Dark adaptation to spatially complex backgrounds

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Introduction

Visual adaptation enables the human visual system to perceive a large range of light intensities. In this paper we specifically address dark adaptation, i.e. the process where the visual system adapts from high to low light intensities.

For many years scientists have been interested in dark adaptation. In these studies the adaptation threshold (i.e., the lowest light level that can be detected) was measured as a function of adaptation time. Typically the following method was used: First, participants were pre-adapted to a bright light, and afterwards they were asked to detect a dim target (of a given luminance) in a dark background. The dependent measure was the time that was needed to detect the target.

The vast majority of studies discussed in literature researched dark adaptation to spatially uniform dark backgrounds. However, one may argue the applicability of such adaptation models to every-day activities as driving at night, where the field of view exists of mixed light and dark areas. For predicting adaptation thresholds for these kinds of activities it seems sensible to use models based on adaptation to complex backgrounds.

Yet, research regarding adaptation to spatially complex backgrounds has been very scarce. Plainis, Murray, and Charman (2005) showed that the adaptation threshold for detecting a target in a uniformly *lit* background was higher than detecting a target in a spatially uniform *dark* background. Moreover, Uchida and Ohno (2013) compared the adaptation threshold (for one point in time) of a spatially *uniform* lit background to a spatially *complex* background, and found that the threshold was higher for the spatially complex background, even though the total luminance level of both backgrounds was equal.

The exact reason why a spatially complex background leads to a higher adaptation threshold than a spatially uniform background of the same total luminance is unclear. A possible explanation may be found in the concept of veiling luminance. A bright source in a dark background may cast a veiling luminance over the entire field of view, leading to a reduction in contrast between the target and the background, which subsequently can lead to a decreased visibility. Still, it is unknown if veiling luminance fully accounts for the increased adaptation threshold, or if the intrinsic adaptation process itself is affected too.

The studies discussed so far led to initial insights in adaptation models which can be applied to real-life situations, but were still limited in the variations in backgrounds and did not describe the full range of adaptation times. Therefore we extended the existing research by investigating full dark adaptation to various spatially complex backgrounds. Additionally, we studied the underlying mechanisms that play a role in the adaptation process, and therefore researched why spatially complex backgrounds lead to higher adaptation thresholds than spatially uniform backgrounds.

To this end, we set up three experiments: Experiment E1 researched adaptation to a spatially uniform dark background, and served as a reference. Experiment E2 researched adaptation to dark backgrounds containing a bright luminescent source. Experiment E3 researched adaptation to backgrounds having different spatial luminance patterns, but with equal veiling luminance and, where possible, total luminance.

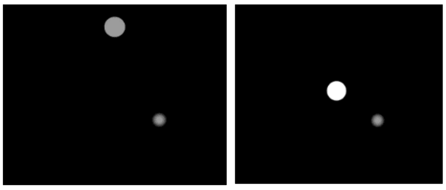

Fig. 1: Backgrounds as used in experiment E2. The left image shows the dark background, containing a target (depicted on the right side) and a subtle luminescent source. The right image shows the background with a target and a harsh luminescent source.

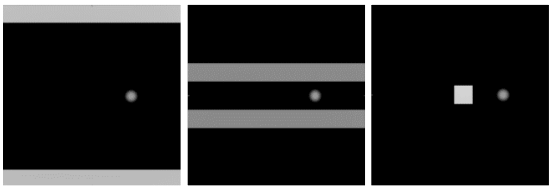

Fig. 2: Backgrounds (including target on the right side) as used in experiment E3. The left image shows a background having two bars at 9° visual angle from the target. The middle image shows a background having two bars at 2.7° visual angle from the target. The right image shows a background having a square in the center.

Methods

In all experiments a similar set up was used. All stimuli were shown on a high brightness display (FIMI-Philips 18” SXGA) of 20º by 20º visual angle, at a fixed viewing distance of 0.75 meters to the participants.

In all three experiments the participants were first adapted to a full white pre-adaptation field of 650 cd/m^2 for 1 minute. Directly after the pre-adaptation field disappeared, a target was shown at the left or the right side of the center of its background. We asked the participants to indicate whether the target was presented at the left or the right side, as soon as they saw the target. The dependent measure was the time that it took till participants were dark adapted enough to detect the target.

The design and independent variables were different per experiment and are explained separately per experiment.

For experiment E1, where adaptation to a dark background was measured, we used a full-factorial within-subjects design with one independent variable, i.e. the luminance of the target (having six levels, ranging from 11.19 cd/m^2 to 0.014 cd/m^2). All target luminance levels were measured six times by all participants. In this experiment the target was presented in a spatially uniform dark background that only contained a small orientation point. The latter was introduced to make a valid comparison to experiments E2 and E3, where the spatial variations in luminance in the background may have served as orientation cue in the further fully dark environment.

For experiment E2, where we studied the effect of adaptation to a dark background containing a luminescent source, a mixed within- and between-subjects design was used. This design existed of two independent variables: the luminance of the target (similar to experiment E1), and variations to the luminescent source. As depicted in Fi2, two types of luminescent sources were researched: A) a ‘subtle’ source, located at 10° from the target, having a luminance of 10 cd/m^2 and B) a ‘harsh’ source, located at 5° from the target, having a luminance of 650 cd/m^2. All participants assessed ten target and background combinations, which were repeated six times.

For experiment E3, where adaptation to various spatial luminance patterns in the background was researched, also a mixed within- and between-subjects design with two independent variables was used. The first variable was the luminance of the target, having eight levels (ranging from 11.19 cd/m^2 to 0.014 cd/m^2). The second variable was the spatial luminance pattern in the background, having three levels (as depicted in Fig 3). The first luminance pattern was made by adding a bar to the top and bottom of the otherwise dark background at 9° visual angle from the target. The second pattern was made by adding two bars to the dark background, located at 2.7° visual angle from the target. The third pattern was created by adding a square to the center of the dark background, in between the two potential positions of the target (located at 4.3° visual angle from each target). In all backgrounds of experiment E3 the veiling luminance (calculated by CIE (1999), equation 11) at the location of the target was 0.07 cd/m^2. The average luminance per pixel of the total background was 1.02 cd/m^2 for the second and the third luminance pattern but had to be higher (8.41 cd/m²) for the first luminance pattern in order to keep the veiling luminance constant. For those backgrounds having equal total luminance and equal veiling luminance, the contrast of the target and the background was equal. All participants assessed eight target and background combinations, which were repeated for four times.

Six participants (four males, two females) with an average age of 28 (Standard Deviation (SD) = 5.1) performed experiment E1. A total of thirty participants (17 males, 13 females) joined experiment E2. Their average age was 27.9 (SD = 4.7). Thirty participants (19 males, 11 females), having an average age of 28 (SD =7.3), joined experiment E3.

The data were analyzed with two Linear Mixed Models (LMM) using IBM SPSS Statistics 20. Firstly, we prepared the data by excluding incorrect measurements, and corrected for guessing. Following this we analyzed the data of experiment E1 compared to experiment E2 in LMM1 and the data of experiment E3 in LMM2. Further, we analyzed the correlation between veiling luminance and adaptation time for the backgrounds of experiment E2.

Results

The results of LMM1 (graphically depicted in Figure 3) showed significantly longer ($p < .001$) adaptation times for detecting a target in the background containing a harsh luminescent source compared to detecting a target in the background containing a subtle luminescent source and detecting a target in the spatially uniform dark background. No significant difference was found between detecting a target in the background containing a subtle luminescent source and detecting a target in the spatially uniform dark background.

The backgrounds studied in experiment E2 showed a high correlation ($r = 0.85$ for a target of 0.014 cd/m²) between the calculated veiling luminance and the measured adaptation time.

The results of LMM2 (see Fig 3) showed significant longer adaptation times ($p < .01$) for detecting a target in the background having a central square, than for detecting a target in the background having two bars at 9° distance. Further, we found a small increase ($p = .056$) in adaptation time for detecting a target in the background having two bars at 2.7° distance, compared to the background having the two bars at 9° distance from the target. No significant difference in adaptation time was found for detecting a target in the background having two bars at 2.7° distance from the target compared to the background having a square in the center.

Discussion

The present study researched the effects of spatially complex backgrounds compared to spatially uniform dark backgrounds on the dark adaptation process, and additionally studied the underlying mechanisms explaining potential differences.

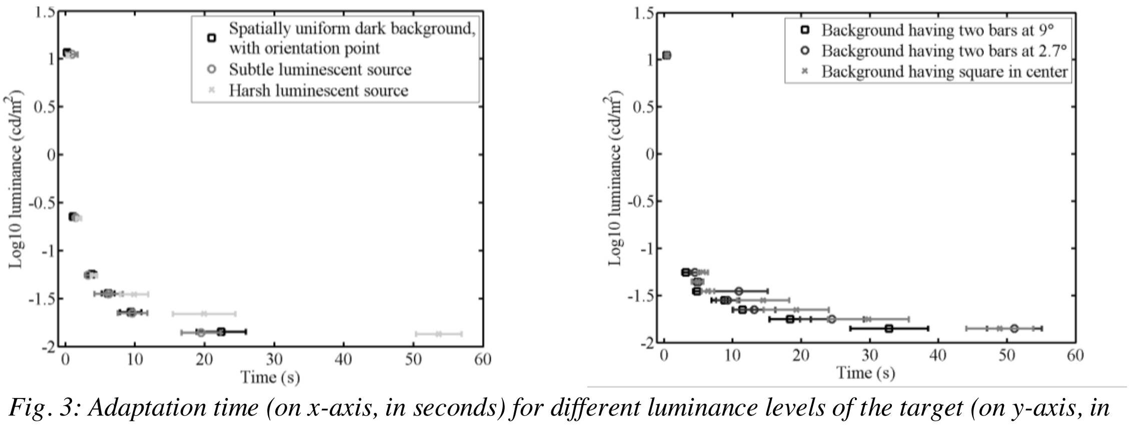

Fig. 3: Adaptation time (on x-axis, in seconds) for different luminance levels of the target (on y-axis, in cd/m²). The left figure presents the results of a spatially uniform dark background, of a background containing a subtle luminescent source, and of a background containing a harsh luminescent source. The right figure presents the results of a background having two bars at 9°, of a background having two bars at 2.7°, and of a background having a square in the center.

We found that a considerable longer adaptation time was required for detecting a target in a background containing a harsh luminescent source than for detecting a target in a spatially uniform dark background. Hence, this finding shows the importance of using models based on spatially complex backgrounds to predict adaptation thresholds for activities as driving at night, because models originating from spatially uniform backgrounds may lead to an overestimation of the visual systems' sensitivity. However, creating such models may not be trivial, since the present study also showed differences in adaptation time depending on the specific shape of the spatially complex background. Detecting a target in a background containing a harsh luminescent source resulted in a longer adaptation time than detecting a target in a background containing a subtle source. Moreover, adapting to a background containing a subtle luminescent source did not differ from adapting to a spatially uniform dark background. As discussed before, these effects may be explained by veiling luminance. Indeed, the correlation analysis confirmed a relationship between veiling luminance and adaptation time. Still, this analysis couldn't reveal whether veiling luminance was the only underlying factor explaining the differences in adaptation time.

Experiment E3 provided additional insights: it demonstrated that differences in adaptation time for detecting a target in a complex background could not exclusively be explained by veiling luminance, since different spatial backgrounds with equal veiling luminance yielded a different adaptation time. Therefore, the results showed that the intrinsic adaptation process was affected as well. More specifically, detecting a target in a spatially complex background having luminescent areas closer to the target (e.g., a background with bars at 2.7° distance from the target and a background with a square at 4.3° distance from the target) resulted in longer adaptation times than detecting a target in a background with bars at 9° distance. This effect was found despite the total luminance of the latter background being higher than the total luminance of the former backgrounds.

No difference in adaptation time was found for detecting a target in the background with the square and in the background with the bars at 2.7° distance. Veiling luminance and total luminance were equal for these two backgrounds, though other features, such as the surface area and location with respect to the potential target, were very distinct. Our first results indicate that these other features are less important in the adaptation process than veiling luminance and total luminance. However, our current experimental design was too limited to draw firm conclusions. Hence, more research is needed to better understand the full extent of the mechanisms underlying dark adaptation to spatially complex backgrounds, in order to create models that are fully applicable to activities as driving at night.

Conclusion

The results of the present study show that detecting targets in spatially complex backgrounds may lead to longer adaptation times than detecting targets in spatially uniform dark backgrounds. Therefore, we conclude that it is important to make use of models based on spatially complex backgrounds when predicting the adaptation threshold of a motorist driving at night. Moreover, we may conclude that besides an effect of veiling luminance, the intrinsic adaptation process itself seems to be affected by the specific shape of the spatially complex background.

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