How are different contrast effects on binocular luster spatially integrated?

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Abstract

In previous studies with dichoptic center-ring-surround stimuli, we found that two properties of the ring element have a strong influence on the phenomenon of binocular luster. The strength of the lustrous impression in the central target patch varies with increasing ring width, with the direction of this variation (increasing or decreasing) depending on the ring's luminance. In this study, we used stimuli in which the ring was split into segments with two different luminances that in uniform rings had opposite effects on perceived luster. The aim was to investigate how the lustrous impression is influenced by combining a weaker and a stronger contrast effect, in particular how they are spatially integrated by the visual system. In a psychophysical matching experiment, subjects had to assess the strength of the lustrous impression in a series of test stimuli with different ring widths, numbers of ring segments, and spatial proportions between the two ring parts. We found that the results of the experiment could neither be explained by a winner-takes-all integration (assuming that the lustrous response is completely determined by the stronger effect) nor by a balanced integration process (assuming equal weights for the two effects). Instead, both effects contribute to the overall lustrous response, with the stronger effect having a greater weight. Interestingly, the magnitude of this weight varied considerably between different groups of subjects. We found two main trends in the data, representing two different types of sensitivity to the phenomenon of binocular luster.

1. Introduction

The phenomenon of binocular luster can be observed when the two eyes are presented with stimuli that differ in color or luminance contrast. For the study of this phenomenon, simple dichoptic center-surround configurations have been established as standard stimuli in which the center patches differ in color or luminance whereas the surrounds are identical (Anstis, 2000, Formankiewicz & Mollon, 2009, Jung, Moon, Park, & Song, 2013, Kiesow, 1920, Malkoc & Kingdom, 2012, Sheedy & Stocker, 1984, Wendt & Faul, 2019, Wolfe & Franzel, 1988, Zhang, 2015). With suitable contrasts, the binocularly combined center patch takes on a strange perceptual quality, usually described as shimmering or lustrous, sometimes also as fluorescent or luminous (see also Wendt & Faul, 2022b). Using this type of stimulus, Anstis (2000) demonstrated that the lustrous impression is significantly stronger when the two monocular half-images have reversed contrast polarities (*inc-dec* stimuli, where a luminance increment is binocularly paired with a luminance decrement) than when the two contrasts have equal polarities (*inc-inc* or *dec-dec* stimuli, respectively) (see also Georgeson, Wallis,

Meese, & Baker, 2016, Hetley & Stine, 2019, Venkataramanan, Gawde, Hathibelagal, & Bharadwaj, 2021, Wendt & Faul, 2019).

In our own experiments on binocular luster, we used a stimulus variant in which the central patches were enclosed by identical rings (Wendt & Faul, 2020, 2022a, 2024, 2025). We found that the magnitude of the lustrous response depends on two properties of the ring element. Firstly, as can be seen in Figure 1, the luster judgments vary strongly with the width of the ring. Secondly, the shape of the resulting "luster curves" is determined by the relationship between the ring's luminance and the luminances of the surround element and the two center patches.

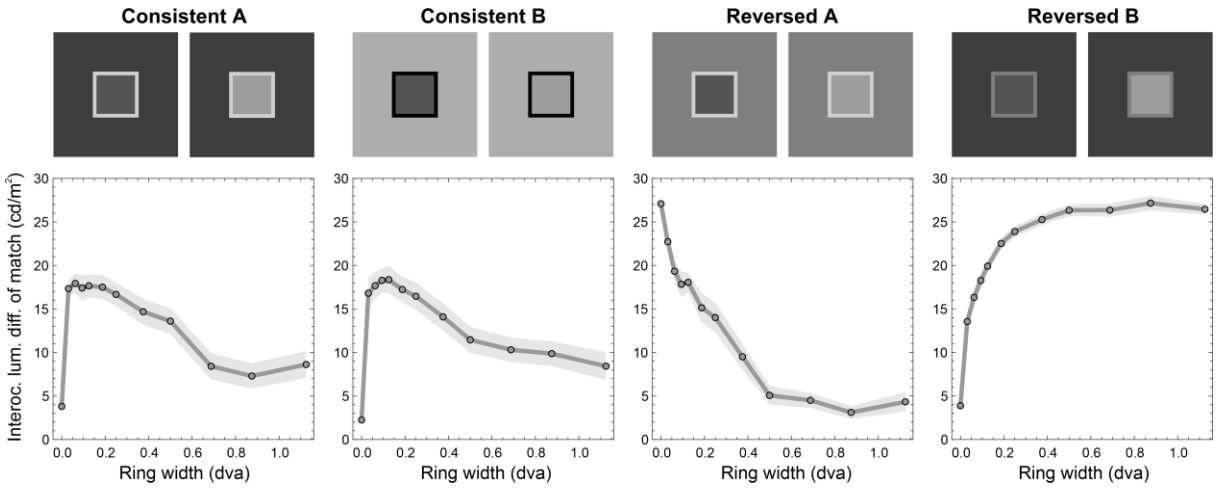

Figure 1: Example results from Wendt and Faul (2025). Observers had to assess the strength of the lustrous impression in the central area of dichoptic center-ring-surround stimuli with varying ring widths. In addition, four different combinations of ring and surround luminance were tested. The strength of the lustrous impression varied strongly depending on the ring width. The shape of the luster curves was determined by the luminance of the ring in relation to the luminances of the surround element and the two center patches. The depicted luster settings were obtained with square center patches with a side length of 4 degrees of visual angle and a luminance difference of 30 cd/m^2 between the monocular center patches. Transparent areas represent the SEM in both directions.

In our previous work, we have shown that all these observations can be explained by a simple neural process located at an early stage of the visual pathway (Wendt & Faul, 2022a, 2025; see Fig. 2). The basic component of this mechanism is a binocular cell that receives its input signals from two types of monocular contrast detector cells whose receptive fields have reversed excitatory and inhibitory areas, making them sensitive to light patterns with opposite polarity. Suitable candidates for such monocular cells include neurons with an antagonistic circular-symmetric center-surround organization of their receptive fields (similar to the retinal ganglion ON- and OFF-center cells; see Schiller, 1992), as well as orientation-selective cells, whose excitatory and inhibitory subregions are arranged side-by-side (for example, with a Gabor-like layout where the ON- and OFF-cells are represented by opposite phases). One main characteristic of the binocular cell is that its response strongly depends on the types of monocular cells that provide the input signals. Signals from monocular cells of the same type

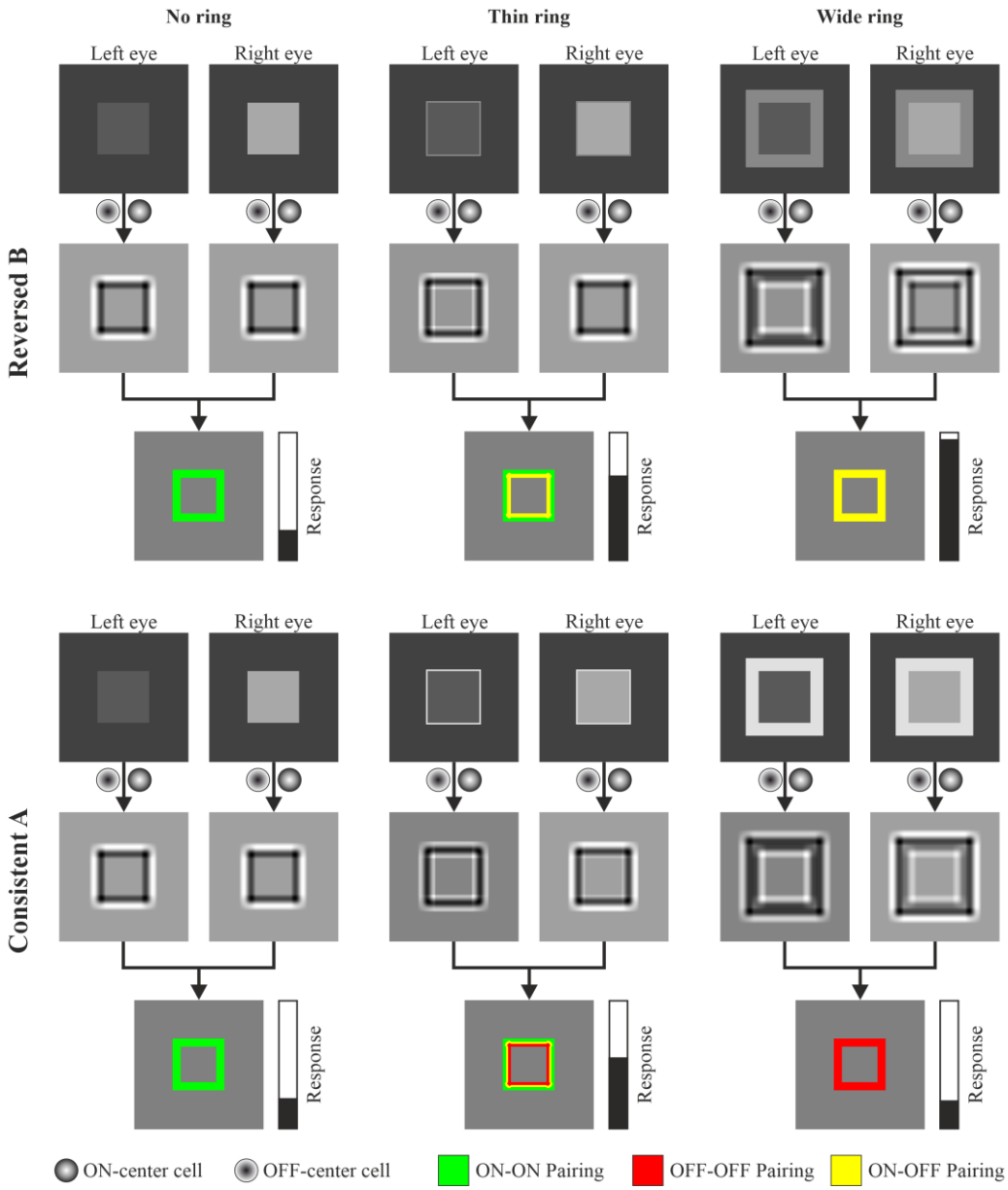

Figure 2: The magnitude of the lustrous response to dichoptic center-ring-surround stimuli can be predicted by a simple low-level process. **Top half**: Three different stimulus pairs of the *Reversed B* condition are shown, differing in the width of the ring element (top row). At the monocular level, either ON- or OFF-center contrast detector cells are triggered by the local luminance pattern (middle row, dark pixels represent the stimulation of an ON-center cell, light pixels the stimulation of an OFF-center cell). At the binocular level (bottom row), corresponding cell responses within the target area are combined into binocular conflict signals. The magnitude of this signal depends on the type of monocular input: The combination of an ON- and an OFF-center cell (ON-OFF pairings, yellow parts) generates much stronger binocular signals than cells of the same type (ON-ON or OFF-OFF pairings). Since the ring luminance lies between the luminances of the two center patches, increasing the ring width increases the amount of strong ON-OFF signals, which in turn leads to a continuous increase in the lustrous response. **Bottom half**: For stimuli of the *Consistent A* contrast condition, where the ring element has a higher luminance than the two center patches, relevant amounts of ON-OFF pairings only occur at smaller ring widths. This explains the non-monotonic shape of the corresponding luster curve (Fig. 1). A more detailed description of the physiologically based interocular conflict model of binocular luster can be found in Appendix A.

(ON-ON or OFF-OFF pairings) produce much weaker responses than the pairing of an ON-mechanism with an OFF-mechanism.

The results of adaptation experiments conducted by Kingdom, Jennings, and Georgeson (2018) support the idea that the phenomenon of binocular luster is mediated by specific

binocular neurons. Evidence for the existence of binocular cells with the above-mentioned response characteristics has already been provided by Poggio and Fischer (1977). These binocular neurons, located in the primary visual cortex and referred to as *tuned-inhibitory* cells, have been shown to be highly sensitive to monocular contrast signals with reversed polarity and may serve as a type of interocular conflict detector (Read & Cumming, 2007; see also Goncalves & Welchman, 2017, Katyal, Engel, He, & He, 2016, Katyal, Vergeer, He, He, & Engel, 2018). Kingdom, Read, Hibbard, and May (2022) therefore assume that these tuned-inhibitory cells may play a crucial role in the luster phenomenon.

Taking two of our standard center-ring-surround conditions as examples (see Fig. 1), we demonstrate in Figure 2 how such a mechanism can account for the existing findings (see also Wendt & Faul, 2022a, 2025). These two contrast conditions also play a central role in the present study, as they have some interesting properties: Although they differ only in the luminance of the ring element, this difference has an almost opposite effect on the luster curves. While the lustrous response in the *Reversed B* condition becomes stronger with increasing ring width, it generally decreases monotonically in the *Consistent A* condition (after an initial steep increase at very small ring widths, see Fig. 1).

In this study, we employed a 'hybrid' of these two contrast conditions to investigate how perceived luster depends on more complex stimulus patterns that combine different contrast effects. This can be achieved by dividing the ring into segments that differ either in luminance alone or in both luminance and width (Fig. 3). Our study specifically addresses three questions: (1) How are the different influences on the luster phenomenon spatially integrated? For example, do they contribute equally to the overall response (balanced integration) or is the response determined by the stronger of the two effects (winner-takes-all)? (2) Can the luster judgments obtained with such mixed stimuli be predicted by our interocular conflict model, which implements a balanced integration (Wendt & Faul, 2022a, 2025)? Would a circular-symmetric layout of the receptive field of the monocular contrast detector cells lead to different predictions than an orientation-selective side-by-side organization of the excitatory and inhibitory regions? (3) Finally, is the lustrous impression within the target area of these mixed stimuli spatially homogeneous, and if not, how does the perceived inhomogeneity affect the overall luster judgments?

2. Methods

2.1. Observers

Eight subjects participated in the experiments, one of them being the first author of the study (GW). Five of the participants were female and three male, with their ages ranging from 20 to 53 years. All subjects had normal or corrected-to-normal visual acuity. Prior to the experiments, we obtained written informed consent from all subjects. The study was conducted in agreement with the ethical standards of the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) and was approved by the Central Ethics Committee of Kiel University (ZEK-18/24).

2.2. Stimuli and apparatus

In order to test how the visual system spatially integrates different contrast effects on binocular luster, we used dichoptic center-ring-surround configurations with a circular shape as test stimuli that were mixed versions of the two original contrast conditions *Consistent A* and *Reversed B* (see Figs. 1 and 2). We used stimuli in which the ring element was subdivided into either 2, 4, 8, or 16 segments, where neighboring segments either differed in luminance only (sub-experiment 1, left panel in Fig. 3), or both in luminance and width (sub-experiment 2, right panel in Fig. 3). In addition, we varied the relative length of the two segment types. The ring proportions are defined by the mixing factor α_{ring}, which represents the relative length of the stronger ring part (based on the *Reversed B* contrast conditions, see Fig. 1), whereas the weaker part (based on the *Consistent A* condition) has a proportion of 1- α_{ring}. Stimuli with α_{ring} = 0, 0.25, 0.5, 0.75, and 1.0 were tested. Stimuli with a_{ring} = 0 and 1.0 are the two original contrast conditions with a uniform ring that served as references. Finally, we varied the width of the ring segments, either equally for the two ring parts (sub-experiment 1), or for one ring part only, while the other ring part was kept at a constant width (sub-experiment 2). Ring widths of 0.0, 0.0625, 0.125, 0.25, 0.375, 0.5625, 0.8125, and 1.0625 dva were used for the varying part of the ring in sub-experiment 2. In sub-experiment 1, however, the no-ring condition (0 dva) was omitted, because this condition would produce identical center-surround stimuli for all combinations of segment number and ring proportion. The

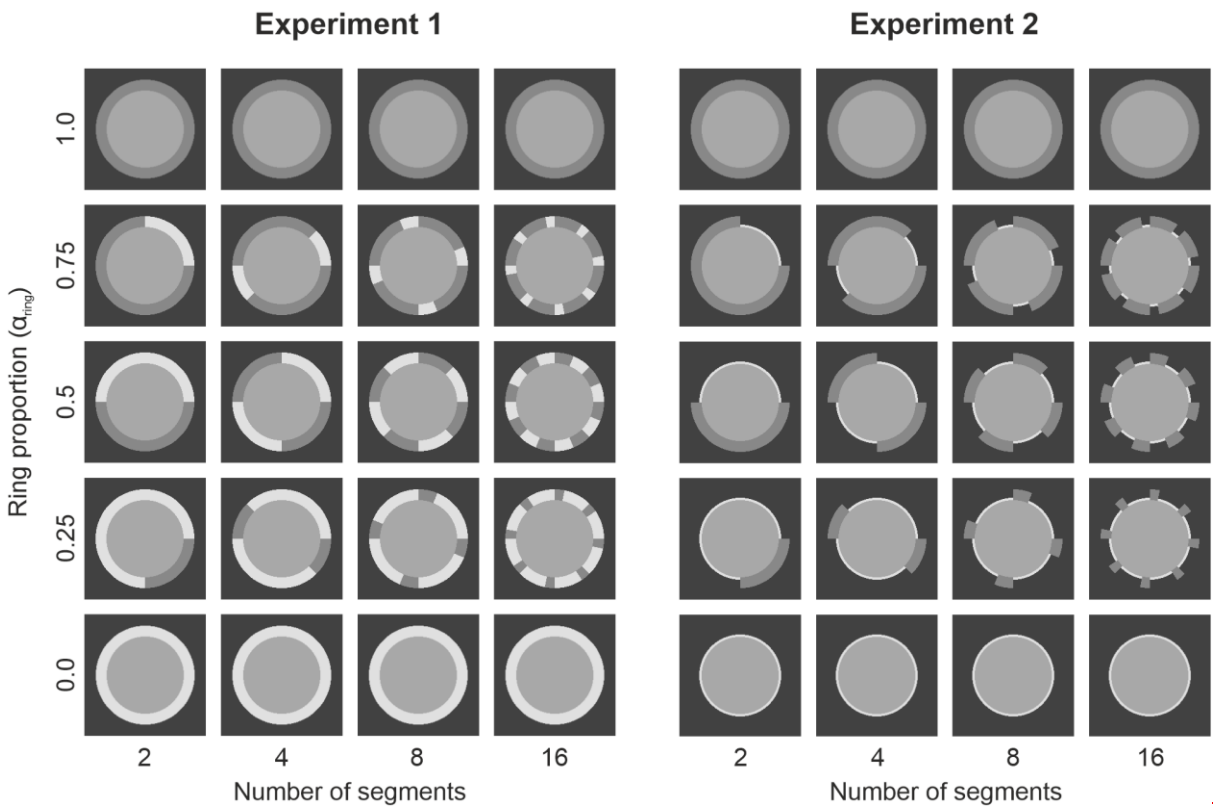

Figure 3: Ring structures as they were used in the two sub-experiments. In sub-experiment 1 (left panel), the two ring parts generally had different luminances (except for stimuli with ring proportions of 0.0 or 1.0, respectively) but the same ring width in each stimulus (here shown with a fixed ring width of 0.5625 dva). In sub-experiment 2 (right panel), one ring part had a constant width of 0.5625 dva and a luminance of 25 cd/m^2, whereas the other ring part had a variable width and a luminance of 75 cd/m^2 (here shown with a constant ring width of 0.125 dva).

luminance of the common surround, which covered the entire upper half of the monitor in which the test stimuli were presented, always had a constant luminance of 5 cd/m^2. The circular center patches, representing the target area of the stimuli, had a radius of 2.0 dva and a luminance of 10 cd/m^2 for one eye and 40 cd/m^2 for the other (these luminances were swapped between eyes in half of the trials to account for potential imbalances in eye dominance).

The stimuli were displayed on a monitor with a diagonal of 24 inches (EIZO CG243W) and a resolution of 1920 × 1200 pixels. To color calibrate the monitor, a JETI specbos 1211 spectroradiometer was used, following a method described in Brainard (1989). The dichoptic stimulus pairs were presented side by side on the screen and fused using a mirror-stereoscope (ScreenScope) mounted on the monitor. The light paths from the screen to the observer's eye had a length of 50 cm.

2.3. Procedure

In each trial, observers evaluated three properties of the test stimulus. First, they had to determine whether the target area of the test stimulus appeared lustrous at all. To this end, the test stimulus (in the top half of the monitor) was presented together with an anchor stimulus (in the bottom half). While the ring structure and the background of the anchor stimulus were always identical to those of the test, the center patches of the anchor always had the same luminance of 22.5 cd/m^2 and thus appeared matte. This reference was meant to facilitate the detection of weaker lustrous sensations in the test. Using the arrow keys on the keyboard, the observer could switch between the two response alternatives "lustrous" and "non-lustrous". If „non-lustrous" was selected, the trial was terminated and the next trial began after a dark adaptation period of three seconds. If „lustrous" was selected, the trial proceeded to the second part, in which the test stimulus was presented together with a matching stimulus consisting of a dichoptic center-ring-surround configuration with a square outline. The center patches of the match had a side-length of 2.0 dva and were enclosed by a 0.125 dva wide ring with a fixed luminance of 25 cd/m^2. The luminance of the common surround, which filled the entire bottom half of the screen, was 10 cd/m^2. Using the arrow keys on the keyboard, the observer had to adjust the interocular luminance difference $|C_l - C_r|$ between the two center patches such that the perceived luster in the match was indistinguishable from that of the target patch of the test stimulus. This luminance difference was used as a measure for the perceived luster strength (see also Wendt & Faul, 2025). This choice is supported by the strong correlations between the interocular luminance difference $|C_l - C_r|$ and corresponding rating values in our previous studies (Wendt & Faul, 2020, 2022a, 2024), in which the observers additionally rated the strength of the lustrous impression on a scale from 0 to 5. The observers adjusted a parameter α from which the two center patch luminances C_l and C_r of the match were determined as follows:

$C_{l,r} = 25 \cdot (1 \pm \alpha^k)$ cd/m^2, for $0 \leq \alpha \leq 1$ and $k = 1/0.77$.

The constant k in these equations was selected such that the relationship between α and the strength of perceived luster was approximately linear (see Wendt & Faul, 2019).

In the third part of a trial, the observer was asked to judge the perceived spatial homogeneity of the luster within the target area. To this end, the same test stimulus as in the previous two parts of the trial was shown in isolation and the observer had to select an integer rating value between 0 (= "extremely inhomogeneous") and 10 (= "perfectly homogeneous") using the arrow keys on the keyboard.

Prior to the experiment, each observer was carefully instructed and a series of test trials had to be performed under the supervision of the experimenter. The stimuli used in these test trials were selected from the entire set of stimulus conditions used in the experiments and provided a wide range of different luster impressions. To ensure that the homogeneity ratings were comparable across experiments, we combined the stimulus conditions from both sub-experiments into a single experiment. In total, 210 different stimulus combinations were tested, each of them with four repetitions. The entire set of trials was presented in random order.

2.4. Calculating the predictions for the mixed-ring conditions

The empirical luster curves were evaluated with respect to two alternative integration mechanisms: a winner-takes-all integration and a balanced integration.

Winner-takes-all

Under a winner-takes-all integration model, the magnitudes of the lustrous responses obtained with the mixed-ring stimuli (combing a stronger and a weaker effect) should equal those of the "pure" condition with the stronger effects. That is, in combinations of the stronger *Reversed B* condition and the weaker *Consistent A* condition, a winner-takes-all mechanism would produce the same lustrous response as *Reversed B* stimuli with a homogeneous ring (with $\alpha_{ring} = 1.0$, see Fig. 3). Therefore, the luster curves associated with the mixed-ring stimuli should then be identical to the curve observed with the stronger effect in the pure condition.

Balanced integration

In a balanced integration model, different predictions for the lustrous responses obtained with the mixed-ring stimuli can be derived. We tested two alternatives:

(1) A very intuitive method is to predict these luster curves on the basis of the two pure reference luster curves. It would be reasonable to assume that the luster curve for the mixed-ring stimuli results from a weighted combination of the two reference curves, with the weights corresponding to the respective ring proportions. That is, with a fixed proportion of α_{ring} it would be a convex combination of the luster curve for the stronger effect weighted by α_{ring} and the luster curve for the weaker effect weighted by $1- \alpha_{ring}$.

(2) As an alternative to this descriptive or data-based method for predicting the luster curves, we applied a method based on our interocular conflict model of binocular luster (Wendt & Faul, 2022a; a detailed description of the model is provided in Appendix A). Since this model incorporates a balanced integration of the conflict signals within the target area, it seems well suited for predicting the luster curves for the mixed-ring conditions. The model was fed with the same stimuli used in the experiment to predict the corresponding empirical luster curves for the mixed-ring stimuli. The model parameters required for calculating these predictions were estimated using the empirical data obtained under the two pure contrast conditions *Consistent A* and *Reversed B*. Furthermore, as mentioned in the Introduction, we used two different variants of the model for the predictions, which differ in the type of filter kernel that represents the monocular contrast detector cells. The receptive field has either a circular-symmetric center-surround organization (simulated with an LoG filter kernel, see Appendix A) or a side-by-side arrangement of the excitatory and inhibitory areas (simulated with Gabor filters, see Appendix B). This comparison was motivated by the fact that mixed-ring stimuli often show a complex pattern of luminance edges that occur not only between the target area and the ring element but also between neighboring ring segments (which produce so-called T-junctions with luminance edges that are orthogonal to each other, see Fig. 3). This suggests that an orientation-selective filter kernel may lead to different predictions than a filter kernel based on an LoG kernel—and, if true, this may provide some deeper insights into the specific types of monocular contrast detector cells involved in the underlying mechanism.

2.5. Results

Since all mixed-ring stimuli combine the pure contrast conditions *Consistent A* and *Reversed B*, we will first take a look at the luster curves for these basic stimulus sets. The luster settings averaged across all eight subjects are shown in the top row of Figure 4 as solid curves (left diagram, yellow for the *Consistent A* and blue for the *Reversed B* condition). Also shown are the corresponding predictions and best-fitting parameter values of the LoG variant (middle diagram, see also Appendix A) and the Gabor variant of the interocular conflict model (right diagram, see also Appendix B). The luster curve for the *Reversed B* condition (blue) is very similar to those from our previous studies (see Figure 1). The curve *for the Consistent A* condition, however, deviates considerably from previous results. The general shape of the curve is similar: it is non-monotonic with a steep increase between the no-ring condition and a ring width of 0.0625 dva, and a smoother decrease at larger ring widths. However, the peak of the curve is shifted to a much larger ring width (at 0.375 dva) and the decrease of the luster settings for subsequent ring widths is much smoother than we previously found.

The reason for this unexpected shape of the *Consistent A* luster curve becomes clearer when comparing the empirical luster settings of the individual subjects (see Appendix C). In the *Reversed B* condition, the luster curves of all subjects have a similar shape: The lustrous response increases sharply with increasing ring width until it reaches an asymptote, with slight variations in the steepness of the increase and the absolute level of the asymptote. However, the subjects show clear differences in their sensitivity to luster in the *Consistent A* condition. There appear to be two main trends, which are also reflected in the parameter

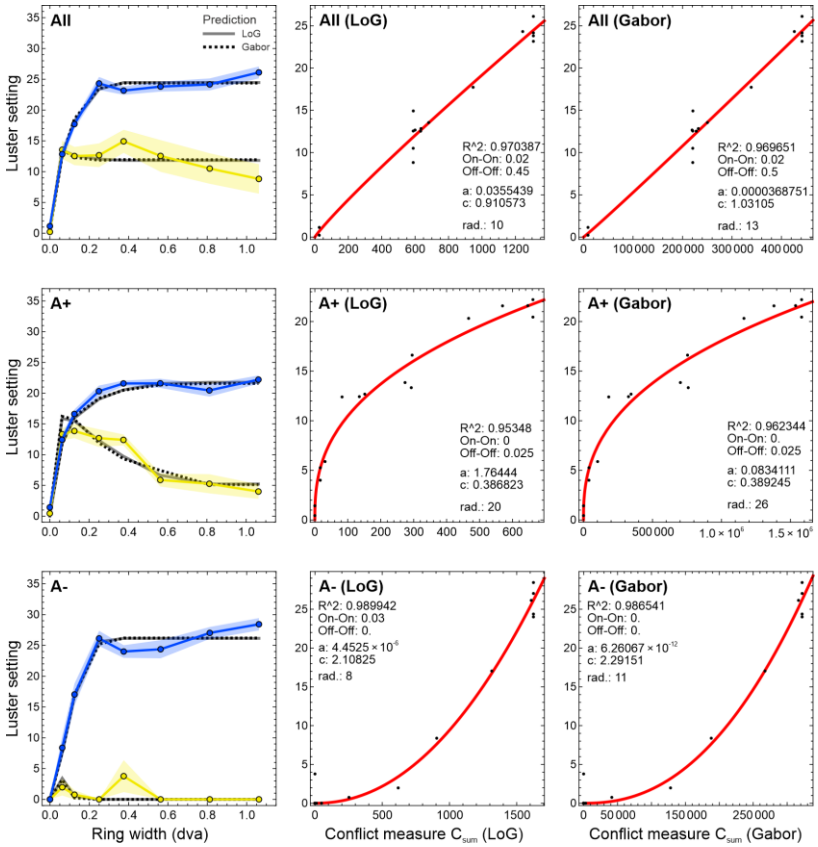

Figure 4: Left column: Empirical luster curves for the pure *Consistent A* (yellow) and *Reversed B* (blue) contrast conditions and their corresponding predictions based on the LoG variant (solid grey lines) and the Gabor variant of the interocular conflict model (dotted lines). The middle and the right diagram show the relationship between the empirical luster settings and corresponding model outputs C_{sum} for the LoG (middle diagram) and the Gabor variant (right diagram), respectively, based on the parameters of the best fit. Corresponding transducer functions are represented by the red curves. The top row shows the results for the entire sample of eight subjects, the middle and bottom rows those for the two sub-groups **A+** and **A-**, respectively.

values of the corresponding model fits. One group of subjects (S01, S02, and S04), who showed high luster sensitivity for stimuli from the *Consistent A* condition (which we will refer to as the **A+** group, see the middle row in Fig. 4), produced luster curves very similar to those we have found in our previous studies. For this group, the best fit was achieved with a large radius of the filter kernel (20 and 26 pixels for the LoG and the Gabor kernel, respectively) and a nonlinear decelerating transducer function (see the red curves in the respective diagrams in Fig. 4). The other group (referred to as **A-**, see the bottom row in Fig. 4), which includes subjects S03, S06, and S07, turns out to be nearly insensitive to stimuli from the *Consistent A* condition. For this group, the best fit was achieved with a comparatively small radius of the filter kernel (8 and 11 pixels for the LoG and the Gabor kernel, respectively) and an accelerating transducer function. The two remaining subjects S05 and S08, although showing a high sensitivity for both stimulus sets, cannot be clearly assigned to either of these two groups as they produced rather unusual and, at least partly, somewhat unsystematic luster curves for the *Consistent A* condition, in combination with comparatively large standard errors. Interestingly, despite large differences in the shapes of the luster curves and corresponding differences in the model parameters, the predictive quality of the model remains very high for both the LoG and the Gabor variant (with R^2 values for the individual datasets between 0.927 and 0.99, except for subject S08 with an R^2 of about 0.85). Since

groups **A+** and **A-** appear to indicate different types of sensitivity to the luster phenomenon, we will conduct our further analyses separately for these two groups.

Figures 5 and 6 show the empirical results of the matching task as well as the corresponding predictions for the **A+** and the **A-** group, respectively. For each of the two sub-experiments (see the top and bottom panels in each figure), the results are shown separately for the four different numbers of ring segments (columns). Each diagram shows the luster curves for the three mixed-ring conditions with the different colors representing the different proportions of the two ring parts. In addition, the two reference curves corresponding to the pure ring conditions are also added to each diagram in a row (see the blue and yellow curves).

We will now compare the findings of both groups, starting with the results of the **A+** group (Figure 5, solid lines in the top row of each panel). In this case, the luster curves for the mixed-ring conditions generally lie somewhere between the two curves predicted by the different types of integration. This is generally true for all three methods that we used to calculate the prediction curves for the balanced integration, that is, the data-based method (dashed curves in the top row of each panel) and the two versions of the model-based method (bottom row in each panel). This already shows that the data cannot be explained by a strict winner-takes-all mechanism. Otherwise, all luster curves for these conditions would have to be equal to the blue curves, which always represent the ring parts with the stronger contrast effect.

In the data of the **A-** group (Figure 6), there is also the general trend for the luster curves of the mixed-ring conditions to lie somewhere between the two prediction curves. However, the empirical curves deviate significantly more from the corresponding model predictions of the balanced integration, with a stronger tendency toward the blue reference curve representing the winner-takes-all integration. There is another interesting effect that is only faintly discernible in the data of the **A+** group (Figure 5): As the number of ring segments increases, the luster curves shift increasingly downward, i.e., the more fragmented the ring is, the weaker the lustrous impression becomes. Interestingly, similar curve shifts also occur in the model-based predictions, an effect that we will explain in more detail in the following discussion section.

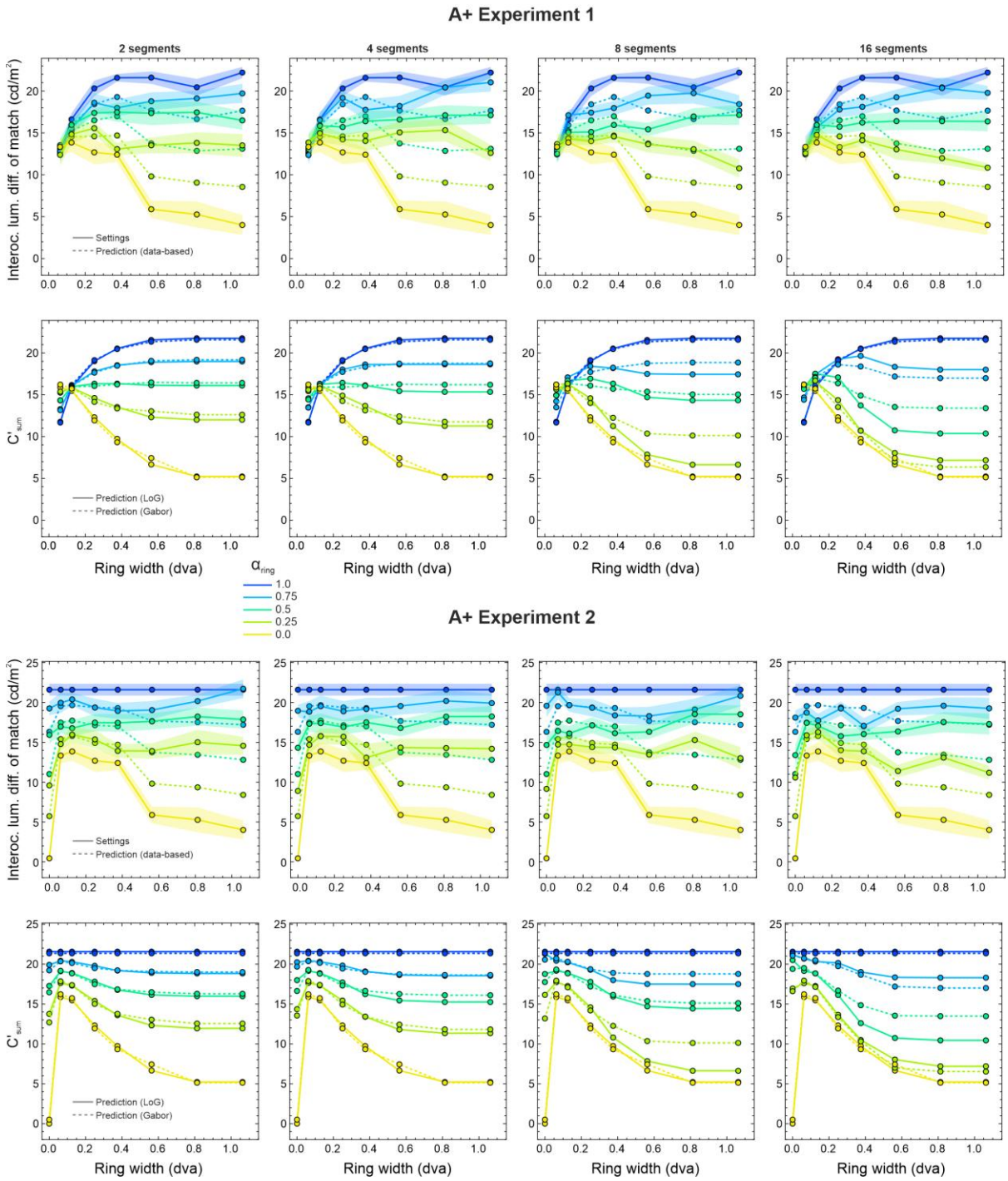

Figure 5: Results of the matching task of group **A+** and corresponding predictions. For each of the two sub-experiments (top and bottom panel), the empirical luster settings (solid lines in the top row of each panel) are shown as a function of ring width, separately for the different segment numbers (columns) and the different spatial proportions for two ring parts (see the differently colored lines in each diagram; the transparent areas represent the SEM in both directions). For the balanced integration method, the corresponding prediction curves of the data-based method are shown as dashed lines in the top row of each panel, those of the LoG (solid lines) and the Gabor variant (dashed lines) of the model-based method are shown in the bottom row of each panel. The predictions for the winner-takes-all integration are always represented by the dark blue lines.

So far, it is obvious that the data cannot be explained by the assumption that in the mixed-ring condition the stronger of the two contrast effects fully determines the lustrous appearance (winner-takes-all). The finding that the empirical luster curves generally lie somewhere between the predictions of the two integration methods suggests that both contrast effects

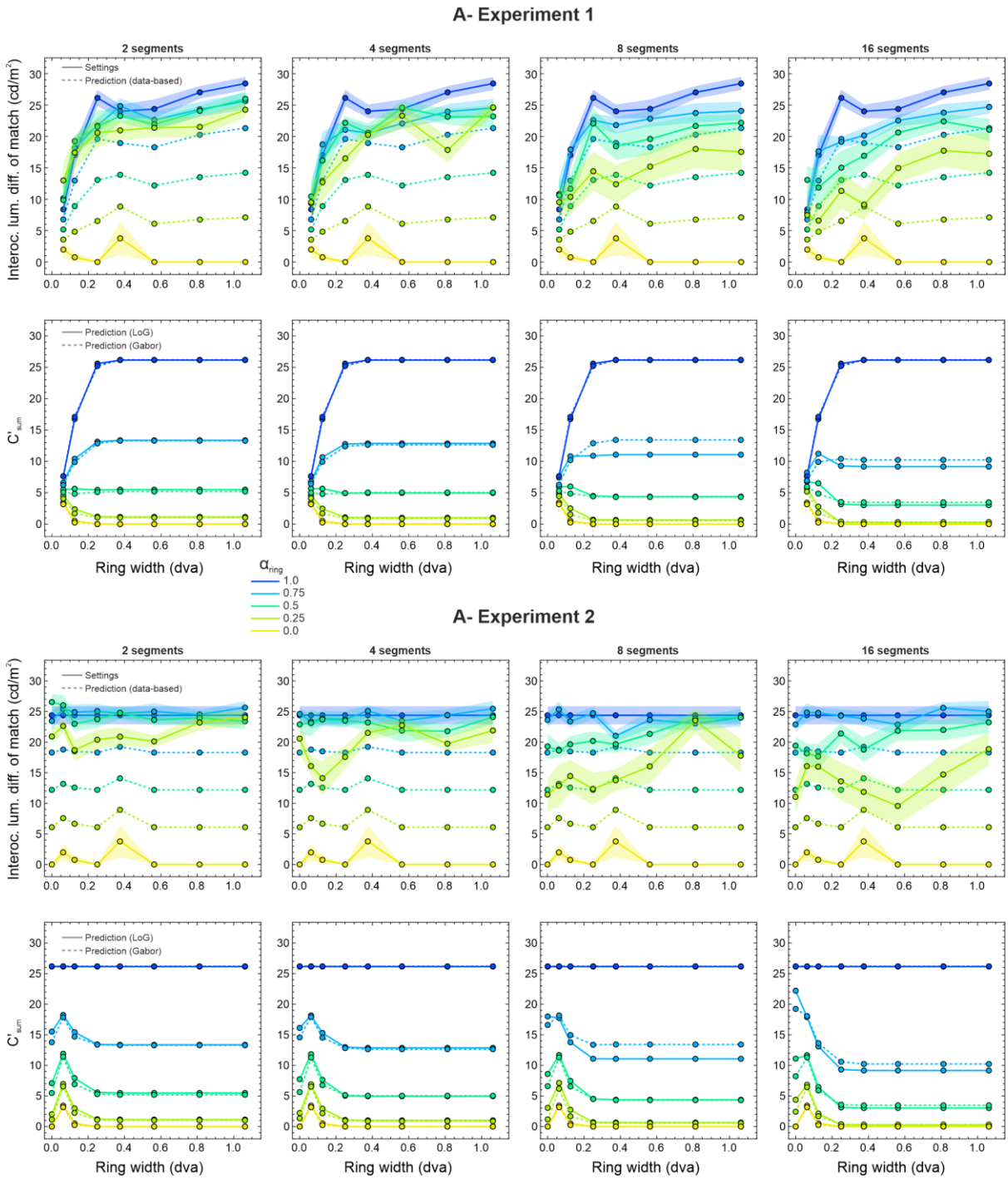

Figure 6: Results of the matching task of group **A-** and corresponding predictions. For each of the two sub-experiments (top and bottom panel), the empirical luster settings (solid lines in the top row of each panel) are shown as a function of ring width, separately for the different segment numbers (columns) and the different spatial proportions for two ring parts (see the differently colored lines in each diagram; the transparent areas represent the SEM in both directions). For the balanced integration method, the corresponding prediction curves of the data-based method are shown as dashed lines in the top row of each panel, those of the LoG (solid lines) and the Gabor variant (dashed lines) of model-based method are shown in the bottom row of each panel. The predictions for the winner-takes-all integration are always represented by the dark blue lines.

contribute to the overall lustrous impression in the target area, but with different weights. From what we have already seen above, it is also to be expected that the weights differ between the two sub-groups **A+** and **A-** and that they also depend on the method used to evaluate the data, that is, the data-based method and the two variants of the model-based

method (see section 2.4). To facilitate the comparison of the results across these different methods, we calculated an index k that expresses the position of each empirical luster curve relative to its two corresponding predictions. For the data-based method, in which each prediction curve is a convex mixture of the two reference luster curves (the blue and the yellow curves in the respective diagrams, see section 2.4), we determined the mixing factor α_{emp} that best fits the empirical luster curve. We then set α_{emp} in relation to the two values representing the two different integration methods, where a_{bal} represents balanced integration (which is identical to the spatial proportion α_{ring} of the mixed-ring stimuli) and $\alpha_{win} = 1.0$ represents winner-takes-all integration (see the left diagram in Fig. 7): $k_{data} = (\alpha_{emp} - a_{bal}) / (1.0 - \alpha_{bal})$. The index k therefore lies in an interval between 0.0 and 1.0, where a value of 0.0 represents a match between the empirical luster settings and the predictions of the balanced integration, and a value of 1.0 represents a match with the prediction of the winner-takes-all integration (note that index k was clamped in cases where it exceeded this interval).

For the model-based method, we had to a use a different approach to determine the best fit for the empirical luster curve, as this method requires actual stimuli to calculate a model output (Appendix A). We therefore needed additional stimuli in addition to those used in the experiments: For each segment number and each ring width, we generated mixed-ring stimuli with spatial proportions α_i for the two ring parts between 0.0 and 1.0 in steps of 0.01 leading in each case to 101 candidate curves. We then determined for each empirical luster curve, which of the 101 curves best fits the empirical curve and set α_{emp} to the corresponding α_i and calculated the index k_{model} in the same way.

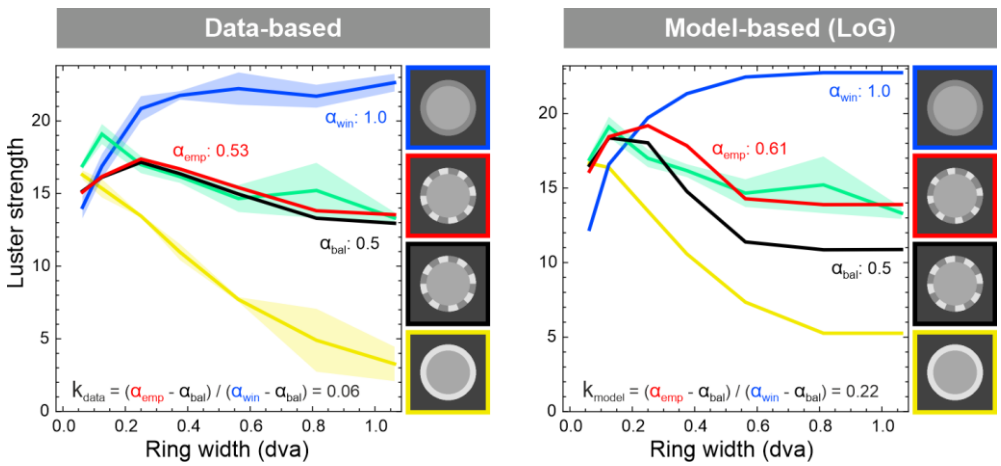

Figure 7: Illustration of how the indices k_{data} (left) and k_{model} (right) are calculated. As an example, we use the luster curve from subject S01 of the first sub-experiment where the mixed-ring condition had 16 segments and a spatial proportion of $\alpha_{ring} = 0.5$ (stimulus with black frame). For the data-based method, the empirical luster curve (green) was fitted with a convex combination of the two reference curves that represent the pure effects (yellow for the weaker effect, blue for the stronger effect). For the model-based method, the parameter α_{emp} represents the spatial proportion of that specific stimulus (with varying ring widths), for which the model calculates a curve (red) that best fits the empirical luster curve (green). In both cases, the index k was determined by the relative position of α_{emp} between the value representing the prediction of the balanced integration (α_{bal}, black) and the value representing the prediction of the winner-takes-all integration (α_{win}, blue, which always has a value of 1.0): $k = (\alpha_{emp} - \alpha_{bal}) / (1.0 - \alpha_{bal})$.

Figure 8 shows the different types of *k* indices (columns) separately for the two groups **A+** (top row) and **A-** (bottom row). For each combination of the four different segment numbers (differently colored lines) and the three different ring proportions (abscissa), the data points represent the average *k* index across the three subjects of a group and, since the empirical luster curves show very similar trends across experiments, the two sub-experiments. A first look at the data confirms our previous observations: The stronger contrast effect in the mixed-ring stimuli contributes more to the overall luster impression than the weaker effect, as all *k* values are above the zero line, which represents a balanced integration process. However, the weight of the stronger effect differs significantly between the two groups of subjects. In group **A-**, the weights are generally much higher than in group **A+**. This is particularly evident in the *k* indices calculated using the model-based method. For both the LoG kernel (middle column) and the Gabor kernel (right column), the k_{model} values in group **A+** are always less than 0.3 and in group **A-** always greater than 0.8. Generally, this trend can also be observed in the *k* indices calculated with the data-based method (first column). However, especially for group **A-**, the range of k_{data} values is considerably larger than that of the k_{model} values. At least in group **A-**, the k_{data} values also show a clear dependence on the number of ring segments—an effect that is much less pronounced in the corresponding k_{model} indices. Specifically, increasing the number of ring segments leads to lower k_{data} indices, indicating that the weights of the stronger and the weaker effect become more balanced as the number of segments in the mixed-ring stimuli increases.

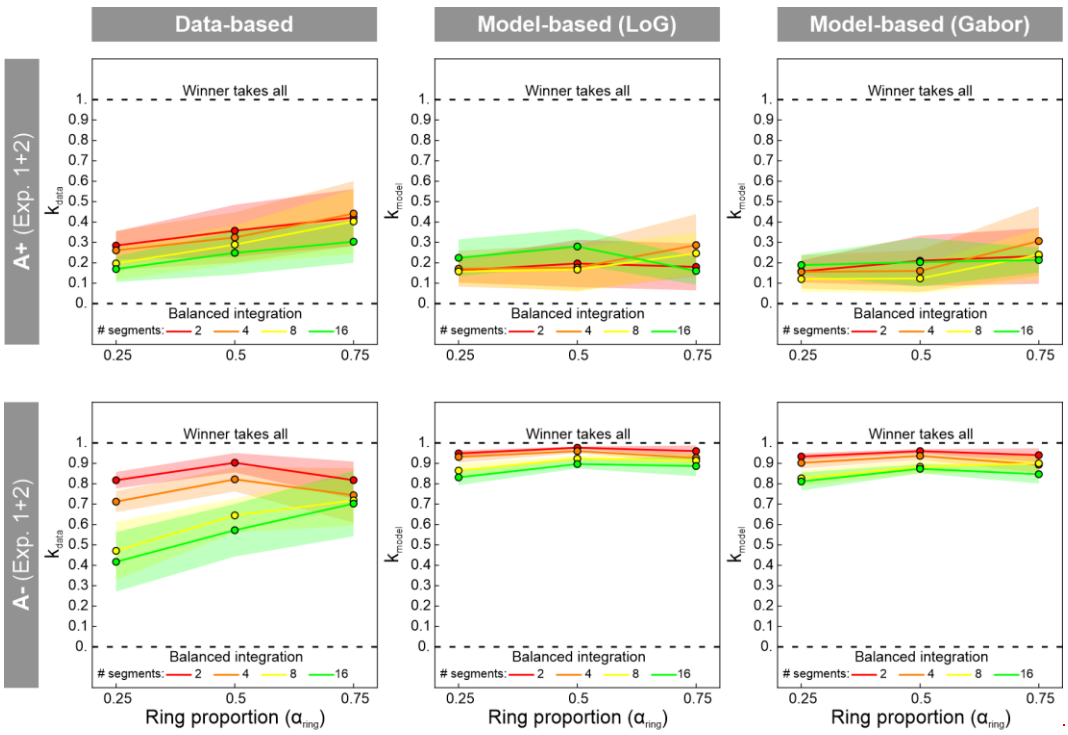

Figure 8: The different types of *k* indices calculated using either the data-based method (left column) or the model-based method (middle column for the LoG variant, right column for the Gabor variant), separately for the two subject groups **A+** (top row) and **A-** (bottom row). In the diagrams, the data points represent the *k* values for each combination of the three different ring proportions (abscissa) and the four different segment numbers (colored lines), averaged across the three subjects in a group and the two sub-experiments. Transparent areas represent the SEM in both directions.

Figure 9 shows the results of the homogeneity rating task, separately for the two groups **A+** and **A-** (note that homogeneity ratings were only obtained for those stimuli that were classified as lustrous during the first part of each trial, see Section 2.3). Panels A and B in Figure 9 reveal two very clear trends. First, both groups perceived the luster in the target area of the mixed-ring stimuli (with spatial proportions between 0.25 and 0.75 or segment numbers greater than 1, respectively) as significantly less homogeneous than in the two pure conditions with a full ring. Second, spatial homogeneity of the lustrous impression was generally rated significantly lower by group **A-** than by group **A+**. This difference is evident even for the two pure conditions, for which spatial luster homogeneity was rated at an average of only 7.77, whereas group **A+** rated these stimuli as almost perfectly homogeneous, with an average rating of 9.41. When considering only the mixed-ring stimuli (Panels C and D in Fig. 9), a general dependence on the number of ring segments emerges, similar to that observed for the *k* indices (see Fig. 8): The greater the number of ring segments, the more homogeneous the luster in the target area appears. In addition, at least for group **A-**, perceived homogeneity appears to increase systematically with increasing ring proportion (Fig. 9 D).

2.6. Discussion

The results of the matching task suggest that the two subject groups **A+** and **A-** differ significantly in how they spatially integrate different contrast effects on binocular luster. Neither a strict winner-takes-all integration nor a pure balanced integration, which assumes equal weights for the two different contrast effects, can explain these results. Instead, our data indicate that both contribute to the impression, but with different weights. In both groups, the stronger of the two contrast effects has a higher weight than the weaker one; however, this weighting asymmetry is considerably more pronounced for group **A-** than for **A+**. This finding is consistent across the different analysis methods employed. However, the model-based method led to much more pronounced *k* indices than the data-based method (see Fig. 8).

We next investigate why the k_{data} and the k_{model} indices differ. By construction, the data-based method produces luster curves that are equally spaced and do not depend on the number of

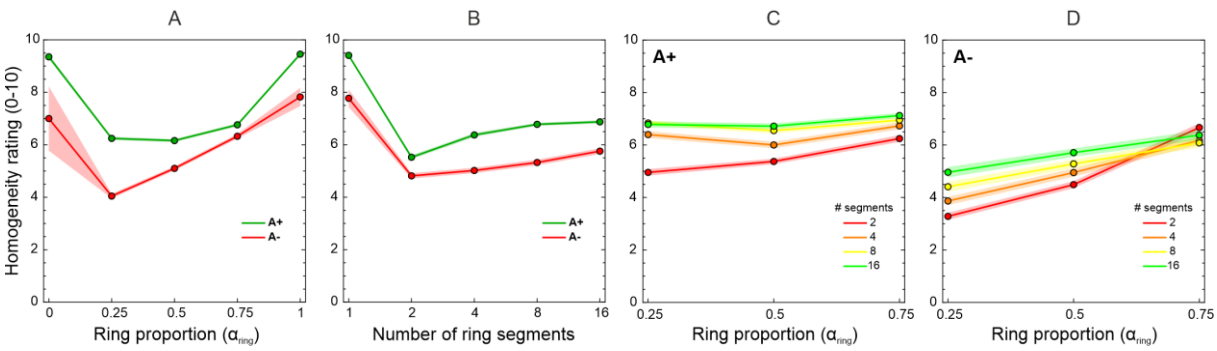

Figure 9: Results of the homogeneity rating task. Diagrams A and B show the mean homogeneity ratings depending on the spatial proportion between the two ring parts (A) and the number of ring segments (B), separately for the two groups **A+** (green lines) and **A-** (red lines). Diagrams C and D show the interactions between these two stimulus parameters exclusively for the mixed-ring conditions for group **A+** (diagram C) and group **A-** (diagram D). The transparent areas represent the SEM in both directions.

ring segments (see the dashed lines in the top diagrams in each panel of Fig. 5 and 6). In contrast, the model-based predictions show shifts that are not only influenced by the number of ring segments but also clearly differ between groups **A+** and **A-**. They also differ to some extent between the two variants of the model, especially at higher ring segment numbers (compare the solid and dashed lines in the bottom diagrams in each panel of Fig. 5 and 6). These shifts are caused by two different components of the model. To illustrate the respective effects in more detail, Figure 10 shows the predictions calculated with the LoG variant of the model for stimuli of sub-experiment 2 using eleven different ring proportions between 0 and 1 in steps of 0.1, separately for the two groups **A+** (top row) and **A-** (bottom row).

The first effect is most clearly observed in the diagrams showing the prediction curves for stimuli with only two ring segments, because these curves are only weakly affected by the second effect, which depends on the number of ring segments (left column in Fig. 10). For group **A+**, the curves become denser with increasing ring proportion (that is, at higher luster strengths), whereas for group **A-**, the curves become denser with decreasing ring proportion (at lower luster strengths). These effects are caused by the different transducer functions of the two groups (see Fig. 4). Due to the decelerating transducer of group **A+**, weaker interocular conflicts are weighted higher compared to stronger conflicts, whereas for group **A-**, the accelerating transducer causes the opposite effect. This implies that the transducers reflect group-specific sensitivities to interocular discrepancies. Group **A+** is much more sensitive to weaker than to stronger interocular conflicts, whereas the reverse holds for group **A-**.

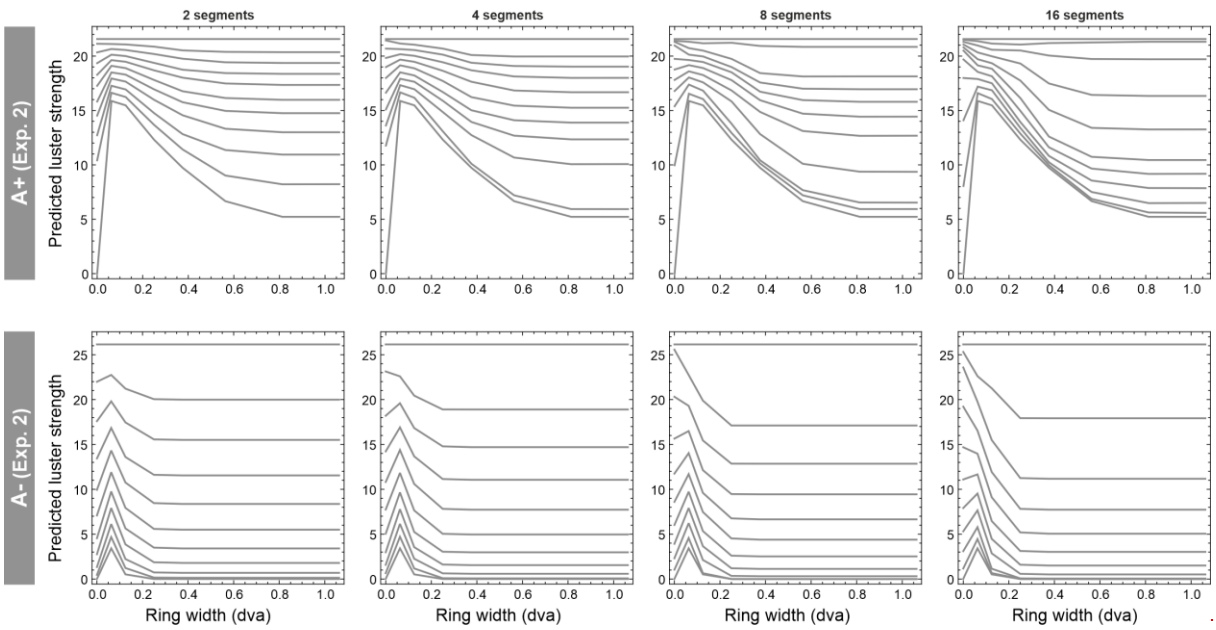

Figure 10: Curve shifts in the model-based predictions. The diagrams show the predicted luster curves for stimuli of sub-experiment 2 based on the LoG variant of the model for eleven different ring proportions (between 0.0 and 1.0 in steps of 0.1) and the four different segment numbers (columns), separately for group **A+** (top row) and **A-** (bottom row). The higher the ring proportion, the higher the magnitude of the model prediction. However, the increase in this magnitude is not proportional to the increase in ring proportion but depends on the different transducer functions of the groups and is also affected by the number of ring segments.

The second effect underlying the shifts of the luster curves strongly depends on the number of ring segments and has its origin at the level of the monocular contrast detectors, which in our model are simulated either with an LoG or a Garbor filter kernel. As shown in Figure 10, with increasing number of ring segments the luster curves tend to move to the bottom reference curve. That is, the more ring segments, the weaker the lustrous impression becomes—an effect that has the same direction for both subject groups. As mentioned in the Introduction, the magnitude of the lustrous response mainly depends on the relative proportion of local conflicts produced by ON-OFF pairings, whereas ON-ON and OFF-OFF pairings contribute much less to the overall response (Fig. 2). Figure 11 illustrates how the proportion of these ON-OFF pairings depends on the number of ring segments, using example stimuli from the first sub-experiment. Figure 11A illustrates which types of monocular contrast mechanisms are activated at different locations within the target area of the stimulus. OFF-center mechanisms are stimulated at corresponding positions when the filter kernels exclusively cover areas that include the lighter ring part (associated with the weaker *Consistent A* condition, see the red areas in Fig. 11). Stronger ON-OFF signals are generated at those locations, at which the filter kernels cover areas that only contain the darker ring part (associated with the *Reversed B* condition, see the yellow areas in Fig. 11). The critical stimulus locations responsible for the reduction of ON-OFF signals are intersections between the two different ring parts where two different ring luminances are spatially integrated by the filter kernels. In these cases, slightly less ON-OFF pairings than pairings with equal polarities are produced. For the stimulus example with two ring segments shown in Figure 11A, the proportion of ON-OFF pairings is about 48%. With increasing number of ring segments, and therefore with increasing number of such intersections, the relative number of ON-OFF pairings continuously decreases until it reaches a proportion of less than 36% with rings having 16 segments (Fig. 11B). Note that this effect also depends on the size of the filter

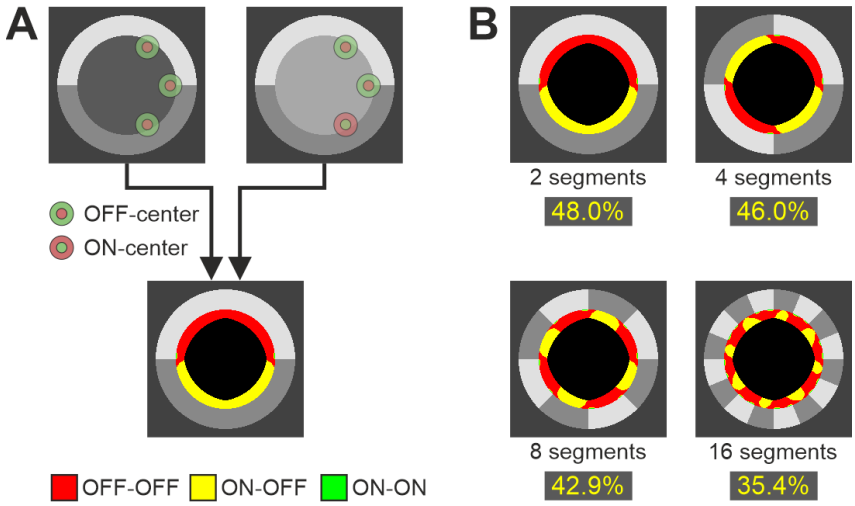

Figure 11: Why do the model-based predictions depend on the number of ring segments? (A) Example stimulus pair from the first sub-experiment with a ring subdivided into two segments. Filter kernels that exclusively cover one ring part either produce weak OFF-OFF pairings (red areas) or strong ON-OFF pairings (yellow areas). At the intersections between two ring parts, at which two different ring luminances are spatially integrated by the filter kernel, more OFF-OFF than ON-OFF pairings are produced. (B) The proportion of ON-OFF signals continuously decreases with increasing number of ring segments, or number of intersections, respectively. Since the magnitude of the model output mainly depends on the number of strong ON-OFF signals, this explains why the model predicts weaker lustrous responses for stimuli with increasing number of ring segments.

kernel. At some locations within the target area, larger kernels can even cover more than two ring segments. This is especially the case for group **A+**, whose estimated model parameters include comparatively large kernel radii. The fact that, for both groups, the sizes of the kernels are always much larger for the Gabor than for the LoG filter (see Fig. 4), also explains the differences between corresponding prediction curves, particularly for stimuli with more than four ring segments (see Figs. 5 and 6).

The differences between the k_{data} and the k_{model} indices are therefore due to the fact the model-based method predicts curve shifts that depend on both the number of ring segments and the different sensitivities to the luster phenomenon, whereas the data-based method does not take either of these influences into account. At least with regard to the number of ring segments, the empirical data indicate that the magnitude of the lustrous response does indeed depend on this variable. In particular, the results of group **A-** clearly show that the lustrous impression becomes increasingly weaker with increasing number of ring segments—in accordance with the predictions of the model.

However, an alternative interpretation for this effect exists that is not based on the properties of our model. The results of the homogeneity task suggest that the number of ring segments also has an influence on the spatial homogeneity of the luster (Fig. 9). As the number of segments increases, the luster within the target area is increasingly perceived as spatially uniform. This could mean that in mixed-ring stimuli with only a few segments, the observers can clearly distinguish between areas with different degrees of luster. The observers may then (consciously or unconsciously) base their judgments more strongly on those areas with stronger luster. As the number of ring segments increases, the two effects may gradually merge into a spatially more homogeneous luster impression, in which the weighting of the two effects becomes more balanced. The stronger impact of the number of ring segments observed in group **A-** could be due to the fact that the perceived difference between the two effects is much greater for group **A-** than for group **A+**. In group **A-**, the stronger effect (caused by those ring parts associated with the *Reversed B* condition) produces a very strong lustrous response, while the weaker effect (associated with the *Consistent A* condition) hardly evokes any impression of luster. In contrast, in group **A+**, both effects generally show some degree of luster.

Interestingly, though, the subjects reported that the homogeneity task was the most difficult and the most time-consuming part of a trial. While they had no problems matching the strength of the lustrous impressions, they described the evaluation of the spatial homogeneity of the luster as a very artificial and abstract task that required direct comparisons between different areas of the stimulus. This could indicate that a greater weighting of the stronger effect during the matching task was, at least, not a conscious strategy.

3. General Discussion

The aim of this study was to investigate how the visual system processes complex luster stimuli in which two different contrast effects are combined. For this purpose, we used dichoptic center-ring-surround stimuli with a ring element that was divided into a varying number of segments, where neighboring ring parts differed in their luminance and in the strength of the effect on perceived luster. We tested in particular how the two different contrast effects are spatially integrated by the visual system.

The results from both the matching experiment and the lustrous/non-lustrous classification task, revealed significant individual differences in sensitivity to binocular luster. We identified two main trends in the data, where one group of subjects (**A-**) strongly responded to stimuli from the pure *Reversed B* contrast condition but barely to stimuli from the other reference condition *Consistent A*, whereas the other group (**A+**) strongly responded to stimuli from both conditions. For both groups, the fit of our interocular conflict model to the luster data was excellent for each of the two basic contrast conditions. However, the parameter values of the best fit differed significantly between the two groups, in particular with regard to the transducer functions, which had a decelerating shape for group **A+** and an accelerating shape for group **A-**. These results indicate that subjects from group **A+** can better discriminate low degrees of interocular conflict, whereas subjects from group **A-** are much more sensitive to differences at higher degrees of interocular conflict (see also Fig. 10). In our more recent studies on binocular luster with different groups of participants, we only found transducer functions comparable to those of group **A+** (Wendt & Faul, 2022a, 2025). They were also compatible with results from Kingdom and colleagues (2019) who measured dichoptic contrast difference thresholds. However, this is actually not the first time we observe different individual sensitivities to luster. In an earlier study (Wendt & Faul, 2019), we directly determined psychophysical luster scales using simple dichoptic center-surround stimuli in an inc-dec arrangement where the luminance difference between corresponding center patches was systematically varied. The resulting scaling functions, which were fitted with power functions, showed large differences across subjects with exponents between 0.187 (that is, with a strongly decelerating shape) and 3.136 (strongly accelerating function).

In the present study, these two groups also differed significantly in their luster settings for the mixed-ring stimuli. We applied two different methods, a data-based and a model-based method, to analyze how the two different contrast effects are spatially integrated by the visual system. The results of the two methods indicate that contrast effects of both ring segment types contribute to the lustrous response, but that the stronger effect has a greater weight than the weaker effect. However, the weight of the stronger effect was much greater for group **A-** than for group **A+**, a difference that was most pronounced in the analysis using the model-based method. The reason for the differences between the k_{data} and the k_{model} indices, which represent the position of the empirical data between corresponding predictions for the two alternative integration processes, was that the two methods handle balanced integration differently. In contrast to the data-based method, the model-based method not only took the different sensitivity functions of the two groups **A+** and **A-** into account, but also predicted a dependence of perceived luster on the number of ring segments. The fact that also the

empirical luster curves show such a dependence could indicate a higher accuracy of the model-based predictions.

We tested two different variants of the model, which differ in their assumption about the type of monocular contrast detector cells involved in the phenomenon of binocular luster. In one variant, these cells were represented by LoG kernels to simulate receptive fields with a circular-symmetric center-surround organization between the inhibitory and excitatory parts. In the other variant, Gabor kernels were used to represent receptive fields with a side-by-side arrangement of these antagonistic parts. There is evidence from neurophysiological studies for the existence of both cell types in the primary visual cortex (Hubel & Wiesel, 1962; Sincich & Blasdel, 2001), making both suitable candidates for representing the monocular level in our model. We found that the luster settings obtained with the two pure contrast conditions *Consistent A* and *Reversed B*, which were used to determine the model parameters, were predicted equally well by both variants (see Figs. 4 and A1). We further found that the parameters of the best fit of the two variants differed mainly in the size of the kernels (with the radii of the Gabor kernel being systematically larger than those of the LoG kernel), resulting in slightly different predictions of the luster curves for the mixed-ring conditions (Figs. 5 and 6). However, these differences did no significant impact on the corresponding k_{model} indices (Fig. 8). In line with our previous findings (Wendt & Faul, 2022a; see also Wendt & Faul, 2024), our model seems compatible with different types of monocular contrast detector cells.

It is not entirely clear how the strength of the lustrous impression was influenced by the perceived spatial homogeneity of the luster within the target area. The results of the homogeneity rating task indicate that different regions were indeed perceived as differently lustrous, especially in stimuli with few ring segments. However, as we have seen, this rating task was considered rather artificial by the observers, while the matching task, during which the subjects had to focus on the central part of the target area, was reported to be unproblematic. Luster stimuli in general tend to be rather unstable as they are usually accompanied by rivalry effects (Alais & Blake, 2005; Blake & Logothetis, 2002), giving them a somewhat fluctuating appearance (Howard, 1995; Wendt & Faul, 2022b). Several studies have found that such temporal variations of the lustrous sensation can be reduced by the addition of a ring, or generally by stimulus features that match between eyes (Blake & Boothroyd, 1985; Jennings & Kingdom, 2016; Meese & Hess, 2005). However, also spatial inhomogeneities seem to be a common property of the luster phenomenon, even in simple center-surround configurations or stimuli with a uniform ring. Binocular luster is often assumed to be a filling-in phenomenon, originating at the edge between the target area and surrounding stimulus elements (Zöller, 1998; Wendt & Faul, 2022b). In line with this assumption, the lustrous impression is stronger at the contour than at the center of the target area, which may explain why even stimuli with a full ring were rated as slightly inhomogeneous by group **A-**. The present version of our interocular conflict model is not able to describe spatial variations of the lustrous impression, as it returns a single measure that represents the strength of the perceived luster in the entire target area. However, this single-valued model output is based on a map of local conflict values (see Fig. 11), which could serve as a direct basis for specifying the spatial distribution of luster. An advantage of this

procedure would be that not only spatial variations of the luster in stimuli with a uniform target area could be analyzed, but also in stimuli in which the target area itself has a complex luminance pattern, such as horizontally-oriented gratings (see, for instance, Georgeson et al., 2016; Kingdom, Mohammad-Ali, Breuil, Chang-Ou, & Irgaliyev, 2023; Kingdom et al., 2018; Kingdom et al., 2019).

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Appendix A Predictions with an LoG-based model

One method to test the assumption that the visual system takes both contrast influences equally into account is to calculate the luster predictions for the mixed-ring stimuli based on our interocular conflict model, which realizes a balanced spatial integration. Since all test stimuli had a target area of constant size, we were able to perform these calculations using the simple version of the model (Wendt & Faul, 2022a), which comprises a total of five

parameters (a more advanced version that accounts for additional effects due to differences in stimulus size can be found in Wendt & Faul, 2025).

The basic output of the interocular conflict model of binocular luster is a global conflict measure C that correlates with the perceived luster strength (Fig. A1). For a given dichoptic stimulus pair, the conflict measure C is the sum of a set of local conflict values $v_{(x,y)}$, which are calculated as follows: In the first step, the two half-images I_l and I_r of the stimulus pair are convolved with an LoG-kernel that simulates the behavior of monocular contrast detector cells with a circular-symmetric center-surround structure of their receptive fields, the radius of which is one of the parameters fitted with the empirical data. The sign of the filter response in the convolved images I_l' and I_r' represents the type of the monocular cell that is stimulated by the luminance pattern covered by the cell's receptive field. A negative sign represents the stimulation of an ON-center cell and a positive sign the stimulation of an OFF-center cell,

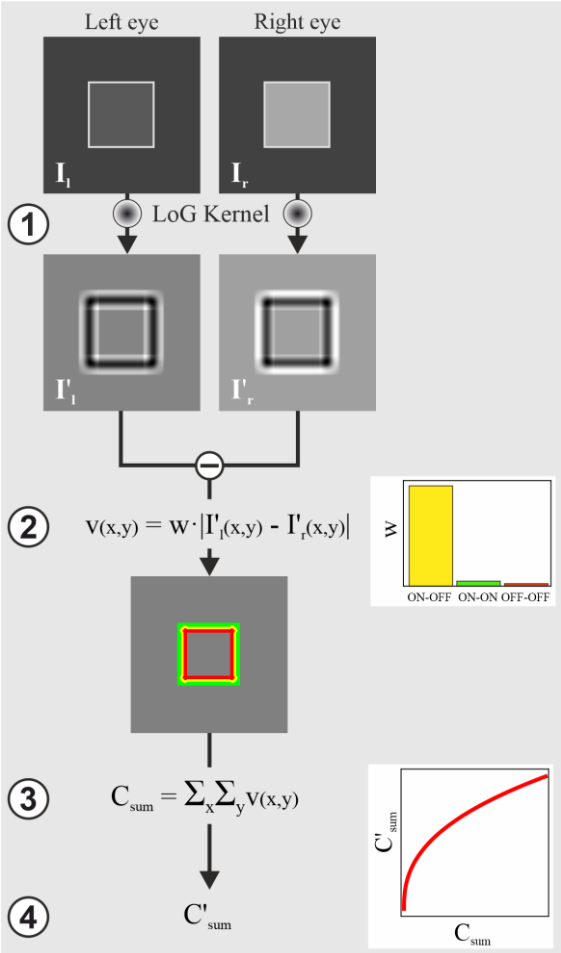

Figure A1: Schematic representation of the LoG variant of the interocular conflict model. (1) The two half-images I_l and I_r of a dichoptic stimulus pair are first convolved with an LoG kernel, simulating the behavior of contrast detector cells with a circular-symmetric center-surround receptive field. Dark pixels in the filtered images I'_l and I'_r represent the stimulation of an ON-center cell, light pixels the stimulation of an OFF-center cell. (2) At the binocular level, corresponding pixel pairs within the target area are then combined into a local binocular conflict signal $v(x,y)$, resulting from the full-wave rectified difference between the two filter responses, weighted by weight w, whose magnitude depends on the polarities of the input signals. (3) The local conflict values are then spatially integrated into a global conflict measure C_{sum} (3). In the final step, a nonlinear transducer is applied to the global conflict measure to produce the adjusted model output C'_{sum}, which represents the strength of the lustrous response.

accordingly. The two monocular signals from corresponding locations within the target area are then combined into a binocular response based on a binocular differencing process (Henricksen & Read, 2016; Georgeson, Sato, Chang, & Kingdom, 2025; Kingdom, 2012), where the resulting signal is full-wave rectified: $|I_l'_{(x,y)} - I_r'_{(x,y)}|$. As mentioned in the Introduction, the response magnitude of this binocular mechanism depends on the type of interocular polarity pairing, where ON-OFF pairings are weighted considerably higher than ON-ON or OFF-OFF pairings, respectively (see Fig. 2). While the weight $w_{ON\text{-}OFF}$ for the ON-OFF parings was set to a fixed value of 1.0, the relative weights $w_{ON\text{-}ON}$ and $w_{OFF\text{-}OFF}$ for the two remaining polarity combinations were further parameters of the fit. To avoid rounding errors, a local conflict value $v_{(x,y)} = w\ |I_l'_{(x,y)} - I_r'_{(x,y)}|$ was calculated only for pixel positions within the target area where at least one of the unsigned corresponding filter values $|I_l'_{(x,y)}|$ and $|I_r'_{(x,y)}|$ exceeded a threshold of 1×10^{-6}. The sum of these local conflict values then represents the global conflict measure $C_{sum} = \sum_x\sum_y w\ |I_l'_{(x,y)} - I_r'_{(x,y)}|$. Since we have found in our previous studies (Wendt & Faul, 2022a, 2025) that the relationship between the conflict measure C_{sum} and the perceived strength of binocular luster L can best be described with a nonlinear transducer function of the form $L = a\ C_{sum}^{c}$, we also had to fit the two parameters a and c of this transducer.

Appendix B Predictions with a Gabor-based model

As a variant of the model, we used Gabor filters in which the antagonistic parts (i.e. filter weights with opposite signs) are spatially arranged side by side. The Gabors had a fixed spatial frequency of 1 cycle/radius. To produce a kernel with an OFF-center structure, we applied a phase shift of π to the Gabor, such that the central part has negative signs and is flanked by parts with positive signs (see Fig. B1-F). In analogy to the LoG-based model, this means that a filter response with a negative sign would represent the stimulation of an ON-center cell and a positive sign the stimulation of an OFF-center cell. For each radius of the Gabor filter, the two half-images of a stimulus pair were convolved with 16 differently oriented kernels (which were sum-normalized to 0 and square-normalized to 1) with orientations between 0° and 168.75° in steps of 11.25° (see the example filter bank in Fig. B1-F).

For the binocular level of the Gabor variant, we first had to define a rule how corresponding monocular signals $I_{l,i(x,y)}$ and $I_{r,j(x,y)}$ (where indices i and j refer to specific orientations of the kernels) are combined to form a local conflict value $v_{(x,y)}$. One variant would be to select the two values from corresponding sets of 16 filter responses that represent the strongest (absolute) filter signals. We investigated whether these two strongest signals are produced by Gabor kernels with same or different orientations and found that, in most cases, the strongest (absolute) signals indeed come from corresponding filters with the same orientation. However, at many locations within the target area of the stimulus, this was not the case, depending on the size of the Gabor and the complexity of the ring structure of the stimulus (in Fig. B1 we show an example with a more problematic ring structure in this regard). Since we consider it more physiologically plausible that, at the binocular level, monocular cells tuned

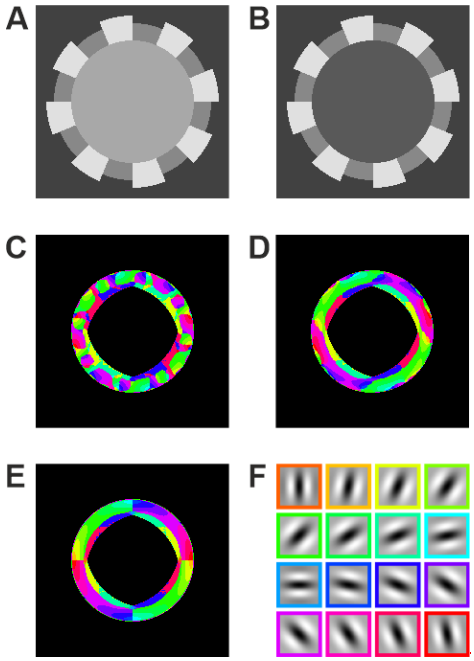

Figure B1: How to combine corresponding monocular signals from Gabor filters? A and B show the left and right half-image of an example dichoptic stimulus pair from sub-experiment 2 with 16 ring segments. C and D show, separately for the two eyes, the orientations of those Gabor kernels that produce the strongest absolute signals for each pixel within the central target area (the different colors refer to different orientations of the kernel, see the filter bank in F; the kernel had a radius of 15 pixels in this example). One can see that the Gabor filters with the strongest responses not always have the same orientation at corresponding pixel positions. To calculate local binocular conflict values, our Gabor variant uses the responses from corresponding kernels with identical orientations showing the strongest difference between these signals (as shown in E).

to the same orientation are paired, we decided to apply a different rule. The local conflict value $v_{(x,y)}$ therefore results from corresponding signals produced by Gabor kernels with same orientations showing the largest absolute difference between them.

$v_{(x,y)} = w\ |I_{l,i(x,y)} - I_{r,j(x,y)}|$, where $i = j$ and $|I_{l,i(x,y)} - I_{r,j(x,y)}| = max$.

As in the LoG-based model (see Appendix A), weight w depends on the interocular contrast polarity combination ($w_{ON\text{-}OFF}$, $w_{ON\text{-}ON}$ and $w_{OFF\text{-}OFF}$). The remaining steps for the calculation of the adjusted global conflict measure C'_{sum} are identical to those of the LoG model (Appendix A).

Appendix C Model parameter estimation for the individual data sets

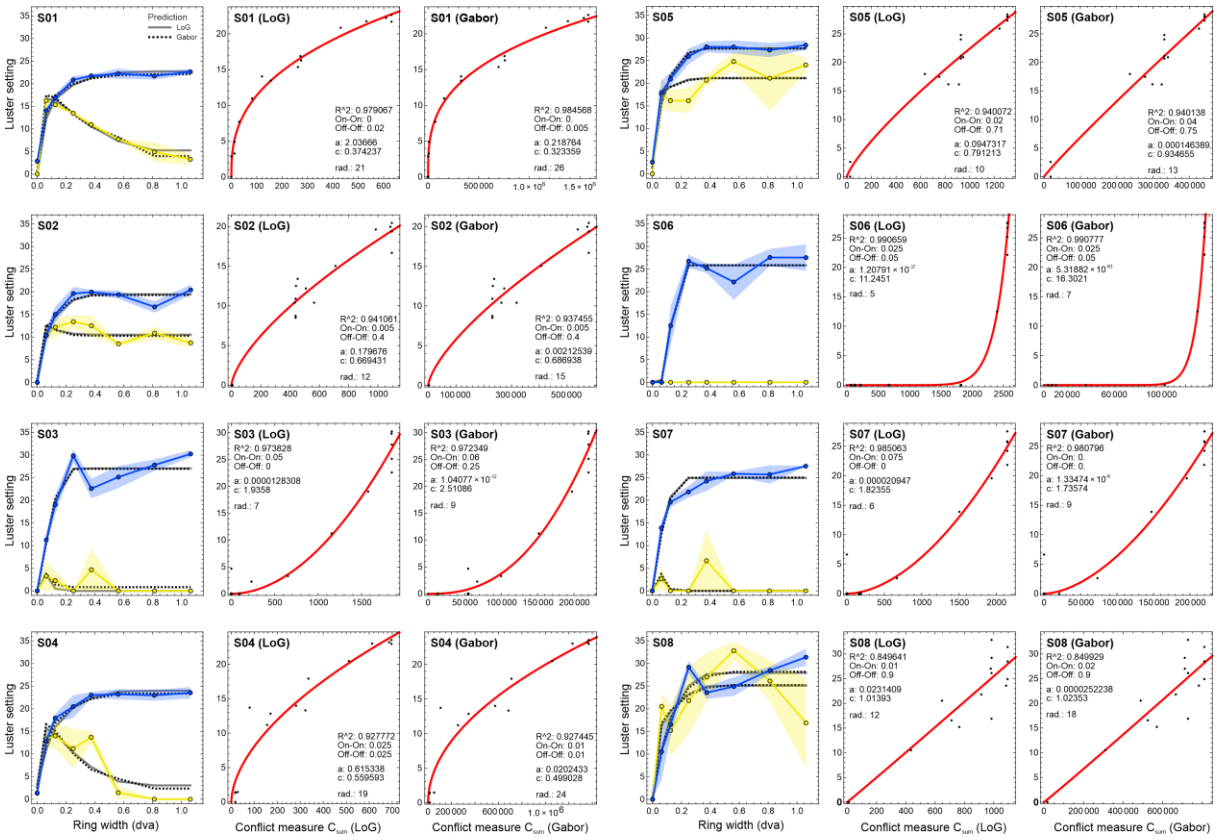

Figure C1: Model parameter estimation for the individual data sets. A set of three diagrams is shown for each of the eight subjects S01 – S08. The left diagram in each set shows the luster settings obtained under the two pure contrast conditions *Consistent A* (yellow curve) and *Reversed B* (blue curve) as function of ring width, with the transparent areas representing the SEM in both directions. In addition, the model predictions based on the best-fitting parameter values are shown for the LoG (solid gray curves) and the Gabor variant of the model (dashed curves). The two remaining diagrams of each set show the relationship between the empirical luster settings and the corresponding model outputs C_{sum} of the LoG variant (middle diagram) and the Gabor variant of the model (right diagram).