

Preliminary study on visual recognition under low visibility conditions caused by artificial dynamic smog

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Abstract

• **AIM:** To quantitatively evaluate the effect of a simulated smog environment on human visual function by psychophysical methods.

• **METHODS:** The smog environment was simulated in a 40×40×60 cm³ glass chamber filled with a PM2.5 aerosol, and 14 subjects with normal visual function were examined by psychophysical methods with the foggy smog box placed in front of their eyes. The transmission of light through the smog box, an indication of the percentage concentration of smog, was determined with a luminance meter. Visual function under different smog concentrations was evaluated by the E-visual acuity, crowded E-visual acuity and contrast sensitivity.

• **RESULTS:** E-visual acuity, crowded E-visual acuity and contrast sensitivity were all impaired with a decrease in the transmission rate (TR) according to power functions, with invariable exponents of -1.41, -1.62 and -0.7, respectively, and R² values of 0.99 for E and crowded E-visual acuity, 0.96 for contrast sensitivity. Crowded E-visual acuity decreased faster than E-visual acuity. There was a good correlation between the TR, extinction coefficient and visibility under heavy-smog conditions.

• **CONCLUSION:** Increases in smog concentration have a strong effect on visual function.

• **KEYWORDS:** visual recognition; low visibility conditions; artificial smog

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INTRODUCTION

China, one of the various countries that suffer from smog, has enlisted smog in the “Natural Disaster Briefing of 2013”. In 2015, for the first time, Beijing set the warning level to the highest one, red. In the worst smog episode of 2016, seventy-one cities’ air pollution level was classified as severe, with the PM2.5 index far higher than 1000, visibility less than 50 m. In 2017, smog pollution was listed as one of the Top Ten Ecological Civilization Concerns. Smog catches our attention year by year. Aside from China, smog also affects other countries and is regarded as a worldwide problem.

Smog is the atmospheric turbulence mainly caused by small suspended particle matter (PM), among which PM2.5, a particle size equal to or smaller than 2.5 μm, is the generally accepted primary characteristic. Small particles carry complex chemical constituents such as water-soluble ionic species (Cl⁻, NO³⁻, SO₄²⁻, NH₄⁺, K⁺, Na⁺, Ca₂⁺, and Mg₂⁺) carbonaceous organic carbon and elemental carbon. Because the relative humidity of the main water-soluble particles listed above is approximately 80%, smog refers to the atmospheric opacity developing at a relative humidity between 80% and 90%^[1]. In past studies, researchers have identified the main sources of PM2.5 in China to be coal combustion, motor vehicle emissions, and industrial sources^[2]. Smog causes blurred vision and deteriorates visibility to less than 10 km. According to the Chinese national meteorological industry standard Haze Level for Observation and Prediction, smog is classified into four grades according to visibility, grade I (5-10 km), grade II mild (3-5 km), grade III moderate (2-3 km), and grade IV severe (<2 km). In our study, the validly simulated smog was of grade IV.

Smog has a detrimental effect on human health. Countless researches have reported that smog increases the incidence of lung cancer^[3] and diseases of the cardiovascular system^[4], the immune system^[5] and other systems. This is due to direct exposure of the human body to smog particles, such as toxic metals and organic compounds. Pathogenesis studies have revealed the mechanism^[6]. However, no equal attention is paid to the functional effect on human through impaired visual function.

There are studies focusing on low visibility affecting drivers’ judgement and control over speed^[7], shortening the allowed response time and altering normal driving behaviours^[8]. Low visibility also affects drivers’ psychology, for example, by

increasing fear and inducing in security^[9]. Many of these researches are taken under computer-simulated low contrast condition. However, rather than smog index, visibility is a more widely used measurement of atmospheric opacity in traffic. Visibility is reported to be negatively correlated to PM_{2.5}, with a coefficient of -0.50^[10]. This relationship occurs because of smog's ability to scatter and absorb light^[11]. Wang *et al*^[12] even found certain differences in the best fits between atmospheric visibility and PM_{2.5} mass concentrations: a power law fit in spring, an exponential fit in summer, a logarithmic fit in autumn, and a power or exponential fit in winter. In addition, relative humidity has been shown to have a slight effect on visibility^[10,13-14]. To better describe the optical characteristics of the medium, researchers have also developed different modulation transfer functions (MTFs). For atmosphere, after considering several factors such as temperature, pressure, humidity, and wind speed, these functions developed from primitively turbulence MTFs to grating patterns, aerosol MTFs, instrumentation-based theory functions, and overall atmospheric MTFs^[15-17]. Each has a specialty, but none is perfect, because there seems to be inexhaustible influence factors. Unluckily, there was still no specific MTF for smog. However, others argue that all smog interactions with human vision contribute to a low contrast target. They have simulated low contrast stimulant in a computer system as an experimental foundation, including some of driving simulations^[18-19].

Given all the known risks, potential effects on driving, and features of visibility and MTFs, there remains several points unanswered. Firstly, no human visual function affected by smog is measured directly. Whatever driver acts under low visibility, the basic is impaired visual function. Visual system has a strong connection with the brain, psychics and motor system. Secondly, it is not clear if it is accurate to equate smog with decreased contrast. If it is such, all the MTFs and visibility studies will suffer a loophole. Our purpose is to exam visual function in simulate smog condition, and to distinguish if the visual function changes are all contributed by low contrast. Because smog in China is currently alarmingly severe, our study focused on the effect of smog classified as heavy. Additionally, heavy smog is much easier to simulate in our lab.

SUBJECTS AND METHODS

Subjects A total of 14 subjects were enrolled in the study, 7 men and 7 women, with a mean age of 24±1.8y. The inclusion criterion was to have each eye's corrected distance vision $\geq 20/20$. The exclusion criteria included ocular diseases such as retinal disease, glaucoma, optic disc disease, optic neuropathy, communication barriers, or non-cooperation. Only right-eye data from each subject were collected. The study protocol was in accordance with the Helsinki Declaration and was approved by the Ethical Committee of the Affiliated Eye Hospital of Wenzhou Medical University. All subjects were informed of



Figure 1 Gamma correction of the CRT monitor with a luminance meter.

the purpose and the potential side effects of the study. Written informed consent was obtained from each subject.

Smog Simulation Smog was simulated with a smog generator (Qingdao Lingding smog generator YWQ-180, China). Through combustion of natural non-toxic oil fuel, the generator produced particles measuring 1-2 μm which was confirmed by the manufacturer. Simulated smog maintained a humidity level between 80% to 90% inside a 40×40×60 cm^3 glass container. Room temperature was maintained at 22°C-25°C by an air conditioning unit. We monitored the condition in real-time using a temperature and relative humidity indicator (Deli, No.9013, China) stuck on the inner wall of the container. To quantify the severity of the smog, we have used an electric light source method to measure the smog percentage concentration. A luminance meter (Konica Minolta LS-100 Brightness Meter, Germany) was used to measure the brightness difference ratio between smog and no smog conditions. We obtained the smog percentage concentration according to the following formula: $\text{TR} = E'/E_0$, where TR refers to the light transmission rate (%), E' refers to brightness through the container with smog (cd/m^2), and E_0 refers to brightness through the container without smog (cd/m^2), which is also called the initial luminance value. The smog percentage concentration is expressed as $\text{P} = 1 - \text{TR}$. Therefore, any smog percentage concentration between 0 and 100% can be obtained. To make the analysis more convenient, we used the transmission rate (TR) as the first choice in model building. The luminance meter was fixed on a frame at 220 cm away from the target, the container was put between the luminance and the target, and the subject's jaw plate was put between the luminance and the container. We analyzed the smog dissipation process at the same time on different days for more than three times to make sure it's repeatable.

Stimulus Display and Visual Function Measurements All visual stimuli were presented on a CRT monitor (CTX VL950T computer display, resolution is 72 Hz) placed 120 cm away from the subject's jaw plate. In order to display an accurate luminance as input, the monitor was Gamma-corrected. The correcting principle is shown in Figures 1 and 2. Visual stimuli were generated by a Freiburg vision test system (FrACT system, Version 3.8.2, Bach, 1996) with an adaptive staircase

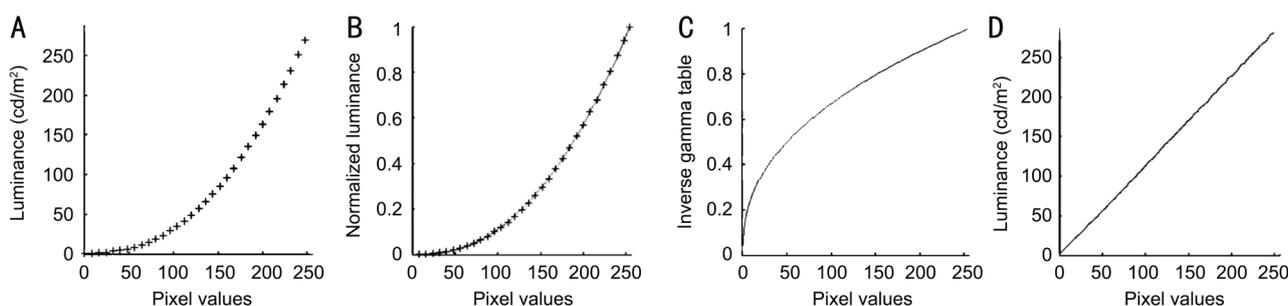


Figure 2 The Gamma correction principle A: The corresponding point between the input brightness value and the actual brightness value of the screen; B: The fitting curve of corresponding points; C: The compensation curve generated by the correction program; D: The corrected program input brightness value and screen actual brightness value.

procedure called best parameter estimation by sequential testing (PEST). The resolution visual acuity was measured based on E-visual acuity and crowded E-visual acuity. It generated crowding by adding two squares to each side of E to create a row of optotypes. Room light was closed during the whole procedure, and the experiment was performed at 7:00 p.m. every night to keep the condition at same scotopic level. The contrast sensitivity of each subject was quantified using a grating with a spatial frequency 5 cycles/degree. For each parameter, there were 24 trails and 4 choices for each trail. The subjects were given 5s to answer each trial and then sound feedback was provided. Other settings were all in accordance to FrACT default of settings.

Experimental Procedure At the beginning, we gave each subject a slit lamp anterior eye exam, history-taking and subjective refraction to make sure meet the inclusion criterion. Then, before the glass container was filled with smog, we measured the initial target contrast and the baseline values of visual function parameters for each subject. After that we inflated smog into the container and measured the target luminance and visual function parameters under the worst conditions. During the gradual dissipation of the smog, we recorded the corresponding smog percentage concentration using the average of three times measurements and then measured visual functions following a fixed sequence as E-visual acuity, contrast sensitivity and crowded E-visual acuity. Each parameter was measured three times and the average was used. The measurement period was repeated until all parameters reached baseline. Whether or not the subjects had time to rest depended on the dissipate velocity.

Statistical Analysis Data were analysed by analyses of variance with subjects as repeated measures. R (i386 3.4.3) software was used for curve fitting and data analysis. If Mauchly's test for sphericity gave a significant finding for a variable, degrees of freedom were adjusted according to the GreenhouseGeisser correction. Post-hoc tests were applied using the Bonferroni correction (*P* value was multiplied by the number of pairwise comparisons). The criterion for significance was *P*<0.05.

Experimental Results

Smog dissipation process The dissipation process was repeatable at the same condition. The common process is that the smog dissipated a bit fast at first, so subject had to keep being tested, after four to five turns, the smog dissipated rather slowly and they had enough time to rest. Generally speaking, the smog dissipated at a slow rate, a relatively smooth and repeatable curve was obtained (Figure 3), giving enough time to measure each parameter (approximately 25-30s for each).

Visual target contrast vs transmission rate As the smog concentration decreases, the rate of light transmission increases. Consequently, the contrast of the black visual target on a white background was increased according to the following power function: $\text{contrast} = 0.09 \times \text{TR}^{0.50}$ ($R^2 = 0.97$), where TR is the transmission rate. At the highest TR, the maximum contrast of the target was approximately 90% according to the abovementioned function (Figure 4).

E-visual acuity and crowded E-visual acuity The best corrected visual acuity (BCVA) and crowded visual acuity (logMAR) were -0.14 for all subjects, and normal levels were achieved with no smog in the glass container.

As the TR increases, both the E-visual acuity and crowded E-visual acuity were improved as a power function of the rate of light transmission: $\text{logMAR} = 3.11 \times \text{TR}^{-1.41}$ ($R^2 = 0.99$) for E-visual acuity and $\text{logMAR} = 2.86 \times \text{TR}^{-1.62}$ ($R^2 = 0.99$) for crowded E-visual acuity (Figure 5). Figure 5 shows that both E-visual acuity and crowded E-visual acuity began to deteriorate quickly once the TR was decreased below 10 percent. Crowded E-visual acuity was decreased faster than E-visual acuity because the absolute invariable exponent was larger.

Contrast sensitivity Without smog, all subjects achieved a contrast sensitivity (%) above 1 (contrast threshold <1%) with a grating at 5 cycles/degree. With the increase in the smog percentage concentration, the rate of light transmission was reduced, and contrast sensitivity was also decreased following a power function: $\text{CS} (\%) = 2.21 - 2.46 \times \text{TR}^{-0.70}$ ($R^2 = 0.96$). Figure 6 clearly shows that contrast sensitivity deterioration was exacerbated once the TR dropped below 10 percent (Figure 6).

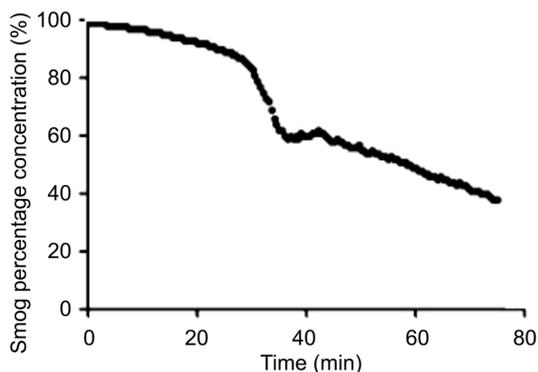


Figure 3 The smog dissipation process curve The dissipation process is not perfectly homogeneous, but it is slow and relatively smooth.

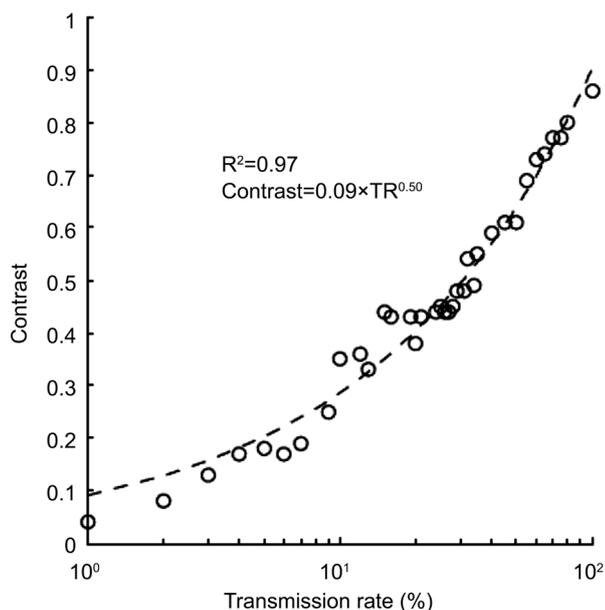


Figure 4 Relationship between transmission rate and visual target contrast As the smog concentration decreased, the rate of light transmission increased, and the visual target contrast increased.

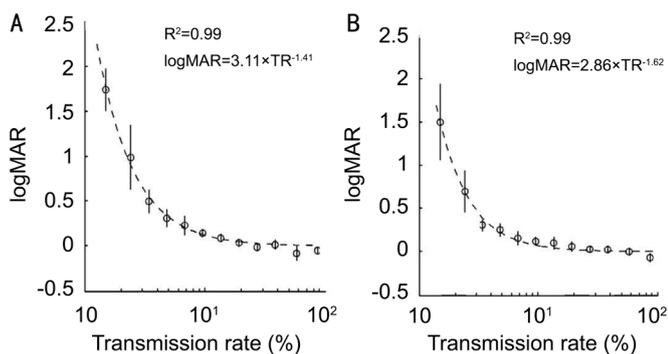


Figure 5 The E-visual acuity model (A) and the crowded E-visual acuity model (B) As the transmission rate increases, both E-visual acuity and crowded E-visual acuity were improved as a power function of the rate of light transmission.

Visibility, beta and smog grade To observe at least the outline of the target, the difference in brightness is the most important factor. This difference is usually expressed as the contrast C , which is the relative difference between the target brightness and the horizon brightness. The smallest contrast

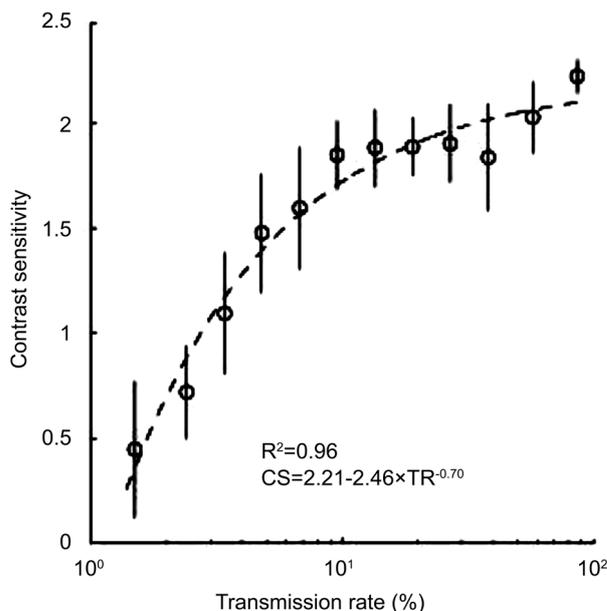


Figure 6 The contrast sensitivity model With the increase in the smog percentage concentration, the rate of light transmission and contrast sensitivity was decreased following a power function.

the eye can perceive is called the contrast threshold. The WHO recommends a value of 0.5%. Once the contrast relative to the background is less than the contrast threshold, objects observed through the atmosphere become invisible. If there is interfering light in the pathway, including that due to aerosol scattering and illumination from the sky, ground, clouds, *etc.*, the contrast of the target will be reduced. The interference function can be expressed as $\exp(-\beta \times D)$. The difference in contrast between the initial threshold and the final target is denoted by $C_{\text{when there is fogging}} - C_{\text{fog-free condition threshold}}$. Horvath's theory^[20] recommends that the two expressions be equal. In addition, according to the Beer-Lambert law, the relationship between meteorological visibility VR and the extinction coefficient β is $VR=3/\beta$. It is a simple but widely used formula.

Because we already know the contrast sensitivity at each TR , the effective contrast of a 100% contrast target perceived through smog, at a particular concentration is also known. Assuming 0.5% as the lowest contrast that an average human can detect in the absence of smog, the beta value and visibility can be calculated based on Horvath's theory^[20].

$$C_{\text{when there is fogging}} - C_{\text{fog-free condition threshold}} = \exp(\beta \times D) \quad (1)$$

$$VR=3/\beta \quad (2)$$

Where $C_{\text{when there is fogging}}$ is the contrast that could be detected in the smog simulation, β is the extinction coefficient, D is the distance length of the smog, and VR is the visibility. In this experiment, $C_{\text{fog-free condition threshold}}=0.5\%$ and D is 60 cm. The mean β values of 14 subjects at different smog concentrations were determined based on formula (1). In addition, we could obtain the visibility at different smog concentrations according to formula (2). Thus, at each specified smog concentration, vision and visibility are linked; that is, the smog percentage

concentration (indicated by the TR), visual acuity and visibility are correlated. The relationship between the light TR, β and visibility is shown in Figure 7.

DISCUSSION

This is the first innovatively designed study to explore how the smog concentration affects the visual function. We tried our best to simulate reality to the maximum extent. By far, it retains the interaction between human and environment as a dioptric media, especially the psychophysics aspect.

Real and Artificial Smog Based on the type, size, and concentration of suspended particles, weather conditions can be classified into air, smog, fog, clouds, and rain. The particle size in smog ranges from 10^{-2} to $5 \mu\text{m}$. In our study, the particle size was controlled to $1\text{-}2 \mu\text{m}$. Intensity and colour, the two main characteristics of natural light, change depending on the interactions of light with the environment, which include emission, absorption and scattering. Among these, scattering caused by suspended particles is of the highest significance because the intensity of scattering is closely related to the size and shape of the particles^[21]. Extinction coefficient β is a part of most meteorological calculations. The most widely used form is $\beta=b_{sp}+b_{sw}+b_{sg}+b_{ap}+b_{ag}$, where b_{sp} is the light scattering of small particles; b_{sw} is light scattering caused by air humidity, it's rather important when humidity is over 70%; b_{sg} is Rayleigh scattering from clean air; b_{ap} is light absorption from small particles, which is the second important factor; and b_{ag} is associated with the concentration of NO_2 ^[22]. All these factors contribute to a decrease in target's contrast and are contained in our electric light source method to measure the smog percentage concentration, which is the biggest advantage of the method. The only factor that cannot be completely included in low contrast is smog motion, especially in heavy smog. As shown in the smog dissipation process curve (Figure 2), there is a bend in the middle, which is caused by particle motion.

The Agreement with the Power Models In Shree and Srinivasa's model, the effect of atmospheric reflected light on scenery was divided into light attenuation of the scene and the addition of ambient light^[23-24]. Light attenuation refers to the part of the light that was reflected by a scene and finally reaches the observer after scattering by atmospheric particles. Atmospheric light refers to light scattered by atmospheric particles and received by the observer directly, which is equivalent to the atmosphere acting as a translucent light source. Combing the effects of those two factors, the atmospheric scattering model states that $L(d, \lambda)=L_h(\infty, \lambda)\{1-\exp[-\beta(\lambda)d]\}$, where λ is the wavelength, d is the propagation distance of light, $L_h(\infty, \lambda)$ is the infinite depth of sky light, and $\beta(\lambda)$ is the scattering coefficient, with the medium measured for different wavelengths of light-scattering ability. In our experiments, the effect of ambient light was not considered. Light attenuation is the essential part, given by: $E(d, \lambda)=E(0, \lambda)\exp[-\beta(\lambda)d]$.

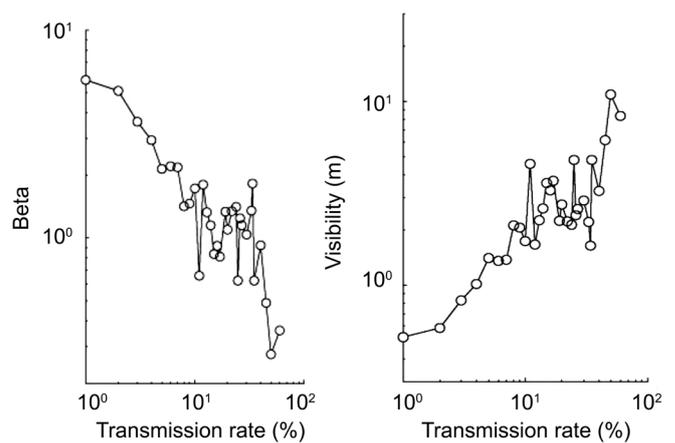


Figure 7 The relationship between TR, β and visibility As the smog concentration decreases and the light TR increases, the value of β decreases quickly. Correspondingly, the visibility increases. At a TR of 10%, at which the decrease in E-visual acuity and crowded E-visual acuity begins to accelerate, the visibility is only approximately 2-3 m. It belongs to grade IV severe in Haze Level for Observation and Prediction.

This function is very close to the primary 'vision-transmitting rate' model of E-visual acuity and crowded E-visual acuity obtained from our experimental results, and was deduced as, $V=A \times \exp[B \times \log(\text{TR})]$, where V is the logMAR visual acuity, TR is the rate of light transmission, and A and B are constants. In our experiments, the length and volume of the container, the brightness of the computer screen light source, and the test distance were fixed. However, after applying other fitting functions, we found that a power model fit our results better, which is what we ultimately adapted. In certain contexts, a power model can be viewed as a special form of an exponential function; therefore, we could not exclude that a power function can be incorporated into the atmospheric scattering model.

Practical Application of Our Findings The decline in E-visual acuity, crowded E-visual acuity, and contrast sensitivity was very slow when the TR was higher than 10%. However, the deterioration of these measurements accelerated when the rate of light transmission decreased below 10%. These results indicate a real need for traffic control or issuing a high-risk warning when the smog percentage concentration approaches 90%.

According to the World Health Organization's classification standards for low vision and blindness established in 1973, grade I low vision means a BCVA lower than 0.5 in logMAR but equal to or better than 1.0; grade II low vision means BCVA lower than 1.0 but equal to or better than 1.3; grade III blind means BCVA lower than 1.3 but equal to or better than 1.7; grade IV blind means BCVA lower than 1.7 but equal to or better than light perception (LP); and no light perception (NLP) is grade V blind^[25]. From our model, we can relate these classification standards to TRs: TRs 2.24%-3.26% reduced VA to lower than 0.5 in logMAR

but equal to or better than 1.0 as grade I low vision and TRs 1.86%-2.24% reduced VA to lower than 1.0 but equal to or better than 1.3 as grade II low vision, TRs 1.53%-1.86% reduced VA to lower than 1.3 but equal to or better than 1.7 as grade III blind, TRs less than 1.53% reduced VA to lower than 1.7 but equal to or better than LP as grade IV blind. Thus, someone with normal visual acuity develops low vision or blindness to some extent in heavy smog. People are only granted a driver's license in China if their BCVA is greater than 0.045^[26]; thus, we can conclude that driving is not allowed when the TR is less than 19.93%.

Leat^[27] defined visual impairment as best monocular or binocular visual acuity <0.097 in logMAR, total horizontal visual field <146 , and contrast sensitivity <1.5 (Pelli-Robson), and visual disability as best monocular or binocular visual acuity <0.301 or a contrast sensitivity of 1.05. From our model, we can easily observe that a TR of 2.9% is equivalent to visual disability and a rate of 6% is equivalent to visual impairment.

Deeper Understanding of Our Visual Function Parameters

In the current study, only three basic but primary parameters were measured, namely: E-visual acuity, crowded E-visual acuity and contrast sensitivity. Using E-visual acuity is the basic method for describing visual function, and it is widely used in many internationally and nationally recognized standards, such as low vision standards and driving license standards. Our results indicate that E-visual acuity was reduced according to a power function.

We adopted crowded E-visual acuity because of its practical meaning in daily activities, particularly in driving and reading. According to previous studies, the crowding effect is defined as a target that becomes increasingly difficult to perceive when embedded among adjacent distractors. This effect is evident in amblyopic patients and normal-sighted children younger than 6y^[28]. More in-depth investigations from previous researches showed that the effect underlies various mechanisms mainly in the primary visual cortex (V1), for example, the space scale hypothesis, unconscious side stimulation hypothesis, and attention deficit hypothesis^[29-30]. With respect to low contrast, previous studies have shown that the crowding effect of low-contrast letters is lower than that of high-contrast letters^[31]. The explanation is that the lateral interaction between two given contours is much weaker for two contours with lower contrast than for two contours with higher contrast. However, according to our results, with decreasing TR, crowded E-visual acuity decreased faster than E-visual acuity, which meant the crowding effect had increased. We thought this may be because our simulative smog was dynamic while others' provided computer-simulated low-contrast conditions. Further studies are needed. Crowded E-visual acuity began to decline at a higher smog percentage concentration than E-visual acuity, perhaps because it had a better base line.

Regarding contrast sensitivity, several scientific studies have shown that contrast sensitivity represents a powerful indicator of functional vision. A meaningful measure of contrast sensitivity can provide a more complete picture of visual function^[32]. The contrast sensitivity function has an inverted U-shape with a peak contrast sensitivity of approximately 4 c/deg or 6 c/deg^[33]. Therefore, we chose 5 c/deg in our experiment according to our reference textbook. It was previously shown that as the luminance increases, the overall contrast sensitivity of the eye increases^[34-35]. Normalized contrast sensitivity to retinal luminance at a spatial frequency of 2 c/deg is an exponential continuous curve with an attenuation constant of 0.0024^[35]. The same trend was observed in our study but using a different model. Possible explanations may be the different spatial frequency or different location in the retina. We limited the age of subjects in our study to 22-29 to avoid the sensitivity loss associated with age-related random cell loss and peripheral attenuation in terms of cortical magnification^[36].

Visibility and Smog Mass Concentration According to the Beer-Lambert law, $VR=3/\beta$. The extinction coefficient β is affected by factors mainly including particles such as PM2.5 and PM10, the relative humidity of the surrounding air, and the wavelength of incident light. In our experiment, except for the mass concentration of particles, all other factors were fixed. Therefore, the particle concentration became the main factor affecting β . According to Yang's analysis of the relationship between PM2.5 and PM10 mass concentration and visibility^[37], visibility decreases with an increase in PM2.5 and PM10 mass concentration. The models for PM2.5 and PM10 in the summer season are $y=-3.22+34.70e^{-0.0061x}$ ($R^2=0.60$) and $y=6.57+202.71e^{-0.018x}$ ($R^2=0.54$), respectively, where y is the visible distance (km) and x is the mass concentration ($\mu\text{g}/\text{m}^3$). But these models cannot be applied to our laboratory experiment because the difference in condition, including temperature, humidity and wind speed. Thus, the relationship between smog mass concentration and visibility must be very complicated, with a lot of variables. Consequently, in the field of transportation, rather than visibility, vision, based on electric light source method, to measure the smog percentage concentration, may be a more physiologically based smog-weather classification indicator to guide traffic. However, the acuity of this measure or its wide practicability requires further research.

Limitations of the Current Pilot Study and Outlook

This is the first study attempting to measure visual function under dynamic artificial smog condition. In our preliminary experiment, we have used randomized table (generated by Microsoft Excel 2016) to decide the measurement sequence of three parameters. Compared to the measurement on a fixed sequence such as E-visual acuity, contrast sensitivity and

crowded E-visual acuity, no difference was noted. Taking into consideration that on a fixed sequence a more consistent measurement of time can be obtained and hence to reduce the impact of smog dissipation, we have finally chosen fixed sequence for our final experiment.

Our starting point was to measure visual function under natural and repeatable conditions. However, a few issues remain to be further addressed. The first is how to create a stable but controllable smog. In fact, it is challenging to establish a random condition and to maintain it for a long time because once the smog in the container is interrupted, it takes a long time for that smog to move around. Thus, our aim was to create a slow, steady and repeatable smog dissipation procedure. In addition, based on our measurement of the dissipation curve at three different times, we are certain that such a procedure is feasible. Second, to make our case more convincing, we would better confirm the feasibility of the procedure with the MTF, which will be the subject of our next study. There are many different MTFs that can be used to describe the optical characters of the atmosphere. The turbulence MTF was basic, and the overall atmospheric MTF^[15] was relatively functional; however, they were limited by instrumentation requirements or other underlying factors, such as wavelength and scattering angle. There is no preferred MTF specific to smog. Third, it was demonstrated that contrast sensitivity could be measured with greater repeatability using letter-based charts, including the Pelli-Robson Chart, than with charts containing gratings^[38]. Since the Freiburg vision test system does not provide such a visual stimulus, we plan to repeat our study using the Pelli-Robson Chart.

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