Original Article

Blue light-blocking efficiency of blue light-blocking and driving spectacle lenses

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ABSTRACT

Background: Retinal damage caused by blue light can result in glare, decreased visual acuity, and accelerated macular degeneration. In clinical practice, blue light-blocking glasses, such as driving glasses, are used to block blue light effectively. This study was aimed at measuring light transmittance to analyze the blue light-blocking efficiencies of blue light-blocking and driving spectacle lenses manufactured with tinting, coating, and only materials and at distinguishing the difference between the two spectacle lenses.

Methods: Blue light-blocking and driving spectacle lenses used to measure light transmittance were manufactured with tinting (blue light-blocking lenses by tinting or "BTL" and driving spectacle lenses by tinting or "DTL," respectively), coating (blue light-blocking lenses by coating or "BCL" and driving spectacle lenses by coating or "DCL," respectively), and only materials (blue light-blocking lenses by material or "BML" and driving spectacle lenses by material or "DML," respectively).

Results: Compared to BTL, DTL had a significantly greater decrease in the light transmission efficiency for visible and blue lights ($P < 0.05$). The blue light hazard function was lower for BML and DML than for conventional coating lenses in both visible and blue lights, although without significant differences between visible and blue lights ($P > 0.05$).

Conclusions: The blue light-blocking spectacle lenses had the highest blue light-blocking efficiency when manufactured with tinting, coating, and only materials, in order. With DML, the blue light-blocking efficiency was lower compared to DTL but higher compared to DCL. Therefore, DML could provide a balanced glare control and clear retinal image overall. To evaluate the detailed performance of the blue light-blocking and driving spectacle lenses presented in this study, a follow-up study on subjective wearing experience is necessary.

KEY WORDS

blue light, visible light, blue light-blocking, hazard function, light transmittance, glare, spectacles

INTRODUCTION

Sunlight and artificial lighting above a certain level may cause glare [1], necessitating light pollution prevention measures [2]. Discomfort glare is caused by excessive luminance, which induces visual annoyance, and is mainly quantified through subjective measures, such as the de Bore glare scale [3–5]. Disability glare refers to reduced contrast sensitivity and severe visual damage caused by scattered light [6,7].

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Mainster and Turner reported that the incident ray on the eyeballs causes glare and suggested four types of glare [8]. Glare measurement has considerable significance in clinical optics related to visual acuity. However, the objective measurement of glare is difficult [9].

Glare may occur during night-driving. Glare followed by minor visual damage is difficult to identify using visual acuity measurements. In addition, even within the normal range, a driver can temporarily experience severe visual impairment and, thus, reduced driving ability [10–12]. Although visual acuity can be used to assess the prerequisite of driving skills, driving is still unsafe until a more detailed evaluation method is applied to screen for potential risk factors, such as glare [13]. The contrast sensitivity test reveals obstructions caused by decreased visibility during night-driving better compared to the visual acuity test [14]. Visual changes are strongly correlated with the safety of drivers and pedestrians. Glare slightly reduces cognitive ability for objects as the driver's contrast sensitivity decreases [15–17].

Regarding a suitable lens for night vision, Koh and Jeon found driving lenses to be more effective in enhancing contrast visual acuity and reducing visual acuity recovery time compared to normal lenses [1]. Park and Chu found that night-driving lenses did not affect accommodation or pupil size [18]. Blue light emitted from a car light source causes glare and reduces visibility at night. In addition to blue light-blocking, driving glasses should block glare in consideration of the intensity and frequency of light emitted from the car light source [19, 20]. The exact blue light-blocking and glare control performances should be considered for driving glasses in clinical practice.

Retinal damage caused by blue light can result in glare, decreased visual acuity, and accelerated macular degeneration [21]. However, patients with pseudophakic eyes should be cautious when exposed to excessive light-emitting diode light [22]. The blue light wavelength (emitted mostly from light-emitting diodes) ranges from 380 to 500 nanometer (nm). It comprises purple, blue, and cyan with wavelengths of 400, 460, and 507 nm, respectively. Blue light is not absorbed by the cornea or crystalline lens and eventually reaches the retina [23]. In clinical practice, blue light-blocking glasses, such as driving glasses, are used to block blue light effectively. Manufacturing methods include tinting, coating, and using only materials [23]. However, the blue light-blocking performance depends on the manufacturer's data, which are lacking.

This study was aimed at investigating the blue light-blocking efficiency for glare control by measuring light transmittance by blue light-blocking and driving spectacle lenses manufactured with tinting, coating, and only materials. The distribution areas were also calculated to confirm the characteristics according to the manufacturing method. Furthermore, we aimed to distinguish between blue light-blocking and driving spectacle lenses.

METHODS

The blue light-blocking and driving spectacle lenses used to measure light transmittance. They manufactured with tinting (hereafter referred to as blue light-blocking lenses by tinting or "BTL" and driving spectacle lenses by tinting or "DTL," respectively), coating (hereafter referred to as blue light-blocking lenses by coating or "BCL" and driving spectacle lenses by coating or "DCL," respectively), and only materials (hereafter referred to as blue light-blocking lenses by material or "BML" and driving spectacle lenses by material or "DML," respectively). In addition, a conventional coating lens (CCL) with refractive index (n) of 1.60 was selected for comparison (producted by SOMO® Opt., , south Korea). The vertex refractive power (D) and n of all glasses were unified as 0.00 and 1.60, respectively (Figure 1).

Light transmittance was measured using a spectral transmittance meter (TM-1, Topcon, Tokyo, Japan). The light source used in this measurement device is D65, which exhibits similar characteristics to natural light during daytime and has a wavelength ranging from 280 to 780 nm. All spectacle lenses were analyzed for visible (380–780 nm) and blue (380–500 nm) lights (Figure 2).

Light transmittance (%) is the ratio of the emitted light intensity to the incident light intensity. Therefore, without glasses, light transmittance within all wavelengths is 100%. For the quantitative analysis of light transmittance, we calculated the distribution area using the integral of the light transmission graph of the blue light-blocking and driving lenses (Figure 3). The blue light blocking efficiency was confirmed by calculating the distribution area of blue light hazard function, which causes glare, by weighing the blue light hazard function to light transmittance of blue light-blocking and driving spectacle lenses according to the international standard (ISO 13666; Figure 4).

For the statistical analysis, Microsoft Excel version 16.41 (Microsoft Co., USA), PASW Statistics version 18 (IBM Co., Chicago, USA), and Origin version 8.5 (OriginLab, Northampton, MA, USA) were used. The independent sample *t*-test was applied to analyze the difference between the two lenses. Following normality assumption, the one-way analysis of variance is used to analyze the difference between more than two lenses. Statistical significance was set at $P < 0.05$.

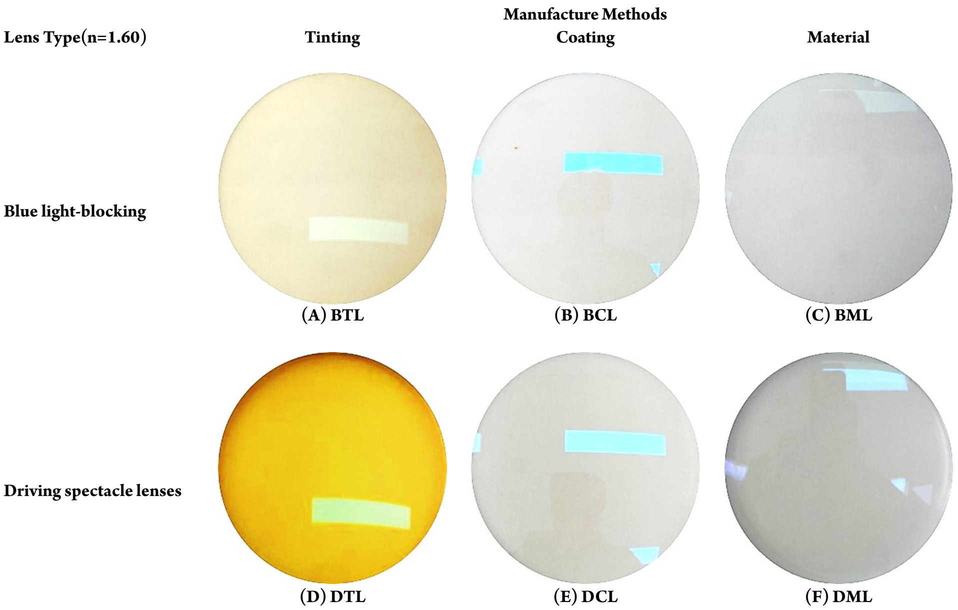
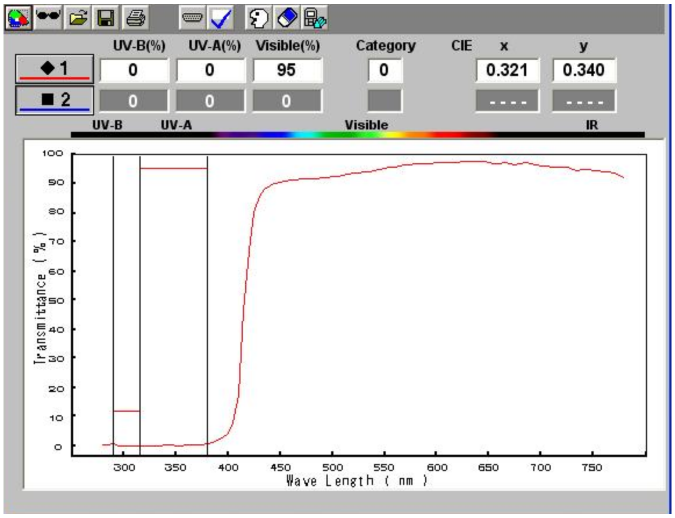


Figure 1. Type and manufacturing method of each lens. Abbreviations: n, refractive index; (A) BTL, blue light-blocking lenses by tinting; (B) BCL, blue light-blocking lenses by coating; (C) BML, blue light-blocking lenses by material; (D) DTL, driving spectacle lenses by tinting; (E) DCL, driving spectacle lenses by coating; (F) DML, driving spectacle lenses by material.



	UV-B(%)	UV-A(%)	Visible(%)	Category	CIE x	y
◆ 1	0	0	95	0	0.321	0.340
■ 2	0	0	0		----	----

Figure 2. Results of the spectral transmittance meter. Abbreviations: %, percentage; nm, nanometer.

RESULTS

Table 1 and Figure 5 show the light transmittance distribution areas for visible and blue lights of the blue light-blocking and driving spectacle lenses manufactured with tinting. The light transmittance distribution areas of BTL and DTL for visible light were 335.058 and 264.965, respectively, and for blue light were 70.658 and 18.072, respectively. Compared to CCL, the differences (%) in the light transmittance distribution areas of BTL and DTL were 7.997 and 27.244 for visible light, respectively, and 22.161 and 80.092 for blue light, respectively. Statistically significant differences were also observed between visible and blue lights ($P < 0.05$). Thus, compared to BTL, DTL exhibited a significantly greater decrease in light transmission efficiency in the visible and blue wavelength ranges (Table 1).

Table 2 and Figure 6 show the light transmittance distribution areas for visible and blue lights of the blue light-blocking and driving spectacle lenses manufactured with coating. The light transmittance distribution areas of BCL and DCL for visible light were 353.868 and 369.298, respectively, and for blue light were 80.297 and 91.623, respectively.

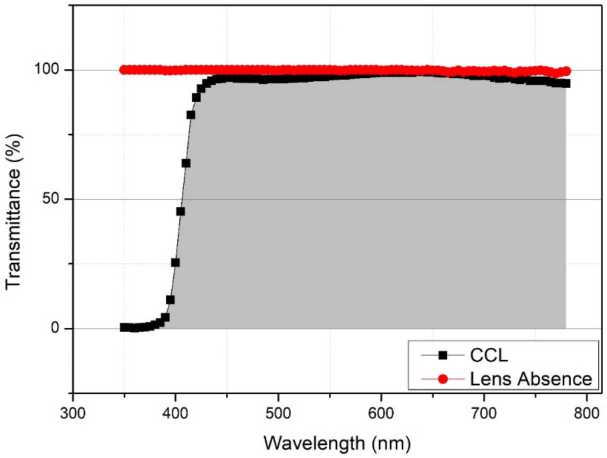


Figure 3. Distribution area (an ash color range) calculation (an example). Abbreviations: %, percentage; CCL, conventional coating lenses; nm, nanometer.

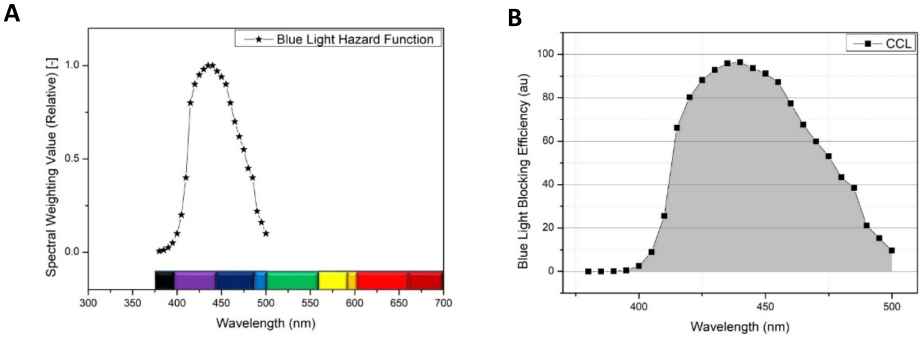


Figure 4. Blue light hazard function distribution area (an ash color range) calculation (an example). (A) Blue light hazard function presented in ISO 13666, (B) Blue light hazard function distribution area. Abbreviations: ISO 13666, the international standard; nm, nanometer; CCL, CCL, conventional coating lenses; au, distribution area.

Compared to CCL, the differences (%) in the light transmittance distribution areas of BCL and DCL were 2.832 and -1.404 for visible light, respectively, and 11.542, and -0.935 for blue light, respectively. However, no significant difference was found between visible and blue lights ($P > 0.05$). Thus, BCL and DCL exhibited similar light transmission efficiencies for visible and blue lights (Table 2).

Table 3 and Figure 7 show the light transmittance distribution areas for visible and blue lights of the blue light-blocking and driving spectacle lenses manufactured with only materials. The light transmittance distribution areas of BML and DML for visible light were 351.063 and 334.245, respectively, and for blue light were 81.515 and 72.978, respectively. Compared to CCL, the differences (%) in the light transmittance distribution areas of BML and DML were 3.603 and 8.221 for visible light, respectively, and 10.200 and 19.606 for blue light, respectively, without any statistically significant difference between visible and blue lights ($P > 0.05$). Thus, BML and DML exhibited similar light transmission efficiencies for visible and blue lights (Table 3).

Table 4 and Figure 8 show the light transmittance distribution areas for visible and blue lights of the blue light-blocking and driving spectacle lenses according to the manufacturing method. The light transmittance distribution areas of BTL, BCL, and BML were 335.058, 353.868, and 351.068 for visible light, respectively, and 70.658, 80.297, and 81.515, for blue light, respectively, showing no statistically significant differences according to the manufacturing method ($P > 0.05$) (Table 4).

The light transmittance distribution areas of DTL, DCL, and DML were 264.965, 369.298, and 334.245 for visible light, respectively, and 18.072, 91.623,and 72.978 for blue light, respectively, showing statistically significant differences according to the manufacturing method ($P < 0.05$) (Table 4).

Table 5 and Figure 9 show the blue light hazard function distribution area for visible and blue lights of the blue light-blocking and driving spectacle lenses according to the manufacturing method.

Table 1. Light transmittance distribution areas of blue light-blocking lenses by tinting (BTL) and driving spectacle lenses by tinting (DTL) with visible (350 ~ 780 nm) and blue lights (380 ~ 500 nm)

n = 1.60	Lens Type	Wavelength Range		Difference (%)	
		Visible Light	Blue Light	Visible Light	Blue Light
Light Transmittance (au)	BTL	335.058	70.658	7.997	22.161
	DTL	264.965	18.072	27.244	80.092
	CCL	364.183	90.774	-	
P-value		**0.003**	**0.000**		

Abbreviations: nm, nanometer; n, refractive index; au, distribution area; %, percentage; CCL, conventional coating lenses. *P*-value < 0.05 is shown in bold.

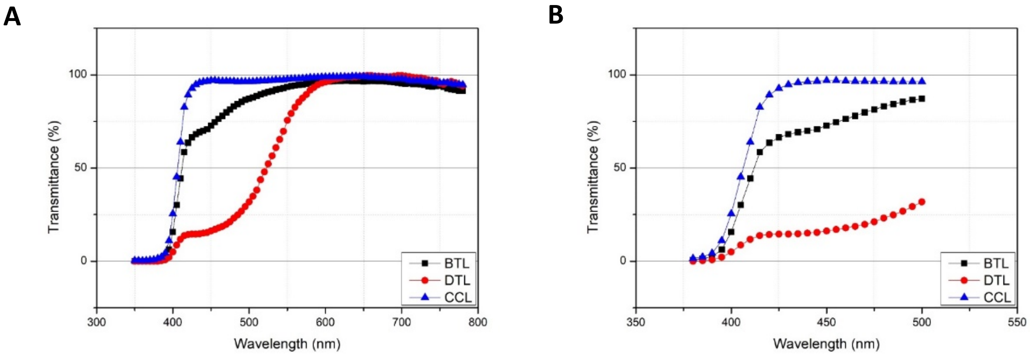


Figure 5. Light transmittance distribution areas of blue light-blocking lenses by tinting (BTL) and driving spectacle lenses by tinting (DTL) with (A) visible (350 ~ 780 nm) and (B) blue lights (380 ~ 500 nm). Abbreviations: %, percentage; nm, nanometer; CCL, conventional coating lenses.

Table 2. Light transmittance distribution areas of blue light-blocking lenses by coating (BCL) and driving spectacle lenses by coating (DCL) with visible (350 ~ 780 nm) and blue lights (380 ~ 500 nm)

n = 1.60	Lens Type	Wavelength Range		Difference (%)	
		Visible Light	Blue Light	Visible Light	Blue Light
Light Transmittance (au)	BCL	353.868	80.297	2.832	11.542
	DCL	369.298	91.623	- 1.404	- 0.935
	CCL	364.183	90.774	-	
P-value		0.865	0.586		

Abbreviations: nm, nanometer; n, refractive index; au, distribution area; %, percentage; CCL, conventional coating lenses.

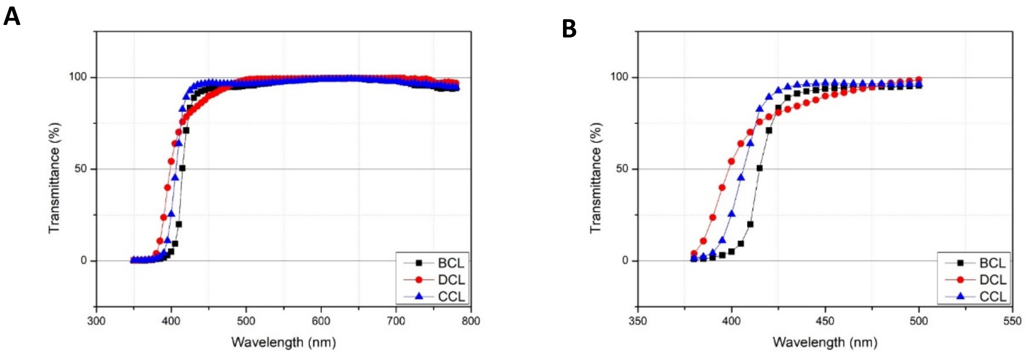


Figure 6. Light transmittance distribution areas of blue light-blocking lenses by coating (BCL) and driving spectacle lenses by coating (DCL) with (A) visible (350 ~ 780 nm) and (B) blue lights (380 ~ 500 nm). Abbreviations: %, percentage; nm, nanometer; CCL, conventional coating lenses.

Table 3. Light transmittance distribution areas of blue light-blocking lenses by material (BML) and driving spectacle lenses by material (DML) with visible (350 ~ 780 nm) and blue lights (380 ~ 500 nm)

n = 1.60	Lens Type	Wavelength Range		Difference (%)	
		Visible Light	Blue Light	Visible Light	Blue Light
Light Transmittance (au)	BML	351.063	81.515	3.603	10.200
	DML	334.245	72.978	8.221	19.606
	CCL	364.183	90.774	-	
P-value		0.594	0.433		

Abbreviations: nm, nanometer; n, refractive index; au, distribution area; %, percentage; CCL, conventional coating lenses.

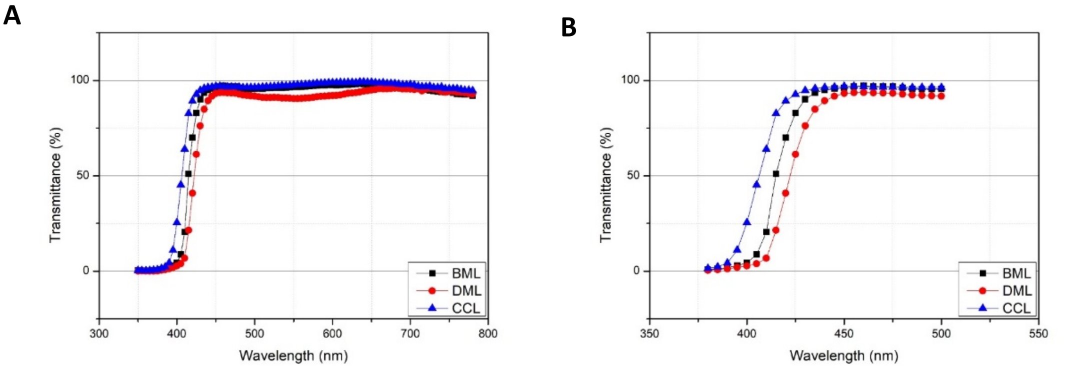


Figure 7. Light transmittance distribution areas of blue light-blocking lenses by material (BML) and driving spectacle lenses by material (DML) with (A) visible (350 ~ 780 nm) and (B) blue lights (380 ~ 500 nm). Abbreviations: %, percentage; nm, nanometer; CCL, conventional coating lenses.

Table 4. Comparison of the light transmittance distribution area between blue light-blocking and driving lenses

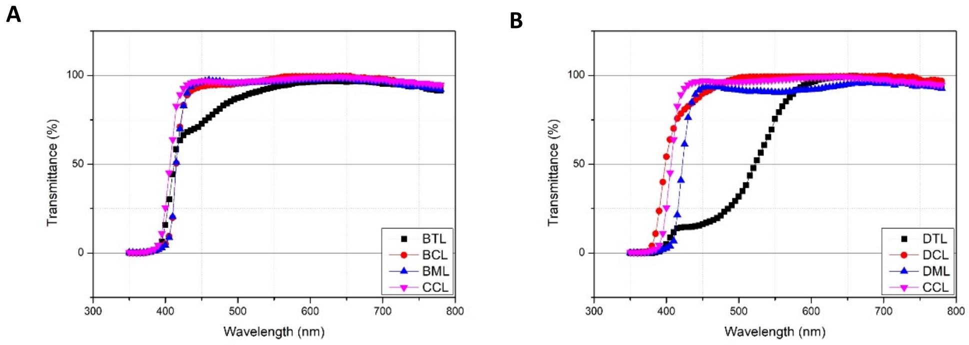
n = 1.60	Light transmittance distribution area (au)					
	Blue light blocking lenses			Driving lenses		
	BTL	BCL	BML	DTL	DCL	DML
Visible Light	335.058	353.868	351.063	264.965	369.298	334.245
P-value	*P* = 0.785 BTL ≈ BCL ≈ BML			***P* = 0.002** DTL ≠ (DCL ≈ DML)		
Blue Light	70.658	80.297	81.515	18.072	91.623	72.978
P-value	*P* = 0.652 BTL ≈ BCL ≈ BML			***P* = 0.000** DTL ≠ (DCL ≈ DML)		

Abbreviations: n, refractive index; au, distribution area; BTL, blue light-blocking lenses by tinting; BCL, blue light-blocking lenses by coating; BML, blue light-blocking lenses by material; DTL, driving spectacle lenses by tinting; DCL, driving spectacle lenses by coating; DML, driving spectacle lenses by material; nm, nanometer. *P*-value < 0.05 is shown in bold. *P*-value < 0.05 is shown in bold. Note: visible ray, 350 ~ 780 nm; blue lights, 380 ~ 500 nm.

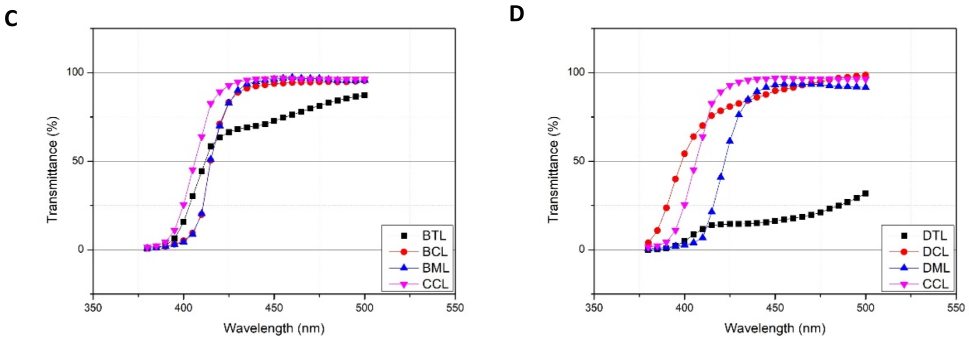
The blue light hazard function distribution areas of BTL, BCL, and BML for visible and blue lights were 460.566, 551.163, and 561.149, respectively, showing no statistically significant differences according to the manufacturing method ($P > 0.05$) (Table 5).

The blue light hazard function distribution areas of DTL, DCL, and DML for visible and blue lights were 108.992, 566.224, and 496.912, respectively, showing statistically significant differences according to the manufacturing method ($P < 0.05$) (Table 5).

The blue light-blocking efficiency did not differ according to the manufacturing method of blue light-blocking spectacle lenses for visible or blue light but did for driving spectacle lenses.



Light transmittance of visible light range (350 ~ 780 nm)



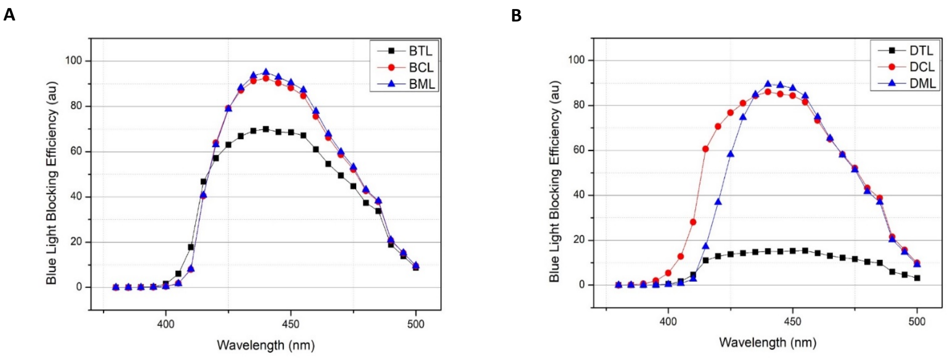
Light transmittance of blue light range (380 ~ 500 nm)

Figure 8. Comparison of the distribution area between (A), (C) blue light-blocking and (B), (D) driving lenses. Abbreviations: %, percentage; nm, nanometer; BTL, blue light-blocking lenses by tinting; BCL, blue light-blocking lenses by coating; BML, blue light-blocking lenses by material; DTL, driving spectacle lenses by tinting; DCL, driving spectacle lenses by coating; DML, driving spectacle lenses by material; CCL, conventional coating lenses.

Table 5. Comparison of the blue light hazard function distribution area between blue light-blocking and driving lenses

n = 1.60	Blue light hazard function distribution area (au)					
	Blue light-blocking lenses			Driving lenses		
	BTL	BCL	BML	DTL	DCL	DML
Blue light	460.566	551.163	561.149	108.992	566.224	496.912
***P*-value**	$P = 0.647$ BTL ≈ BCL ≈ BML			$\mathbf{P = 0.000}$ DTL ≠ (DCL ≈ DML)		

Abbreviations: n, refractive index; au, distribution area; BTL, blue light-blocking lenses by tinting; BCL, blue light-blocking lenses by coating; BML, blue light-blocking lenses by material; DTL, driving spectacle lenses by tinting; DCL, driving spectacle lenses by coating; DML, driving spectacle lenses by material; nm, nanometer. *P*-value < 0.05 is shown in bold. Note: blue light, 380 ~ 500 nm.



Blue light hazard function (380 ~ 500 nm)

Figure 9. Comparison of the blue light hazard function distribution area between (A) blue light-blocking and (B) driving lenses. Abbreviations: au, distribution area; nm, nanometer; BTL, blue light-blocking lenses by tinting; BCL, blue light-blocking lenses by coating; BML, blue light-blocking lenses by material; DTL, driving spectacle lenses by tinting; DCL, driving spectacle lenses by coating; DML, driving spectacle lenses by material; CCL, conventional coating lenses.

DISCUSSION

In our study, compared to BTL, DTL had a significantly greater decrease in light transmission efficiency for visible and blue light. The difference (%) of the blue light hazard function distribution areas of BML and DML were lower than those of CCL for both visible and blue lights, although without statistical significance.

Blue light, a part of visible light that emits high energy, is harmful. However, retinal damage and macular degeneration inhibitions caused by wearing blue light-blocking glasses require further clinical studies [24]. Blue light-blocking can yield a clearer retinal image [25].

Most blue light-blocking and driving glasses are manufactured with tinting, coating, and only materials [23], with each method having its own characteristics. High-quality blue light-blocking spectacle lenses should offer high light transmission and blue light-blocking efficiency [26]. Tinting is more difficult to perform compared to coating, and color perception may be distorted by reducing light transmittance to part of the visible light. In our study, the blue light-blocking and driving spectacle lensesmanufactured with tinting had lower light transmittance and blue light hazard function distribution areas compared to those manufactured with coating or only materials. DTL showed < 50% light transmittance and increased blue light-blocking efficiency in the 450–500-nm wavelength range compared to BTL. Accordingly, glare could be controlled at an appropriate level. However, with low ambient lighting, such as when driving or parking at night without light, drivers may experience loss of cognitive function for an observed object or narrowing of visual fields; therefore, caution should be exercised.

In a previous study, the blue light-blocking efficiency was lower for glasses manufactured with coating than for those manufactured with tinting [27], consistent with our study. However, DCL exhibited increased blue light-blocking efficiency compared to BCL. BCL had higher efficiency within the wavelength range of 425–450 nm, while DCL had higher efficiency within the wavelength range of 400–425 nm. Therefore, the total distribution area of DCL was larger. We expected this to reduce glare by transmitting a more extensive blue light range at a low level, unlike BCL, which is manufactured to block blue light. However, visual acuity can be reduced owing to the provision of blurred retinal images. Further research is required to confirm whether or not driving spectacle lenses manufactured with coating are effective in actual glare control.

Koo and Lee reported that blue light-blocking spectacle lenses manufactured with only materials showed lower blue light-blocking efficiency compared to those manufactured with tinting or coating [28]. The light transmittance and blue light hazard distribution areas of DML decreased more than those of BML, within the wavelength range of 400–425 nm. This result explains the characteristics of a driving spectacle lens aimed at controlling glare.

The blue light-blocking spectacle lensesmanufactured with tinting showed the highest blue light-blocking efficiency, followed by those manufactured with coating or only materials. The blue light-blocking efficiencies of BML and BCL were similar but of DML was higher than that of DCL and lower than that of DTL. Thus, DML could provide balanced glare control and a clear retinal image overall.

Unlike visual acuity, glare is affected by the characteristics of the optical performance of spectacle lenses and subjective judgment of the wearer. To evaluate the detailed performance of the blue light-blocking and driving spectacle lenses presented in this study, a follow-up study on subjective wearing experience is necessary.

CONCLUSIONS

The blue light-blocking efficiency of DTL was the highest for visible and blue lights. Accordingly, glare blocking could improve. However, light transmittance decreased to a partial range of visible light, and caution should be exercised when using it in dim lighting because of visual side effects, such as color perception distortion.

BCL and DCL showed the lowest blue light-blocking efficiency. Unlike the other lenses, DCL showed a lower light transmittance distribution area and blue light-blocking efficiency compared to BCL because it transmitted a wide range of blue light at a lower level. Therefore, DCL performed better glare-blocking compared to BCL.

BML and DML showed lower blue light-blocking efficiency compared to BTL and DTL but higher compared to BCL and DCL. Compared to BML, DML showed a greater decrease in light transmittance and blue light hazard function distribution areas, within the wavelength range of 400–425 nm. This is a characteristic of driving spectacle lenses aimed at blocking glare.

BTL showed the highest blue light-blocking efficiency, followed by BCL and BML. DML had a higher blue light-blocking efficiency compared to DCL but lower compared to DTL. Therefore, DML could provide balanced glare control and a clear retinal image.

ETHICAL DECLARATIONS

Ethical approval: None.
Conflict of interests: None.

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