DiCE: Dichoptic Contrast Enhancement for VR and Stereo Displays (Supplemental Material)

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In this supplemental document we present three additional experiments to determine the maximum difference of contrasts and luminance between the two eyes in dichoptic stimulation before rivalry can be perceived (Experiments 1a and 1b), and to determine the effect of ocular dominance (Experiment 4).

Additional Key Words and Phrases: Visual Perception, Head Mounted Displays, Stereo, Binocular Vision

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1 EXPERIMENT 1A: REDUCING RIVALRY — CONTENT DEPENDENCE

We conducted an additional experiment to determine the maximum difference of contrasts between the two eyes in dichoptic stimulation before rivalry can be perceived. The experimental hypotheses were that (i) rivalry thresholds would vary in the population and (ii) contrast, luminance or frequency would affect the thresholds.

Apparatus and Participants. The experiment was performed on a 24-inch NEC PA241W sRGB colorimetrically calibrated display with an attached stereoscope in a dark room (Figure 1). The optical path to the display was 36cm (2.77D). Nine volunteers participated (two female, mean age 32.9, SD 8.4 years). Before the actual experiment, we read the consent form to each participant and demonstrated in a short demo what rivalrous and non-rivalrous stimuli looked like.

Stimuli and Procedure. A Two Alternative Forced Choice (2AFC) method in conjunction with a staircase-based contrast manipulation protocol were employed to determine rivalry thresholds. In each trial, participants were shown two sinusoid gratings for 1 second, one at the top of the screen and one at the bottom (Figure3). One grating (top or bottom randomly selected) was dioptic — had identical luminance, frequency and contrast for the two eyes. The other dichoptic stimulus contained gratings of the same luminance and frequency as the dioptic grating, but of different contrast for each eye, such that the fused contrast was the same as for the dioptic grating, as predicted by the contrast fusion model (Equation ??). The experimental task was to determine the maximum contrast difference that is not perceived as rivalrous. Participants were requested to point using the up/down arrow keys to the stimulus that seemed rivalrous as instructed during the training session. The sinusoidal gratings were generated as a factorial combination of 3 mean luminances (10, 30 and 100 nits), 2 contrasts (0.2 or 0.4) and 3 frequencies (1, 3 or 5 cpd); in total 18 thresholds were measured in equal staircase procedures. The staircase parameters were determined using Parameter Estimation by Sequential Testing (PEST) [Taylor and Creelman 1967].

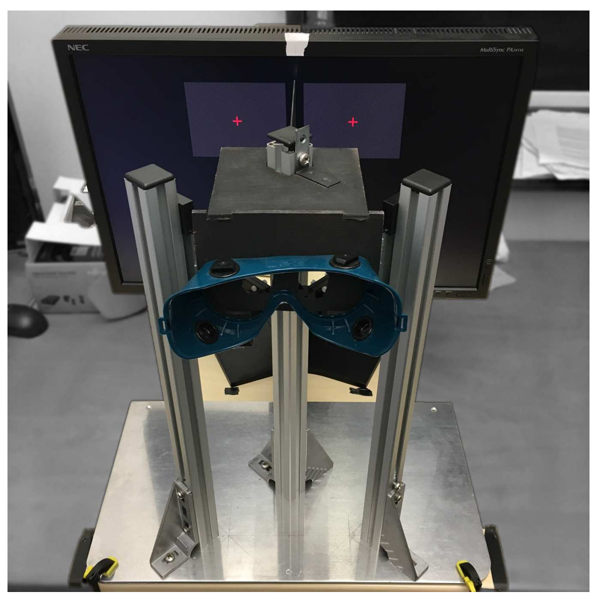

Fig. 1. The display and attached stereoscope of the experimental setup.

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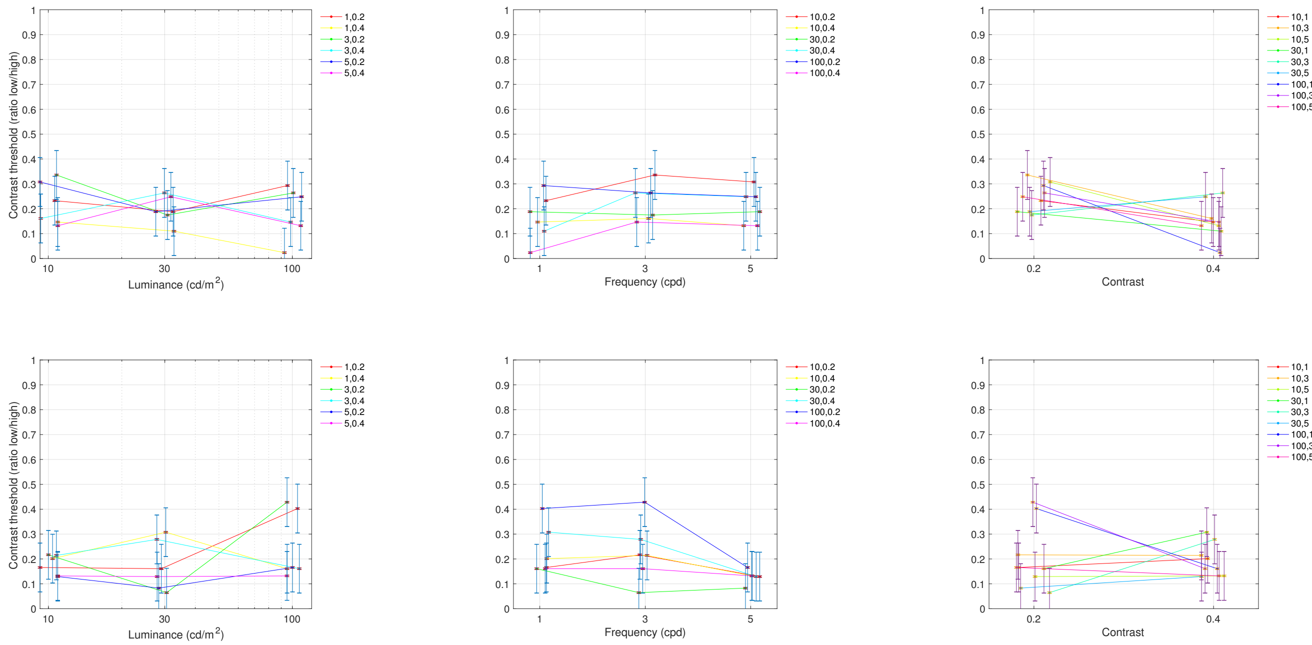

Fig. 2. Normalized contrast threshold (contrast difference between eyes divided by perceived contrast) as a function of luminance, frequency and contrast for two observers (top and bottom row respectively). A higher threshold denotes higher tolerance. Burgundy bars denote the 5% confidence interval of the psychometric function fit and cyan bars the 95% confidence interval. Individual differences are apparent.

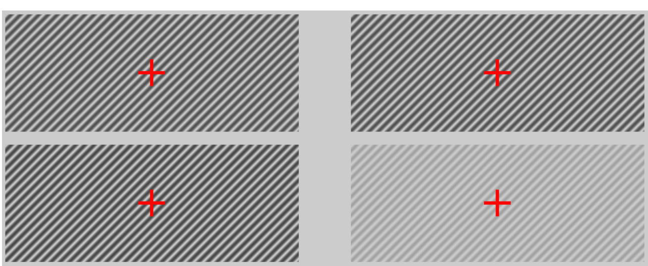

Fig. 3. An example of a binocularly fused stimulus. In this case, the standard/dioptic condition is at the top and the dichoptic at the bottom. The dichoptic should be perceived as rivalrous in this case.

Data analysis. We found the contrast threshold for each participant, luminance level, frequency and contrast of the dioptic grating by fitting a psychometric function to 2AFC responses. It should be noted that our experimental procedure identifies the contrast differences where rivalry begins to be *perceived* not becoming *irritating*. As such, in reality, larger contrast differences can be tolerated.

1.1 Results

The experimental results indicated that there exist significant differences between observers in rivalry thresholds, but there was no effect of either luminance, frequency or contrast for the tested values, contrary to our hypotheses. Further testing with one observer for extremely low luminances did indicate an effect of luminance on rivalry perception. Two observer's results are shown in Figure 2.

This is a positive outcome for us as it means that image content (luminance, contrast and spatial frequency) has little influence on the tolerable level of dichoptic contrast presentation. But we also found that the thresholds are notably different for different observers, meaning that our method needs to be customized for each observer. As the experiment was conducted on basic stimuli, its findings do not easily translate to the parameters of the dichoptic tone curves we need to control. For that reason, we conducted another experiment, as explained in the next section.

2 EXPERIMENT 1B: RIVALRY DUE TO LUMINANCE DIFFERENCES

We conducted an experiment to determine the maximum difference of log10-luminance between the two eyes in dichoptic presentation before strong rivalry is reported.

Apparatus and Participants. This experiment shares the same setup as Experiment 1A. Five volunteers participated (mean age 25.2, SD 2.2 years). Before the actual experiment, they read the consent and briefing forms. In a short demo, they experienced what rivalrous and non-rivalrous stimuli looked like.

Stimuli and Procedure. The stimuli were similar to the one shown in Figure 3, except that no reference dioptic stimulus was shown. The gratings shown to each eye had the same contrast and frequency, but differed in luminance. Participants were asked to adjust the difference of luminance given the same criteria as in Experiment 1A. 6 sinusoidal gratings were generated: a factorial combination of 2 contrasts (0.2 or 0.4) and 3 frequencies (1, 3 or 5 cpd). Each condition was measured three times and the order of all trials was randomized.

Results. The 25th, 50th, 75th percentile of the data for the threshold of luminance difference are 0.51, 0.66 and 0.80 in log-10 units. The results for three observers are shown in Figure 4.

3 EXPERIMENT 4: OCULAR DOMINANCE

We conducted an experiment to investigate if ocular dominance influences the perception of dichoptic contrast.

Apparatus and Participants. This experiment shares the same setup as Experiment 1A and Experiment 1B. Six volunteers participated (mean age 27.3, SD 7.4 years). Three of the participants have a left ocular dominance while the other three have a right ocular dominance. We verified this by asking the participants to align a distant object with the thumb keeping their both eyes open. We then asked them to close one eye. If the alignment does not break, the open eye is the dominant eye. Before the actual experiment, they read the consent and briefing forms. In a short demo, we explained to them what a high-contrast and low-contrast stimuli were.

Stimuli and Procedure. The stimuli included a textured pattern, a sinusoidal grating, and a natural image shown in Figure 6. For each image, we generated two pairs of dichoptic images so that in the first pair the left eye could see a higher contrast and in the second pair the right eye could see a higher contrast (images shown to each eye were swapped between the two pairs). The image pairs were generated with our DiCE technique and we relied on the fact that the technique enhances contrast in one half of the tonal range and reduces in the other. To control which eye can see higher contrast, we asked observers to fixate on a specific part of the image: the vegetables on the counter in the natural image and on the green pattern in the abstract texture image. The sine grating falls within the upper part of the tonal range.

In each trial, the participants were asked to compare the two pairs and select the pair for which they perceived a higher contrast. We measured the response for each image ten times and randomized the order of all trials.

Results. Figure 5 shows the percentage of votes for images in which higher contrast was presented to the right or the left eye, separately for the participants with the left and right ocular dominance. The results show that for a large portion of images, observers could see higher contrast when the higher contrast image was presented to the right eye. The results do not vary substantially between left-eye and right-eye dominant observers. Therefore, we cannot justify the observed bias with ocular dominance.

Our experiment has detected that the difference in perceived contrast depends whether higher contrast is shown to the left or right eye. The experiment, however, does measure the magnitude of the effect. The magnitude of the effect has been in fact captured in the contrast matching experiments by Legge & Rubin [1981] and Kingdom & Libenson [2015], in which higher contrast was shown to both left and right eye. Their data shows a very small effect, at least for sinusoidal gratings. Therefore, we conclude that from a practical perspective swapping the DiCE images have a detectable but probably negligible effect.

REFERENCES

Frederick A. A. Kingdom and Lauren Libenson. 2015. Dichoptic color saturation mixture: Binocular luminance contrast promotes perceptual averaging. *Journal of Vision* 15, 5 (apr 2015), 2. https://doi.org/10.1167/15.5.2

Gordon E Legge and Gary S Rubin. 1981. Binocular interactions in suprathreshold contrast perception. *Attention, Perception, & Psychophysics* 30, 1 (1981), 49–61.

MiM Taylor and C Douglas Creelman. 1967. PEST: Efficient estimates on probability functions. *The Journal of the Acoustical Society of America* 41, 4A (1967), 782–787.

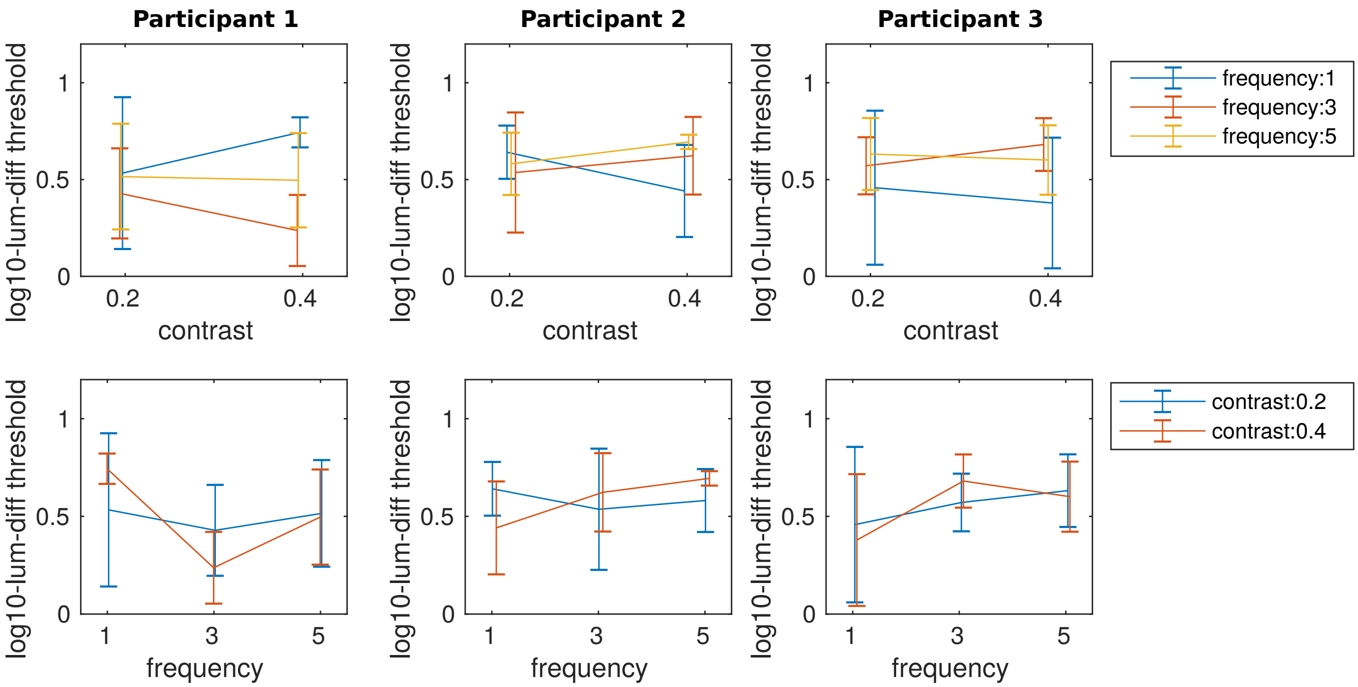

Fig. 4. log10-luminance difference threshold as a function of contrast and frequency. Data from three observers are displayed in respective columns. A higher threshold denotes higher tolerance.

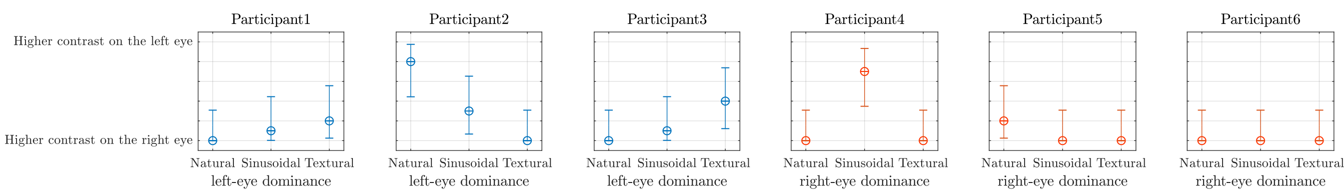

Fig. 5. Results for the ocular-dominance experiment. The ratio of the votes for the pair in which higher contrast was shown on the left or the right eye. Left-dominant participants are shown in the first three plots on the left, and the right-dominant observers in the three plots on the right.

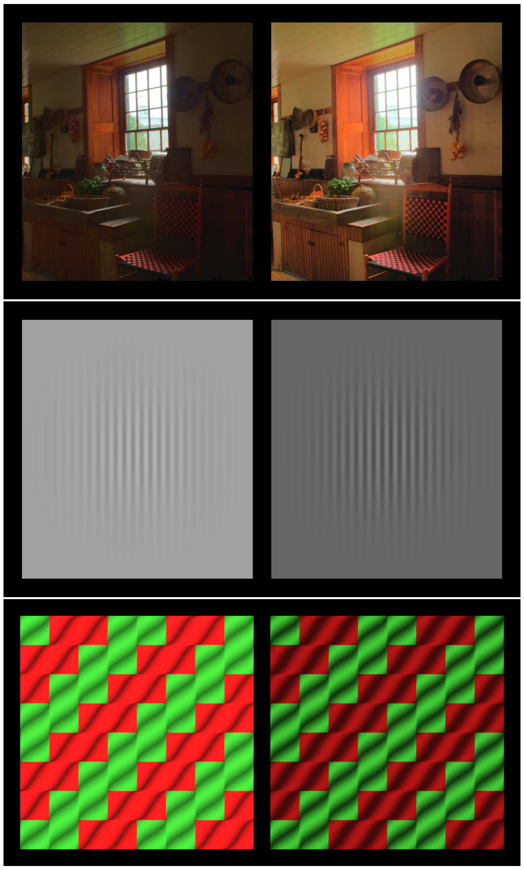

Fig. 6. Dichoptic image pairs used in Experiment 4: (from top to bottom) natural image, sinusoidal grating, and textural image. In these images, a higher contrast is shown on the right. The positions of the left and right images were interchanged during the experiment for observers to compare.

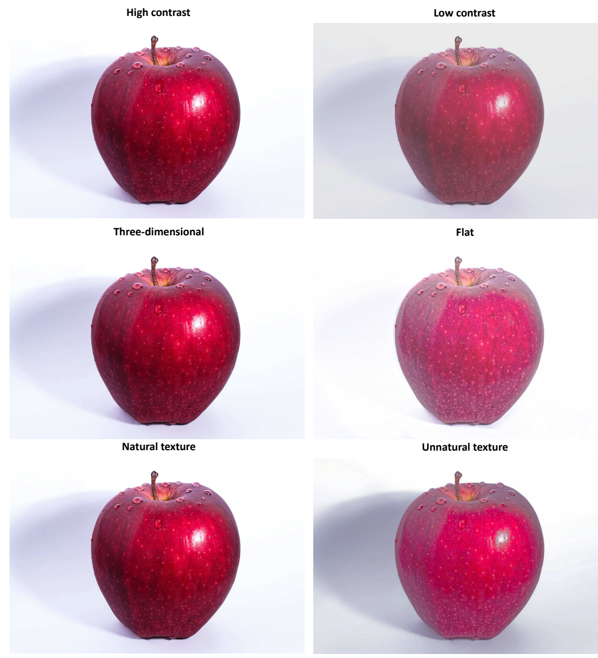

Fig. 7. Training images for Experiment 3