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Comparing the Chromatic Contrast Sensitivity in Vertical and Oblique Orientations

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Abstract

While for many years achromatic contrast sensitivity has been widely studied by different research groups from various fields of work, the same attention has not been paid to chromatic contrast sensitivity. Due to the challenging nature of contrast sensitivity tests even the limited number of studies in the field do not agree on different issues. In this work, through a subjective test, we aim to further investigate the relationship between the chromatic contrast sensitivity for the red-green channels in the vertical (0°) and oblique (45°) orientations. The results show that the contrast sensitivity between the two different orientations is similar.

Introduction

The Human Visual System (HVS) has long been an interesting topic of research for different scientific communities. This inter-disciplinary field of work has not only attracted research groups such as psychologists, cognitive scientists, and neuroscientists but also researchers in fields such as computer vision, image processing, and color science. The fundamental research done on the HVS along with the inter-disciplinary nature of the research has made any advancement in this field of knowledge important for different research communities.

Among different topics addressed in research on the HVS, dealing with different aspects of contrast in an image (such as evaluation, enhancement, and modeling) especially with regards to chromatic contrast in the HVS is of high interest for different research groups. Possible applications of such research especially in the field of computer vision and image processing are objective image and video quality assessment, image and video compression, gamut mapping, and halftoning [1, 2, 3, 4]. In all such applications researchers try to model the HVS in the best possible way to provide an accurate method and approach. In this work through a subjective test we aim to compare the chromatic contrast sensitivity for the red-green color channels in the vertical (0°) and oblique (45°) orientations.

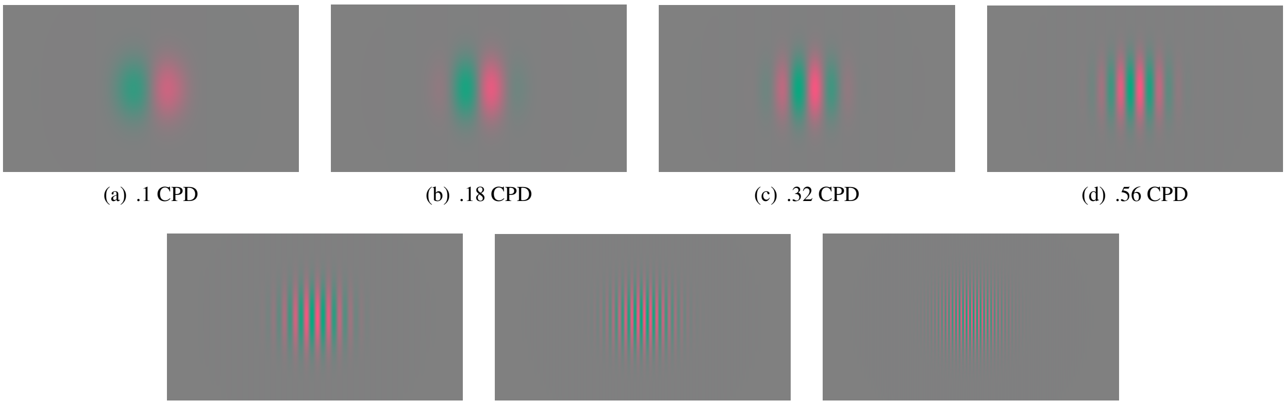
This paper is organized as follows. First, we present relevant background including state-of-the-art. Then we introduce the experimental procedure, followed by analysis of the results. At last we conclude and propose future work.

Background

As like any other subjective term, various description of contrast, such as the difference in visual properties which makes an object distinguishable, or the difference between light and dark part of an image has been used to describe contrast [5]. An image with low contrast corresponds to an image with a flatter picture while an image with a high contrast represents a deeper picture [6]. Properties such as the viewing condition (viewing distance, lightning conditions, viewing surround, etc.) along with the resolution of the image, and image content are believed to play an important role in the perception of contrast [5].

Our ability to perceive the difference between luminance levels in an image is measured by contrast sensitivity while the relationship between contrast sensitivity and spatial frequency is defined as the Contrast Sensitivity Function (CSF). It is important to point out that the contrast sensitivity does not only vary between observers, but it also changes over time and spatial frequencies [7]. The CSF is different between chromatic and achromatic stimuli, and while the achromatic CSF has been studied in detail [5, 8, 9], not much attention has been paid to the Chromatic Contrast Sensitivity Functions (CCSFs). Contrast masking is another visual phenomenon closely linked with CSFs, where a certain region of an image can hide information or distortions better than other regions [10]. It has been stated that the lack of models of the CCSF (including contrast masking) for simulating these aspects of the HVS is one of the major reasons why image and video quality metrics cannot predict perceived quality [11]. Accurate models of the HVS is considered as one of the fundamental unsolved challenges in the field of image quality [11, 12].

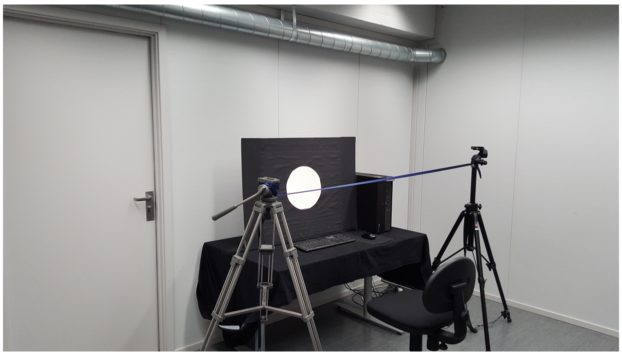
CSFs are the bases for most methods which take the HVS filtering into account. CSFs are commonly performed on opponent color channels in which the sensitivity to luminance and the two opponent color channels (red-green and blue-yellow) are measured [13, 14]. As mentioned earlier, a huge number of researches have focused on specifying the achromatic CSF, while only few have worked on CCSFs [11, 14, 15]. One of the first but most important works on CCSFs was performed by Mullen [13]. In this work, after pointing out the fact that there is no adequate and global definition of color contrast for all color combinations, through various observation tests different relationships between monochromatic and CCSFs is also pointed out. Johnson and Fairchild have provided a great review on some of the most well-known CSFs in which they point out that many CSFs are implemented in the frequency domain [16]. They start by mentioning that the opponent color space used in the S-CIELAB model [17] seems to be a good starting point for contrast sensitivity modulation which are based on the pattern color separability experiments introduced by Mullen. They point out that using the sum of two Gaussian functions fitted previous works well and move on to propose new CCSFs. In their work, Johnson and Fairchild also emphasize on the fact that orientation selectivity plays an important role in CSFs. Furmanski and Engel stated also the same [18]. To a human observer, horizontal and vertical lines are more visible than diagonal ones. The so-called oblique effect has been known for many years, where the contrast sensitivity decreases considerably for oblique ratings. Experiments have shown contradictory findings for whether this oblique effect exists for chromatic gratings or not. Kelly [9] found that the oblique effect is not evoked by the chromatic gratings. However,



(a) .1 CPD (b) .18 CPD (c) .32 CPD (d) .56 CPD

(e) .1 CPD (f) 1.78 CPD (g) 3.16 CPD

Figure 1. *Seven different spatial frequencies used in our experiments.*



(a)

Figure 2. *Experimental setup. A large black cardboard with a circular opening covering the display to avoid the observer from seeing what orientation the display was tilted at.*

experiments carried out by Murasugi and Cavanagh [8] found evidence for orientation selectivity in the chromatic channel. Results by Reisbeck and Gegenfurtner [19] show an oblique effect for the orientation discrimination of isoluminant gratings, and that it is as strong as for luminance gratings. There is clearly a need to accurately define CCSFs.

Xu et al. [20] measured the CCSF along six different chromatic directions at two different background colors. They used horizontal and vertical spatial orientations for the chromatic stimuli defined in the CIELUV color space and up to 3.84 Cycles Per Degree (CPD). The results from the experimentation showed that the HVS is least sensitive to a chromatic modulation oriented at around 120° from the positive a^*-axis in the CIELAB color space. An extension of this study was done by Kitanovski et al. [21], where they did measurement of CIELAB spatio-chromatic contrast sensitivity in different spatial and chromatic directions. In their experiment they used five different spatial frequencies (up to 19.1 CPD), in which a Gabor stimulus was modulated along six different chromatic directions in the a^*-b^* plane of the CIELAB color space. Their results showed lowest contrast sensitivity in the chromatic direction of around 120° from the positive a^*-axis, similar to Xu et al. [20]. They also showed that the contrast sensitivity in the diagonal spatial orientation is to some degree lower compared to the vertical orientation.

Experimental procedure

Similar to most other such datasets we used a horizontal sine-gratings [22, 23, 24]. Seven different frequencies (Figure 1) was evaluated in our experiments. The contrast sensitivity was measured in two different orientations, vertical (0°) and oblique (45°). For the oblique orientation the monitor was physically rotated to 45°. To remove external visual cues about orientation a large black cardboard with circular opening in the center was placed in front of the display (Figure 2). The circular opening covered only the displaying area, and it had a diameter of 34 visual degrees. To keep the viewing distance constant over the long duration of the test the observers were asked to keep their forehead on the ribbon crossing the table. For displaying the red-green ((0.68,0.31,19.11) and (0.22,0.69,54.4) respectively in the CIE *xyY* color space) gratings we used a 10-bit Eizo LCD Color Edge CG246 display which was calibrated to the Adobe RGB profile using an i1pro spectrophotometer. Prior to selecting the display, a spectroradiometer was used to check the color uniformity of the different displays. In the case of the selected display, while non-uniformity was observed when comparing the center of the display to the edges of the display, the central circle which we use in our experiment is nearly uniform. An observation distance of 86 cm was used in the experiment.

For each spatial frequency, over 100 trials of the QUEST method [25] was performed to find the exact threshold. 25 different regions on the display is predefined in the experiment which the observers are not been informed about (Figure 3). At each trial the red-green grating is shown on one of the 25 different regions which is selected randomly. The observer is then asked to click on where he/she sees the grating at. Based on an audio feedback, after each click the observer will be informed if the correct region in the display is selected or not. Depending on the correct or wrong answer the observer gives, the QUEST method is then used to calculate the degree of contrast for the next grating (Figure 4). Simply said, a correct answer will decrease the contrast value while a wrong answer will increase it. While the response time for each trial is recorded by the program the observers are given no time limits and can look for the patch as long as they need. On average, it took observers an average of half an hour to complete 100 trials for a single orientation for each frequency. To complete the test observers attended the test over a duration of days. 100 trials for each frequency were used to ensure convergence of the results and reduce the variability in the results.

At the start of each session the observer spends a few min-

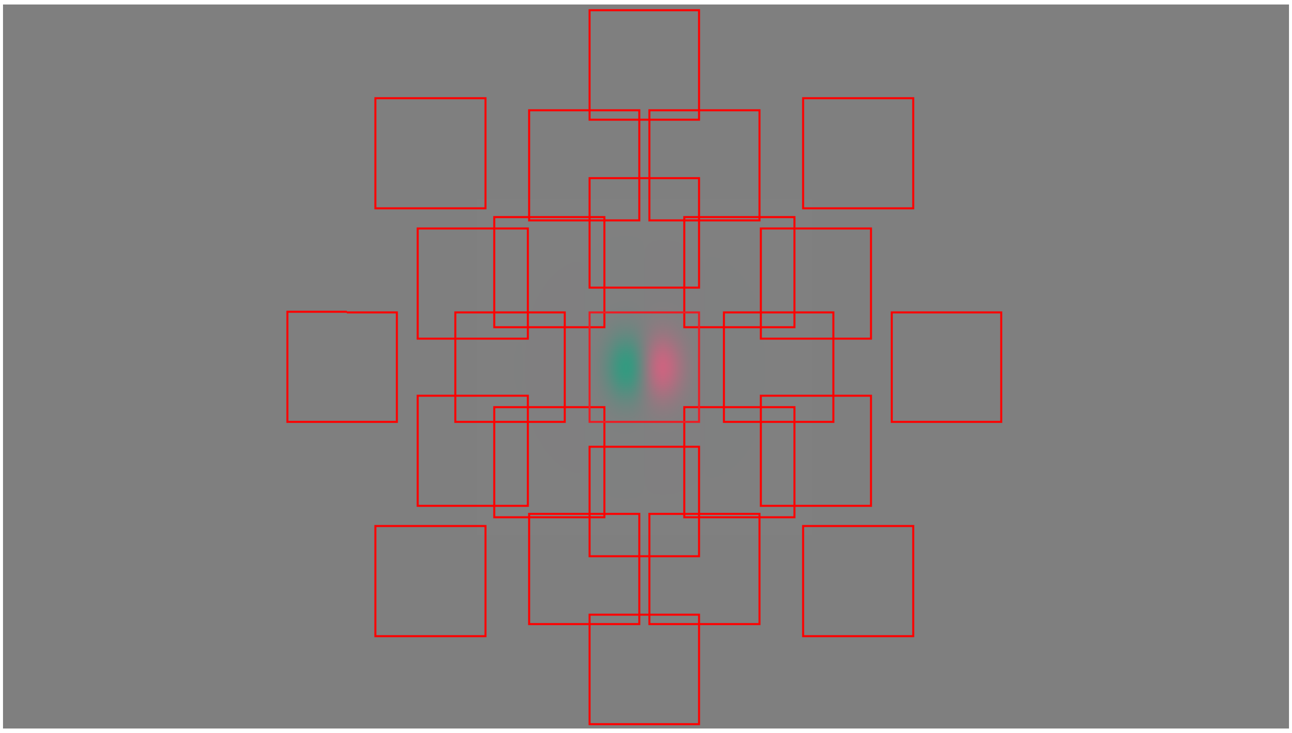


Figure 3. 25 possible locations for the grating to be shown on the display. You can see the grating in the central box.

utes in the room to adapt him/herself to the viewing conditions and the darkness of the room. Before starting the test and at the first session an isoluminance test [26] is performed for each observer using the same gratings and frequencies in the test. This will allow us to make the necessary changes in the luminance values for each observer so that the gratings look visually similar for all participants. The test starts with the grating having the highest possible contrast to the neutral (grey) background (Figure 3) so that the observer has an understanding on how the grating looks like (Figure 4). After each click there will be a two second break before showing the next grating. The break is done automatically by showing a neutral background with a white + sign shown in the middle of the screen. This will also remove any possible after images from the previous grating shown. All seven observers completed all the seven frequencies in the vertical orientation before moving to the oblique orientation. The order that gratings with different frequency is shown to each observer is randomized so that no two observers evaluate the gratings in the same order while at the same time keeping the order constant for the vertical and oblique orientation for each observer.

7 observers (5 males and 2 females) conducted the experiment in the vertical orientation and 6 observers (4 males and 2 females) conducted the experiment in the oblique orientation. Apart from these observers others also participated in the experiment but since they did not finish the experiment their results are not included in this study. The average age of the observers was around 29 years old.

Results

To evaluate the results we assume the final contrast value of a correctly detected grating as the contrast sensitivity value for each spatial frequency (Figure 5). Observing the contrast sensitivity values between different observers in both vertical and oblique orientations show similar band-pass shape in log-log coordinates. This is similar to what was previously reported in [27, 28, 29]. The average contrast sensitivity for 0° and 45° orientations based on the average observer results in similar looking curves (Figure 6 and Table 1). We should point out that the lines connecting the points in the figure are not fitted to the data points but only connecting the points itself. In the case of oblique orientations while a lower standard deviation among the contrast sensitivity is seen in higher spatial frequencies, low spatial frequencies also show close contrast sensitivity values between different observers (Table 1).

Conclusion and future work

In this paper, using a subjective test we showed that the chromatic contrast sensitivity for the red-green channels in the vertical (0°) and oblique (45°) orientations are similar. We collected subjective data for seven observers which to the best of our knowledge makes this dataset one of the largest in its field of work.

For future work we plan to increase the number of observers in the dataset and perform an in-depth analysis of the subjective data collected.

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References

[1] Farah Torkamani-Azar, Hassan Imani, and Hossein Fathollahian. Video quality measurement based on 3-d. singular value decomposition. *Journal of Visual Communication and Image Representation*, 27:1–6, 2015.

[2] Toshio Asano, Yuji Takagi, Takahiro Kondo, Jun Yao, and Wei Liu. Image quality evaluation based on contrast sensitivity function. In *2011 IEEE International Conference*

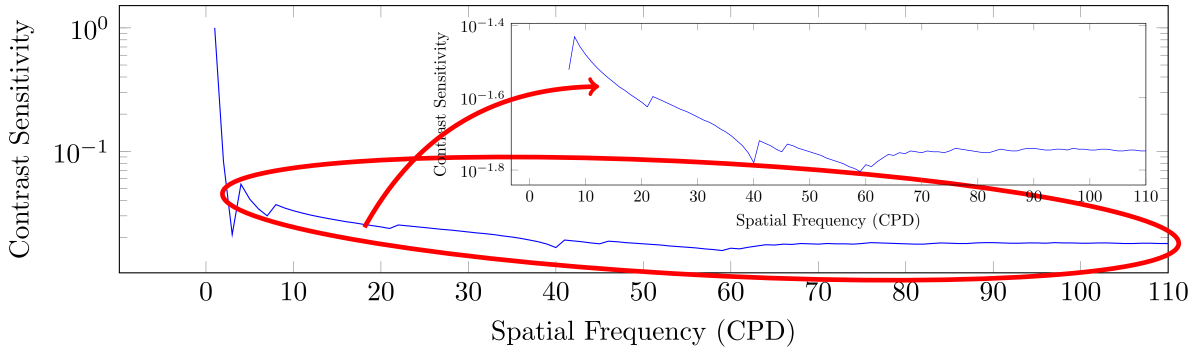
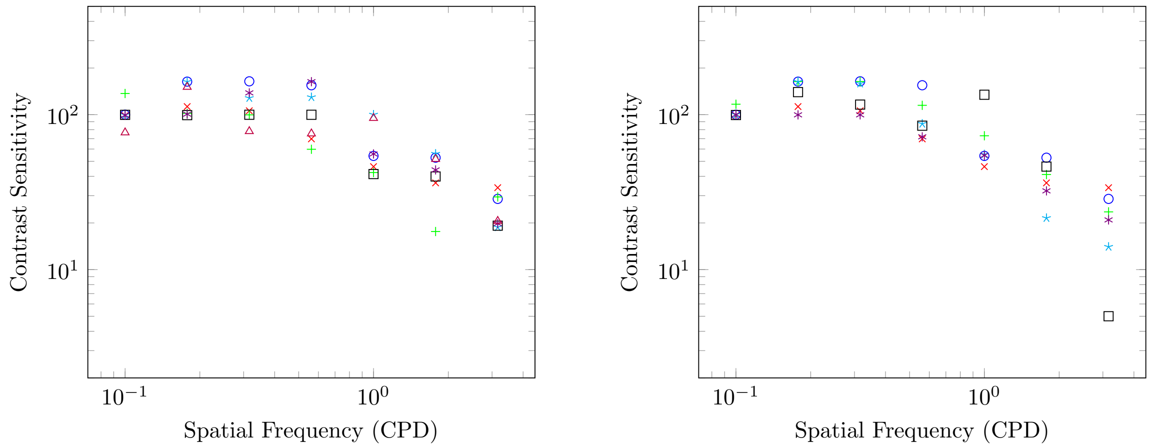


Figure 4. *Sample contrast values predicted by QUEST. You see a drop in the value when an observer correctly detects the grating while the value increases when the observer is not able to detect the grating. A zoomed in version of the region in the red ellipse is also shown in the figure.*



(a) vertical (0°) orientation

(b) oblique (45°) orientation

Figure 5. *Measurement of chromatic contrast sensitivity function for the gratings in the frequencies shown in Figure 1 for the vertical (0°) and oblique (45°) orientations. Each color/mark corresponds to the contrast sensitivity of one observer.*

Table 1: Average and standard deviation of contrast sensitivity values between different subjects for the vertical (0°) and oblique (45°) orientations.

		0.1 CPD	0.1778 CPD	0.3162 CPD	0.5623 CPD	1 CPD	1.778 CPD	3.162 CPD
0°	average	101.52	127.44	116.31	107.52	62.13	42.59	24.31
	standard deviation	17.78	30.22	28.92	42.08	24.85	13.14	6.13
45°	average	102.46	140.38	134.73	97.28	69.658	38.348	20.99
	standard deviation	7.03	28.27	30.588	32.48	32.95	10.97	10.32

on Mechatronics and Automation, pages 658–663. IEEE, 2011.

[3] Ping Zhao, Marius Pedersen, Jean-Baptiste Thomas, and Jon Yngve Hardeberg. Perceptual spatial uniformity assessment of projection displays with a calibrated camera. In *Color and Imaging Conference*, volume 2014, pages 159–164. Society for Imaging Science and Technology, 2014.

[4] Theophano Mitsa and Krishna Lata Varkur. Evaluation of contrast sensitivity functions for the formulation of quality measures incorporated in halftoning algorithms. In *1993 IEEE International Conference on Acoustics, Speech, and Signal Processing*, volume 5, pages 301–304. IEEE, 1993.

[5] Gabriele Simone, Marius Pedersen, and Jon Yngve Hardeberg. Measuring perceptual contrast in digital images. *Journal of Visual Communication and Image Representation*, 23(3):491–506, 2012.

[6] Marius Pedersen, Alessandro Rizzi, Jon Yngve Hardeberg, and Gabriele Simone. Evaluation of contrast measures in relation to observers perceived contrast. In *Conference on Colour in Graphics, Imaging, and Vision*, volume 2008, pages 253–258. Society for Imaging Science and Technology, 2008.

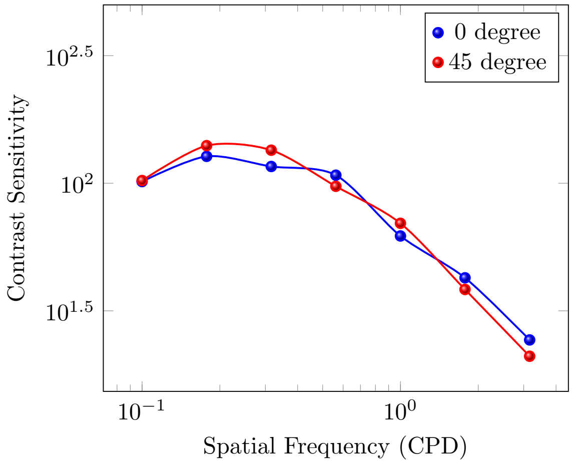


Figure 6. *Average chromatic contrast sensitivity for the vertical (0°) and oblique (45°) orientations between different observers. The lines connecting the points in the figure are not fitted to the data points but only connecting the points itself.*

[7] Peter GJ Barten. *Contrast sensitivity of the human eye and its effects on image quality*, volume 21. Spie optical engineering press Bellingham, WA, 1999.

[8] CHIEKO M Murasugi and PATRICK Cavanagh. Anisotropy in the chromatic channel: a horizontal-vertical effect. *Spatial vision*, 3(4):231–291, 1988.

[9] DH Kelly. No oblique effect in chromatic pathways. *Journal of the Optical Society of America*, 65(12):1512–1514, 1975.

[10] Gordon E Legge and John M Foley. Contrast masking in human vision. *Journal of the Optical Society of America*, 70(12):1458–1471, 1980.

[11] Michael P Eckert and Andrew P Bradley. Perceptual quality metrics applied to still image compression. *Signal processing*, 70(3):177–200, 1998.

[12] Damon M Chandler. Seven challenges in image quality assessment: past, present, and future research. *ISRN Signal Processing*, 2013, 2013.

[13] Kathy T Mullen. The contrast sensitivity of human colour vision to red-green and blue-yellow chromatic gratings. *The Journal of physiology*, 359(1):381–400, 1985.

[14] Gerard JC Van der Horst and Maarten A Bouman. Spatiotemporal chromaticity discrimination. *Journal of the Optical Society of America*, 59(11):1482–1488, 1969.

[15] Allen B Poirson and Brian A Wandell. Appearance of colored patterns: pattern–color separability. *Journal of the Optical Society of America A*, 10(12):2458–2470, 1993.

[16] Garrett M Johnson and Mark D Fairchild. Darwinism of color image difference models. In *Color and imaging conference*, volume 2001, pages 108–112. Society for Imaging Science and Technology, 2001.

[17] Xuemei Zhang, Brian A Wandell, et al. A spatial extension of CIELAB for digital color image reproduction. In *SID international symposium digest of technical papers*, volume 27, pages 731–734. Citeseer, 1996.

[18] Christopher S Furmanski and Stephen A Engel. An oblique effect in human primary visual cortex. *Nature neuroscience*, 3(6):535, 2000.

[19] Tobias E Reisbeck and Karl R Gegenfurtner. Effects of contrast and temporal frequency on orientation discrimination for luminance and isoluminant stimuli. *Vision Research*, 38(8):1105–1117, 1998.

[20] Qiang Xu, Qiyan Zhai, Ming Ronnier Luo, Haiting Gu, and Dragan Sekulovski. A study of visible chromatic contrast threshold based on different color directions and spatial frequencies. In *Color and Imaging Conference*, volume 2018, pages 53–58. Society for Imaging Science and Technology, 2018.

[21] Vlado Kitanovski, Alastair Reed, Kristyn Falkenstern, and Marius Pedersen. Measurement of CIELAB spatiochromatic contrast sensitivity in different spatial and chromatic directions. In *Color and Imaging Conference*. Society for Imaging Science and Technology, 2019.

[22] Kil Joong Kim, Rafal Mantiuk, and Kyoung Ho Lee. Measurements of achromatic and chromatic contrast sensitivity functions for an extended range of adaptation luminance. In *Human Vision and Electronic Imaging XVIII*, volume 8651, page 86511A. International Society for Optics and Photonics, 2013.

[23] Andrew B Watson. Visual detection of spatial contrast patterns: Evaluation of five simple models. *Optics Express*, 6(1):12–33, 2000.

[24] Sophie M Wuerger, Andrew B Watson, and Albert J Ahumada. Towards a spatio-chromatic standard observer for detection. In *Human Vision and Electronic Imaging VII*, volume 4662, pages 159–173. International Society for Optics and Photonics, 2002.

[25] Andrew B Watson and Denis G Pelli. Quest: A bayesian adaptive psychometric method. *Perception & psychophysics*, 33(2):113–120, 1983.

[26] Zhong-Lin Lu, Luis A Lesmes, and George Sperling. The mechanism of isoluminant chromatic motion perception. *Proceedings of the National Academy of Sciences*, 96(14):8289–8294, 1999.

[27] Yeon Jin Kim, Alexandre Reynaud, Robert F Hess, and Kathy T Mullen. A normative data set for the clinical assessment of achromatic and chromatic contrast sensitivity using a qCSF approach. *Investigative ophthalmology & visual science*, 58(9):3628–3636, 2017.

[28] Jyrki M Rovamo, Mia I Kankaanpää, and Heljä Kukkonen. Modelling spatial contrast sensitivity functions for chromatic and luminance-modulated gratings. *Vision research*, 39(14):2387–2398, 1999.

[29] DH Kelly. Spatiotemporal variation of chromatic and achromatic contrast thresholds. *Journal of the Optical Society of America*, 73(6):742–750, 1983.

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