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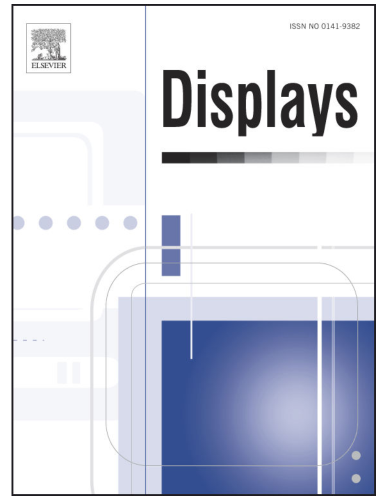

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Lighting for Road Tunnels: The Influence of CCT of Light Sources on Reaction Time

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Abstract

Drivers' visual performance is closely related to traffic safety in a real driving environment. In order to improve the traffic safety of road tunnel lighting, the effect of LED lighting on human visual performance was investigated using reaction time as a parameter. The experiment was performed with a scale model that can simulate a road tunnel lighting environment. Reaction times were measured under different values of luminance, correlated colour temperature (CCT), eccentricity, and contrast. The results show that visual performance can be improved by increasing the CCT of the light sources. The improvement of visual performance is greater in peripheral vision than that in foveal vision. The shortest reaction times were measured at a luminance level of 10 cd/m^2 and at a CCT of 5000 K. An appropriate luminance value with high CCT is recommended for tunnel lighting in interior and transition zones.

Keywords: tunnel lighting, traffic safety, visual performance, reaction time, CCT.

1 Introduction

A tunnel is a tubular semi-enclosed traffic area. Tunnel lighting regulations are complex, with different lighting level requirements for different zones (Commission International de l'Eclairage, 2004). Indeed, these lighting regulations have different effects on drivers' visual performance, and this can induce traffic accidents. Once a traffic accident occurs, the consequences are extremely serious. For example, on March 1, 2014, a traffic accident in the Shanxi Yanhou tunnel in China caused the death of 40 people and injured 12 others. The direct economic loss amounted to US $12 million (State Administration of Work Safety of China, 2014). Another recent traffic accident in the

Hachihonmatsu tunnel in Japan on March 17, 2016 resulted in the death of 2 people with 70 people injured (Japan Today: Japan News and Discussion, 2016). Thus, it is important to improve the traffic safety of road tunnels by improving the drivers' visual performance. In addition, lighting must be provided in tunnels 24 h a day. The electrical consumption statistics of the Chongqing Highway tunnel shows that the average annual cost of electricity in the tunnel is US $62,000 per kilometer, and the total annual electrical cost of road tunnels in China is US $1 billion, of which lighting accounts for ~30% (Xingmao et al., 2015). As tunnel lighting consumes a notable share of total energy, it is imperative to research tunnel lighting from the perspective of traffic safety and energy savings.

The current tunnel lighting standard includes the recommended values for luminance, luminance uniformity, and threshold increment for different tunnel zones (Commission International de l'Eclairage, 2004). However, these luminance parameters based on photopic photometry cannot reflect the spectral sensitivity at low light levels (Lit et al., 1971; Pollack, 1968). At the same time, the colour characteristic described with the CCT and the general colour rendering index (CRI), which is defined by the spectral power distribution, is also a factor that affects visual performance (Ylinen et al., 2011). Therefore, the current lighting standards may not be appropriate for improving traffic safety in tunnels.

Many studies (Fotios and Cheal, 2009; Fotios S. A.; Cheal, 2007; Islam et al., 2015; McGloughan et al., 1999) have been conducted to determine the relationship between lighting characteristics and luminance level. McCloughan et al. (McGloughan et al., 1999) studied the systematic influences of lighting on the driver's mood using lighting parameters such as CCT. They demonstrated that lighting quality has initial effects, linking illuminance with sensation-seeking and CCT with hostility, and longer-term effects, implying complex effects involving gender, illuminance, and CCT. Suzer et al. (Suzer et al., 2018) studied the effects of CCT on wayfinding in a virtual airport environment, the wayfinding performance were evaluated in five criteria: Time spent in finding the final destination, Number of errors in finding the final destination, Number of decision points necessary to find the final destination, Number of hesitation points in finding the final destination, and Route choice, which indicated that the CCT have significant effect on the frequency of experiencing hesitations and the number of hesitations decreased when CCT increased from 3 000 K to 12 000 K of the male test subjects. Meanwhile, the user acceptance in LED office lighting was studied by Islam et al. (Islam et al., 2015). They showed that spatial brightness is affected by the spectral power distribution (SPD) of the lamps, and observers preferred the task illuminance in which they found the lighting environment appeared brighter. Research of lighting for subsidiary streets was carried out by Fotios and Cheal (Fotios and Cheal, 2009; Fotios S. A.; Cheal, 2007) who showed that reduced visual performance can be compensated by the SPD of the lamps.

Only a few studies based on visual performance have been conducted regarding tunnel lighting. In the study by Liu et al. (Yingying L, Ji W, Jianzhong C, 2013), LEDs (in five different CCTs: 2432 K, 3686 K, 4446 K, 4806 K, and 5128 K) and other two traditional light sources (a high pressure sodium lamp in 1919 K and a metal halide lamp in 2789 K) were studied at three light levels (4.5 cd/m^2, 45 cd/m^2, and 85 cd/m^2). They showed that the influence of light source CCT and optical biological effects must be considered when choosing suitable light sources in different sections of tunnel lighting. The visual performance of different light sources in the mesopic level (1–5 cd/m^2) was studied by Yang et al. (Yang et al., 2015), who showed that visual recognition in mesopic level evaluated by using the photopic function is an inappropriate method, and that the increase of CCT (from 1958 K to 5537 K) can improve the reaction speed in the mesopic level. However, there is no similar study conducted on the influence of CCT on foveal and peripheral vision in the mesopic range and in the level from photopic to mesopic (from dozens of cd/m^2 to 1 cd/m^2), which is very important in the transition and interior zones of a tunnel. There is little research on visual performance influenced by the spatial brightness in road tunnel lighting in previous studies.

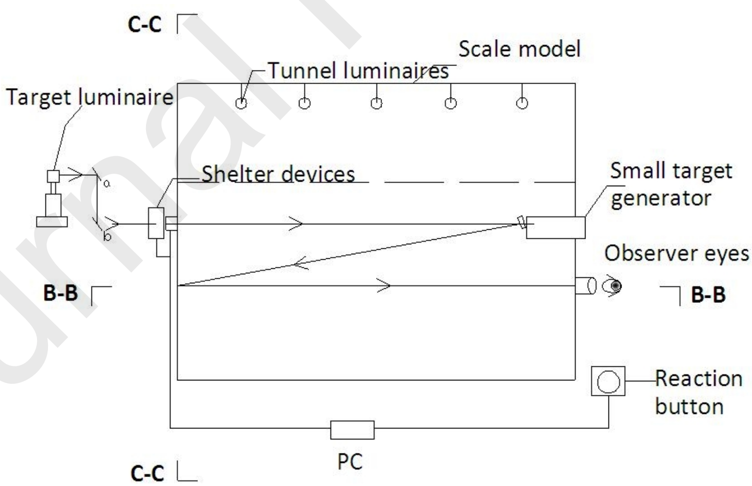
Road tunnel lighting resembles road lighting, but has its unique requirements due to the entrance and exit of the tunnel. In order to study the relationship of CCT, spatial lighting (i.e., tunnel lighting), and visual performance, a 3D scale model was developed to simulate the real tunnel lighting environment. With the reaction time measurement devices, this study focuses on the relationship between reaction time and the CCT of tunnel light sources, which is regarded as a suitable starting point to improve tunnel lighting quality. It is expected that this study will provide a new method to optimize the existing design methods of tunnel lighting, and to make the tunnel lighting environment conform better to actual visual performance.

2 Methods

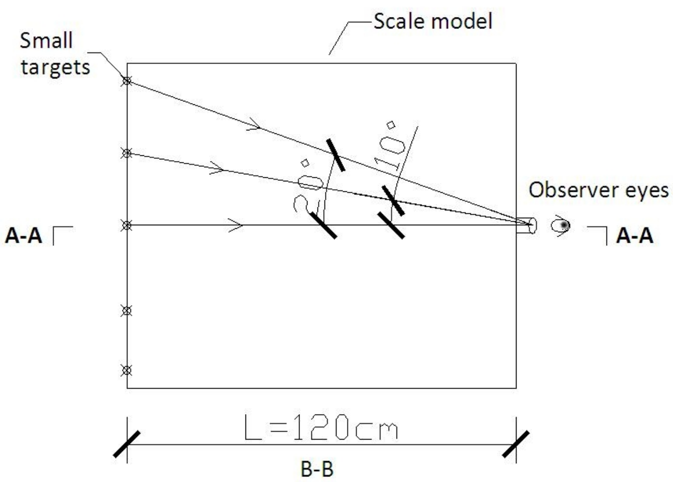
2.1 Design of test system

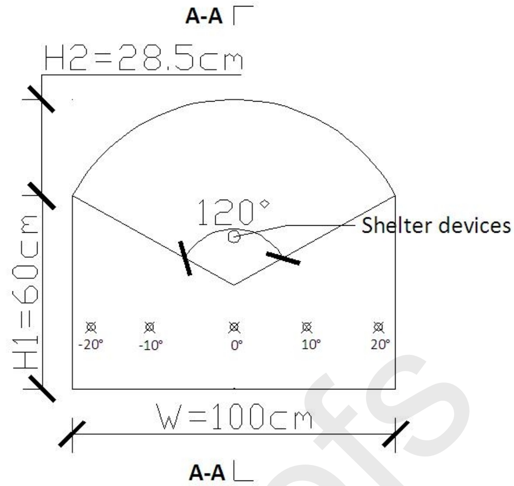
For the complex lighting environment in the highway tunnel, the driving task mainly includes four processes: preview, perception, judgment, and response. In the above mentioned four tasks, the driver's preview-perception process is mainly affected by the road tunnel lighting environment, and this is of great significance to traffic safety, and relates to the timely detection of other traffic targets and vehicle scheduling. This paper focuses on the influence of the tunnel lighting environment on the driver's visual preview-perception process. Through this experimental device, the light environment and the visual task of randomly generating the target in the tunnel lighting environment were created. The purpose of this study is to demonstrate the impact of the tunnel lighting environment on driving behavior and on the driver's visual preview-perception process.

In order to study the relationship between the reaction time and the CCT of the light source, a 10:1 indoor scale model of road tunnel lighting was developed to simulate different kinds of lighting environments and measure the reaction time of the driver. The actual size of the road tunnel scale model is 120 cm × 88.5 cm × 100 cm (length × height × width) (Figure 1). The tunnel ceiling height is 88.5 cm, which includes the height of the cylindrical ceiling (28.5 cm, cylinder diameter 57 cm). Figure 1 (a) illustrates the structural representation of the whole device. Figure 1 (b) presents the horizontal section (B-B) of the de vices and the location of the test subject’s eyes and targets. Figure 1 (c) shows the cross section (C-C) of the devices and the relative target location of the road tunnel scale model.



(a) A-A section of the devices.





(b) B-B section of the devices. (c) C-C section of the devices.

Fig. 1 Structural representation of the device

The scale model is used to simulate the road tunnel lighting environment by using a tunnel light source (Figure 1 (a)). The target is produced from the target light source, and is projected to the specified areas by using an optical path and then detected by the observer. The reaction-time measuring device is used to measure the time from the target appearance to the target detection by the test subject.

Three factors should be considered in this type of target setting: (1) the contrast between the target and the background luminance used to represent the traffic target (such as broken-down vehicles and pedestrians.) with different reflectivity. (2) The angle between the target and the test subjects' eye sight to be tested, which is used to represent the different positions of obstacles present in the highway tunnel lighting environment. (3) The technical parameters of the target luminaire as shown in Table 1.

2.2 Test light sources

LED luminaires were used in the scale model in which the CCT and light level can be changed. The target light source was also an LED luminaire. The specific technical parameters of the LED luminaires are listed in Table 1.

Table 1 Technical parameters of test light sources

Light sources	Power	Luminous Flux	CRI	CCT
Tunnel Luminaires	5 W	0–370 lm	≥ 72	2700–6500 K
Target Luminaire	80 W	7650 lm	≥ 70	5000 K

Note: The target of the test device is produced by three reflections of the plane mirrors, so the target luminaire power is great compared to the tunnel luminaires of the model. CRI refers to the CIE colour rendering index in this paper.

2.3 Test conditions

To test the influence of light sources' CCT on reaction time, auxiliary parameters such as contrast, background luminance, and eccentricity were selected for the experiment. The specified parameter values are listed in Table 2.

Table 2 Value of test parameters

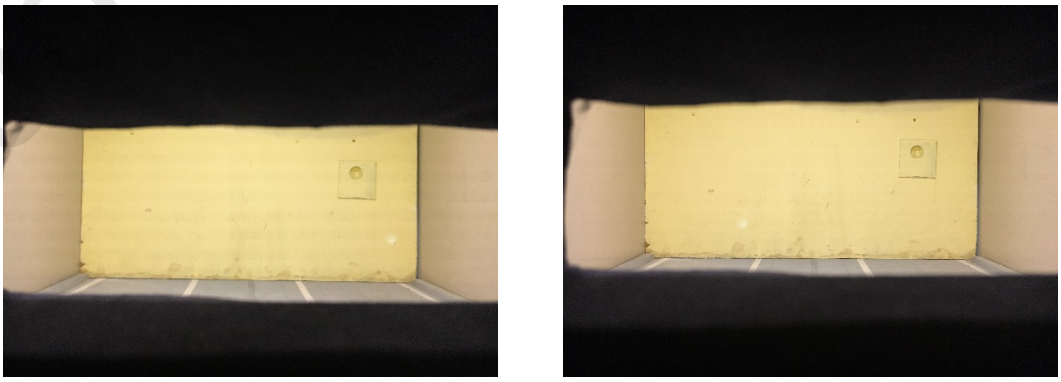
Experimental parameters	Values		
CCT	3000 K	4000 K	5000 K
Contrast	0.2		0.5
Background Luminance	2 cd/m^2	6 cd/m^2	10 cd/m^2
Eccentricity	θ = 0°	θ = ±10°	θ = ±20°

The contrast is the relationship between the luminance of the objects and their background. The contrast is calculated using

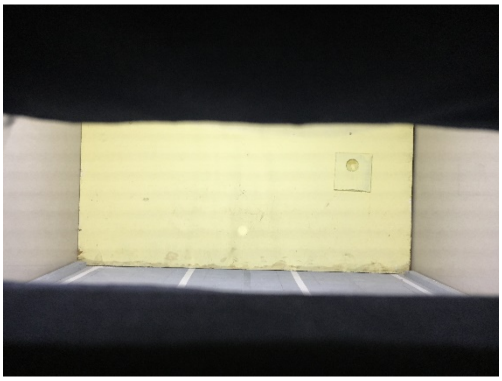
$$C = \frac{L_t - L_b}{L_b}, \qquad (1)$$

where C is the contrast, L_t is the target luminance, and L_b is the background luminance.

A target of 1.5° was projected onto the background plane at five different locations (see Figure 1 (b)). The horizontal eccentricity values were −20°, −10°, 0°, 10°, and 20° based on the angle between the line of sight and the centerline of the test devices, which is shown in Figure 1(b). The vertical eccentricity was 0° to ensure that the test subject's eyes and the targets were at the same level. The lighting environment of the visual field of the test subjects in different test parameters was shown in Figure 2.



(a) CCT=3000 K, C=0.2, θ = 20° **(b)** CCT=4000 K, C=0.2, θ = -10°



(c) CCT=5000 K, C=0.5, θ = 0°

Fig 2 Lighting environment of the visual field of the test subjects in different test parameters while the background luminance is 6 cd/m^2

2.4 Test procedures

54 people were selected as test subjects, including 27 men and 27 women. Their age ranged from 18 to 40 years, and their colour vision was tested to be normal with the Ishihara colour vision test.

The measured reaction times included a delay caused by the interconnection of the devices in the system, which is a very short time. However, the time delay was constant, as the test procedure was the same, and it was included in the measured reaction times.

Figure 3 (a) Outside view of the device**(b)** Test subjects looking through the observation hole

Note: The photographs in Figure 3(b) were taken before the test, because the test was performed in the dark.

Test procedures were as follows:

1) The lab lighting was turned off when the test began. The test subjects adapted to the background light of the scale model for 15 min at the beginning of the test.

2) A small target would appear in the designated location by operating the small target generator in the target generation simulation system.

3) Once the "Start" button was triggered at the beginning of the experiment, light would enter the scale model and generate a target on the background plane. The target position on the background plane appeared according to the order in Table 3.

4) The stop button was touched when the small target was recognized by the test subjects. The reaction time was recorded by a timer. The procedures were repeated in order (Table 3) until the test was completed.

Table 3 Test procedure parameters

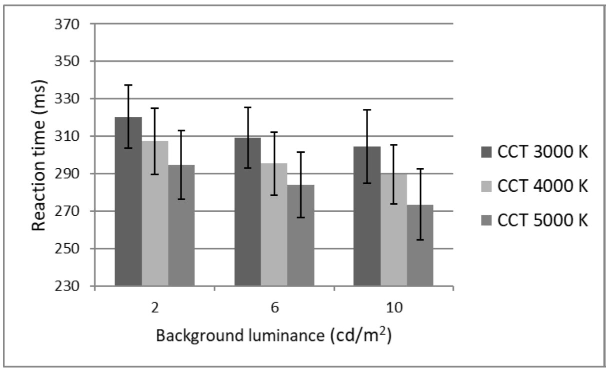
No.	Contrast, Background luminance	Eccentricity	No.	Contrast, Background luminance	Eccentricity
1	$C = 0.2$, $L_b = 2$ cd/m^2	0°, 10°, 20°	4	$C = 0.5$, $L_b = 2$ cd/m^2	0°, 10°, 20°
2	$C = 0.2$, $L_b = 6$ cd/m^2	0°, 10°, 20°	5	$C = 0.5$, $L_b = 6$ cd/m^2	0°, 10°, 20°
3	$C = 0.2$, $L_b = 10$ cd/m^2	0°, 10°, 20°	6	$C = 0.5$, $L_b = 10$ cd/m^2	0°, 10°, 20°

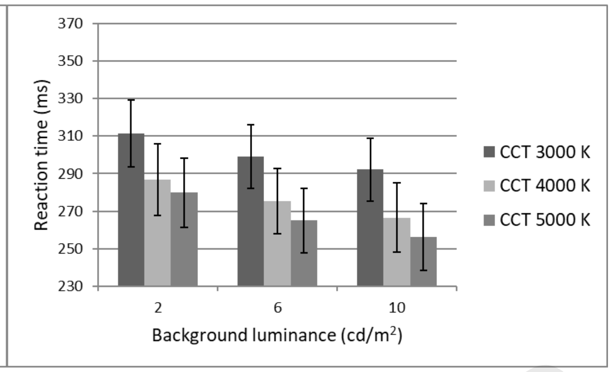
Note: The procedures were repeated from low contrast ($C = 0.2$) to high contrast ($C = 0.5$), as well as from low background luminance ($L_b = 2$ cd/m^2) to high background luminance ($L_b = 10$ cd/m^2). However, the eccentricity was assigned randomly in each procedure.

3 Results

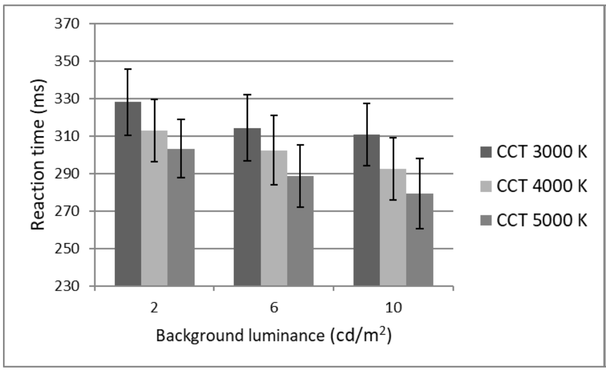
The reaction times of each test subject were obtained under different conditions through the procedures of the experiment. The mean reaction time of the 54 test subjects was calculated, and is shown in Appendix A1. The data was analyzed according to different test conditions. To simplify the data analysis, the eccentricities of 20° and −20°, as well as −10° and 10°, were considered to be the same.

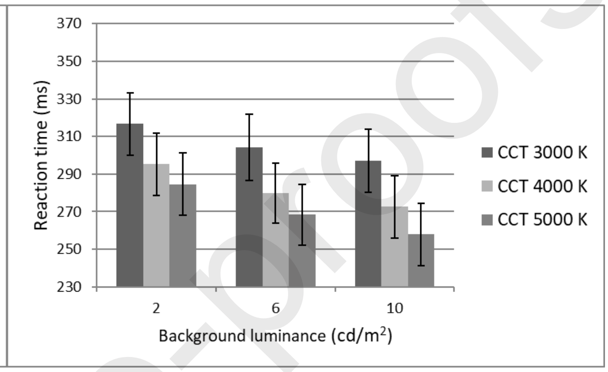
The eccentricity values were 0°, 10°, and 20°; the contrast ratio values were 0.2 and 0.5; and the tunnel light source CCT values were 3000 K, 4000 K, and 5000 K. The reaction time and the background luminance are shown in Figure 4 (a)–(f), with different eccentricities and contrasts.



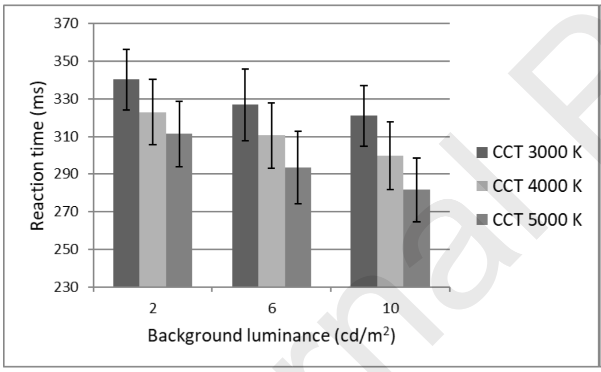


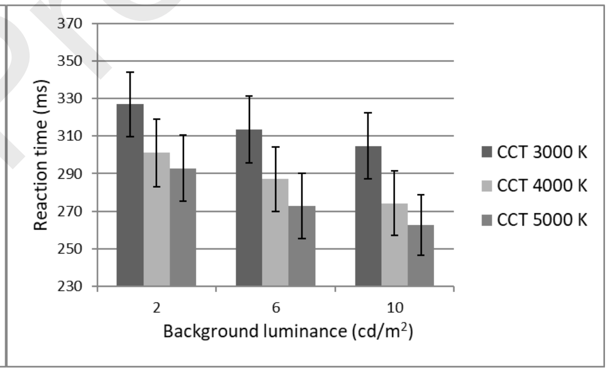
(a) Eccentricity θ = 0°, C = 0.2 (b) Eccentricity θ = 0°, C = 0.5





(c) Eccentricity θ = 10°, C = 0.2 (d) Eccentricity θ = 10°, C = 0.5





(e) Eccentricity θ = 20°, C = 0.2 (f) Eccentricity θ = 20°, C = 0.5

Fig 4. Relationship between the background luminance and reaction time under the conditions of θ = 0°, 10°, 20° and C = 0.2, 0.5. The error bars indicate the standard deviation.

For the same eccentricity and contrast, the mean reaction time corresponding to the three CCT values were compared in Figure 4 (a)–(f). This indicates that the mean reaction time decreases when the CCT increases from 3000 K to 5000 K under the same background luminance. The mean reaction time decreases when the background luminance increases from 2 cd/m^2 to 10 cd/m^2 for the same CCT values. For the dispersion of reaction time, the error bars showed no significant difference across different background luminance and CCTs.

Table 5 presents the decreases in the mean reaction times when the background luminance increases from 2 cd/m^2 to 10 cd/m^2. This shows that the decrease in mean reaction times is increased when the CCT values increase from 3000 K to 5000 K for the same eccentricity and contrast. In addition, the decrease in the mean reaction time is increased when the eccentricity increases from 0° to 20° for the same contrast.

Table 5. The difference (decrease) in mean reaction times when the background luminance increases from 2 cd/m^2 to 10 cd/m^2) (Unit: ms).

θ, C / CCT	0°, 0.2	0°, 0.5	10°, 0.2	10°, 0.5	20°, 0.2	20°, 0.5
3000 K	16	19	17	20	19	22
4000 K	17	20	20	22	23	27
5000 K	21	24	24	27	29	31

Note: Here is the calculation of the decrease in the total mean reaction times under the condition of that background luminance (L_b) increases from 2 cd/m^2 to 10 cd/m^2 straight with different eccentricities and contrasts. The same calculation is summarized in Table 6.

Table 6 shows the increases in mean reaction times when the eccentricity increases from 0° to 20°. It indicates that the increases in the mean reaction time decreases when the CCT values increase from 3000 K to 5000 K for the same background luminance and contrast. In addition, the increase in the mean reaction time decreases when the background luminance increases from 2 cd/m^2 to 10 cd/m^2 for the same CCT values.

Table 6. The difference (increase) in mean reaction times when the eccentricity increases from 0° to 20°. (Unit: ms)

L_b, C / CCT	2 cd/m^2, 0.2	2 cd/m^2, 0.5	6 cd/m^2, 0.2	6 cd/m^2, 0.5	10 cd/m^2, 0.2	10 cd/m^2, 0.5
3000 K	20	16	18	15	17	13
4000 K	16	14	15	12	10	7
5000 K	16	13	9	8	8	6

For the test data, an analysis of variance (ANOVA in SPSS IBM 23) was used with a significance level of 0.05. The background luminance and CCT were considered as independent variables. A two-way ANOVA was performed that showed there was no significant interaction between the background luminance and CCT. Therefore, one-way ANOVAs were performed for the main factors of background luminance and CCT (Appendix Table A1). A post hoc analysis was performed using the Turkey procedure to investigate the background luminance values and CCTs for which the mean reaction times are significantly different (Table 7).

Table 7. Multiple comparisons of background luminance values and CCTs in the Turkey procedure. The significance level is 0.05.

Eccentricity, contrast	CCT (K)	L_b (cd/m^2)	L_b (cd/m^2)	p values	L_b (cd/m^2)	CCT (K)	CCT (K)	p values
θ = 0°, C = 0.2	3000	6	2	0.004	2	4000	3000	0.001
			10	0.334			5000	0.001
	4000	6	2	0.001	6	4000	3000	<0.001
			10	0.175			5000	0.002
	5000	6	2	0.008	10	4000	3000	<0.001
			10	0.009			5000	<0.001
θ = 0°, C = 0.5	3000	6	2	0.001	2	4000	3000	<0.001
			10	0.088			5000	0.142
	4000	6	2	0.005	6	4000	3000	<0.001
			10	0.036			5000	0.006
	5000	6	2	<0.001	10	4000	3000	<0.001
			10	0.034			5000	0.009
θ = 10°, C = 0.2	3000	6	2	<0.001	2	4000	3000	<0.001
			10	0.515			5000	0.008
	4000	6	2	0.005	6	4000	3000	0.002
			10	0.010			5000	<0.001
	5000	6	2	<0.001	10	4000	3000	<0.001
			10	0.015			5000	<0.001
θ = 10°, C = 0.5	3000	6	2	0.001	2	4000	3000	<0.001
			10	0.081			5000	0.003
	4000	6	2	<0.001	6	4000	3000	<0.001
			10	0.089			5000	0.002
	5000	6	2	<0.001	10	4000	3000	<0.001
			10	0.003			5000	<0.001
θ = 20°, C = 0.2	3000	6	2	<0.001	2	4000	3000	<0.001
			10	0.181			5000	0.001
	4000	6	2	0.001	6	4000	3000	<0.001
			10	0.005			5000	<0.001
	5000	6	2	<0.001	10	4000	3000	<0.001
			10	0.002			5000	<0.001
θ = 20°, C = 0.5	3000	6	2	<0.001	2	4000	3000	<0.001
			10	0.029			5000	0.045
	4000	6	2	<0.001	6	4000	3000	<0.001
			10	0.001			5000	<0.001
	5000	6	2	<0.001	10	4000	3000	<0.001
			10	0.006			5000	0.001

For the same CCT, Table 7 indicates that the effect of background luminance values 2 cd/m^2 and 6 cd/m^2 on mean reaction times are significantly different when θ is 0° and 10° under different contrast values. The effect of the background luminance values 2 cd/m^2 and 6 cd/m^2 on mean reaction times are more significant than that between 6 cd/m^2 and 10 cd/m^2 when θ is 20° under different contrast values. For the same background luminance values, the effect of CCTs on mean reaction times are significantly different under the condition of different eccentricity and contrast. Meanwhile, the effect of CCT = 3000 K and 4000 K on mean reaction times are more significant than that between 4000 K and 5000 K for different eccentricity and contrast. This means that the increased luminance level (6 cd/m^2 to 10 cd/m^2) and light source CCT (4000 K to 5000 K) are not significant factors to shorten the reaction time. The analysis showed that the decrease of the mean reaction time is lower when the background luminance increases from 6 cd/m^2 to 10 cd/m^2 than when it increases from 2 cd/m^2 to 6 cd/m^2. The decrease of mean reaction time is also lower when the CCT increases from 3000 K to 4000 K than when it increases from 4000 K to 5000 K.

4 Discussion and Conclusions

The CCT of the tunnel light sources and reaction time are inversely proportional. The reaction time can be shortened and the visual performance can be improved with the increase of CCT values of the light sources within a certain range (from 3000 K to 5000 K). The foveal and peripheral visual performance are both improved with higher CCTs of light sources. The improvement in the peripheral vision is greater than that in the foveal vision (Table 5). The decrease of the mean reaction time is lower when the background luminance increases from 6 cd/m^2 to 10 cd/m^2 than when it increases from 2 cd/m^2 to 6 cd/m^2 (Table 7). The decrease of mean reaction time is also lower when the light sources CCT increase from 4000 K to 5000 K than when it increases from 3000 K to 4000 K (Table 7). This means that the increased luminance level (6 cd/m^2 to 10 cd/m^2) and light sources CCT (from 4000 K to 5000 K) are a limited factor to shorten reaction times. Increasing the luminance level from 2 cd/m^2 to 6 cd/m^2 and CCT from 3000 K to 4000 K was found to be more effective compared to the increase of luminance and CCT from 6 cd/m^2 to 10 cd/m^2 and 4000 K to 5000 K, respectively. However, the shortest reaction times were found at high luminance (10 cd/m^2) and CCT (5000 K).

According to CIE technical report 88-2004 (Commission International de l'Eclairage, 2004), the recommended luminance value is 1–6 cd/m^2 in the interior zones of long tunnels in low traffic flow conditions, and in the second part of the interior zone of very long tunnels. The luminance value is 10 cd/m^2 in the interior zones of long tunnels in heavy traffic flow condition. The increase of CCT values (from 3000 K to 5000 K) in these zones can be used to decrease the test subjects' reaction time and improve their visual performance. However, the decrease of the reaction time was greater when the luminance was changed from 2 cd/m^2 to 6 cd/m^2 and the CCT from 3000 K to 4000 K than when the luminance was increased from 6 cd/m^2 to 10 cd/m^2 and the CCT from 4000 K to 5000 K. The shortest reaction times were found at 10 cd/m^2 and 5000 K, in this set of measurements. The influences of SPD and CRI of the light sources on visual performance remain undefined in road tunnel lighting. In order to improve the overall lighting quality in tunnels, further studies are needed to determine appropriate values for luminance, CCT, SPD, and CRI.

The design of road tunnel lighting should consider both traffic safety and energy savings by conducting research on visual performance and lighting quality. On the basis the results of this study, it is concluded that in road tunnel interior zones where the luminance level is low (1–6 cd/m^2), the driver's visual performance can be improved by increasing the light sources CCT. For example, sufficient luminance values (1–6 cd/m^2) with higher CCT (4000 K or 5000 K) can be used to improve the traffic safety in the interior zone of road tunnel lighting. However, the road tunnel lighting standards (Commission International de l'Eclairage, 2004; Ministry of Transport of the People's Republic of China, 2014; The Illuminating Engineering Society of North America, 2011) do not give any recommendations for the CCT of the light sources. In highway tunnel lighting, visual performance can be improved by adopting higher-CCT light sources when the visual performance is increased with the increasing luminance value.

This study simplified the reaction time data regarding the eccentricity of the target: The reaction times were grouped in eccentricities of 0°, 10°, and 20°, regardless of the target being on the left or right side of the central line of vision. In previous research, no notable difference was found whether the target was on the left or right side of the visual field at a uniform background, according to a visual performance measurement (Cengiz C, Puolakka M, 2015; "CIE 145:2002 The Correlation of Models for Vision and Visual Performance," ; International Commission on Illumination, 2010). However, driver's eye movements have been found to differ depending on the different geometric and illumination conditions (Suh et al., 2006). In addition, visual performance was found to be different when the target was on the left or right side of the visual field at a non-uniform background luminance (Cengiz et al., 2016). Further study should focus on the potential differences between the eccentricity of −20° and 20°, as well as −10° and 10°, in both uniform and non-uniform backgrounds when the luminance increases from 1 cd/m^2 to 10 cd/m^2 in different road tunnel lighting conditions.

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APPENDIX

Table A1. Mean reaction times (Unit : s) and the associated standard deviations of different background luminances, CCT, contrast and eccentricity.

Eccentricity, contrast	CCT		2 cd/m^2	6 cd/m^2	10 cd/m^2
θ =0°, C=0.2	3000 K	Mean	320	309	304
		SD	17	16	20
	4000 K	Mean	307	295	290
		SD	18	17	16
	5000 K	Mean	295	284	274
		SD	18	18	19
θ =0°, C=0.5	3000 K	Mean	311	299	292
		SD	18	17	17
	4000 K	Mean	287	275	267
		SD	19	17	18
	5000 K	Mean	280	265	256
		SD	18	17	18
θ =10°, C=0.2	3000 K	Mean	328	314	311
		SD	18	18	17
	4000 K	Mean	313	302	293
		SD	16	18	17
	5000 K	Mean	303	289	279
		SD	16	17	19
θ =10°, C=0.5	3000 K	Mean	317	304	297
		SD	17	18	17
	4000 K	Mean	295	280	273
		SD	17	18	17
	5000 K	Mean	285	268	258
		SD	17	16	17
θ =20°, C=0.2	3000 K	Mean	340	327	321
		SD	16	19	16
	4000 K	Mean	323	311	300
		SD	17	17	18
	5000 K	Mean	311	294	282
		SD	17	19	17
θ =20°, C=0.5	3000 K	Mean	327	313	305
		SD	17	18	18
	4000 K	Mean	301	287	274
		SD	18	17	17
	5000 K	Mean	293	273	262
		SD	18	17	16

Highlights

1. The influence of CCT of light sources of road tunnels on human visual performance was invested using reaction time.

2. Reaction times were measured under different values of correlated colour temperature (CCT) with a scale model that can simulate an interior road tunnel lighting environment.

3. The visual performance can be improved by increasing the CCT of the light sources, the improvement of visual performance is greater in peripheral vision than that in foveal vision.

Conflicts of interest

There are no conflicts of interest！