Detection threshold of luminance contrast under strong light transition in tunnel driving

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Abstract. Drivers may be exposed to strong light transitions when entering a tunnel in daytime conditions. Good detection and visibility of on-road objects shortly after entering the tunnel is of great importance for safety concerns. In this study we tested several strong light transition levels as drivers may be challenged at real tunnel portals in a laboratory setup. Participants were exposed to a strong glare scene transiting to a dark scene. Contrast detection thresholds were measured in the transient adaptation process in dark. Results (N=17) showed a much higher contrast detection threshold in the transition from a glare scene of 14000 cd/m^2 than of 2000 cd/m^2. By raising the dark adaptation luminance from 8 to 60 cd/m^2, contrast sensitivity was improved by a factor of four. Illumination status at tunnel portal areas should be re-examined carefully.

Keywords. luminance contrast, disability glare, light transition, eye adaptation, tunnel driving, traffic safety

1. Introduction

A strong glare scene, or the so-called disability glare, causes visual discomfort and impairs certain visual functions (Boyce 2003). In our everyday driving routine, such glare disturbance may be seen in a low-sun condition or by facing the headlamp of a oncoming car, for instance, and might play a role in driving safety and quality. Particularly, in tunnel driving, drivers are facing tough challenges when abrupt and strong light transition takes place at portal areas. High-level glare may be seen in daytime conditions when one drives towards the tunnel entrance. Direct sunlight and/or reflection of sunlight on the portal surface could affect drivers' performance while causing strong glare and impairing visual abilities. In comparison to the highly-illuminated exterior of the tunnel, the interior of the tunnel is usually at a relatively low luminance level. When entering a tunnel, light adaptation of the eye is stressed by the strong light transition all in a sudden. Such abrupt as well as strong light transition might affect drivers' visual functions to a certain extent, and drivers may be unable to cope with such demands (Babizhayev 2003, Gray & Regan 2007).

One of the known issues is the reduced contrast sensitivity, which might be a critical factor regarding traffic safety concerns. Drivers might fail to see or detect the on-road objects clearly, e.g. the front car, traffic signs, the pavement, etc., and we might expect risky driving events to happen. Previous studies have shown that immediately after being exposed to high-level glare conditions, the contrast threshold in a dark visual environment is increased. Increase in contrast threshold during the phase of transient adaptation, i.e. the phase between two levels of light adaptation, has been studied by Greule (1993). Stronger effect has been shown with increasing step size of transition of luminance levels. Greule has examined contrast threshold for the light transition from 8000 cd/m^2 to 8 cd/m^2, and showed that the effect on contrast sensitivity loss is roughly seven times larger when compared to the effect at a weaker transition from 2000 cd/m^2 to 8 cd/m^2. In our actual tunnel driving in Switzerland, an even much stronger light transition has been found, e.g. from 14000 cd/m^2 to 15 cd/m^2, and could cause more severe impact on our contrast vision performance. Such lighting transitions have been measured at the south-east portal of the Uetliberg tunnel (Menozzi 2009).

By our knowledge the literature lacks from reporting about the loss of contrast sensitivity during the transient adaptation process at higher luminance ranges as investigated by Greule (1993). Therefore we have conducted the transient adaptation experiment in this study in order to better understand the discrimination function in terms of the contrast detection threshold when encountering strong light transitions as in reality for tunnel driving. In addition, considering an important prerequisite for reducing the abovementioned risk is a smoother light transition of adaptation levels, we have investigated the potential influence of an improved illumination condition in the dark adaptation phase at tunnel entrance areas on the contrast performance.

2. Methods

A laboratory transient adaptation experiment has been carried out in a dark room. The experiment required the participants to detect the orientation of a visual target, i.e. a Landolt ring, during the transition adaptation process shortly after a light transition took place. The luminance level of the Landolt ring varied during the test and the contrast detection thresholds were estimated under several transition conditions.

2.1 Experimental procedure

Participants were asked to perform a forced choice task in detecting the orientation of a visual target appearing shortly after the light transition takes place. The visual target used in this experiment was a Landolt ring with four possible orientations (up, right, down, and left) and varied in its contrast level. There were five light transition conditions being tested in this study - Condition 1: from 2000 cd/m^2 to 8 cd/m^2; Condition 2: from 6000 cd/m^2 to 8 cd/m^2; Condition 3: from 10000 cd/m^2 to 8 cd/m^2; Condition 4: from 14000 cd/m^2 to 8 cd/m^2; and Condition 5: from 14000 cd/m^2 to 60 cd/m^2. There were 30 trials in each test condition. A training session lasting for 1 minute was given before the main experiment. In the main experiment, the contrast detection thresholds were examined at two adaptation time durations, i.e. 100 ms and 500 ms after exposure to glare, for each test condition. Participants were explained that in each trial, a bright white screen would appear for the duration of 3 s and shortly after the bright scene disappears, a Landolt ring would be presented for the duration of 50 ms. Participants were asked to perform the task as accurate as possible and within 2 s after the display background turned to dark.

2.2 Instrumentation

Participants were seated at a viewing distance of 45 cm to a projection panel (H x V : 18.9° x 14.2°). Two projectors (Acer PD321) with specific optical settings were used to in the experiment. One projector projected the background scene from bright glare scene (14000 cd/m^2, 10000 cd/m^2, 6000 cd/m^2, or 2000 cd/m^2) transiting to a dark scene (8 cd/m^2 or 60 cd/m^2). The other projector projected the visual target, i.e. a Landolt ring, varying in various luminance levels superimposed centrally on the background scene. The presented Landolt ring corresponded to a decimal visual acuity level of 0.28. An arrow key set on a PC keyboard was used for the participants to report the orientation of the Landolt ring being detected. A Nyctometer test (Rodenstock Nyktometer, Plate 501) was run before the main experiment, in order to measure the dark adaptation performance and sensitivity for dazzling.

2.3 Participants

A total of 17 participants, 10 females and 7 males, took part in this study. Participants ranged in age from 14 to 55 years, with the mean age of 32.5 years. None of the participants reported any ocular diseases. All had normal or corrected-to-normal binocular acuity (decimal acuity 1.0) as determined by the vision examinations for a viewing distance of 45 cm. Participants wore their habitual optical correction for near vision during the experiment, if applied. The experiment consisted of one session of vision examination and one session of transient adaptation test, for a total of 30 minutes, approximately. Participants were recruited from the ETH Zurich and the University of Zurich campuses and were rewarded a small gift after completing the experiment.

The present study has been approved by the Research Ethics Committee of ETH Zurich. All participants were given a full explanation about the experimental procedures orally and in a written form. A consent form was obtained with the right to withdraw from the study at any time without giving reasons and without any negative consequences.

3. Results

Table 1 shows the average ΔL thresholds among the total 17 participants under two light transition conditions (Condition 1: from 2000 cd/m^2 to 8 cd/m^2 and Condition 5: from 14000 cd/m^2 to 60 cd/m^2) measured at two dark adaptation time τ of 100 ms and 500 ms after the light transition took place. Additionally, tab. 1 reports Weber contrast thresholds for the two conditions of dark adaptation time (τ).

Table 1. *Experimental results of the total participants (N=17) under two light transition conditions. Average ΔL ($L_{Landolt\ ring}$ - $L_{background}$) and contrast thresholds at adaptation time τ = 100 ms and 500 ms, where Weber contrast C = ΔL / $L_{background}$ x 100%.*

Light transition condition	**Dark adaptation time τ**	**Threshold expressed as ΔL (cd/m^2)**	**Threshold expressed as Weber contrast (%)**
Condition 1: 2000 cd/m^2 ↓ 8 cd/m^2	100 ms	16.35	212.3
	500 ms	5.93	77.1
Condition 5: 14000 cd/m^2 ↓ 60 cd/m^2	100 ms	181.11	301.9
	500 ms	69.42	115.7

Contrast detection thresholds under the total five light transition conditions (Condition 1, 2, 3, 4, and 5) were examined among five of the total participants (2 females and 3 males, 24 to 55y with an average of 36.8y). In Fig. 1 we have plotted the experimental results graphically.

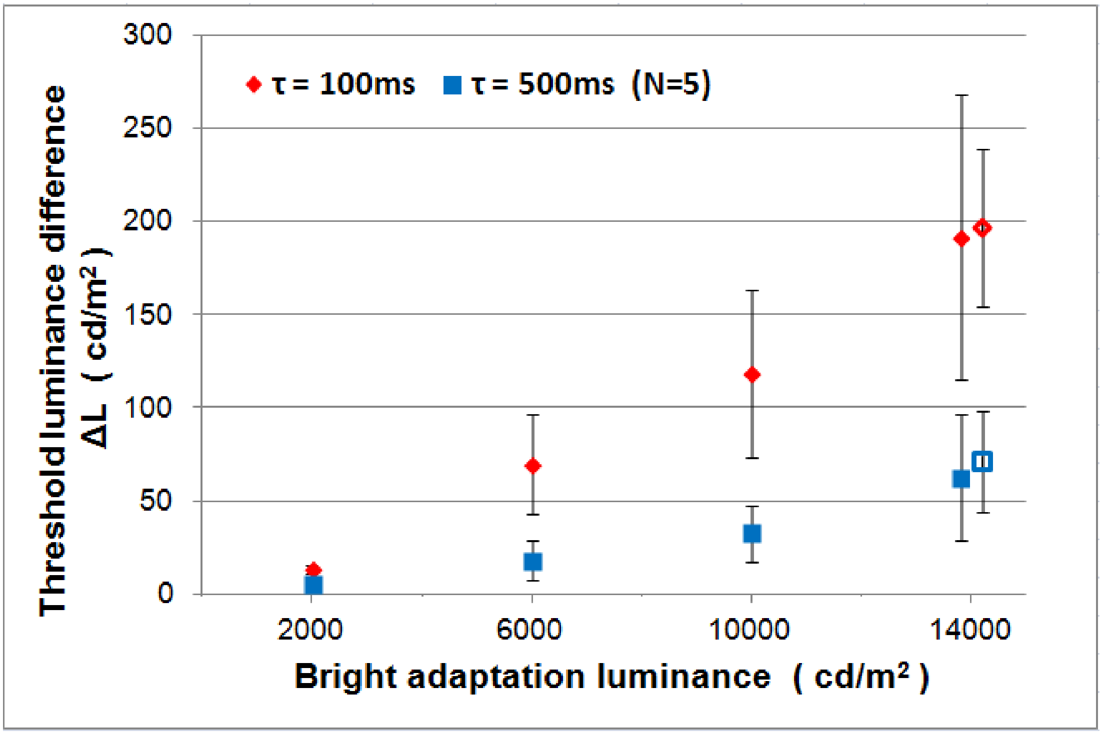

Figure 1. *Graphical representation of the contrast thresholds expressed as ΔL ($L_{Landolt\ ring}$ - $L_{background}$) at two adaptation points (τ = 100 ms and 500 ms) under five light transition conditions. The filled symbols represent a light transition from the indicated bright adaptation luminance (2000 / 6000 / 10000 / 14000 cd/m^2) to a dark adaptation luminance of 8 cd/m^2. The open symbols represent the light transition from 14000 cd/m^2 to 60 cd/m^2.*

4. Discussion

In parts of the transient adaptation experiment, we were able to replicate the contrast sensitivity performance for low(-er) luminance visual environment as addressed in previous studies (Greule 1993; Blackwell 1946; Newacheck et al. 1990; Sturgis & Osgood 1982). Experimental results from this study showed quite a reasonable range of contrast sensitivity when comparing with others' observations for steady-state contrast sensitivity, thus revealed a convincing setup from our experimental designs.

In the weaker light transition situations, i.e. from 2000 cd/m^2 to 8 cd/m^2, the required liminal luminance difference of the visual target after 100 ms adaptation time was 16.35 cd/m^2, which corresponded to a contrast threshold of 212.3%. When the eyes got more adapted to the dark environment, at 500 ms after the light transition, the contrast threshold then dropped to 77.1%, about one-third at 100 ms adaptation time, where a lower contrast threshold indicates a better performance in contrast sensitivity. In other words, when car drivers are travelling from such light transition, the on-road objected are much more difficult to be detected right after entering the dark interior. In our daily tunnel driving, the light transition could be much stronger than the abovementioned cases. As we may see from the results as shown in Fig. 1, with increasing luminance level of the bright adaptation phase, the required threshold luminance difference of the target increased dramatically.

In order to compare our data to Greule, where Greule mainly used the contrast threshold increasing factor φ for comparing the results in different transition conditions (Greule 1993), we have taken the referenced steady-state contrast thresholds from previous literatures to assess the estimated contrast threshold increasing factor φ in our experiments (Blackwell 1946; Newacheck et al. 1990; Sturgis & Osgood 1982). In Greule's study, φ has been defined as the contrast threshold at adaptation time τ divided by the contrast threshold after a 60 sec adaptation period. We have assumed the steady-state contrast thresholds of 7% and 12% at the background luminance levels of 60 cd/m^2 and 8 cd/m^2 respectively in our study. In table 2 we have indicated obtained φ values from our experiments and from Greule. As we can see from table 2, when a fixed luminance level of the dark environment was given, i.e. 8 cd/m^2, a larger φ was shown when a stronger light transition took place. This is in accordance with our knowledge that a higher glare level would cause stronger effects on the adaptation mechanism and cause lower contrast performance.

Table 2. *The contrast threshold increasing factor φ under different light transition conditions. φ = contrast threshold C_τ / steady-state contrast threshold $C_{steady\text{-}state}$. * In Greule's data (1993), the φ was defined as contrast threshold C_τ / contrast threshold $C_{\tau = 60\ sec}$..*

	φ	
Light transition conditions	**τ = 100 ms**	**τ = 500 ms**
Condition 1: 2000 cd/m^2 to 8 cd/m^2	14.1	5.1
Condition 2: 6000 cd/m^2 to 8 cd/m^2	75.3	19.3
Condition 3: 10000 cd/m^2 to 8 cd/m^2	117.4	32.1
Condition 4: 14000 cd/m^2 to 8 cd/m^2	190.1	61.9
Condition 5: 14000 cd/m^2 to 60 cd/m^2	46.8	16.9
*Greule: 2000 cd/m^2 to 8 cd/m^2	14.1	4.4
*Greule: 4000 cd/m^2 to 8 cd/m^2	32.5	8.7
*Greule: 4000 cd/m^2 to 16 cd/m^2	22.4	5.6
*Greule: 6000 cd/m^2 to 8 cd/m^2	50.8	12.5
*Greule: 6000 cd/m^2 to 24 cd/m^2	28.4	6
*Greule: 8000 cd/m^2 to 8 cd/m^2	90.5	21.5

Another important finding from table 2 would be, when we fixed the extreme glare condition at a luminance level of 14000 cd/m^2 and raised the dark adaptation luminance from 8 cd/m^2 to 60 cd/m^2, we may notice that a considerable improved contrast sensitivity was achieved by a factor of four.

5. Conclusions

Contrast detection thresholds have been investigated under several rapid and strong light transitions in this study aiming to better understand the contrast performance of drivers in certain critical driving events at tunnel portals. Experimental results revealed a noticeable increasing contrast detection threshold measured in the dark adaptation phase in a stronger transition from 14000 cd/m^2 to 8 cd/m^2 than in a weaker transition from 2000 cd/m^2 to 8 cd/m^2. The on-road objects inside the tunnel must be much brighter, i.e. 4.5 times, than the background environment to be seen well or recognized. This shows us a very critical driving task near the tunnel portal area. Even when we have adapted to the darkness for 500 ms, i.e. corresponding to a travelling distance of 13.9 m at a speed of 100 km/h, a contrast threshold of 166%. We still have a bad contrast sensitivity for retrieving the visual objects.

As we have increased the darkness from 8 to 60 cd/m^2, the contrast sensitivity has been significantly improved. In our tunnel driving, we may not be able to change the strong glare from the sunshine, however, we may expect a much more reliable contrast performance when the illumination condition of the tunnel interior near the portal area has been improved.

6. References

Babizhayev M (2004) Glare disability and driving safety. Ophthalmic research 35: 19-25.

Blackwell HE (1946) Contrast threshold of the human eye. Journal of the Optical Society of America 36(11): 624-643.

Boyce PR (2003) Human Factors in Lighting. second ed., 162-191. New York: Taylor & Francis.

Gray R, Regan D (2007) Glare susceptibility test results correlate with temporal safety margin when executing turns across approaching vehicles in simulated low-sun conditions. Ophthalmic and Physiological Optics 27: 440-450.

Greule R (1993) Kontrastschwelle bei transienter Adaptation. Dissertation an der Universität Fredericiana, Karlsruhe.

Menozzi M (2009) Expertengutachten zu den Lichtverhältnissen an Tunnelportalen der Westumfahrung und der A4 Knonaueramt zuhanden der Baudirektion des Kantons Zürichs. ETH Zürich.

Newacheck JS, Haegerstrom-Portnoy G, ADAMS AJ (1990) Predicting visual acuity from detection thresholds. Optometry and Vision Science 67(3): 184-191.

Sturgis SP, Osgood DJ (1982) Effects of glare and background luminance on visual acuity and contrast sensitivity: implications for driver night vision testing. Human Factors 24(3): 347-60.

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