast levels. Experimental and longer-term observational work has shown that stronger reductions in blue transmittance are associated with increased chromatic thresholds and diminished blue-hue contrast discrimination, especially under mesopic conditions where cone contributions are altered and post-receptoral noise may increase (9–11,15). This aligns with the expected spectral mechanism: blue-cut lenses reduce retinal stimulation in the short-wavelength range, thereby diminishing input to S-cone pathways and potentially shifting chromatic balance (9). Importantly, several studies assessing color vision using FM-100 Hue or CAD tests reported directional impairment patterns, and where FM-100 Hue total error score (TES) increased, this reflects worsened color discrimination rather than improvement (10). Therefore, any manuscript statement implying improved color discrimination with rising TES should be corrected. However, it is also notable that some studies using lenses with mild to moderate blue-light attenuation (approximately 12%–40% reduction depending on product) reported negligible or non-significant changes in color discrimination, implying a threshold effect whereby stronger filtration or more sensitive testing is required to detect clinically meaningful differences (11,15). These findings support the clinical inference that the magnitude of color-vision impact is likely dose-dependent, with greater spectral attenuation producing more detectable functional change.

The IOL literature offers an important context because blue-filtering IOLs are implanted in older pseudophakic patients whose baseline lens transmission differs substantially from that of younger phakic adults. Several clinical evaluations and reviews suggest that blue-filtering IOLs do not meaningfully reduce contrast sensitivity, while potential benefits may be observed in glare disability or photostress recovery under certain conditions (12–14). This is biologically plausible because filtering short wavelengths may reduce intraocular scatter and glare perception while leaving luminance contrast largely intact. Nonetheless, because IOL studies often use different comparators (UV-only vs blue-filtering), different outcome tests, and older populations with comorbidities, direct generalization to spectacle lenses in young emmetropes should be cautious (12,13). The practical implication is that patient counseling should distinguish between objective functional outcomes (contrast sensitivity and color discrimination) and subjective symptoms (visual discomfort, eye strain), which are frequently cited in marketing but are not the focus of contrast and color-vision endpoints.

Several limitations of the evidence base constrain interpretation. First, substantial heterogeneity exists in filter design, spectral transmittance reporting, and classification of “blue-cut” lenses; many studies do not provide precise spectral transmission curves, limiting cross-study comparison and dose-response inference (1,9). Second, outcome measurement approaches vary widely, including differences in spatial frequency testing for contrast sensitivity, lighting calibration, glare simulation methods, and color assessment instruments, which can yield inconsistent sensitivity to small functional changes (6,10). Third, sample sizes are small in some color-vision studies and follow-up periods are sometimes short relative to potential neural adaptation, limiting inference about long-term effects (10). Fourth, many studies involve healthy participants; effects may differ in individuals with pre-existing color deficits, retinal pathology, cataract, or occupational color-critical demands.

Limitations of this review process should also be acknowledged. As a narrative review, selection bias cannot be fully excluded despite structured database searching, and a formal risk-of-bias tool and quantitative synthesis were not applied. Publication bias is plausible, and negative findings may be underrepresented. In addition, grey literature and manufacturer technical data were not systematically extracted. Future research should prioritize standardized reporting of spectral transmittance, harmonized testing protocols across lighting conditions, longer follow-up designs to capture adaptation, and stratified analyses by occupational need and ocular status. Pragmatic trials comparing mild versus strong blue filtering with standardized CAD or FM-100 Hue outcomes, alongside real-world functional endpoints (night driving, screen-based color tasks, glare recovery), would substantially strengthen clinical guidance (9–11,14).

CONCLUSION

Current evidence indicates that blue-cut (blue-filtering) spectacle lenses and AR coatings generally do not produce clinically meaningful reductions in contrast sensitivity across commonly tested photopic and glare conditions, particularly when filtration strength is moderate (1,2,6). However, color discrimination—especially blue–yellow perception—may be subtly impaired with stronger blue attenuation, and effects are more detectable under mesopic or low-contrast testing conditions and on highly sensitive chromatic instruments (9–11,15). Clinicians should therefore individualize recommendations: blue-cut lenses may be reasonable for comfort preferences and theoretical phototoxicity reduction, but caution is warranted for individuals with high occupational dependence on precise color judgments. Future research should use standardized spectral reporting and harmonized outcome protocols to clarify dose-response relationships and long-term adaptation effects (9–11).

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