# Contrast vision performance during transient adaptation phase under glare disruption

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**Abstract.** Unfavorable light events bring on visual discomfort and affect certain visual functions when human operators are facing tough challenges or conducting a task. Hence, considerable inefficient performance and human errors may lead to serious problems and unexpected costs in an overall system performance. Various forms of glare are influential factors impacting on the performance of works because of certain psychological effects as well as physiological effects. However, the data reported about contrast vision performance of the eye in critical light environments is either limited or old. In this study, we focused on investigating the physiological effects of light events involving strong glare disturbance on human vision. We aim to measure and establish a database of the dark-adapted contrast vision of human subjects as a first step. Participants are exposed to several strong and fast light events, i.e. luminance levels change extremely within a short time. A set of optics instrument with vision measure system and display media are developed and constructed for exploring the visual performance and characteristics during the transient adaptation phase. We aim to further analyze and characterize the dynamics of contrast vision recovery mechanism. The result of this study is anticipated to realize more clearly about our contrast vision performance under transient and heavy light events. Besides, as different ages may have different visual performance, the contrast vision recovery mechanism built in this prospective study can be a basis or comparison for other ages in the later studies. Furthermore, the findings can be applied and explored in existing work environments and luminance conditions, providing more safe, productive, comfortable, and effective human use in ergonomics concerns.

**Keywords:** contrast vision, transient, adaptation, glare, visual discomfort, recovery mechanism

## 1. Introduction

Strong glare causes visual discomfort and impairs certain visual functions. Among many daily glare-related events, one critical situation occurs at tunnel portal areas – drivers are facing tough challenges when abrupt and strong light transition is involved. High-level glare may be seen in daytime conditions while driving towards the tunnel entrance. Direct sunlight and/or reflection of sunlight on the portal surface could affect drivers' performance while impairing visual ability. In comparison to the highly-illuminated exterior of the tunnel, the interior of the tunnel is usually at a very low luminance level. When entering a tunnel, such strong light transition causes adaptation problems of the eyes all in a sudden. 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/detect the on-road objects clearly, e.g. the front car, traffic signs, the pavement, etc., and we might expect dangerous driving events to happen.

Previous studies have shown that immediately after being exposed to high-level glare conditions, the contrast threshold in dark visual environment is increased. Increase in contrast sensitivity during the phase of transient adaptation, i. e. the phase between two levels of light adaptation, has been studied by Greule (1993). The effect has been shown to increase with step size of transition of luminance (Greule 1993). Greule has examined contrast sensitivity for the light transition from 8'000 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 transition from 2'000 cd/m$^2$ to 8 cd/m$^2$. In our actual tunnel driving, an even much stronger light transition, e.g. from 14'000 cd/m$^2$ to 60 cd/m$^2$ was measured at a tunnel portal in Switzerland, could cause severer impact on our contrast sensitivity. 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 loss of contrast sensitivity during transient adaptation at higher luminance ranges as investigated by Greule (1993). Therefore we have conducted the transient adaptation experiment in order to better understand the contrast performance when encountering strong light transition as in the real case for tunnel driving.

## 2. Methods

A laboratory transient adaptation experiment has been carried out in a dark room. The experiment required the participants to detect a visual target appearing shortly after the light transition took place, i.e. 100 ms and 500 ms (after exposure to glare), which varied in its contrast level. There were a total of five light transition conditions applied: from 2’000 cd/m$^2$ to 8 cd/m$^2$, from 6’000 cd/m$^2$ to 8 cd/m$^2$, from 10’000 cd/m$^2$ to 8 cd/m$^2$, from 14’000 cd/m$^2$ to 8 cd/m$^2$, and from 14’000 cd/m$^2$ to 60 cd/m$^2$. Two experimental sets were conducted: in Set A (as a pilot study), five participants were measured for all five light transition conditions; in Set B, 17 participants were measured for only two light transition conditions (from 2’000 cd/m$^2$ to 8 cd/m$^2$ and from 14’000 cd/m$^2$ to 60 cd/m$^2$).

The visual target used in this experiment was a Landolt ring with four possible orientations (up, right, down, and left) and corresponded to a decimal visual acuity level of 0.28. In this study, the Landolt ring subtended a visual angle of 17.5' (minutes of arc) with the opening subtending a visual angle of 3.5'. Participants were guided to use the arrow keys on a keyboard to indicate the orientation of the Landolt ring being detected.

Participants were seated at a distance of 50 cm to a projection panel (H x V : 20° x 15°). Two projectors (Acer PD321) with specific optical settings were used to project the viewing background from glare (2’000 cd/m$^2$, 6’000 cd/m$^2$, 10’000 cd/m$^2$, or 14'000 cd/m$^2$) transiting to darkness (8 cd/m$^2$ or 60 cd/m$^2$) and the target varying in various luminance levels superimposed centrally on the background. In the main experiment, the first section was examining the required contrast threshold in a dark environment of 8 cd/m$^2$ and 100 ms after the glare exposure of 2'000 cd/m$^2$. A total of 30 trials were included in the section. Each trial started with the full screen of glare scene (2'000 cd/m$^2$) for 3 sec and then changed to the dark scene (8 cd/m$^2$). A Landolt ring was presented 100 ms after the background transited to the dark scene. The Landolt ring was presented for a duration of 50 ms. After the Landolt ring disappeared, the dark scene background remained for a duration of 2 sec and the participant was asked to report the orientation of the ring within this 2 sec. The orientation of the Landolt rings were chosen randomly.

A staircase method was applied to alternate the luminance levels of the Landolt rings among the 30 trials. In the second section, the visual targets were presented 500 ms after the light transition from 2'000 cd/m$^2$ to 8 cd/m$^2$. The other sections were similar to the first two section in principle. For instance, in the last two sections, the visual targets were presented 100 ms or 500 ms after the light transition from 14'000 cd/m$^2$ to 60 cd/m$^2$.

## 3. Results

Experimental results from the five participants in Set A (two females and three males, 24y to 55y, mean age of 36.8y) were included in the following sessions (In Set B with 17 participants, we measured only two light transitions and compared the results with the Set A. Results have shown that participants from both experimental sets had close performance. We assume that the smaller group (n = 5) may represent the general data. Therefore, in this study, we focus our evaluation and analysis based on the Set A.) All participants had normal or corrected-to-normal visual acuity, and wore their habitual corrections during the experiment, if applied. From each section, we have obtained the luminance levels of Landolt rings being detected among the total 30 trials based on the staircase method selecting process. For each participant, we have considered the average luminance (ΔL) of the last 5 turning points in the staircase procedure as his/her luminance threshold per condition. Table 1 shows the average ΔL thresholds in Set A (n = 5) under the light transition condition from 2’000 cd/m$^2$ to 8 cd/m$^2$ at τ = 100 ms and 500 ms after the light transition took place. In addition, the Weber contrast thresholds for the two conditions of target onset time (τ) has been reported as well.

***Table 1:*** *Average ΔL ($L_{Landolt\ ring}$ - $L_{background}$) and contrast thresholds under the light transition condition from 2’000 cd/m2 to 8 cd/m2 (τ = 100 ms) and section 2 (τ = 500 ms). Weber contrast C=ΔL/Lbackground x100%.*

| | Threshold expressed as ΔL (cd/m$^2$) | Threshold expressed as Weber contrast (%) |
|---|---|---|
| τ = 100 ms | 22.53 | 292.6 |
| τ = 500 ms | 9.45 | 122.7 |

In Table 2 we have shown the average ΔL and contrast thresholds assessed in the light transition condition from 14'000 cd/m$^2$ to 60 cd/m$^2$ at two time points (τ = 100 ms and 500 ms) after the light transition in Set A (n = 5).

***Table 2:*** *Average ΔL ($L_{Landolt\ ring}$ - $L_{background}$) and contrast thresholds under the light transition condition from 14’000 cd/m² to 60 cd/m² (τ = 100 ms) and section 4 (τ = 500 ms). Weber contrast C=ΔL/Lbackground x100%.*

| | Threshold expressed as ΔL (cd/m²) | Threshold expressed as Weber contrast (%) |
|---|---|---|
| τ = 100 ms | 271.65 | 452.8 |
| τ = 500 ms | 99.62 | 166 |

## 4. Discussion and Conclusions

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 and 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 2'000 cd/m² to 8 cd/m², the required liminal luminance difference of the visual target after 100 ms adaptation time was 22.53 cd/m², which corresponded to a contrast threshold of 292.6%. When the eyes got more adapted to the dark environment, at 500 ms after the light transition, the contrast threshold then dropped to 122.7%, less than half 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 or recognized right after entering the dark environment.

In our daily tunnel driving, the light transition could be much stronger than the abovementioned cases. In the stronger light transition experiment sections, i.e. from 14'000 cd/m² to 60 cd/m², at the adaptation time of 100 ms, we found the required liminal luminance difference of the target was increased to 271.65 cd/m², which corresponded to a high contrast threshold of 452.8%. A higher contrast threshold shows a more critical situation in our contrast sensitivity function. This result shows that when car drivers enter a tunnel in a sunny day, for a short moment they are unlikely being able to detect their visual targets well. This could be a very dangerous and critical moment for the tunnel driving. After a 500 ms adaptation time from the strong light transition, the luminance difference threshold decreased to 99.62 cd/m², which corresponded to a contrast threshold of 166%.

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 1990, Sturgis 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/m² and 8 cd/m² respectively in this study.

In Table 3 we have indicated the obtained φ values from our experiments and from Greule. When a fixed luminance level of the dark environment was given, i.e. 8 cd/m², 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. We may expect a much larger φ, in comparison to the 8’000 to 8 cd/m² situation (φ = 90.5) from Greule's data, to be found in a 14’000 to 8 cd/m² case, if any.

***Table 3:*** *The contrast threshold increasing factor φ in different light transition conditions. φ = contrast threshold $C_\tau$ / steady-state contrast threshold $C_{steady\text{-}state}$. * In Greule's data, the φ was defined as contrast threshold $C_\tau$ / contrast threshold $C_{\tau = 60\ sec}$.*

| | φ | |
|---|---|---|
| Light transition conditions | τ = 100 ms | τ = 500 ms |
| From 14’000 cd/m² to 60 cd/m² | 64.7 | 23.7 |
| From 2’000 cd/m² to 8 cd/m² | 24.4 | 10.2 |
| Greule: 8’000 cd/m² to 8 cd/m² | 90.5 | 21.5 |
| Greule: 6’000 cd/m² to 24 cd/m² | 28.4 | 6.0 |
| Greule: 6’000 cd/m² to 8 cd/m² | 50.8 | 12.5 |
| Greule: 4’000 cd/m² to 16 cd/m² | 22.4 | 5.6 |
| Greule: 4’000 cd/m² to 8 cd/m² | 32.5 | 8.7 |
| Greule: 2’000 cd/m² to 8 cd/m² | 14.1 | 4.4 |

Another important finding would be, when we fixed the light level of the glare source and changed the dark background luminance, we may notice that a better contrast sensitivity was achieved when the dark environment was set to a higher luminance level. Our current setting of a light transition from 14’000 cd/m² to 60 cd/m² showed an increasing contrast threshold factor of 64.7 at the adaptation time of 100 ms, and still as high as 23.7 at the adaptation time of 500 ms. As mentioned before, we would expect a φ (much) larger than 90.5 in a light transition from 14’000 to 8 cd/m² at τ = 100 ms. As we have increased the darkness from 8 to 60 cd/m², the contrast sensitivity has been significantly improved to 64.7. In our tunnel driving cases, we may not be able to change the strong glare from the sunshine, however, we may expect our contrast sensitivity performance improved by increasing the interior luminance level of the tunnel near the portal area.

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