IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received November 6, 2018, accepted November 25, 2018, date of publication December 7, 2018,
date of current version January 4, 2019.

Digital Object Identifier 10.1109/ACCESS.2018.2885533

Optical Modeling and Physical Experiments on Ocular UV Manikins Exposure

RENTONG CHEN[1], NAN WANG[1], HUI HUA[1], LITING HUANG[1], MENGLIN LI[1], ZHENZHEN ZOU[1], FANGFANG MA[1], XIN LI[1], DAN YANG[1], YAN DENG[1,2], FENGRONG OU[3,4], AND YANG LIU[1]

[1]Department of Environmental Health, School of Public Health, China Medical University, Shenyang 110013, China
[2]Editorial Department of the Chinese Journal of Health Statistics, China Medical University, Shenyang 110013, China
[3]School of Public Health, China Medical University, Shenyang 110013, China
[4]Academic Affairs Office, China Medical University, Shenyang 110013, China

Corresponding author: Yang Liu (yangliu@cmu.edu.cn)

This work was supported by the National Natural Science Foundation of China under Grant NSFC81673133.

ABSTRACT The prevalence of age-related cataracts is higher in Asians than Caucasians. Ocular ultraviolet (UV) exposure is an important environmental risk factor leading to age-related cataracts. The purpose of this paper is to clarify the effects of facial anatomy on ocular UV exposure between Asians and Europeans. We built optical models with 3D-printed Asian and European manikins that could truly reflect the typical facial features of Asians and Europeans, monitored the ambient and ocular UV exposure using these models in Fuxin (42.00°N, 121.69°E), China, and used 3ds Max software to model the effects of the facial anatomy structures on the light entering the eyes by rendering the resulting shadows. We found that the ocular UV exposure intensity in the Asian manikin was higher than that in the European manikin at a rotation angle of 282° to 354° when the solar elevation angle (SEA) was approximately 30° to 60° and at a rotation angle of 150° toward the sun when the SEA was approximately above 60°. Based on the optical models we built, we conclude that, due to the differences in the superciliary arch and glabella, the risk of high ocular UV exposure is greater in the Asian manikin than in the European manikin. Our findings provide grounds for speculation about whether the blocking effect of the superciliary arch and glabella of the European manikin on ocular UV exposure is one of the reasons for the higher prevalence of age-related cataracts in Asians than in Europeans.

INDEX TERMS Anatomical structure, anthropometry, ultraviolet sources, modeling, physical optics, Europe, Asia.

I. INTRODUCTION

Cataracts constitute a global disease that affects quality of life and is a common and significant cause of visual impairment and blindness worldwide [1]. A WHO report noted that 20 million people worldwide are blinded by cataracts [2]. Epidemiological evidence indicates that the age-standardized disability-adjusted life years (DALYs) rate of cataract vision loss is highest in Southeast Asia, whose population is predominantly of Asian descent, followed by the Eastern Mediterranean, Africa, and Western Pacific, and is the lowest in the United States and Europe, which are inhabited predominantly by Caucasians [3], [4]. Meanwhile, the prevalence of cataracts is higher in Asians than in Caucasians [5] and other races.

The eyes are known to be one of the main target organs for ultraviolet exposure, and ultraviolet light is one of the important environmental risk factors leading to age-related cataracts [6], [7]. The intensity level of ultraviolet (UV) radiation at different latitudes and altitudes directly affects the human ocular UV exposure intensity among ethnic groups in different regions. In addition, can the anatomy around the human eye also affect the intensity of ocular UV exposure? The 1902 edition of the Encyclopedia Britannica states that in Caucasoid, ‘‘brow-ridges are strongly developed’’, whereas in Mongoloids, ‘‘prominent brow-ridges’’ are usually absent [8]. The dominant characteristics of the Asian face include a wider intercanthal distance [9], a higher facial convexity angle [10], a lower angle of nasal inclination [11], [12],

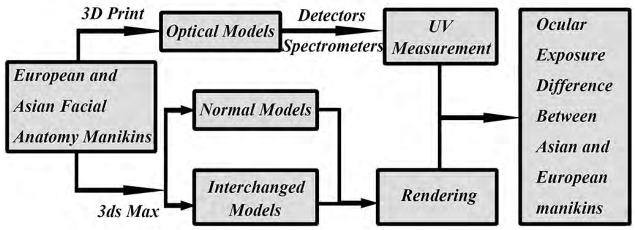


FIGURE 1. The flowchart of the process.

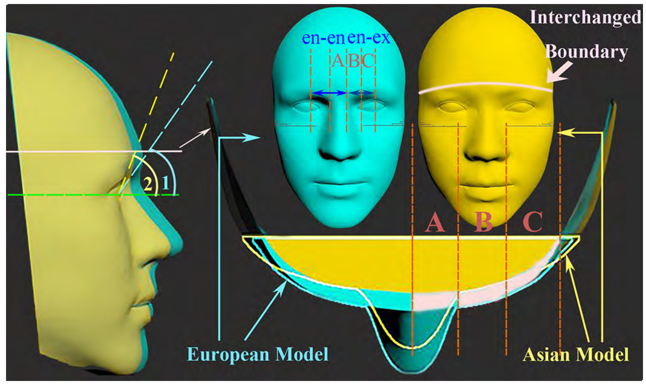


FIGURE 2. Facial difference between Asian and European models. *∠1: upper angle of visibility in European model; ∠2: upper angle of visibility in Asian model.

TABLE 1. Facial measurement parameters of Asian and European models.

Measurement	Asian	European
A area (mm^{-2})	272.85	285.38
B area (mm^{-2})	207.74	265.21
C area (mm-^{2})	163.65	175.89
en-ex (mm)	27.70	28.30
en-en (mm)	35.20	32.10
upper angle of visibility (°)	74	60

Notes: A represents the glabella; B represents the medial superciliary arch; C represents the lateral superciliary arch; en-ex represents eye breadth; en-en represents interocular breadth.

a higher degree of lip protrusion [13], a shorter palpebral fissure, and a narrower mouth [14] than the Caucasian face. These types of differences in facial morphology result in differences in the superciliary arch and glabella between Asians and Caucasians.

Some studies have shown that nose [15], [16], facial and vault shapes [17] may have been driven by local adaptation to climate in some ways, and a cold climate may be an explanation for several special craniofacial features, such as large masticatory components and a pronounced glabellar region and supraorbital ridge, which are found in Fuegian and south continental Patagonian samples [18] but not in Asians. In this study, we speculate that compared with Asians and other races, the characteristics of the superciliary arch and glabella in Caucasians may block more ocular UV exposure. This explanation may be another reason for the difference in the level of ocular UV exposure intensity between Caucasians and other races, in addition to differences in environmental UV exposure intensity levels.

Therefore, in this study, we built optical models with three-dimensional (3D) Asian and European heads provided by FaceGen Modeller software [version Demo 3.14] to monitor UV exposure intensity in Fuxin, China, and explore the impact of facial morphology differences on ocular UV exposure intensity between Asians and Caucasians.

II. METHODS

The flowchart of the process is shown in Fig. 1

A. 3D ASIAN AND EUROPEAN FACIAL ANATOMY MANIKINS

The facial anatomy models with typical average facial features of Asians and Europeans were provided by FaceGen Modeller software. This software was used by Thoma *et al.* [19] to create stimuli, by Souto *et al.* [20] to reproduce images and develop 3D avatars for emotion expression, and by Ma *et al.* [21] to generate emotionally neutral faces with direct gazes. This software was able to create average 3D facial models for different racial groups. We chose the 3D facial models with typical average facial features of Asians and Europeans to represent Asians and Caucasians, respectively. The facial measurement parameters are shown in Fig. 2 and Table 1.

We used 3D printing technology to print the Asian and European facial anatomy models and placed them on the previous manikins [22] as 3D facial anatomy manikins for UV exposure monitoring.

B. OPTICAL MODELS

The optical models consisted of a turntable base, a middle shelf, and the upper part of 3D Asian and European facial anatomy manikins, which are shown in Fig. 3. The eye position of manikins is approximately 1.6 meters; the visual line is parallel to the horizontal line to ensure that the head model is in the natural head position (NHP). Two computer-controlled dual-channel miniature fiber optic spectrometers were used to measure the ocular and ambient UV intensities, which had two detectors for each spectrometer and were placed on the shelf.

The fiber optic spectrometer (AvaSpec-ULS2048XL-2-USB2, The Netherlands) (Fig. 4) we used to measure UV spectral irradiance was a high UV- and NIR-sensitivity back-thinned charge-coupled device (CCD) spectrometer. The spectrometer is based on a 75 mm focal length symmetrical Czerny-Turner optical bench and has large monolithic pixels of 14x500 microns. The stray light is less than 0.5%, the ultraviolet quantum efficiency is 60%, and the signal-to-noise ratio is 525dB. The spectrometer is equipped with a 16-bit AD conversion card and a USB 3.0 high-speed interface. The transmission speed of each spectrum is 2.44ms. The detectors (Fig. 4) used in this study are a cosine corrector (CC-UV/VIS) with an effective diameter of 3.9 mm and a

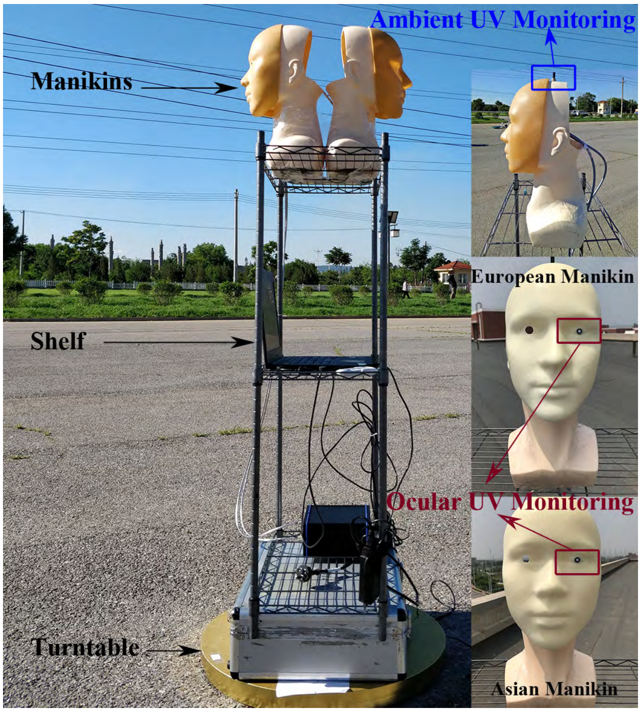


FIGURE 3. Optical models for monitoring the ocular and ambient UV irradiance.

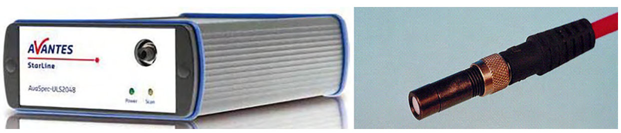


FIGURE 4. Fiber optic spectrometer and detector.

Teflon (polytetrafluoroethylene) diffusing material optimized for the 200-800 nm spectrum.

Because this study was a measurement of absolute irradiance, the spectrometer was radiometrically calibrated by the National Physical Laboratory (NPL GB) and configured with a spectral range of 200 nm to 800 nm before the experiment.

Two detectors of one spectrometer were placed on the plane tangent to the left cornea of the European and Asian manikin at the most anterior point for ocular UV monitoring. One detector of another spectrometer was placed at the vertex of the head of the manikin to simultaneously monitor the ambient UV exposure.

C. STUDY LOCATION AND METEOROLOGICAL CONDITIONS

The monitoring location was a wide square located in Fuxin (42.00°N, 121.69°E, altitude 46 m) in the province of Liaoning, China. The background was pavement, and the reflectivity was 0.08 and 0.05 for the UVA and UVB bands, respectively. The monitoring days were from June 28 to July 4 in 2018, during which the maximum solar elevation angle (SEA) was 71.33°. The measuring time was from 7:00 to 18:00 China Standard Time (CST) each day. July 2 was the best monitoring date and was chosen for the main monitoring day on which $PM_{2.5}$ was $14\mu g/m^3$ and the ozone concentration was 307 DU.

D. UV IRRADIANCE MEASUREMENTS

Measurements were conducted under a clear sky. Measurements taken when small clouds were present low on the horizon were included in the study. During data collection, the manikins were rotated clockwise at a constant speed (360°/min, equivalent to 6° /s). For each measurement progression, the Asian and European manikins were rotated 360° over 1 min simultaneously; from 7:00 to 12:00, the beginning direction was the Asian manikin facing toward the sun and the European manikin facing away from the sun; and from 12:00 to 18:00, the beginning direction was opposite. The position of manikins facing toward the sun was determined by the direction of the shadow. The measurement interval was 15 min.

The UVA and UVB irradiances (unit W/m^2) were calculated over a range of 315-400 nm and 300-315 nm, respectively, at 1 nm intervals. Sixty groups of irradiance data of each detector per revolution were collected.

The maximum and the average value of each revolution were chosen to simulate the maximum and average ocular UV exposure, respectively. The ambient values at the same time points were also obtained for comparison. The differences between the Asian and European manikins were calculated by subtracting the ocular UV exposure intensity of the European manikin from that of the Asian manikin. From our monitoring data, the 150° rotation angle range facing the sun was the rotation angle of approximately 0° to 72° and 282° to 354°, and the 210° rotation angle range facing away from the sun was the rotation angle of approximately 78° to 276°.

E. ESTIMATED AMBIENT UV INTENSITY

The estimated ambient UV intensity ($UV_{estimated}$) was calculated by dividing the average ocular UV irradiance of the European manikin by the exposure ratio of ocular to ambient in the Asian manikin, where the exposure ratio of ocular to ambient in the Asian manikin was calculated by dividing the average ocular UV irradiance by the ambient UV exposure intensity at the same time points.

F. RENDERING

In this study, we imported the optical models into 3ds Max software [version 2017] to express the effect of anatomical structure on the light entering the eyes by rendering the resulting shadow. We interchanged the upper and lower skulls of Asian and European models with the upper and lower edge of the eyelid as the boundary (Fig. 2).

The daylight module was set up with the longitude, latitude, date and time according to the geographical location of Fuxin and the measuring time of the main monitoring day. The changes in the SEA and the rotation angle during rendering for the two models are shown in Fig. 5. Then, we rendered the normal and interchanged Asian and European model with

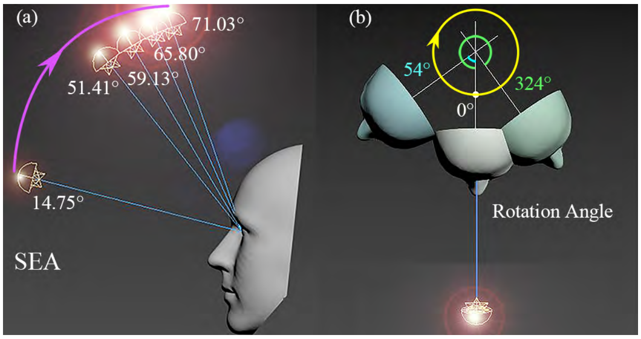


FIGURE 5. The SEA and rotation angles change in rendering.

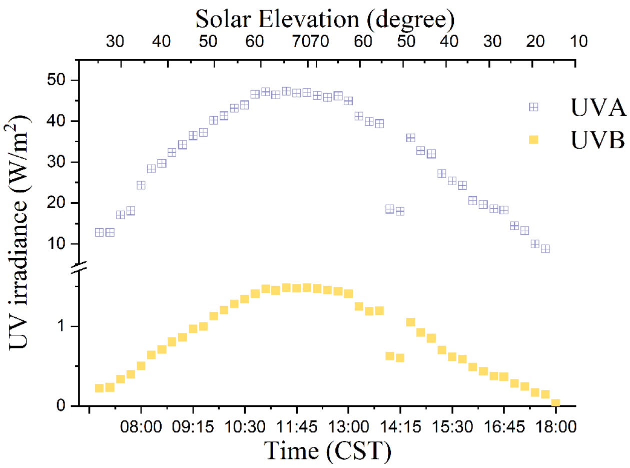


FIGURE 6. Diurnal variations of the ambient UV irradiance.

the daylight module in the same geographical location and time as the actual monitoring day.

III. RESULTS

A. DIURNAL VARIATION IN OCULAR AND AMBIENT UV IRRADIANCE

Diurnal variations in ocular and ambient UV irradiance of the main monitoring day are shown in Fig. 6 - 9. The highest SEA of the monitoring day was 71.03°. The ambient intensity of UVA and UVB irradiance showed a bell-shaped curve with time and increased with increasing SEA (Fig. 6).

The ocular UV intensity of the Asian and European manikins for the UVA and UVB bands showed a bimodal curve with time at which the peak of SEA appeared at 46° and 54°, respectively (Fig. 7 and Fig. 8). For the maximum ocular UV exposure (Fig. 9), when the SEA was approximately below 60°, the ocular exposure intensity of the UVA and UVB bands in the Asian manikin changed similar to the European manikin. When the SEA was approximately above 60°, the ocular UV exposure intensity of the European manikin suddenly decreased, reaching the lowest value when the SEA was approximately 65° and maintaining a relatively stable state, whereas the UV exposure intensity of the Asian manikin still decreased slowly. The ocular UV intensity of Asian and European manikins decreased with the increasing

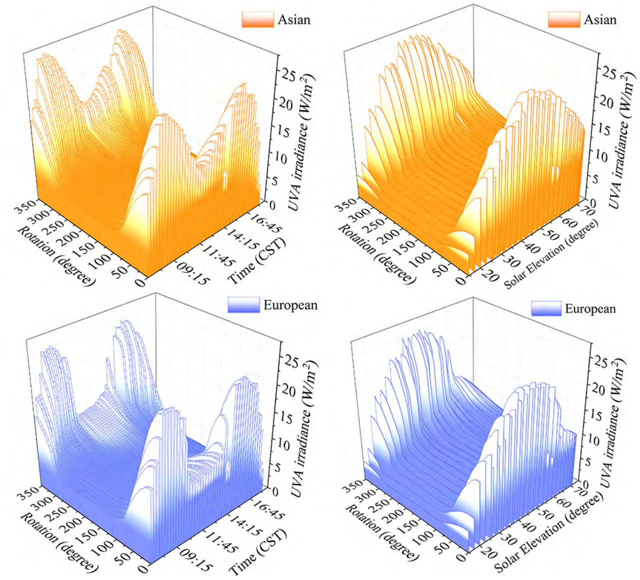


FIGURE 7. Diurnal variations of the ocular UV irradiance for the UVA band.

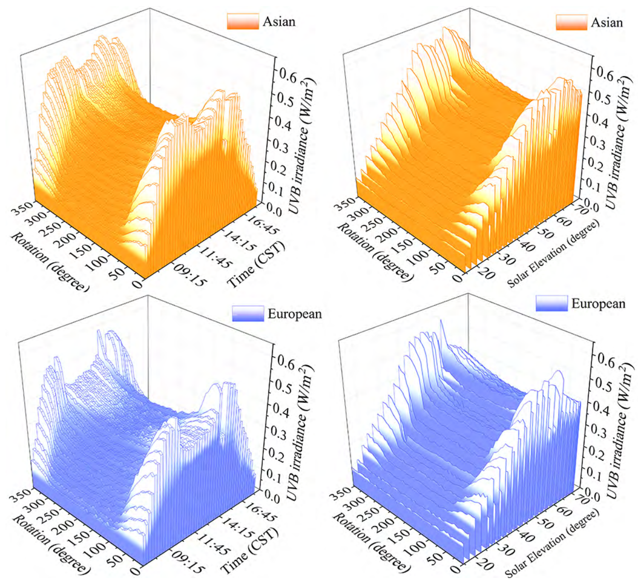


FIGURE 8. Diurnal variations of the ocular UV irradiance for the UVB band.

rotation angle in the range of 0°-72°, remained a small change in the range of 78°-276°, and increased as the rotation angle increased in the range of 282°-354°. Because the clouds occurred from 14:00-14:15 (SEA from 58.22° to 55.96°), the ambient and ocular UV intensities were lower.

B. OCULAR UV EXPOSURE INTENSITY CHANGES WITH ROTATION ANGLES

We conducted 45 monitoring episodes during the main monitoring day. The SEA range was from 14.75° to 71.03°. Six key SEAs were selected to illustrate the difference in ocular UV exposure between Asian and European manikins and are shown in Fig. 10 and Fig. 11 (see Fig. S1-Fig. S10 in Supplemental Material for other SEAs). For the UVA and UVB

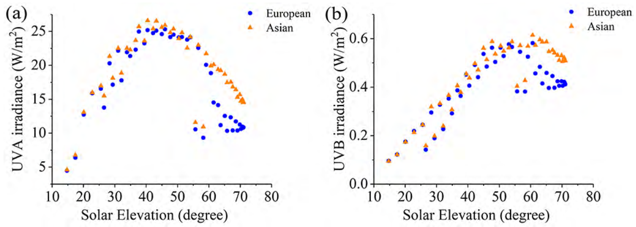


FIGURE 9. The maximum ocular exposure changes with SEA: (a) UVA irradiance; (b) UVB irradiance.

bands, the ocular UV exposure intensity per rotation at each time was two arcs with opposite center angles and unequal arc lengths. The maximum difference in the ocular UV exposure intensity between Asian and European manikins appeared at SEAs of 48.72° and 51.41°, respectively. When the SEA was approximately below 30°, the difference value of the ocular UV exposure intensity between Asian and European manikin was relatively small; when the SEA was approximately in the range of 30° to 60°, the difference value was relatively large only when the rotation angle was approximately in the range of 282°-336°, and peaked, at the rotation angle of 324°; when the SEA was approximately above 51.41°, the difference value also increased when the rotation angle was approximately in the range of 24°-72° and peaked at the rotation angle of 54°; when the SEA was approximately in the range of 60° to 71.03°, the difference value was relatively large at the 150° rotation angle range facing the sun and peaked at the rotation angle of 0°. The difference value was very small when the rotation angle was in the 210° rotation angle range facing away from the sun.

C. THE DIFFERENCES IN SHADOW CAUSED BY SUPERCILIARY ARCH AND GLABELLA BETWEEN ASIAN AND EUROPEAN MANIKINS

From all rendering results, we observed that the shaded area of the pupil in the left eye in Asian and European manikins changed with the ocular UV intensity according to the SEA and rotation angle (see Supplemental Material, Renderings). The more lights the superciliary arch and glabella blocked, the larger the shadow area.

We chose three representative daylight renderings, which are shown in Fig. 12. Taking SEA51.41° as an example, the shadow area of European model in the rotation angle range of 288° to 336° was much smaller than that in the symmetrical rotation angle range from 24° to 72°, and these differences were mainly caused by the glabella. This type of difference also existed in the Asian model, but because of the flatter glabella than the European model, the difference was smaller in the Asian model. Additionally, when the two manikins were rotated to 300°, the shadow area of the Asian manikin began to decrease, but for the European manikin, the shadow area decreased until it was rotated to 336°, when the light in the left eye of the European manikin was blocked more by the medial superciliary arch (part B in Fig. 2) and

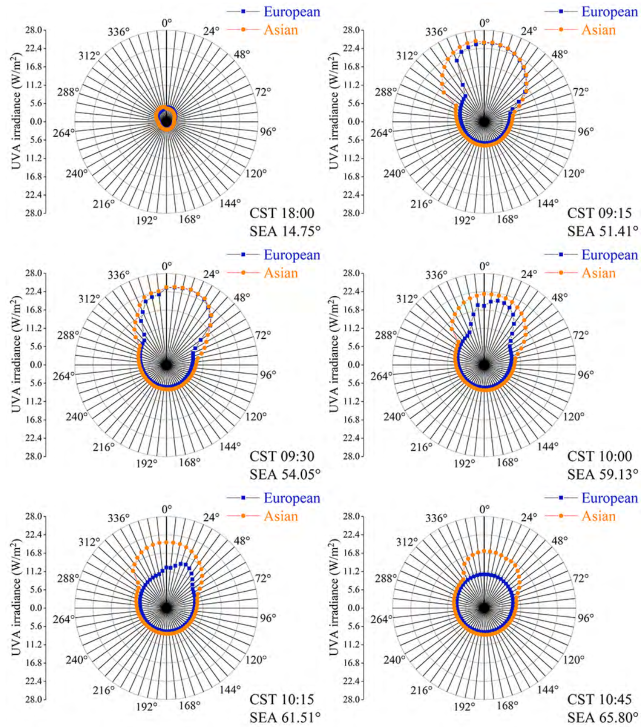


FIGURE 10. Ocular UV exposure changes with rotation angles in Asian and European manikins for UVA bands.

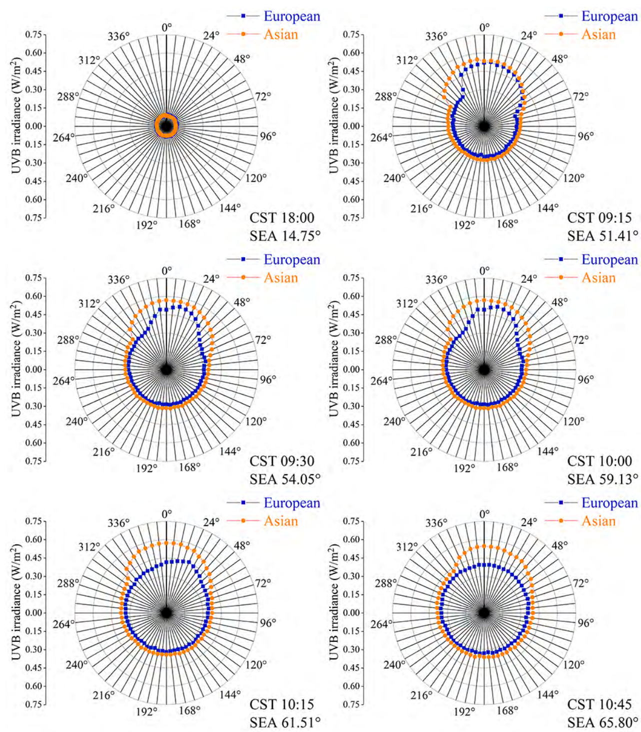


FIGURE 11. Ocular UV exposure changes with rotation angles in Asian and European manikins for UVB bands.

glabella (part A in Fig. 2), and the maximum difference in the shadow between the two manikins appeared at the rotation angle of 324° (Fig. 12a).

TABLE 2. Cumulative difference in ocular and ambient UV exposure.

SEA	Ocular Maximum Difference				Ocular Average Difference				Ambient Intensity	Percentage of Estimated Ambient Intensity	
	150°	Percent	210°	Percent	150°	Percent	210°	Percent	Average	Average	Maximum
UVA											
14°-30°	4.941	82%	2.535	51%	9.984	7%	0.356	9%	11.819	7.53%	12%
30°-60°	11.308	115.49%	2.245	34%	15.577	11%	0.707	11%	27.809	11.77%	21%
60°-71°	9.206	86.87%	1.578	16%	10.733	19%	0.938	11%	44.801	20.66%	29%
UVB											
14°-30°	0.045	47%	0.022	32%	0.007	4%	0.004	3%	0.211	4.80%	10%
30°-60°	0.187	63%	0.051	18%	0.036	10%	0.021	9%	0.717	10.16%	17%
60°-71°	0.186	47%	0.062	18%	0.078	19%	0.037	10%	1.386	15.60%	21%

Notes: The unit is W m^{-2} for UVA and UVB bands; 150° represents the 150° rotation angle range facing the sun; 210° represents the 210° rotation angle range facing away from the sun; percent was calculated by dividing the difference value by the UV exposure intensity of the European manikin.

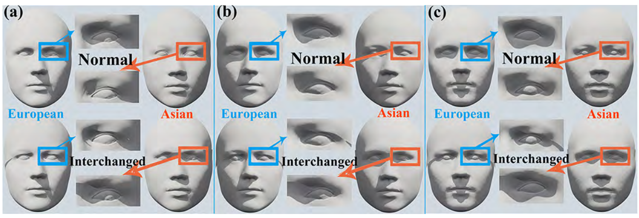


FIGURE 12. Rendering results of normal models and interchanged models: (a) the SEA was 51.41°, the rotation angle was 324°; (b) the SEA was 59.13°, the rotation angle was 54°; (c) the SEA was 65.80°, the rotation angle was 0°.

Taking SEA59.13° as an example, when the two manikins were rotated to 24°, the shadow area of the European manikin began to increase, but for the Asian manikin, when the shadow area increased until it was rotated to 72°, the light in the left eye in the European manikin was blocked more by the lateral superciliary arch (part C in Fig. 2), and the maximum difference in the shadow between the two manikins appeared at the rotation angle of 54° (Fig. 12b).

Taking SEA65.80° as an example, the shadow area in the Asian manikin was smaller than that in the European manikin when facing the sun; at this time, the light in the left eye in the European manikin was blocked by the whole superciliary arch and glabella, and the maximum difference in the shadow between the two manikins appeared at the rotation angle of 0° (Fig. 12c). After the upper parts of the two manikins' skulls were interchanged, the shadow area of the pupil in the left eye of the Asian model shifted to the European model (Fig. 12).

D. UVA AND UVB CHANGES OF TWO MANIKINS WITH DIFFERENT SEAS AND ROTATION ANGLES AND ESTIMATION OF ENVIRONMENTAL UV INTENSITY

The cumulative difference in the ocular UV exposure and the estimation of environmental ultraviolet intensity are shown in Table 2. For the UVA bands and UVB bands, the maximum difference in the ocular UV exposure between Asian and European manikins appears at the rotation angle of 324° when the SEA was in the range of 30° to 60°. The maximum difference value is 1.15 times and 0.63 times that of the European manikin, respectively. However, the largest average difference value appears at the rotation angle of 150° toward the sun when the SEA was above 60°. The average difference for the European manikin is 0.29 times for the UVA band and 0.19 times for the UVB band.

Based on the ratio of the Asian ocular exposure to ambient irradiance, it was estimated that the fitting ambient UV exposure intensity corresponding to the ocular UV exposure of the European manikin under the same conditions is much lower than the actual ambient UV exposure intensity. For the UVA and UVB bands, when the SEA was above 60°, the $UV_{estimated}$ exposure intensity can be up to 28.56% and 20.78% below the actual ambient UV exposure intensity.

IV. DISCUSSIONS

In this study, we built optical models that could truly reflect the facial features of Asians and Europeans to explore the impact of facial morphology differences on ocular UV exposure intensity between Asians and Caucasians by UV monitoring and 3ds MAX rendering.

Based on the data we collected from the optical models and the rendering results, we found that the difference in superciliary arch and glabella between the Asian and European manikins resulted in a significant difference in the ocular UV exposure in different SEAs. For the rotation angles, the difference in the ocular UV exposure is mainly caused by the glabella, and the superciliary arch mainly influenced the ocular UV exposure for different SEAs. As we know, the directed, reflected and scattered light entering the eyes is approximately blocked by the superciliary arch and glabella from above, the cheeks from below and the nose from the side. Based on the data in this study, the ocular UV exposure intensity of the two manikins was similar when the manikins were facing away from the sun; therefore, we speculate that the difference in the ocular UV exposure intensity between the two manikins was caused mainly by the superciliary arch and glabella. Meanwhile, the rendering results of interchanged models also support these types of effects due to these anatomical structures.

Compared with the European manikin, the relatively increased intensity in the ocular UV exposure in the Asian manikin may increase the risk of high UV exposure at rotation angles of 282° to 354° when the SEA is approximately 30° to 60° and at a rotation angle of 150° toward the sun when the SEA is approximately above 60°. Because the monitoring position was the left eye, the results of the ocular UV exposure for the right eye should be symmetric with the rotation angle 0° for each SEA; thus, the ocular UV exposure in the right in the Asian manikin should increase the risk of high UV exposure at a rotation angle of 6° to 78° when the SEA is approximately 30° to 60° and at a rotation angle of 288° to 360° and 6° to 78° when the SEA is approximately above 60°.

The differences in anatomy between Asians and Caucasians have been studied in clinical, stomatological, forensic and anthropological research for orthodontic treatment [23], aesthetic plastic and reconstructive surgery [24] and human evolutionary research [25]. In this study, we further studied the effects of these anatomical differences on ocular UV exposure.

It is well known that cataracts are most commonly caused by aging; risk factors include smoking tobacco, alcohol and trauma [26], [27]. Additionally, genes play an important role in the development of cataracts [28]. Meanwhile, the ambient UV exposure intensity is also one of the factors and varies from region to region. Based on our data, in the case of other conditions being equal, we speculate that the European superciliary arch and glabella can approximately reduce the ambient UV exposure by up to 28.56% and 20.78%, respectively, compared with the Asian model for UVA and UVB bands. Our findings provide grounds for speculation about whether the blocking effect of the superciliary arch and glabella of the European manikin on the ocular UV exposure is one of the reasons why the prevalence of age-related cataracts is higher in Asians than in Europeans.

In this study, in the absence of large-scale populations for UV monitoring, we used two average facial models—one with typical Asian features and another with European typical features—as the Asian and Caucasian monitoring models which may not adequately represent the difference between the Asian and Caucasian populations. We only approximately expressed the different effects of the superciliary arch and glabella between Asian and European manikins. Because both visible light and ultraviolet light have independent light propagation, the blocking effect of the superciliary arch and glabella on the ocular exposure is similar; however, because the default rendering light of the 3ds Max daylight system is visible light instead of ultraviolet light, UV exposure simulation cannot be performed. It is undeniable that the different rates of cataracts onset between Asians and Caucasians could be better justified by UV levels in North America and Europe compared to those in South East Asia. Furthermore, wearing corrective glasses or contact lenses, different levels of UV filters in the ocular lens of Asians and Caucasians, the altitude, geographical location, outdoor activity time, the pupil, eyelid and background [29] can also influence the ocular UV exposure.

In this study, the measurement was carried out at high latitudes, and we found that the ocular UV exposure of the Asian and European manikins for the UVA and UVB bands showed a bimodal curve with time at which the peak of SEA appeared at 46° and 54°, respectively. In our previous study, we conducted the ocular UV exposure monitoring in Sanya (18.42°N, 109.77°E, altitude 7 m), China, and found that the ocular UV intensity showed a bimodal curve with time [29]. Since the maximum SEA that can be achieved at high latitude sites is lower than that at lower latitudes or equatorial Asian areas, the ambient UV intensity is lower. Thus, we speculate that the variation of ocular UVA and UVB exposure intensity with SEA and rotation angle at lower latitudes is similar to that of high latitudes, and the difference value may be even larger.

Since the data in this study were collected under a clear sky and the background was pavement, the data may be slightly different for other monitoring conditions, and the data provided above are only for reference. In this study, only Asian and Caucasian manikins were used as research objects, and the effect of the superciliary arch and glabella on the ocular UV exposure in other human races remains to be studied in our future work.

V. CONCLUSIONS

Based on the optical models we built, we conclude that due to the differences in the superciliary arch and glabella, the risk of high ocular UV exposure is greater in the Asian manikin than in the European manikin.

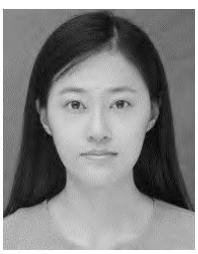
ACKNOWLEDGMENT

(Rentong Chen and Nan Wang are co-first authors.)

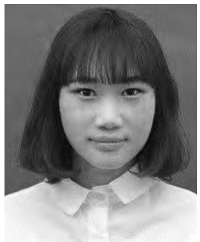
REFERENCES

[1] D. Pascolini and S. Mariotti, "Global estimates of visual impairment: 2010," *Brit. J. Ophthalmol.*, vol. 96, no. 5, pp. 614–618, Dec. 2012.
[2] S. P. Mariotti, "Global data on visual impairments 2010," World Health Org., Geneva, Switzerland, Tech. Rep. WHO/NMH/PBD/12.01, 2012.
[3] M. Khairallah *et al.*, "Number of people blind or visually impaired by cataract worldwide and in world regions, 1990 to 2010," *Invest. Opthalmol., Vis. Sci.*, vol. 56, pp. 6762–6769, Oct. 2015.
[4] M. He, W. Wang, and W. Huang, "Variations and trends in health burden of visual impairment due to cataract: A global analysis," *Invest. Opthalmol., Vis. Sci.*, vol. 58, pp. 4299–4306, Aug. 2017.
[5] J. Chua *et al.*, "Ancestry, socioeconomic status, and age-related cataract in asians," *Ophthalmology*, vol. 122, no. 11, pp. 2169–2178, 2015.
[6] J. C. S. Yam and A. K. H. Kwok, "Ultraviolet light and ocular diseases," *Int. Ophthalmol.*, vol. 34, no. 2, pp. 383–400, 2014.
[7] A. Midelfart, "Ultraviolet radiation and cataract," *Acta Ophthalmologica Scandinavica*, vol. 83, no. 6, pp. 642–644, 2005.
[8] S. Baynes and W. R. Smith, "Anthropology," in *Encyclopaedia Britannica*. New York, NY, USA: The Werner Company, 1902, p. 113.
[9] L. G. Farkas *et al.*, "International anthropometric study of facial morphology in various ethnic groups/races," *J. Craniofacial Surg.*, vol. 16, no. 4, pp. 615–646, 2005.
[10] B. Khosravanifard, V. Rakhshan, and E. Raeesi, "Factors influencing attractiveness of soft tissue profile," *Oral Surg., Oral Med., Oral Pathol. Oral Radiol.*, vol. 115, no. 1, pp. 29–37, 2013.
[11] H. A. Hashim and S. F. AlBarakati, "Cephalometric soft tissue profile analysis between two different ethnic groups: A comparative study," *J. Contemp. Dental Pract.*, vol. 4, no. 2, pp. 60–73, 2003.

[12] K. K. Lew, K. K. Ho, S. B. Keng, and K. H. Ho, "Soft-tissue cephalometric norms in Chinese adults with esthetic facial profiles," *J. Oral Maxillofacial Surg., Off. J. Amer. Assoc. Oral Maxillofacial Surgeons*, vol. 50, no. 11, pp. 1184–1189, 1992.
[13] H.-S. Hwang, W.-S. Kim, and J. A. McNamara, Jr., "Ethnic differences in the soft tissue profile of Korean and European-American adults with normal occlusions and well-balanced faces," *Angle Orthodontist*, vol. 72, no. 1, pp. 72–80, 2002.
[14] T. T. Le, L. G. Farkas, R. C. K. Ngim, L. S. Levin, and C. R. Forrest, "Proportionality in Asian and North American Caucasian faces using neoclassical facial canons as criteria," *Aesthetic Plastic Surg.*, vol. 26, no. 1, pp. 64–69, 2002.
[15] Y. Cui and S. Leclercq, "Environment-related variation in the human mid-face," *Anatomical Rec.*, vol. 300, no. 1, pp. 238–250, 2017.
[16] A. A. Zaidi, B. C. Mattern, P. Claes, B. McEcoy, C. Hughes, and M. D. Shriver, "Investigating the case of human nose shape and climate adaptation," *PLOS Genet.*, vol. 13, no. 3, p. e1006616-1–e1006616-16, 2017.
[17] L. P. Menéndez, "Moderate climate signature in cranial anatomy of late holocene human populations from Southern South America," *Amer. J. Phys. Anthropol.*, vol. 165, no. 2, pp. 309–326, 2018.
[18] V. Bernal, S. I. Perez, and P. N. Gonzalez, "Variation and causal factors of craniofacial robusticity in Patagonian hunter-gatherers from the late Holocene," *Amer. J. Hum. Biol.*, vol. 18, no. 6, pp. 748–765, 2006.
[19] P. Thoma, D. S. Bauser, and B. Suchan, "BESST (Bochum Emotional Stimulus Set)—A pilot validation study of a stimulus set containing emotional bodies and faces from frontal and averted views," *Psychiatry Res.*, vol. 209, no. 1, pp. 98–109, 2013.
[20] T. Souto, A. Baptista, D. Tavares, C. Queirós, and A. Marques, "Facial emotional recognition in schizophrenia: Preliminary results of the virtual reality program for facial emotional recognition," *Arch. Clin. Psychiatry (São Paulo)*, vol. 40, no. 4, pp. 129–134, 2013.
[21] F. Ma, F. Xu, and X. Luo, "Children's and adults' judgments of facial trustworthiness: The relationship to facial attractiveness," *Perceptual Motor Skills*, vol. 121, no. 1, pp. 179–198, 2015.
[22] F. Wang *et al.*, "Risk of ocular exposure to biologically effective UV radiation in different geographical directions," *Photochem. Photobiol.*, vol. 90, no. 5, pp. 1174–1183, 2014.
[23] J. Wirthlin, C. H. Kau, J. D. English, F. Pan, and H. Zhou, "Comparison of facial morphologies between adult Chinese and Houstonian Caucasian populations using three-dimensional imaging," *Int. J. Oral Maxillofacial Surg.*, vol. 42, no. 9, pp. 1100–1107, 2013.
[24] Y. Gu, J. A. McNamara, L. M. Sigler, and T. Baccetti, "Comparison of craniofacial characteristics of typical Chinese and Caucasian young adults," *Eur. J. Orthodontics*, vol. 33, no. 2, pp. 205–211, 2011.
[25] E. Pearce and R. Dunbar, "Latitudinal variation in light levels drives human visual system size," *Biol. Lett.*, vol. 8, no. 1, pp. 90–93, 2012.
[26] W. G. Christen *et al.*, "A prospective study of cigarette smoking and risk of cataract in men," *J. Amer. Med. Assoc.*, vol. 268, no. 8, pp. 983–989, 1992.
[27] W. G. Christen *et al.*, "Smoking cessation and risk of age-related cataract in men," *J. Amer. Med. Assoc.*, vol. 284, no. 6, pp. 713–716, 2000.
[28] A. Shiels and J. F. Hejtmancik, "Molecular genetics of cataract," *Prog. Mol. Biol. Transl. Sci.*, vol. 134, pp. 203–218, Jun. 2015.
[29] G.-C. Liu *et al.*, "The enhancement of biological ocular UV radiation on beaches compared to the radiation on grass," *J. Photochem. Photobiol. B, Biol.*, vol. 141, pp. 106–112, Dec. 2014.



RENTONG CHEN born in Yingkou, Liaoning, China, in 1991. She received the B.M. degree from China Medical University, China, in 2014, where she is currently pursuing the Ph.D. degree in labor and environmental hygiene. Her main research aims at the study of ultraviolet exposure in China and exploring the associations between ocular UV exposure and human facial anatomy.



NAN WANG received the B.M. degree from China Medical University, China, in 2016, where she is currently pursuing the Ph.D. degree in labor and environmental hygiene. Her main research aims at the study of ultraviolet exposure in China and exploring the associations between $PM_{2.5}$ and ocular exposure.

HUI HUA received the B.M. degree from China Medical University, China, in 2014, where she is currently pursuing the Ph.D. degree in labor and environmental hygiene. She aims to explore the ultraviolet exposure intensity in China outdoors and indoors. Her research also focused on the mechanism of the process of cataractogenesis *in vivo* and *in vitro*.

LITING HUANG received the B.M. degree from China Medical University, China, in 2017, where she is currently pursuing the master's degree with the School of Public Health. Her main research aims at the study of ultraviolet exposure in China and exploring the associations between various age groups and ocular UV exposure.

MENGLIN LI was born in Anqing, Anhui, China, in 1994. She received the B.M. degree from Anhui Medical University, China, in 2017. She is currently with the School of Public Health, China Medical University. Her main research aims at the study of sunlight exposure in different ethnic groups and exploring the associations between visible light exposure and human orbital structure in different facial model.

ZHENZHEN ZOU received the B.M. degree from the Liaoning University of Traditional Chinese Medicine, in 2017. She is currently pursuing the master's degree with the School of Public health, China Medical University. Her main research aims at the study of ultraviolet exposure in China and the relationship between eyeball protrusion and eyelid structure.

FANGFANG MA received the B.S. degree in preventive medicine from Jining Medical University, Jining, Shandong, in 2016. She is currently pursuing the M.S. degree with China Medical University. Her research interest includes ultraviolet biological effect.

XIN LI received the B.M. degree with Xinxiang Medical University, in 2016. She is currently pursuing the master's degree with the School of Public Health, China Medical University, China. Her main research aims to study the relationship between ultraviolet radiation and outdoor activity time in China, and to explore the relationship between ultraviolet radiation and meteorological factors.

DAN YANG received the B.M. and M.M. degrees from China Medical University, China, in 2015 and 2018, respectively, where she is currently pursuing the Ph.D. degree with the School of Public Health. Her main research aims at the study of ultraviolet exposure in China and exploring the associations between environmental factors and malarial risk through processing big data.

YAN DENG received the B.M. and M.M. degrees from China Medical University, China, in 2010 and 2013, respectively, where she is currently pursuing the Ph.D. degree in labor and environmental hygiene. She is currently with the Editorial Department of the Chinese Journal of Health Statistics, China Medical University, as an Editor. Her main research aims at the study of ultraviolet exposure in China, text mining of medical big data, and the evaluation of science and technology productivity.

FENGRONG OU is currently a Professor with the School of Public Health and the Director of the Academic Affairs Office, China Medical University, Shenyang, Liaoning, China. She has carried out epidemiological investigations of the quality of life in the impoverished population and ultraviolet exposure measurement. Her main research aims at the study of group health and management research and the evaluation of science and technology productivity.

YANG LIU received the bachelor's degree from the Department of Public Health, China Medical University, China, in 1983, and the master's and Ph.D. degrees from China Medical University in 1997 and 2002, respectively. He was with Jichi Medical University, Japan, and Fukushima Medical University, Japan, as a Visiting Scholar, in 1996 and 2000, respectively. He is currently a Professor with the Department of Environmental Health and Environmental Physical Factors and Health, School of Public Health, China Medical University. He has authored or co-authored over 30 refereed publications in international journals. He supervised dozens of master's and Ph.D. students in China Medical University. His research interests include the study of ultraviolet exposure and the evaluation of science and technology productivity.