Colour desaturation in the periphery is explained by general mechanisms of contrast sensitivity and constancy

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ABSTRACT (150 words)

Colours appear less saturated in the visual periphery than in the fovea. We revisit this well-known phenomenon by characterising parafoveal perceived contrast as a function of size. Observers (n = 20) matched perceived contrast of a parafoveally presented comparison disc (2° - 0.33°) to a standard 2° disc. For chromatic stimuli, desaturation increased with decreasing size. Unexpectedly, a similar amount of desaturation occurred for luminance-defined discs, once their perceived contrast was adjusted to match the standard chromatic discs. Desaturation was reduced as standard stimulus contrast increased, in line with contrast constancy theory, which predicts constant appearance for stimuli that are sufficiently distant from threshold. Since chromatic contrast sensitivity is reduced away from the fovea, contrast constancy is unachievable within the monitor gamut. In conclusion and somewhat counter-intuitively, the appearance of colour and luminance in the periphery is affected similarly, governed by general laws of contrast sensitivity and constancy.

KEYWORDS: Colour vision, saturation, perceived contrast, contrast constancy, luminance contrast

INTRODUCTION

Saturation is a perceptual property of colour that describes the vividness of its hue. Saturation depends on both colourfulness and lightness (Fairchild, 2013). Colourfulness denotes the amount of chromatic content (Schiller et al., 2018). Saturation increases with an increase in chromatic content but also decreases with an increase in lightness. Meanwhile, perceived contrast of a chromatic stimulus also varies depending on the stimulus' spatial properties and location on the retina. Chromatic patches appear desaturated when presented parafoveally (McKeefry et al., 2007). Furthermore, chromatic patches of smaller sizes appear desaturated compared to patches of larger sizes (Abramov et al., 1991; Knau & Werner, 2002). These well documented phenomena can be linked to clear demonstrations of saturation constancy with size scaling in the periphery (Tyler, 2015).

Sensitivity is also reduced in the periphery (Gordon & Abramov, 1977; Johnson, 1986; Mullen, 1991). For chromatic stimuli, a steeper decline in sensitivity with increasing distance from the fovea can be recorded for the red-green opponent mechanism compared to a more gradual decline for the yellow-blue mechanism (Hansen et al., 2009; Mullen & Kingdom, 2002). These findings are not surprising, as the density of L and M cones drops off steadily with eccentricity while S-cone density is more even across the retina (Curcio et al., 1991). Furthermore, the amount of cone cells relaying information to a single ganglion cell increases with periphery (Dacey, 1993). Taken together, these physiological factors impact the amount of chromatic signal capture and the associated processing noise, leading to decreased saturation the periphery.

Contrast sensitivity function (CSF) captures how detection thresholds relate to spatial properties of the stimulus. Sensitivity is the inverse of threshold, i.e., the lower the amount of contrast required at a given spatial frequency for the stimulus to be detected, the higher the sensitivity for this frequency. For luminance-defined stimuli, this follows a bandpass curve (Campbell & Robson, 1968). Contrast sensitivity reduces due to multiple factors, for example with eccentricity (Rovamo et al., 1978), while higher spatial frequencies are specifically affected by ageing (Ashraf et al., 2020; Ross et al., 1985). Contrast sensitivity function can also be measured for chromatic patches. Chromatic CSF follows a low-pass shape for the

yellow-blue and red-green contrast alike, with sensitivity dropping off faster with an increase in spatial frequency for yellow-blue contrast, compared to red-green (Mullen, 1985a). Sensitivity for chromatic stimuli shows a notable drop at the upper end of the curve (i.e. at higher frequencies) with increasing parafoveal presentation (Ashraf et al., 2024). This is in line with Tyler's (2015) demonstration of how retinal eccentricity can be compensated for by an increase in stimulus size, as reductions in stimulus size expand the range of spatial frequency detectors involved in processing the stimulus.

The specificities of vision at or near detection threshold cannot be fully interpolated to suprathreshold vision (Cannon, 1985; Vanston & Crognale, 2018). Still, the domains of threshold and suprathreshold vision are linked through the notion of contrast constancy (Georgeson & Sullivan, 1975), which describes perceived contrast of a suprathreshold stimulus as a function of contrast detection threshold for the same stimulus. The higher the detection threshold for a certain spatial pattern, the higher suprathreshold contrast required to make it equal in perceived contrast to a different spatial pattern associated with a lower detection threshold. Since detection thresholds increase with eccentricity from the fovea, the decrease in saturation could be described as a consequence of contrast constancy– i.e., higher absolute contrast is required to rectify the loss of sensitivity in the periphery. Translated to stimulus size, increasing the stimulus as it moves towards the periphery rectifies the loss of sensitivity in higher spatial frequency channels.

In this study, we characterise desaturation as a function of size away from the fovea for colours that isolate the two cone-opponent mechanisms and compare it between chromatic and luminance isolating stimuli matched in perceived contrast. We also evaluate desaturation following reduction in stimulus size for chromatic stimuli presented on pedestals of varying levels of luminance contrast, using stimuli with a sharp and a blurred edge. Combined, our experiments will answer the following question: is desaturation in the periphery specific to colour or is it governed by more general contrast constancy laws that apply equally to luminance-defined stimuli?

In our experiments, participants match perceived contrast of a comparison stimulus to that of a standard, fixed-size stimulus. If desaturation away from the fovea with a reduction of stimulus size is fully explained by contrast constancy, we should observe a gradual reduction of desaturation for both chromatic and achromatic stimuli as standard stimulus contrast increases and moves away from threshold. Additionally, if desaturation in the parafovea always occurs for colour, addition of luminance contrast pedestals should not markedly reduce it, regardless of the luminance contrast added. On the contrary, if desaturation is a product of general laws that apply equally to luminance and chromatic vision, then it should follow a pattern predicted from these models when luminance pedestals are added. As a final test for this, we directly manipulate the edge of the standard disc to evaluate the dependence of perceived contrast on information carried by lower and higher spatial frequency channels.

METHODS

Participants

A total of 20 participants (15 female, aged 20 – 32 years, M_{age} = 26) took part in the experiments. All observers had normal colour vision as checked by City University Colour Vision Test (Fletcher, 1984) and normal or corrected to normal visual acuity according to an EDTRS chart check for viewing at 68 cm distance. Written informed consent was obtained from participants. The study was conducted in line with the Declaration of Helsinki (1964)

and received ethical approval from University of Aberdeen School of Psychology Ethics Committee.

Apparatus

Stimulus presentation was controlled by a VISaGe visual stimulus generator (Cambridge Research Systems, UK) and presented on a Display++ monitor (CRS, UK), using CRS toolbox and CRS colour toolbox (Westland, Ripamonti, & Cheung, 2012) for Matlab (Mathworks, USA). Responses were collected using a Cedrus RB-540 button box (Cedrus, USA). Colours were calculated on the basis of monitor spectra measurements (SpectroCAL, CRS, UK) and 2° cone fundamentals (Stockman & Sharpe, 2000). Participants were seated in a dark room at a 70 cm distance from the display, which was the only source of light.

Stimuli and Procedure

Baseline Measurements

To ensure the absence of luminance contrast from colour-only stimuli, we measured the point of isoluminance for both red-green and yellow-blue colours for each individual observer (see Figure 1 for an outline of experimental steps). Details of the heterochromatic flicker spectrometry (HCFP, Walsh, 1958) task used for this purpose are provided in the Supplementary Materials. Colours were defined to isolate the cardinal directions of chromatic mechanisms as represented in the DKL colour space (Derrington, Krauskopf, & Lennie, 1984). Background was set to 0.3127, 0.3290, 22.9298 cd/m2 in CIE 1931 xyY coordinates, which is metameric to the neutral illuminant D65.

To ensure that standard stimuli defined along different chromatic and luminance axes were equally salient to each other, perceived contrast was matched between 2° parafoveal discs (Figure 1) by a subgroup of our observers in a baseline adjustment task (Switkes & Crognale, 1999). Further details of the task are again provided in Supplementary Materials.

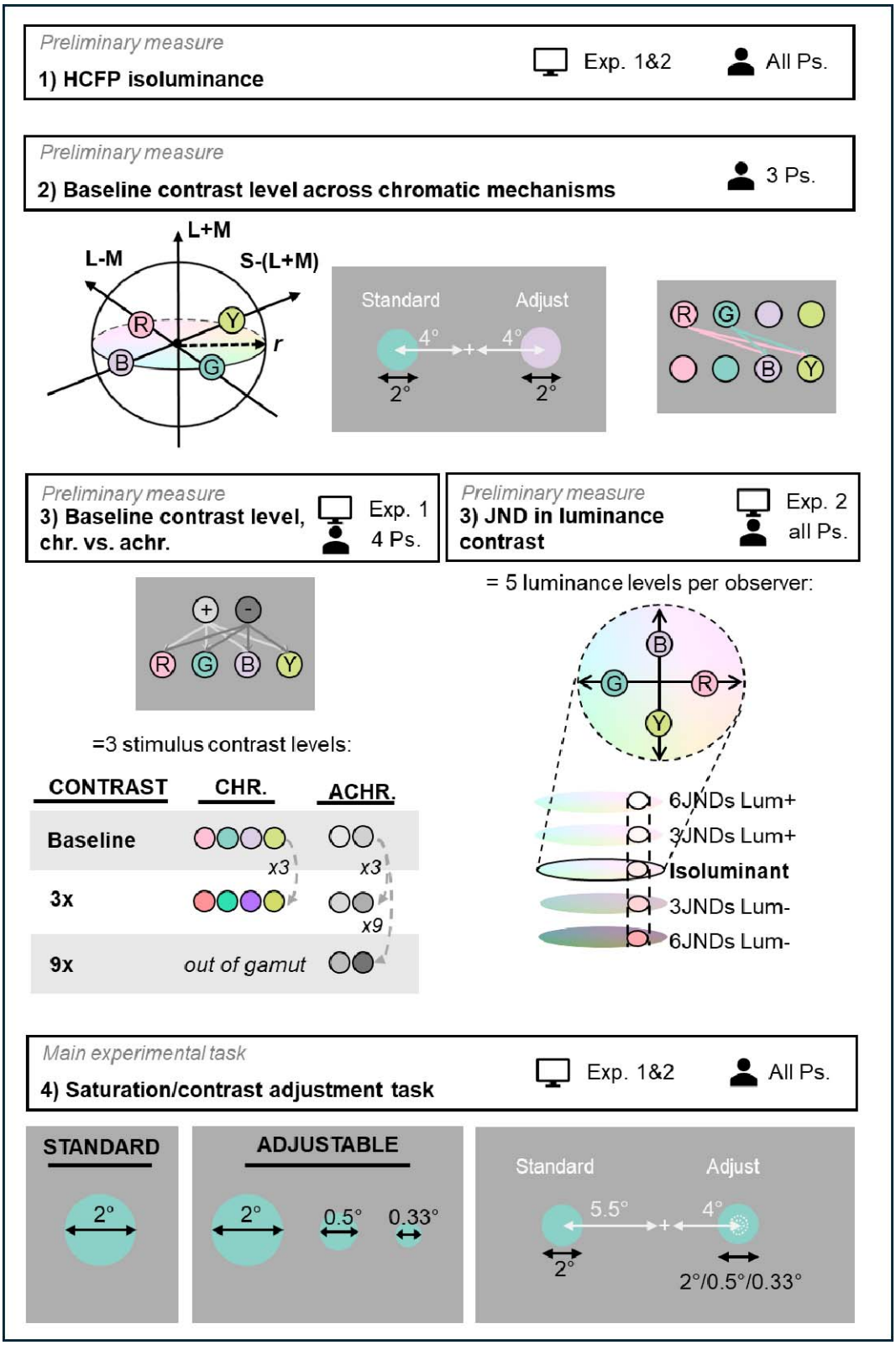

Figure 1. **Schematic Representation of the Experimental Paradigm.** Both experiments started with participants completing a HCFP task for establishing individual isoluminance (Panel 1 and Supplementary Materials). A subgroup of 3 participants completed an asymmetric matching task between cardinal colours of DKL colour space (Panel 2 and

Supplementary Materials). The standard contrast levels obtain with this baseline measurement were then used match them to achromatic stimuli by a subgroup of 4 participants (Experiment 1), and to obtain JNDs in luminance contrast for all participants for Experiment 2 (Panel 3). The main experimental task was the same saturation/contrast adjustment task in both experiments (Panel 4). Standard stimulus, always 2° in size was presented parafoveally at 5.5° distance from fixation. The edge of standard stimulus varied between conditions and was sharp of blurred. The adjustable stimulus varied in size between conditions and was presented at 4° eccentricity. In the adjustment task, the standard and adjustable stimulus were always presented in the same colour or luminance polarity and at the same level of contrast. The position of the stimuli (left or right of the fixation cross) was counterbalanced between conditions for all experiments.

Experiment 1: Saturation at progressive levels of suprathreshold chromatic and luminance contrast

To compare the effect of desaturation in the periphery, we collected contrast adjustment data for isoluminant chromatic stimuli and luminance-only stimuli at multiple values of standard contrast.

Prior to the main task, a baseline contrast level was determined in another experiment-specific preliminary measurement where an achromatic comparison stimulus of either positive or negative luminance polarity defined in the DKL colour space was matched to chromatic standards. Of the total 20 observers, 10 (8 female, aged 20 – 32 years, M_{age} = 26) completed the first set of measurements, establishing isosalient perceived contrast for small parafoveal discs at multiple levels of contrast. The detailed description of this asymmetric contrast matching task is provided in Supplementary Materials.

The same 10 observers completed the main saturation adjustment task. Luminance standards were presented at three levels of contrast. This was either perceptually matched to contrast of chromatic isoluminant standard stimuli (as determined in the baseline measurements) or set at 3- or 9-fold multiples of that standard contrast. Colour standards could only be presented at a 3-fold increase in contrast, as it was the maximum that could be achieved within the gamut of the monitor. The standard and comparison stimuli always appeared in the same colour or polarity. The stimuli were presented at 4° eccentricity from the central fixation cross, either to the left or to the right, with the location counterbalanced. The standard was 2° while the size of comparison was either 2°, 0.5° or 0.33° of visual angle. Participants adjusted the contrast of the comparison stimulus using a button box, with the left button increasing the contrast and the right button decreasing the contrast, until a perceptual match was achieved. Participants were asked to complete the task whilst fixating a centrally positioned cross. Each of the 36 conditions (3 levels of contrast, 2 polarities, 3 sizes and 2 standard edge conditions) for the achromatic matching was presented 8 times, for a total of 288 trials. There was a total of 256 matches made for the chromatic matching task (32 conditions - 2 levels of contrast, 4 colours, 3 sizes; presented 8 times each).

Experiment 2: Saturation of lighter and darker coloured discs with sharp and blurred edges

In the second part of the study, all 20 observers completed the same adjustment task but with chromatic contrast presented either at isoluminance or upon progressive luminance pedestals (i.e., lighter or darker than the background).

First, to match the amount of contrast between observers, Just Noticeable Differences (JNDs) for discriminating positive and negative luminance polarity contrasts combined with chromatic contrast (red, green, blue and yellow) were measured for each participant (further details in Supplementary Materials). The luminance contrast JNDs were recorded for each stimulus size (2°, 0.5° and 0.33°). Participants were presented with a 2-alternative forced choice task where a standard and a comparison stimulus of the same colour and size briefly appeared for 200 ms. Each of the two stimuli was presented at 4° eccentricity from the fixation cross, one to the right and one to the left. The standard was always presented at observer isoluminance and the comparison contained an amount of luminance contrast controlled by a staircase, with positive and negative luminance polarities measured in separate interleaved stairs. Participants were asked to respond with a button press if the disc on the right or the left of the fixation cross appeared lighter whilst fixating the cross and not looking at the chromatic stimuli directly. The staircases were managed using the Palamedes toolbox (Prins & Kingdom, 2018).

Based on these data, we determined colours to be used for each participant. In addition to an isoluminant chromatic setting (identical to the one used in the first experiment), the same chromatic information was also presented with an addition of a positive or negative luminance pedestal, equal to a value of 3 or 6 multiples of JNDs for a given colour direction. In the main experimental task, participants were again asked to adjust saturation of a comparison stimulus to match that of a standard stimulus whilst fixating the central cross. The two circular stimuli were presented at 4° eccentricity left or right of the foveal fixation cross and always appeared in the same colour (reddish, greenish, bluish or yellowish) and luminance pedestal (isoluminant, 3 or 6 JNDs positive or negative luminance contrast pedestal). The location of the standard and comparison stimulus was counterbalanced, and the presentation of colours randomised. All conditions with the same luminance contrast pedestal were blocked (split into two parts to allow for breaks) and the order of these pedestal blocks was randomised.

The standard stimulus was always a 2° disc whilst the size of the comparison stimulus was either 2° (baseline comparison), 0.5° or 0.33° of visual angle. Observers were asked to adjust the amount of chromatic contrast of the comparison stimulus to match the saturation of the standard stimulus using a button box (left button increasing, right button decreasing). Adjustments were made 8 times per condition (4 colours, 3 comparison stimulus sizes, 5 luminance contrast pedestal conditions and two standard stimulus edge definitions; see Fig. 1), with a total of 960 trials. Trials for two standard stimulus edge conditions were split into two testing sessions, each lasting up to 2 hours for participants to complete, depending on chosen duration of breaks.

Finally, this experiment also manipulated stimulus spatial properties by blurring the edge of the standard disc to reduce the information carried by the higher spatial frequency channels. The stimulus edge was blurred by adding an outer ramp encompassing 15% of the stimulus area, within which contrast was reduced linearly (Figure 2a). This resulted in 7.5% difference in overall contrast between the sharp and blurred edge standard stimulus. The standard 2° stimuli (sharp edge and blurred edge) still have comparable amount of information in the lower spatial frequency range, but the blurred edge standard stimulus is better matched in energy to smaller, sharp edge comparison stimuli in the higher frequency domains (Figure 2b).

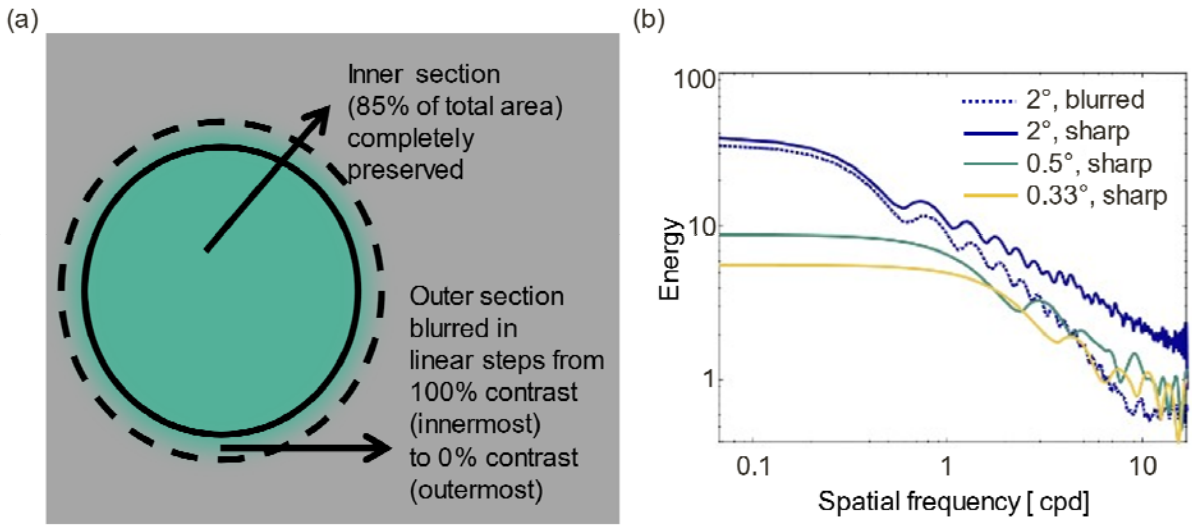

Figure 2. **Schematic Representation of Stimulus Edge Blurring (a) and Stimulus Energy as a Function of Spatial Frequency (b) for blurred and sharp edge stimuli of different sizes**. The contrast of the central region (labelled "inner section" in panel A) is set to identical contrast levels for all discs depicted in panel B. Note that the higher frequency content of a 2° disc stimulus depends overwhelmingly on its edge – once the edge is blurred by adding a linear contrast ramp over its outer area, the disc maintains a highly similar amount of energy in the lower spatial frequencies (< 0.2 cycles per degree) but its higher spatial frequency content (>2 cycles per degree) has dropped off significantly and is now within the range of the smaller 0.5° and 0.33° discs.

Statistical Data Analysis

We used linear mixed effect models on log-transformed contrast adjustment data and therefore report effect sizes as odds ratios (ORs). Analyses were implemented in R 4.3.1 (R Core Team, 2024) using the following packages: lmerTest 3.1-3 (Kuznetsova et al., 2017) emmeans 1.10 (Lenth et al., 2025), lmeresampler 0.2.4 (Loy et al., 2023), DHARMa 0.4.6 (Hartig et al., 2024) and simr (Green & MacLeod, 2016). For further details of statistical analysis, see Supplementary Materials, where we also report statistical sensitivity analyses, all properties of best fitting models as well as post-hoc pairwise tests.

RESULTS

1. **Comparing desaturation with size between chromatic and luminance stimuli**

We analysed the chromatic and luminance data using linear mixed effect models. For colour, we could only achieve a threefold increase in standard contrast, whilst for luminance we also tested standards that were nine times higher, so we fitted two separate models to these datasets.

First, a linear mixed effects model was fitted to chromatic and luminance data, predicting adjustment as a function of size, colour and contrast level (baseline level and 3x higher contrast). The best fitting model with random by-participant intercepts explained r^2=0.589

variance, with fixed effects accounting for r^2=0.432. Figure 3a shows the prominent reduction of perceived contrast for smaller stimuli (0.5° vs 2°: OR 1.132, 95%CI 1.107-1.157, t(491)=9.740, p<.001; 0.33° vs. 0.5°: OR 1.081, 95%CI 1.054-1.108, t(491) = 5.779, p<.001). A significant interaction between size and contrast level was present, with desaturation significantly reduced for higher contrast stimuli at 0.33° (OR 1.073, 95%CI 1.031-1.115, t(491) = 3.596, p=.003). Desaturation with size also significantly differed across colours, with a higher loss of perceived contrast for positive luminance polarity at 0.5° against all the hues except blue – a loss which at the smallest, 0.33° size had become more uniform across colours (see Supplementary Materials for all the post-hoc tests).

A linear mixed effects model was also fitted to the achromatic data (Figure 3b), predicting contrast adjustment as a function of size, contrast level, luminance polarity and edge definition. The best-fitting model explained r^2=0.633 through the fixed effects, rising to r^2=0.745 with the inclusion of random by-participant intercepts. The three-way interaction between size, contrast level and polarity was significant - as the standard contrast was tripled, desaturation of 0.33° discs was lowered for negative luminance polarity only (3x contrast vs. baseline: OR 1.124, 95%CI 1.048-1.200, t(369) = 3.403, p = 0.028). With a further tripling of luminance contrast, perceived contrast was even less affected by stimulus size for negative luminance polarity discs (9x vs. 3x contrast: OR 1.162, 95%CI 1.084-1.240, t(369) = 4.353, p<.001). In fact, at 9 times higher contrast a flat profile is observed for negative polarity stimuli, with a lack of statistically robust differences (2° vs 0.5°: OR 1.024, 95%CI 0.955-1.093, t(369) = 0.676, p = 1.00; 0.5° vs. 0.33°: OR 0.972, 95%CI 0.906-1.038, t(369) = -0.814, p=1.00; see Supplementary Materials for further details of the post-hoc tests).

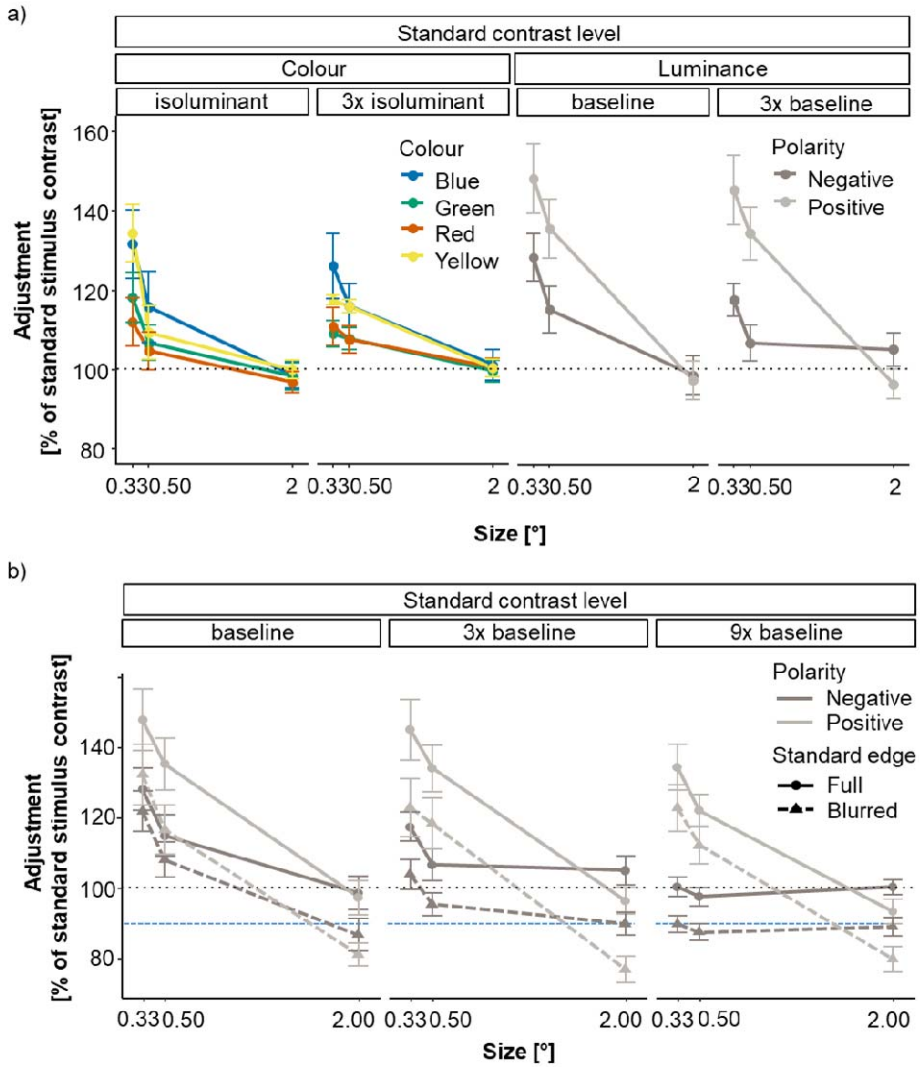

Figure 3. **Perceived contrasts for chromatic and luminance-defined stimuli of different sizes.** (a) Isoluminant colour stimuli and luminance-defined stimuli matched to suprathreshold standards of equal salience (i.e, at a relatively well-saturated level within the monitor gamut) as well as to standards 3 times higher in contrast. (b) Luminance-defined stimuli as a function of stimulus size, depicting matches for a suprathreshold contrast level (left) and for three (middle) and nine (right) times higher contrast for sharp (full line) and blurred edge (dashed line) stimuli. Note that the left and middle panels for sharp edge stimuli are identical to the luminance-defined conditions in (a) and are replotted to facilitate comparisons. To compare the extent of desaturation between chromatic and luminance-defined stimuli, we represent saturation in units of standard stimulus contrast. Therefore, an adjustment value of 200% would indicate twice the amount of contrast in the standard stimulus was required for the comparison stimulus to achieve the same perceived saturation. The dotted line at 100% indicates the contrast of the central region of the standard stimulus, which in the case of sharp-edge standards is identical to their full contrast. Dashed blue line indicates absolute contrast value for blurred edge stimuli (92.5%). Error bars denote 2 standard errors.

As can be seen from Figure 3b, contrast adjustments were consistently higher when luminance-defined stimuli were matched to a sharp edge standard than to a standard with a blurred edge. The effect of blurring surpasses the difference in overall contrast between the standard sharp-edged and blurred-edge stimulus (t-test against contrast of 92.5% t(9)=-10.848, p<.001, mean = 83.778,% 95%CI 81.354%-86.201%, d = -3.43), demonstrating the importance of edges in driving our perceptual experience of contrast (see also Figure 4 for convergent findings from our 2nd experiment).

2. Desaturation with a reduction of stimulus size for light and dark coloured discs with blurred or sharp edge

A linear mixed-effects model was fitted to the data from the 2nd experiment, predicting perceived contrast as a function of size, colour, luminance contrast pedestal and edge definition (for full details, see Supplementary Materials). There was a series of two-way interactions between the factors, with the best-fitting model explaining about half of the variance in the dataset (Marginal R^2 = 0.537, Conditional R^2 = 0.663). First, an interaction between colour and size replicated our previous findings: as shown in Figure 4, reduction of stimulus size led to desaturation: the amount of contrast required to achieve equal saturation of the comparison stimulus increased as stimulus size decreased (2° vs. 0.5°: OR 0.848, 95%CI 0.840-0.856, t(2297) = -34.688, p<.001; 0.5° vs. 0.33°: OR 0.944, 95% CI 0.935-0.953, t(2297) = -11.854, p<.001). Desaturation was highest for blue (vs. yellow: OR 1.053, 95%CI 1.041-1.065, t(2297)=9.145, p<.001), followed by yellow (vs green: OR 1.048, 95% CI 1.037-1.059, t(2297)=8.806, p<.001; for further post-hoc tests, see Supplementary Materials).

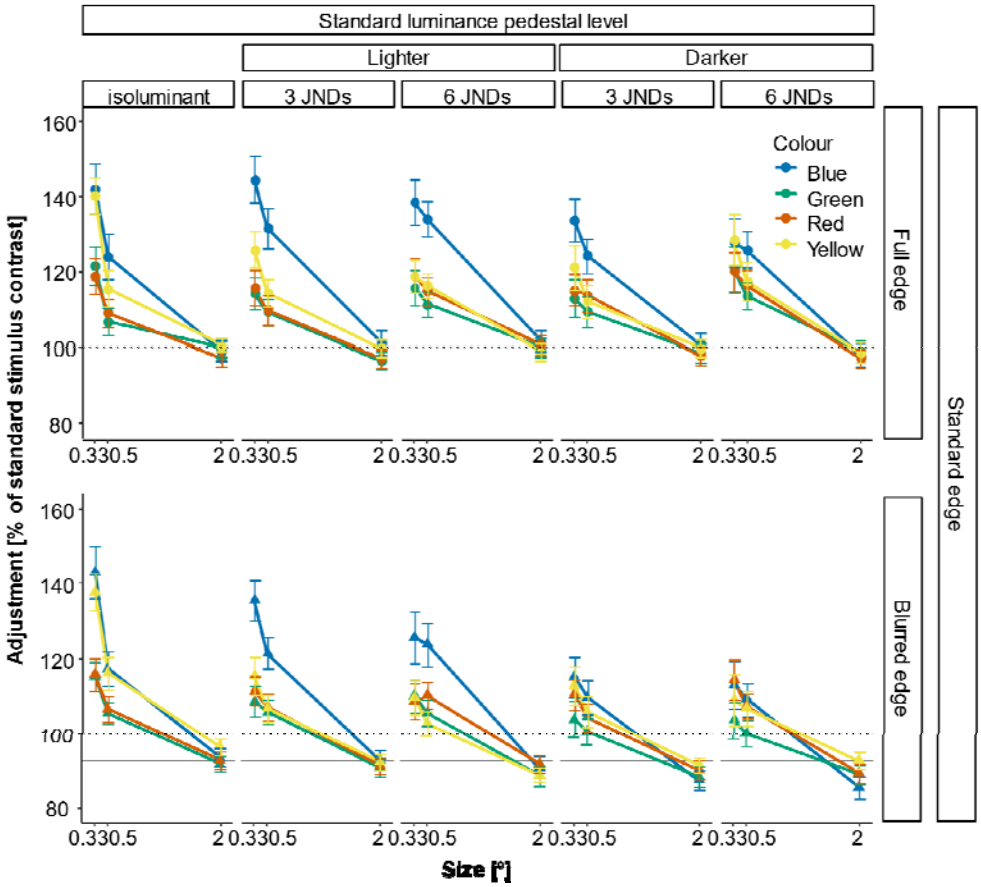

Figure 4. Perceived contrast for coloured discs of different size, presented with and without a luminance pedestal (i.e., lighter: 3 JND+ and 6 JND+ and darker: 3 JND- and 6JND-, with + standing for positive and – for negative luminance polarity), matched to either a sharp-edged or blurred-edge standard stimulus. Adjustment is expressed as percentage of standard stimulus contrast, as in Figure 3. The dotted line at 100% indicates the contrast of the central region of the standard stimulus, which in the case of sharp-edge standards is identical to their full contrast. In the lower panel, an additional grey line indicates the actual contrast of the blurred edge stimulus (92.5%). Error bars represent 2 standard errors.

Luminance pedestals interacted with colour, as well as with size. Addition of luminance pedestals had a very small effect on desaturation of red or green. However, yellow and blue were both significantly and systematically affected. For yellow, all of the luminance pedestals led to less desaturation compared to isoluminance, without significant differences between the different pedestals. For blue, desaturation was reduced only by negative luminance pedestals (see Supplementary Materials for all post-hoc tests of this interaction). Interaction of luminance pedestal with size was such that pedestals led to no significant changes in perceived contrast for the 2° stimulus, but produced significantly less desaturation compared to isoluminance for the 0.33° stimulus (again, see Suppl. Materials for all the details of the post-hoc tests).

Together with our predictions of less desaturation with the addition of luminance pedestals, we also predicted blurring of the standard stimulus edge to decrease perceived contrast.

This would mean that less contrast would be required to find a match with a blurred-edge standard, compared to a sharp-edge standard. There was also a significant interaction between edge definition and luminance pedestal: for blurred-edge discs, the isoluminant condition required more contrast to achieve equal salience in relation to all conditions with luminance pedestals except for the positive pedestal of 3 JNDs, which similarly to isoluminance required significantly more contrast than the negative pedestal conditions (again, see Suppl. Materials for all the details of the post-hoc tests). This is in line with our prediction that blurring the edge would particularly affect perceived contrast once colour is combined with luminance information.

DISCUSSION

We demonstrate that parafoveal desaturation with a reduction in stimulus size is characteristic of general contrast processing by the visual system, rather than specific to colour. This may appear counterintuitive, as it is generally accepted that colour perception is a specialisation of foveal vision. However, we show that once achromatic stimuli are perceptually matched in contrast with chromatic stimuli, they exhibit the same changes in appearance with a reduction in stimulus size as chromatic stimuli. We demonstrate that this effect can be reduced when overall contrast of chromatic stimuli is sufficiently increased or shifted towards higher spatial frequency channels through the addition of luminance pedestals. In fact, at contrast levels tested in this study, reduction in perceived contrast with a decrease in stimulus size is eliminated for negative but not for positive luminance polarity stimuli. It is not possible to achieve sufficient contrast levels within a monitor's gamut to alleviate the desaturation with size for purely chromatic stimuli. We also show that the extent of desaturation differs between the two chromatic mechanisms and that it can be reduced for the most impacted blue-yellow mechanism when presented in combination with luminance contrast pedestals. These findings highlight that general contrast mechanisms can explain loss of perceived contrast as experienced in the parafovea with a reduction in stimulus size.

Contrast constancy theory (Kulikowski, 1976) account for our findings fairly well. For positive luminance contrasts detection threshold is higher (Lu & Sperling, 2012), which would make low contrast stimuli closer to threshold and thus reduced in perceived contrast, especially when parafoveally presented. Contrast constancy can be achieved when physical contrast is sufficiently higher than threshold. For low to medium contrast gratings or Gabors, the point of constancy depends on spatial frequency (Georgeson & Sullivan, 1975) but for disc stimuli it depends on the length of an edge, with the decrease in sensitivity as size reduces well explained by probability summation over multiple edge detectors, following the envelope of the CSF (Ashraf et al., 2023). When contrast is at threshold, only the most sensitive channel processes the information (Kulikowski, 2003). When contrast is sufficiently increased, it breaches the contrast sensitivity limitations of other channels and they begin to contribute to contrast perception. Our investigation of perceived contrast with blurred edge standards (i.e., reduced high-frequency information) confirms this: matches of full-edge comparison discs to blurred edge standards are affected across all sizes, with the effect on appearance far exceeding the overall change in stand ard stimulus contrast (see Fig. 4).

Similar findings on perceived contrast across chromatic and achromatic stimuli in the periphery are reported by Jiang and colleagues (2022). Their observers compared perceived contrast of a peripheral stimulus to the foveally presented standard at varying suprathreshold contrast levels until the point of objective equality (PSE) was achieved. Whilst constancy was achieved at higher contrasts, the upper range of spatial frequencies appeared less contrasty than predicted by the contrast constancy model when the standard was presented

at low or middle contrast (for consistent findings of deviations from contrast constancy, see Ashraf et al., 2022). This suggests a ‘hybrid model’ of contrast constancy, where constancy is not entirely achievable for higher-frequency stimuli at lower or mid-ranges of contrast. Such a hybrid model is in line with our own observations here. Put together, these findings point towards desaturation as a consequence of low-level contrast bottlenecks. Our smaller stimuli appear desaturated as the general contrast sensitivity for high spatial frequencies is low for chromatic information (Mullen, 1985) and decreases further with eccentricity (Anderson et al., 1991). Due to their small size (0.33° and smaller), their energy distribution cannot be effectively processed in the parafovea. Saturation for larger discs depends on summed information from a larger number of channels and is therefore preserved at these eccentricities.

Luminance contrast pedestals play an important role in preserving saturation for blue and yellow stimuli. For yellow, change is observed even with lower positive and negative luminance pedestal magnitudes, whereas for blue, only negative polarity pedestals increase perceived contrast and thus reduce desaturation with size. The blue-yellow mechanism CSF has a lower spatial frequency cut off than the red-green mechanism (Wuerger et al., 2020). The actual number of spatial channels within each of the mechanisms has not yet been definitely established (Peterzell & Teller, 2000), but previous research suggests three channels for red-green (Losada & Mullen, 1994) and two channels for blue-yellow, matching the sensitivity of the two lowest spatial frequency luminance channels (Humanski & Wilson, 1992). Inclusion of additional luminance contrast energy exciting the range of higher spatial frequency channels within the luminance CSF envelope would be expected to decrease detection threshold and hence increase perceived contrast. Different impact of luminance contrast on yellow compared to blue may be due to differently spatially tuned Short-wavelength-ON (responding to blue) and Short-wavelength-OFF mechanisms (responding to yellow; Hardman & Martinovic, 2021).

Finally, we need to consider if our results are influenced by eye movements. This is unlikely for several reasons. Our experienced psychophysical observers were instructed to only perform the task when steadily fixating, and produced patterns of desaturation consistent with low-level influences on perception, as described above. Jiang et al. (2022) obtained highly convergent patterns of results with a very similar adjustment task. In fact, if participants were foveating the stimuli consecutively, they would have produced flat lines in both our studies, without any effects of eccentricity.

In conclusion, perceptual experience of colour saturation is comparable to the well-explored contrast perception of luminance stimuli. This means that further insights into low-level mechanisms of contrast processing, across both luminance and colour, can better inform our understanding of high-level colour properties such as saturation and how these can be accurately represented in models of colour appearance. Similar research programmes have already led to a collection of large-scale threshold and suprathreshold datasets whose modelling not only has practical applications in the domain of display technologies (e.g., Ashraf et al., 2024) but can also lead to interesting predictions in relation to human perception mechanisms. For example, they would accurately predict our current findings, dispelling the often-accepted myth that it is only colour whose appearance is affected when presented in the periphery.

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