The Age Effects of Traffic Signs on Visual Performance

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Abstract: Since drivers aged 70-74 are twice as likely to die when involved in a crash compared to drivers aged 30-59 (for drivers aged 80 and older the risk is five times as high), their need when an accident occur differs from younger people, according to the study conducted by American Automobile Association (AAA, 2012). Other Researches also show senior drivers need significantly more light to see than young drivers. That's because pupils get smaller and don't widen as much in dark conditions and making senior harder to see. This diminished vision is a significant problem (Green, 2008). The goal of this paper is to identify the impact of legibility, luminance contrast of signs on driver's ages. A series of experiments are conducted to investigate the effects of light and age on the threshold and the confident recognition of traffic signs. The experimental results have shown that subjects above the age of 65 have a decrease in visual search performance in the evening since the transmittance of short-wave region (blue lights) within visible range decreases with age because of the loss of luminance and color contrast. The nighttime, raining and evening tests revealed that the older group had significantly longer decision sight distance compared to the younger group ($p < 0.000$, T-tests of 95% significance). The results indicate that observed age-related evening and raining legibility performance decreases visual acuity, which therefore significantly increase chances for an accident. This study helps highlight the fact that when people ignore visual performance in evening and raining conditions it may cause accidents. More importantly, our study has set up the foundation for future work with contributing a dedicated viewpoint for traffic signs and visual performance under evening and raining conditions.

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1. Introduction

A study on senior driving by AAA indicates that older driver involvements in police reported crashes and fatal crashes by aged 65 and older will account for 25% of the total driver fatalities in the US by year 2030. Due to the high accident casualty rate for elderly drivers, many countries are constantly devoted to improving elderly driver safety. How to suppress the increase in traffic accidents has thus become a government challenge and needs to take a more dedicated study on this issue. To tackle this problem, the purpose of this paper was set to investigate the influence of light conditions on sign visibility for elderly drivers.

Many traffic sign studies have researched on sign visibility (Kline, Ghali, and Kline, 1990), sign luminance (Graham and King, 1997), sign legibility (Schieber and Goodspeed, 1997) and sign comprehensibility (Madani, 2000). Common experiences express that luminance (light quantity) and color temperature (light quality) make various psychological impressions on human. The research of Kruithof (1941), Wade and Brožek (2001) on these psychological and interactive effects of color temperature and luminance produced a curve illustrating a range of comfort, with luminance on the vertical axis and color temperature on the horizontal (see Fig. 1). Researchers have also found out that the luminaries type, arrangement, and height can create sufficient visual conditions in road lighting for traffic safety and comfort (Goodspeed and Rea,1999, Schnell,2004, Smiley,2008).

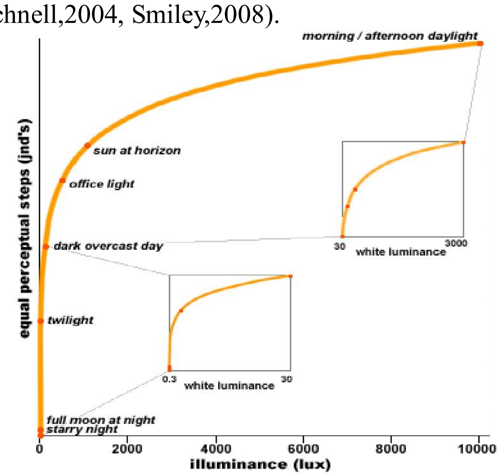


Figure 1. The curve illustrating a range of comfort with luminance on the vertical axis and color temperature on the horizontal.

However, the influence of evening and raining light condition on sign legibility had not been fully addressed. In practice, it is found that there is often no additional light on the road and most drivers do not turn the head light on in the evening and raining. In that case, it might affect the ability of drivers to concentrate on traffic signs while driving and could substantially influence road user safety, driving effectiveness and overall traffic flow. Other characteristics that could affect legibility and recognition performance are discussed as follows. Previous researches have proposed some solutions to reduce reading time and improve the accuracy of traffic signs, such as enlarging the physical letter sizes on signs (Huang, Wang and Chen 2010; Mace), using highly -efficient retroreflective sheeting or increasing the sign luminance by adding assistance lighting (ASTM, 2009). Legibility luminance is an essential factor on vision modality. The minimum readable brightness and contrast depends on other factors, such as font type and size.

Perception distance in driving can be defined as the minimum (visibility) distance of being able to acquire the information conveyed from a sign. The performance measured in this study was highly correlated with the relative visual performance values. In a context directly related to highway signs, subjects were exposed to varying levels of surrounding complexity and luminance contrast. The source analysis is a relatively easy-to-read visual performance model (REA 1988 and Ouellette). This model provides a calculation of distance with an input parameter for the speed and accuracy of visual information. To take a more detailed analysis, our experiment is based on the following factors: the age of the subject, the size of the visual target, the brightness of the visual contrast between the target and its background, and the brightness around the visual target environment.

2. The Proposed System Framework

To investigate the effects of the traffic sign on visual search performance under different light conditions, the experiment was designed to examine the decline in sensitivity to luminance contrast and color temperature by age in a VR simulation system. In our experiments, the same observation method with subjects in the car is used in a correct and coherent way. There were three kinds of signs used in the study: (1) A white and circular one with a black number and a red border; (2) a white and triangular one with a black symbol and a red border; (3) a red and octagonal one with Chinese texts in white and a white border. Three combinations of number, text, shape, and color were used. The symbols such as narrow road signs, Chinese text stop signs, and speed limit signs were selected. Different scenes generated in the VR system are illustrated in Fig. 2.

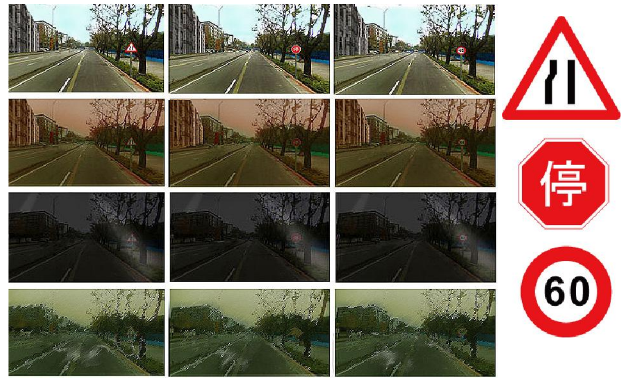


Figure 2. Three combinations of signs were set up in the VR scenes by four color temperatures.

Each subject was required to perform a visual search task under day time, evening, raining, and night conditions, and then completed a workload assessment based on five 7-point rating scales using the NASA - TLX (Task Load Index) method, a multi-dimensional rating scale in which information about the magnitude and sources of several workload-related factors are combined to derive a sensitive and reliable estimate of workload (Hart and Staveland, 1988).

2.1 Experiment Participants

A total of 30 subjects were selected into two groups: 15 younger subjects (aged 20~29 with an average of 27.4 years old, i.e., M = 27.4) and 15 older subjects (aged 65~78 with an average of 73.8 years old, i.e., M = 73.8). Both groups participated in the same tasks in the simulation experiment.

2.2 Pre-Experiment Preparation

The VR scene was created in 3Ds Studio Max, and with all the elements for the creation of one perfect image, including global illumination (Fritchman, 2005), anti-aliasing, and color temperature. A series of pictures were taken crossing through daylight, twilight, raining, and night conditions from 2:00pm to 8:00pm on different days over the course of a month in order to backup the rendering results. The camera was set to the wide-angle setting and the images were adjusted according to the response curve constructed in the laboratory. The results we carried out were almost matched with those of real scenes by simulating standard atmospheric conditions. It remains a challenge, however, that atmospheric model parameters can be automatically determined such that twilight renderings perfectly match actual twilight recordings. Next, we set up the color temperature with the Intensity/Color Attenuation tool in the 3Ds Studio Max to reproduce the realistic scenes as (1) daylight: 6504 K, CIE D65, (2) evening: 4100K, CIE F11, (3) raining: 3400K, and (4) night: 2860 K, CIE A, 120W incandescent light. The luminance contrast ratio was ranged as 8:1, 5:1, 3.4:1, and 2.8:1, controlled by the contrast analyzer version tool (see Fig. 3).

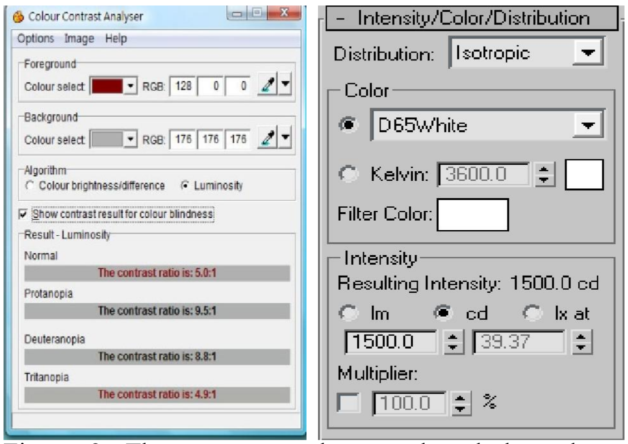


Figure 3: The contrast analyser tool and the color temperature tool in 3Ds Studio Max.

Consequently, the selected background and legend luminance levels were intended to match the credible luminance contrast levels in a real-world environment. The collected data was processed and analyzed with appropriate statistical techniques. The results of our study have presented more functional information and could be used as a source of recommendations for better light quality and quantity, and furthermore, to improve traffic sign perception.

3. Experiment Procedures

The following experiment was performed under rendering light in the VR scene for the quality of the illuminant to remain the real lights continuous. In this case, rheostats were not used to dim the light because the attendant would change the color or the quality of the light. We presented a real-time, fully-textured and anti-aliased 3D graphical scene of a virtual world, which was projected at a resolution of 1024×768 pixels by a projector on a single 120 inch screen in front of the subjects. The total horizontal field of view was 60 degrees and the vertical field of view was 46.8 degrees. The frame rate was constant at 60 Hz. A NI USB-6221 data acquisition device collected the dynamic data at 250 KS/s. The virtual road was a roadway about 1,500m long with signs posting numbers (speed limit), Chinese text (stop), and symbols (lane ends). The roadway was at a low-density traffic, mimicked with two 3.5 m-wide sidewalks and their surrounding virtual environment. The driving speed was set at 5 km/h, which was controlled by the simulator.

4. Statistical Analysis

The mean legibility distances of young and old subjects were statistically significant ($p < 0.001$) in which young subjects had a better legibility skill than older subjects by 45%. Symbolic signs in any condition of light were better for legibility for all subjects in the simulation conditions. Analysis of experiment variance revealed the following:

(1) The difference between symbol and Chinese text background luminance contrast combination was statistically significant ($p < 0.000$). The effect of number and Chinese text background luminance contract combination was statistically significant ($p < 0.002$). Cross-comparisons between different signs showed that Chinese text under any light conditions had considerably poorer legibility distances compared to other signs. On the other hand, symbols had best legibility at perception distance and 53% better than Chinese text as shown in Table 1.

Table 1. Multiple Comparisons of signs.

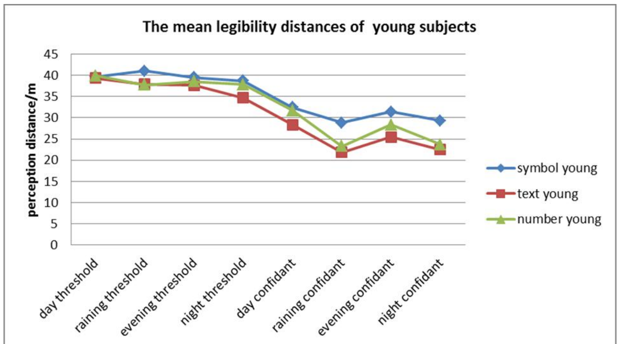
(I) signs	(J) signs	(I-J)	SD	P value(a)
number	text	3.370(*)	.735	.002
	symbol	1.271	.679	.098
text	number	-3.370(*)	.735	.002
	symbol	-2.099(*)	.343	.000
symbol	number	-1.271	.679	.098
	text	2.099(*)	.343	.000

(2) Younger subjects showed faster response to the threshold and a higher percentage of incorrect response by 25%. Younger subjects also had better literacy rates than older subjects by 54% under rainy condition, 42% at night, 40% in the evening, and 12% in the afternoon. Moreover, the mean confidence legibility distance of younger and older subjects in the VR scenes were statistically significant ($p < 0.000$), as summarized in Table 2.

Table 2. Multiple Comparisons of ages.

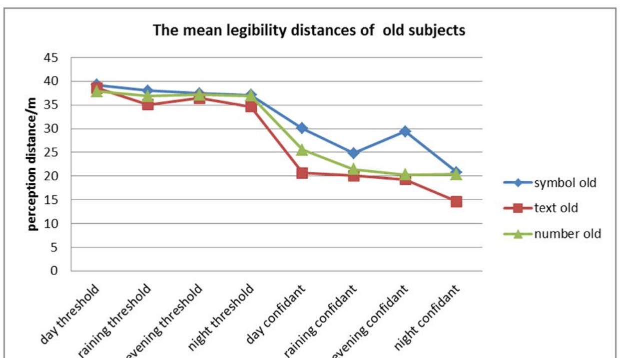
(I) age	(J) age	M	(I-J)	SD	P value(a)
Young younger	old older	32.89	3.205(*)	.714	.000

(3) Evening and raining confidence level interaction was statistically insignificant. The effect of day and night level interaction was statistically significant ($p < 0.024$). The effect of day and evening level interaction was statistically significant ($p < 0.005$). Multivariate test of the differences between light and age ($p < 0.005$) was also statistically significant.



Threshold and confidence legibility distances under different light conditions.

Figure 4. The mean legibility distance of younger subjects.



Threshold and confidence legibility distances under different light conditions.

Figure 5. The mean legibility distance of older subjects.

From Fig. 4 and Fig. 5, it is concluded that signs without any additional lighting in the evening had poor legibility for older subjects ($p < 0.003$). Older subjects need to come extra 60% closer to the signs under evening and raining condition to perceive them correctly.

(4) Issues on subjective workload and Igroup Presence Questionnaires (IPQ) are discussed as follows. The NASA –TLX developed by Hart and Staveland (1988) is a subjective workload assessment tool while the Igroup Presence Questionnaire (IPQ) is a scale for measuring the sense of presence experienced in a virtual environment (VE). Subscales of the NASA-TLX by mean scores (on 7 point scale) were used to measure the performance of mental demand, effort, and presence in our experiment. The effect of the virtual space on subjects was a significant main effect of age on the reaction time ($p < 0.023$) but the judgment in the VR world was not influenced by age ($p > 0.19$). More importantly, on most subscales, older and younger adults did not change in their judgment of subjective workload and senses of acting in the virtual space. Bigger estimates of subjective workload under low luminance conditions were found on all subscales ($p < 0 .001$). 92% of younger subjects felt present in the virtual space and 89% of older subjects were captivated by the virtual world. The results of IPQ showed that the VR scenes produced realistic effects.

5. Experimental Results

The results indicate that observed age-related evening and raining legibility performance decreases visual acuity results. Older subjects had a longer perception reaction time than younger ones ($p < 0.000$). The nighttime, raining and evening tests revealed that the older group had significantly longer decision sight distance compared to the younger group (T-tests of 95% significance). However, younger subjects showed an earlier start of response execution relative to the threshold of response preparation and a higher percentage of incorrect response by 32% in the VR scene. Multivariate test of differences between light and age was statistically significant ($p < 0.005$), and the difference between signs and light was also statistically significant ($p < 0.032$). Signs with symbols possessed superior mean legibility in comparison to the Chinese text signs by 53% ($p < 0.01$) and numerical text of speed limit signs by 49% ($p < 0.01$).

The poor legibility distances were provided by the letter/background combinations of Chinese character sign yielding contrast ratios of 3:1 and 5:1. Chinese text signs had poor legibility in the evening and night tests. Symbol signs can be an effective way to convey information if the subject is already familiar with the meaning of the icon or the symbol. The higher the contrast level, the better the recognition level for high contrast signs. At or above that level, the symbol recognition is simply driven by the visual acuity performance of the reader, which can easily be predicted by reference to the resolution of the smallest relevant (critical) detail. Bigger and brighter signs are more effective, and it took less time to provide a very high readability signs. It leads to a 45% enhancement in reaction time by enlarging the size 25% of the sign in the experiments.

6. Discussion and Future Work

It is obvious that visibility of traffic signs is critically important for driving safety; therefore, age-related changes in the human visual system must be taken into account in designing traffic signs to assure safe driving for older people. In this paper, to address this issue, some age-related changes of visual functions are investigated in relation to visibility of traffic signs. It is concluded that traffic sign legibility under different light conditions may be affected by age-related vision. Practical suggestions are provided after discusses on the suitability of current traffic sign standards. Moreover, according to the results of questionnaires used in conducting this research, only 18% of younger drivers and 28% of older drivers would turn on their headlights in the evening; 22% of younger drivers and 34% of older drivers would turn on their headlights on a rainy day. It also indicates the importance of our study because all of these factors affect a driver's vision and will therefore significantly increase chances for an accident.

Evening driving, for instance, is in twilight conditions, in which eyes could find it particularly difficult to differentiate relative brightness of red and blue objects, which phenomenon is called the "Purkinje effect" (Schnell, Aktan, Li, 2004). The "Purkinje effect" is the tendency of the peak luminance intensity of the eyes to transfer to the blue end of the color spectrum at low light beam levels (Purkinje,1825, Wade and Brožek, 2001). This effect introduces diversity in color contrast under different levels of illumination. For example, in clear sunlight, flowers appear to be bright red against the green of their leaves, but in the same scene viewed in the evening, the color contrast is reversed, with the red petals appearing a dark red or black, and the leaves appearing relatively bright. The phenomenon explains why signs in red will appear darker in the evening. The results also conveyed that evening driving results in poor perception accuracy distance for older drivers. Evening driving could be afflicted due to the Purkinje effect because the human eye lens become yellow and the transmittance for the short-wave region in the visible range (blue lights) decreases with age (ERGO 2001). Therefore, it is suggested that sufficient light should be provided for safe driving in the evening.

According to our study, we highly recommend all drivers should turn on the headlights not only in the night but also in raining and evening conditions. Most visual conditions can be perceived with the road luminance levels which are even lower than the recommended today (Artal P, 2012). Such signs are expected to engage driver's attention and have the potential to reduce driver workload and improve safety. Older people can process information from traffic signs efficiency by increasing light in the evening or on a raining day. Therefore, it is suggested that controlling lights by setting up environment light detector sensors on highways, designing light detector sensors to automatically turn on the car headlights or use the night vision equipment when color temperature is under 4100K and luminance contrast ratio is under 5:1. Our study also helps highlight the fact that when people ignore visual performance in evening and raining conditions it may cause accidents. More importantly, our study has set up the foundation for future work with contributing a dedicated viewpoint for traffic signs and visual performance under evening and raining conditions. Potential applications of this study include observations of visual search behavior in the VR world for the design of better simulation experiments.

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References

1. AAA Senior Driving 2012. http://seniordriving.aaa.com/understanding-mind-body-changes/vision/light-requirements
2. ASTM D 4956-09e1:2009. Standard specification for retroreflective sheeting for traffic control.
3. ERGO 2001. User's guide. Pasadena: Avery Dennison Corporation.
4. Fritchman Thompson Barbara.: 2005. Astronomy hacks tips and tools for observing the night sky.
5. Goodspeed, C. H., Rea, M. S.:1999. The significance of surrounding conditions for roadway signs, Journal of the Illuminating Engineering Society 28(1) :164-173.
6. Graham, J. R., Fazal A. and King L. E.: 1997. Minimum luminance of highway signs required by older drivers, Transportation Research Record 1573:91-98.
7. Madani, H.AI.: 2000. Influence of drivers' comprehension of posted signs on their safety related characteristics, Accident Analysis and Prevention 32:575-581.
8. McLaughlin, P.M. and Murtha, S.J.: 2010 Jul. The effects of age and exogenous support on visual search performance. Exp Aging Res 36(3): 325-45.
9. Hart, S.G. and Staveland, T.E.: 1988. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. In: Hancock PA, Meshkati N, Eds. Human Mental Workload. Amsterdam: North-Holland. pp.139- 178 .

10. Huang, K-C., Wang, H-F., Chen ,C-C.: 2010. Effects of shape, size, and chromaticity of stimuli on estimated size in normally sighted, severely myopic, and visually impaired students. Perceptual and Motor Skills 110:931-940.
11. Kline, T. J. B., Ghali, L.M. and Kline, D.W.: 1990. Visibility distance of highway signs among young, middle-aged, and older observers: icons are better than text, Human Factors 32: 609-619.
12. Kruithof, Arie and Tubular, Andries.: 1941. Luminescence Lamps for General Illumination. Philips Technical Review 6 (3): 65–96.
13. Green, Marc Ph.D. Co-Authors: Merrill, J. Allen O.D., Ph.D., Abrams ,Bernard S. O.D., Weintraub , Leslie O.D.: 2008.Contributor: Odom, J. Vernon Ph.D. Forensic vVision with application to highway safety with CD-Rom 3rd Edition. ISBN 10: 978-1-933264-54-7 Copyright Date Ed.
14. Wade, Nicholas J and Brožek, Josef.: 2001 Purkinje's Vision. Lawrence Erlbaum Associates pgs 13. ISBN 9780805836424.
15. Purkinje, JE. Neue Beiträge zur Kenntniss des Sehens in Subjectiver Hinsicht.: 1825. Reimer Berlin. pp.109–110.
16. Schieber, F. and Goodspeed, C.H.: 1997. Nighttime conspicuity of highway signs as a function of sign brightness, background complexity and age of observer, Proceedings of the Human Factors and Ergonomics Society 41st Annual Meeting. Santa Monica, CA: Human Factors and Ergonomics Society. pp. 1362-1366.
17. Schnell, T., Aktan, F., Li, C.: 2004. Traffic sign luminance requirements of nighttime drivers for symbolic Signs. Transportation Research Record No. 1862: Journal of the Transportation Research Board. pp.24-35.
18. Schwarz, C., Cánovas C., Mira-Agudelo A.: 2012. Night myopia studied with an adaptive optics visual analyzer, PLoS ONE 7(7): e40239. doi:10.1371 /journal. pone. 0040239
19. Smiley, A.: 2008. Driver behavior: A moving target. TR News 254:19-24. US Department of Transportation.
20. Mace, D.J., P.M. Garvey, and R.F Heckard.: 1994. Relative visibility of increased legend size Vs. brighter materials for traffic signs. FHWA-RD- 94-035, Federal Highway Administration, Washington, D.C.

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