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Local computation of lightness on articulated surrounds

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Abstract. Lightness of a grey target on a uniform light (or dark) surround changes by articulating the surround (articulation effect). To elucidate the processing of lightness underlying the articulation effect, the present study introduced transparency over a dark surround and investigated its effects on lightness of the target. The transparency was produced by adding a contiguous external field to the dark surround while keeping local stimulus configuration constant. Results showed that the target lightness did not change on the articulated surround when a dark transparent filter was perceived over the target, although it did on the uniform surround. These results suggest that image decomposition into a transparent filter and an underlying surface does not necessarily change lightness of the surface if the surface is articulated. Moreover, the present study revealed that articulating the surround does not always enhance lightness contrast; it can reduce the contrast effect when the target luminance is not the highest within the surround. These findings are consistent with the theoretical view that lightness perception on articulated surfaces is determined locally within a spatially limited region, and they also place a constraint on how the luminance distribution within the limited region is scaled.

Keywords: lightness perception, articulation effect, transparency, lightness contrast, anchoring, image decomposition.

1 Introduction

Lightness, which is the perceived reflectance of a surface, can be influenced by spatial context in which the surface is embedded. For example, a target field on a dark surround in Figure 1a is perceived lighter than that on a light surround. This lightness contrast effect, or lightness perception in general, has been traditionally investigated using spatially uniform surrounds (Heinemann, 1955; Wallach, 1948). However, recent studies showed that when a target was placed on a spatially inhomogeneous surround, its perceived lightness changes from that on a uniform surround (Adelson, 2000; Bressan & Actis-Grosso, 2006; Gilchrist et al., 1999; Schirillo & Shevell 1996). For example, the lightness difference on the uniform surround demonstrated in Figure 1a becomes larger when the surrounds are replaced by the ones composed of small patches having different luminances (Figure 1b, articulated surrounds). That is, the target appears lighter on the dark articulated surround and darker on the light articulated surround. This occurs even if the spatially averaged luminance is kept constant (Bressan & Actis-Grosso, 2006).

The articulation effect, that is, the change in lightness due to articulating the surround, has been mainly explained from two theoretical views concerning lightness computation. One assumes that the visual system decomposes an image into a set of separate layers, each corresponding to the contribution of illumination, reflectance of object surfaces, and intervening transparent media (or surfaces) to retinal luminance (Anderson & Winawer 2005, 2008; Barrow & Tenenbaum, 1978). We call this view the 'image decomposition hypothesis'. In this view, the variations in the retinal luminance are attributed to different causal layers and thus the perception of illumination greatly affects lightness computation (Anderson & Winawer, 2005, 2008; Lotto & Purves, 1999; Schirillo, 1999a, 1999b; Soranzo & Agostini, 2006a, 2006b; Zavagno, 2005). According to this view, articulating the surround as in Figure 1b facilitates the inference that the two surrounds are in different illuminations (Lotto & Purves, 1999; Schirillo, 1999a, 1999b; Soranzo & Agostini, 2006a, 2006b) and promotes the perception that low illumination (such as shadow) is cast over the dark articulated surround. Thus, when

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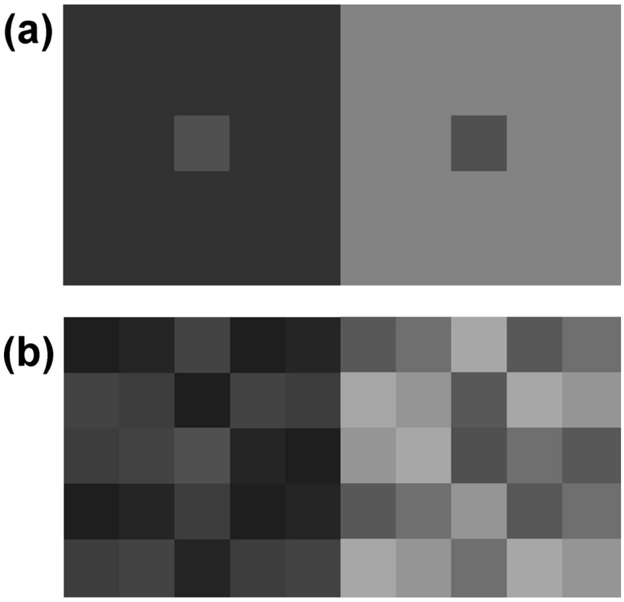

Figure 1. Lightness contrast and an articulation effect. (a) A classic lightness contrast phenomenon. Target lightness on a dark uniform surround is perceived lighter than that on a light surround. (b) The lightness difference between the targets on the light and dark surrounds changes (becomes larger in this case) on articulated surrounds, which demonstrates an articulation effect.

computing lightness of the target, low (high) illumination is discounted and the target is perceived lighter (darker) on the dark (light) surround. The image decomposition hypothesis corresponds to layer models that have been discussed in contrast to framework models by Anderson and Winawer (2008). We prefer the name the image decomposition hypothesis here because the name describes distinctive processing assumed in the hypothesis to account for lightness perception.

The other theoretical view, which we call the 'local computation hypothesis', assumes that the visual system scales the luminance distribution within a spatially limited region in lightness computation (Adelson, 2000; Economou, Zdravkovic, & Gilchrist, 2007; Gilchrist et al., 1999; Gilchrist & Annan, 2002). This hypothesis has also been called framework models (Anderson & Winawer, 2008) that include theoretical schemes proposed by Gilchrist et al. (1999) and Adelson (2000). An anchoring theory proposed by Gilchrist et al. (1999) assumes that the image is segmented into distinct regions and each of them becomes a framework. Within the framework, the region of the highest luminance is assigned the highest lightness value (i.e., white). This serves as the anchor for lightness computation in the framework, and lightness values of other darker regions are scaled relative to this anchor (see also Land & McCann, 1971; Wallach, 1948). When a region is in multiple global and local frameworks, its lightness value is computed relative to the anchor in each framework and then the lightness values are combined in a weighted average in proportion to the strength of each framework. This theory explains the articulation effect by assuming that the weight for a local framework becomes larger when the degree of articulation in the framework becomes higher. A closely related theoretical scheme proposed by Adelson (2000) assumes that lightness of a region is determined through statistical estimation from luminance samples within a sampling window. The sampling window can change its size depending upon the number of luminance samples in an image. The window becomes larger when there are only a few samples and smaller when there are more than enough. According to this explanation, the window becomes larger on the uniform surround (Figure 1a) because there are only a few luminance samples. Thus, lightness of the target is determined globally. The lightness difference between two targets on the light and dark surrounds is estimated smaller because the large windows, used to compute lightness of two targets, include similar regions in the image. In contrast, on the articulated surround (Figure 1b), the window becomes smaller because there are a lot of luminance samples, and thus the target lightness is determined locally. The target lightness on the dark (or light) articulated surround is estimated higher (or lower) because the luminance of the target region is relatively higher (or lower) in the sampling window.

The present study investigated the processing of lightness underlying the articulation effect in view of the image decomposition and the local computation hypotheses. For that purpose, we created a situation where the two hypotheses lead to different predictions. Specifically, we introduced the perception of transparency over a dark surround (i.e., impression of being covered with a larger dark filter) by adding a contiguous external field of a lower luminance to the dark surround. Then, we compared lightness perception in this condition with that in the condition where the perception of transparency was disrupted without changing local stimulus configuration within the surround (see Figure 2). Here, the dark filter may be considered functionally similar to a shadow (low illumination). The image decomposition hypothesis predicts that the target on the dark surround would be perceived lighter when the perception of transparency was introduced because the generation of a layered image representation associated with transparency would cause the low luminance of the dark surround to be attributed to the dark transparent filter. In contrast, the local computation hypothesis predicts that target lightness would not change because the local configuration remains constant regardless of the manipulation of transparency. The effects of a similar stimulus manipulation have been investigated using uniform surrounds in previous studies and the results showed that the perception of transparency (or low illumination) increased the target lightness (Gilchrist, Delman, & Jacobsen, 1983; Kingdom, Blakeslee, & McCourt, 1997). However, to our knowledge, the effects have never been tested using articulated surrounds. As will be shown, somewhat surprisingly, the articulation effect in the present stimulus display can be accounted for in view of the local computation hypothesis alone.

2 Experiment 1

In the first experiment, the different predictions made by the image decomposition and the local computation hypotheses were investigated. In addition to lightness matching, transparency rating was carried out to confirm the effect of the stimulus manipulation.

2.1 Methods

2.1.1 *Observers*

Seven observers participated in Experiment 1. They had normal or corrected to normal visual acuity. They were naive to the purpose of the experiment.

2.1.2 *Apparatus*

The stimuli were generated using MATLAB 7.1 in conjunction with the Psychophysics Toolbox 3 (Brainard, 1997; Pelli, 1997). They were displayed on an accurately calibrated 22-inch TOTOKU colour monitor (CV921X) driven by an NVIDIA video card with a pixel resolution of 1,280 × 1,024 and a frame rate of 100 Hz. The intensity of each phosphor could be varied with 10-bit resolution. A chinrest was used to maintain a viewing distance of 57 cm. The experiment was run in a dark room.

2.1.3 *Stimuli and procedure*

Light and dark surrounds of 5° × 5° were placed side-by-side which were either spatially uniform or articulated (Figure 2). By adding a contiguous external field of a lower luminance to the dark surround, the perception of transparency was produced in the contiguous condition (Figure 2b, top). In the gapped condition (Figure 2b, bottom), the perception of transparency was disrupted by making a gap of 15 min of arc. thick at the borders around the dark surround. Local stimulus configuration within the surround was kept constant between the contiguous and the gapped conditions.

The articulated surround was composed of small patches of 1° × 1° having different luminances, and their luminance ranged from 0.81 to 1.40 log cd/m^2 in the light articulated surround and from 0.01 to 0.60 log cd/m^2 in the dark articulated surround. The spatially averaged luminance of the light and dark surrounds was 1.20 and 0.40 log cd/m^2, respectively, both in the uniform and articulated surround conditions. Luminance of the dark contiguous region was -0.15 log cd/m^2. The gap in the gapped condition had the same luminance as the background (0.65 log cd/m^2).

A square target of 1° × 1° was centred on the light and dark surrounds, and its luminance was 0.70 log cd/m^2. A matching stimulus of the same shape and size was used in lightness matching, which was placed on a checkerboard surround of 5° × 5° composed of light (1.20 log cd/m^2) and dark (0.40 log cd/m^2) checks of 10 × 10 min of arc.

In lightness matching, observers matched lightness of the target on the light or dark surround by adjusting the luminance of the matching stimulus. Before the lightness matching, the observers were

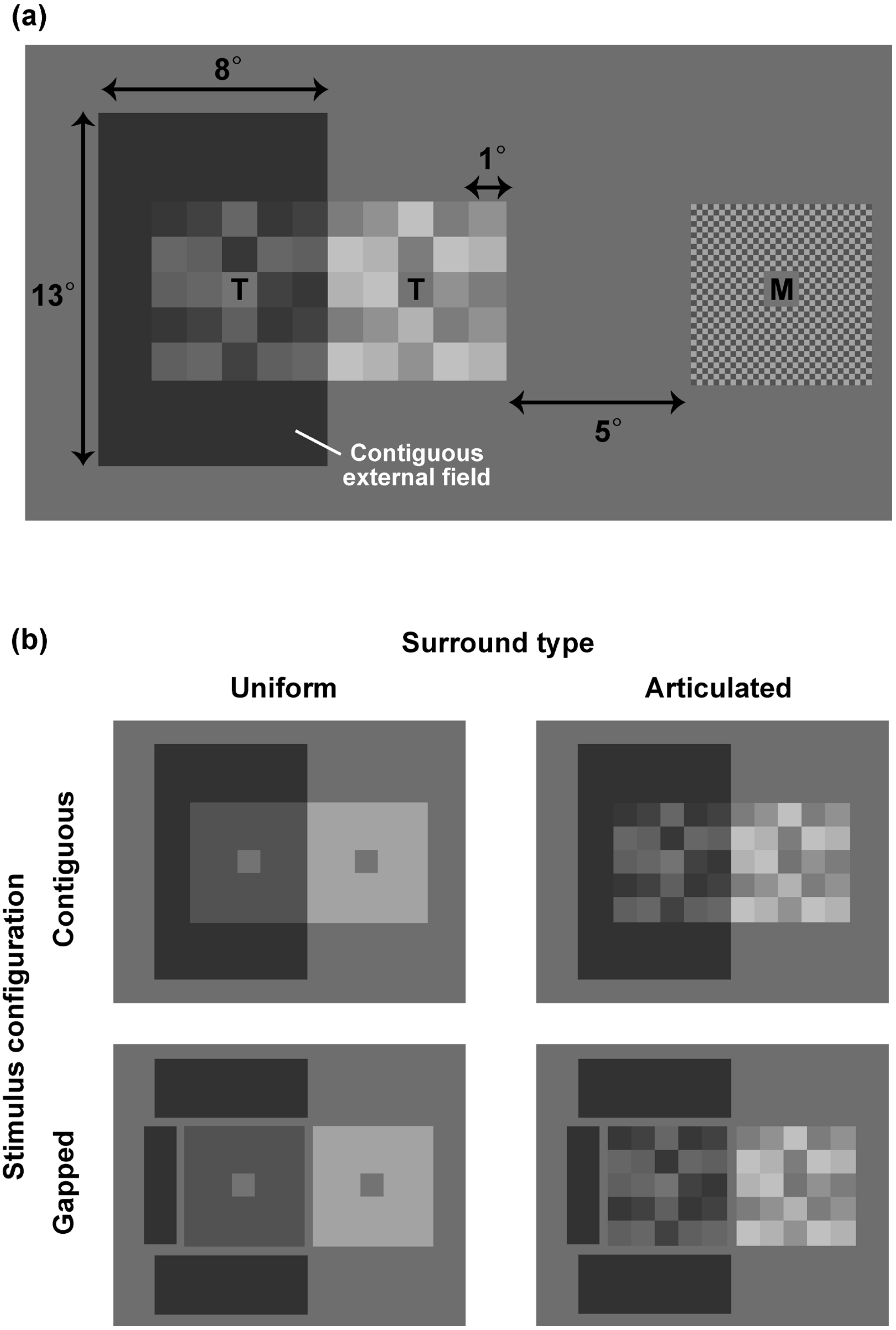

Figure 2. Stimulus configuration and conditions in Experiment 1. (a) A schematic diagram of the stimulus display (contiguous condition). The light and dark surrounds were presented on the left side of the display and the matching stimulus was on the right side. The symbols ‘T’ and ‘M’ indicate the target and matching stimuli, respectively. The target was centred on the light or dark surround. (b) Stimulus conditions used in the experiment. The surrounds were either uniform (left) or articulated (right). In the contiguous condition (top), the perception of transparency was produced by adding a darker contiguous field to the dark surround. In the gapped condition (bottom), the perception of transparency was disrupted by making a gap at the border between the dark surround and the contiguous region.

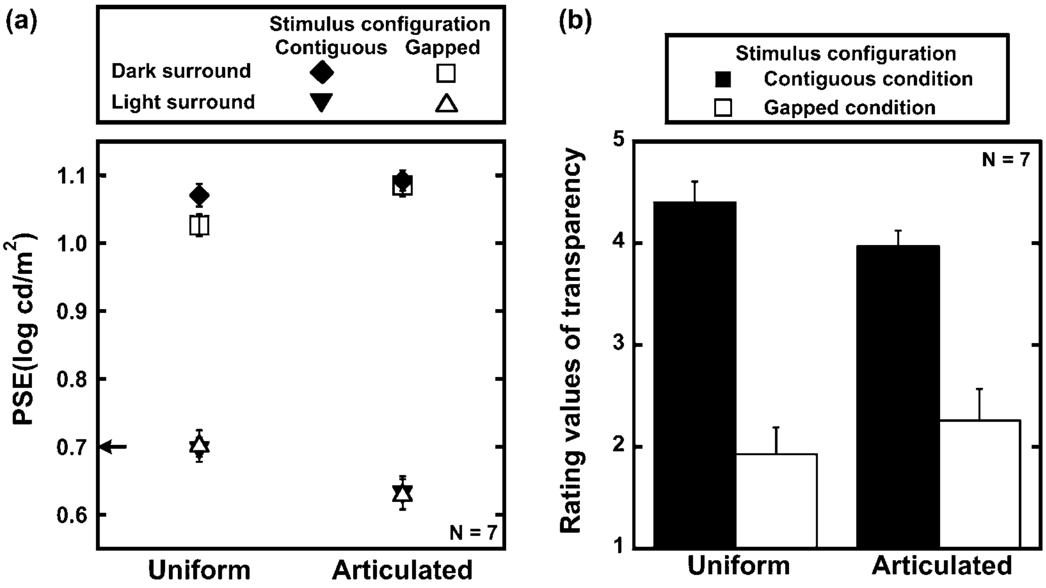

Figure 3. Results of Experiment 1. (a) Results of the lightness matching. The PSEs of the target lightness were plotted as a function of surround type (i.e., uniform vs. articulated). Different symbols indicate the results in different stimulus conditions as shown in the legend. Filled symbols denote the results in the contiguous condition, whereas open symbols designate those in the gapped condition. Error bars indicate ±1 *SEM* across observers. An arrow on the vertical axis denotes the target luminance used in the experiment. (b) Results of the transparency rating. Rating values were shown for the uniform and articulated surround conditions. Black and white bars indicate the results in the contiguous and the gapped conditions, respectively. Error bars indicate +1 *SEM* across observers.

explained about the difference between ‘lightness’ (defined as perceived reflectance) and ‘brightness’ (defined as perceived luminance). Then, they were instructed that the target was the small square located at the very centre of the light or dark surround and asked to make the matching stimulus appear as if it were ‘cut from the same piece of paper’ (Arend & Reeves, 1986) as the target.

In transparency rating, the observers rated the degree of perceived transparency over the target and dark surround region using a 5-point scale. A score of 5 meant that a dark transparent layer was definitely perceived over the region, and a score of 1 meant that the region did not appear transparent at all.

The lightness matching and the transparency rating were conducted in different sessions. At the beginning of each daily session, the observers dark-adapted for at least 5 min and then preadapted to the uniform background for 2 min. In the lightness matching, each stimulus condition, which composed of a combination of stimulus configuration (contiguous or gapped) and surround type (uniform or articulated) conditions, was tested in a pseudo random order within each session. Within a session, the target to be matched was fixed for the one on the light or dark surround. Each session was repeated twice on different days and each stimulus condition was tested 20 times in total for each observer.

After all sessions of the lightness matching were finished, the transparency rating was carried out. The same stimulus conditions as in the lightness matching were tested in a pseudo random order, and each condition was tested 20 times in total for each observer.

2.2 Results and discussion

Figure 3a plots the points of subjective equality (PSEs) of the target lightness averaged across different observers in different stimulus conditions. The PSEs were analyzed with a three-way repeated-measures ANOVA, with stimulus configuration (contiguous or gapped), surround type (uniform or articulated), and surround luminance (light or dark) serving as the within-subject variables. The main effects of stimulus configuration and surround luminance were statistically significant, $F(1, 6) = 9.81$, $p < .05$ and $F(1, 6) = 141.55$, $p < .0001$, respectively, but the main effect of surround type was not, $F(1, 6) = 4.37$, ns. All interactions were statistically significant ($p < .05$).

The post hoc analysis of the interaction between surround type and surround luminance showed that the lightness difference between two targets on the uniform light and dark surrounds became larger when the surrounds were articulated. When the surround was dark (squares or diamonds in

Figure 3a), the target lightness on the articulated surround was significantly higher than that on the uniform surround, $F(1, 12) = 16.46$, $p < .005$. Conversely, when the surround was light (upright or reversed triangles in Figure 3a), the target lightness on the articulated surround was significantly lower than that on the uniform surround, $F(1, 12) = 49.88$, $p < .0001$. Thus, the articulation effect was confirmed in the present study.

Importantly, the post hoc analysis of the second-order interaction showed that when the surround was spatially uniform, the target lightness on the dark surround was higher in the contiguous condition (diamond in Figure 3a) than in the gapped condition (square in Figure 3a), $F(1, 24) = 55.64$, $p < .0001$. These results were consistent with the previous findings using uniform surrounds (Gilchrist et al., 1983; Kingdom et al., 1997). In contrast, when the surround was spatially articulated, the lightness difference between the targets on the dark surrounds in the contiguous and the gapped conditions (diamond and square in Figure 3a), was not statistically significant, $F\ (1, 24) = 1.12$, ns, and, in fact, the PSEs were almost the same. Thus, lightness perception on the articulated surround was not affected by manipulating the stimulus configuration. These results are consistent with the prediction by the local computation hypothesis.

The differential effect of the stimulus manipulation on target lightness was not easily attributable to failure of the manipulation because the results of the transparency rating confirmed that the manipulation changed the perceived transparency of the articulated as well as of the uniform regions, as intended (Figure 3b). A two-way repeated-measures ANOVA for the rating values showed a significant main effect of stimulus configuration, $F(1, 6) = 37.06$, $p < .0001$, whereas neither the main effect of surround type nor the interaction between these two factors were statistically significant, $F(1, 6) = 0.05$, ns and $F(1, 6) = 5.16$, ns, respectively. Thus, the stimulus manipulation changed the perceived transparency of the target in a similar fashion on both uniform and articulated surrounds.

However, little effect of the manipulation of transparency on the articulated surround might also be accounted for in view of the image decomposition hypothesis. Articulating the surrounds may have enhanced the inference that the targets on the light and dark articulated surrounds were under different illuminations (Schirillo, 1999a, 1999b; Soranzo & Agostini, 2006a, 2006b) even in the gapped condition. Thus, introducing the perception of transparency in the contiguous condition did not produce a further effect on target lightness. The inference could be unconscious (von Helmholtz, 1866/2000; Soranzo & Agostini, 2006a, 2006b) and thus might not have been reflected in the transparency rating. In addition, it is conceivable that the articulation effect already reached a maximum in the gapped condition (ceiling effect). To explore these important possibilities, we conducted Experiment 2 using a lower target luminance as well. This investigation would also be important in view of the local computation hypothesis to elucidate lightness computation within the dark surround, because the highest luminance has been postulated to play a special role in lightness processing in the anchoring theory (e.g., Gilchrist et al., 1999).

3 Experiment 2

The articulation effect was further investigated using two levels of target luminance; the highest in the dark surround and a lower luminance.

3.1 Methods

3.1.1 *Observers*

The same seven observers as in Experiment 1 participated in this experiment. They were naive to the purpose of the experiment.

3.1.2 *Stimuli and procedure*

The target luminance was 0.70 or 0.47 log cd/m^2. The former was the same as in Experiment 1 and the highest in the dark articulated surround, whereas the latter was not although it was higher than the spatially averaged luminance (0.40 log cd/m^2). Only the target on the dark surround was used for the lightness matching in Experiment 2. All other aspects of the methods were the same as those in Experiment 1.

3.2 Results and discussion

Figure 4a plots the PSEs of the target lightness averaged across different observers in different stimulus conditions. The PSEs were analyzed with a three-way repeated-measures ANOVA, with stimulus

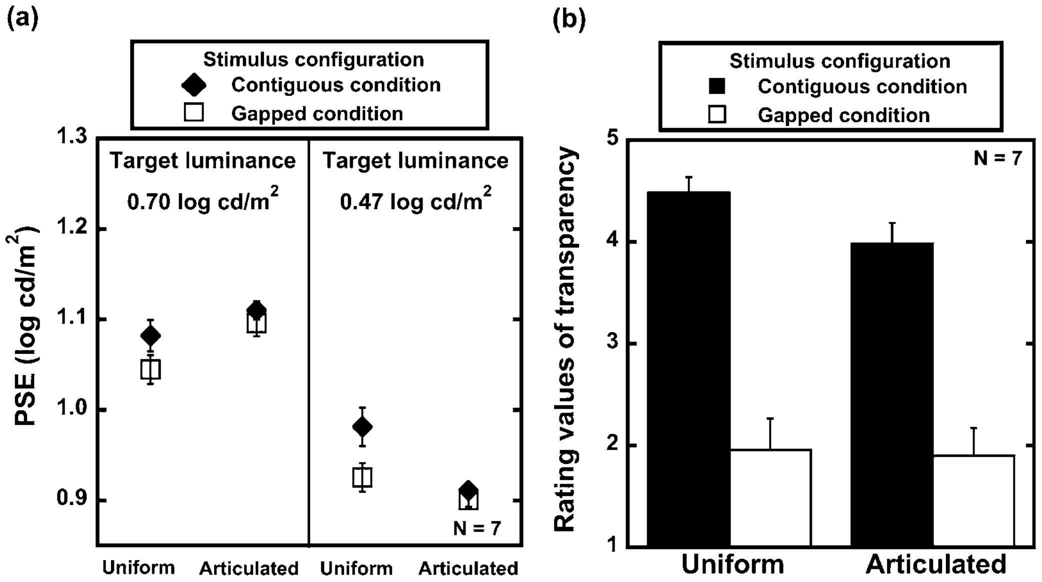

Figure 4. Results of Experiment 2. (a) Results of the lightness matching. The left and right panels show the results when the target luminance was 0.70 and 0.47 log cd/m^2, respectively. In each panel, the PSEs of the target lightness on the dark surround were plotted as a function of surround type. Different symbols denote the results in different configuration conditions as shown in the legend. (b) Results of the transparency rating. The rating values measured with different target luminances were pooled because a preliminary analysis showed no significant effect of target luminance. Black and white bars indicate the results in the contiguous and the gapped conditions, respectively. Other aspects of the figure are the same as those in Figure 3.

configuration, surround type, and target luminance serving as the within-subject variables. The main effects of stimulus configuration and target luminance were statistically significant, $F(1, 6) = 36.00$, $p < .001$ and $F(1, 6) = 174.60$, $p < .0001$, respectively, but the main effect of surround type was not, $F(1, 6) = 0.09$, ns. The interaction between stimulus configuration and surround type and the one between surround type and target luminance were statistically significant, $F(1, 6) = 12.12$, $p < .05$ and $F(1, 6) = 25.11$, $p < .005$, respectively, while the interaction between stimulus configuration and target luminance and the second-order interaction were not, $F(1, 6) = 1.66$, ns and $F(1, 6) = 5.6$, ns, respectively.

The post hoc analysis of the interaction between stimulus configuration and surround type showed that when the surround was spatially uniform, the target lightness was higher in the contiguous condition (diamond in Figure 4a) than in the gapped condition (square in Figure 4a), $F(1, 12) = 43.65$, $p < .0001$. In contrast, when the surround was spatially articulated, the lightness difference between the targets in the contiguous and the gapped conditions (diamond and square in Figure 4a) was not statistically significant, $F(1, 12) = 2.09$, ns, and, in fact, the PSEs were almost the same. Thus, lightness perception on the uniform surround was affected by manipulating the stimulus configuration, whereas that on the articulated surround was not.

The results in transparency rating confirmed the effects of the stimulus manipulation (Figure 4b). A two-way repeated-measures ANOVA on the rating values showed a significant main effect of stimulus configuration, $F(1, 6) = 42.73$, $p < .001$, whereas neither the main effect of surround type nor the interaction between these two factors were significant, $F(1, 6) = 1.92$, ns and $F(1, 6) = 2.38$, ns, respectively. These findings are consistent with the prediction by the local computation hypothesis as in Experiment 1.

Importantly, the post hoc analysis of the interaction between surround type and target luminance showed that the direction of the articulation effect changed with target luminance. When the target luminance was the highest within the dark surround (Figure 4a, left), the target on the articulated surround was perceived lighter than that on the uniform surround, $F(1, 12) = 7.93$, $p < .05$. However, when it was not (Figure 4a, right), the target on the articulated surround was perceived darker than that on the uniform surround, $F(1, 12) = 10.91$, $p < .01$. Thus, articulating the surround can reduce lightness contrast. These results indicate that the articulation effect cannot be simply conceptualized as an enhancement of lightness contrast, as have been done in previous studies (e.g., Bressan & Actis-Grosso, 2006). This finding is also inconsistent with the possibility that the ceiling effect generally accounts for little effect of transparency on the articulated surround. Furthermore, these results cannot be easily reconciled with the image decomposition hypothesis because attributing low luminance to the dark filter should have made the target on the dark articulated surround lighter than that on the dark uniform surround regardless of target luminance.

4 General discussion

The objective of the present study was to investigate visual mechanisms underlying the articulation effect in view of two hypotheses, that is, the image decomposition and the local computation hypotheses. These two hypotheses provided different predictions when the perception of transparency was introduced over a dark articulated surround while keeping local stimulus configuration constant. The image decomposition hypothesis predicted that a target on the dark surround would be perceived lighter when the stimulus appeared transparent in the contiguous condition because low luminance of the dark surround would be partially attributed to a dark filter (or low illumination). However, the present results were inconsistent with this prediction. Experiments 1 and 2 showed that the target lightness on the articulated surround did not change with the manipulation of stimulus configuration, although that on the uniform surround certainly changed. The image decomposition hypothesis involving perceived illumination was also falsified by previous studies (e.g., Rutherford & Brainard, 2002; Todorović, 2006). One might argue that the matching procedure used in this study may not be favourable to the image decomposition hypothesis. That is, positioning the matching stimulus away from the main stimulus and comparing its lightness with the target lightness on the dark (or light) surround may have encouraged observers to pay close attention to a spatially limited region around the target. However, we confirmed in an additional experiment that even when the matching stimulus was placed on the centre of the light surround and its lightness was matched to the target on the dark surround to promote a more global analysis of the stimulus, the results were essentially the same as those in Experiment 2 (the results are not shown for brevity). Furthermore, the result of Experiment 2 that articulating the surround can reduce as well as enhance lightness contrast depending on target luminance placed a constraint on how lightness on the articulated surround is computed. The theoretical account that can only predict unidirectional articulation effects cannot be satisfactory.

Decrease in simultaneous contrast due to articulating the surround was also reported in Spehar, Debonet, & Zaidi (1996) which investigated brightness induction using variegated surrounds composed of binary random textures (see their Figure 13). They account for their results by a model in which brightness induction is characterised as a weighted linear spatial summation of the induced effects from individual surrounding regions. The model assumes that the weighting function of the effects is described by a negative exponential of the distance between the target and the surrounding region and that the magnitude of induction from each surrounding region is gain controlled by a decreasing function of the difference between the mean luminance of the target and the individual surrounding regions. Because the model predicts that the surrounding regions having similar luminance to the target would produce a larger inducing effect, it can account for the differential changes in target lightness depending on target luminance on the articulated surround, if we apply the model to lightness perception as well. However, the model would have difficulty to account for the result that the stimulus manipulation changed the target lightness on the uniform surround but not that on the articulated surround. Because the stimulus manipulation was applied similarly to different surround types, the model would predict a significant effect of the manipulation on the articulated surround as well. Considering the fact that the model was proposed to deal with variegated, nonfigural images, it can be said that the effects of figural factors such as transparency and three-dimensional layout are beyond the scope of the model. Moreover, other previous studies also reported that qualitative, rather than quantitative, luminance relationships, between the target and the surround can play an important role in lightness perception. The target whose luminance is intermediate to those of surrounding inducing regions can be influenced differently from the targets whose luminance is the highest or lowest in a given stimulus display, particularly when figural factors are involved (e.g., Ripamonti & Gerbino, 2001; Spehar, Clifford, & Agostini, 2002).

The present results found in both experiments were consistent with the local computation hypothesis. This hypothesis assumed that lightness on the articulated surround is computed within a local sampling window or framework. It predicted that the target lightness on the articulated surround would not change with the manipulation of stimulus configuration because local stimulus configuration remained constant. In accord with this prediction, the present results consistently showed that stimulus changes introduced outside of the dark articulated surround did not affect lightness perception within the surround, although they significantly changed apparent transparency of the stimulus.

If lightness perception on the articulated surround is determined locally, how are different luminance values mapped onto the scale of lightness? The result of Experiment 2 suggested that the highest luminance within the surround plays a crucial role in lightness scaling. In fact, this result can be qualitatively explained in view of the anchoring theory proposed by Gilchrist et al. (1999). According to the theory, when the luminance of the target was the highest within the dark surround, the highest lightness would be assigned locally to the target on the uniform as well as on the articulated surrounds. However, because the higher degree of articulation leads to stronger local anchoring, the target lightness on the articulated surround would not be much affected by the anchor in the global framework which corresponded to a region of the highest luminance in the entire stimulus (i.e., a region on the light surround). Thus, target lightness would become higher on the articulated surround than on the uniform surround. In contrast, when the target luminance was not the highest, target lightness would be scaled depending on the relative luminance of the target to the highest luminance anchor within the dark articulated surround and thus it could be lower than that on the uniform surround. Overall, the present findings, that is, little effect of stimulus manipulation on the articulation effect and changes in the direction of the articulation effect depending on target luminance, can be understood in view of the anchoring theory (Gilchrist et al., 1999).

The present results suggest that even when transparency is perceived, and thus a stimulus image is decomposed into different layers of a transparent dark filter (or low illumination) and an underlying surface, apparent lightness of the surface does not necessarily change when the surface is articulated. However, we would like to emphasize that the present findings do not rule out the contribution of the processing of illumination to the articulation effect. With differently configured articulated stimuli from those in the present study, previous studies showed that the processing of illumination contributes to lightness perception on articulated surrounds (Schirillo & Shevell, 1997, 2002; Soranzo & Agostini, 2006a, 2006b). Moreover, other studies also demonstrated that image decomposition can produce strong lightness illusions (e.g., Anderson & Winawer, 2005, 2008). There seem to be some critical factors, presumably in stimulus configuration, which set off the influence of image decomposition on lightness perception on articulated surrounds. Perhaps, possible factors include the ones that make the stimulus look much like an actual scene rendered with a proper lighting. Future studies are needed to specify these factors.

In summary, the present study suggested that lightness computation can be dissociated with image decomposition into layered representations when the image is articulated. This dissociation implies that lightness computation of natural articulated objects can proceed separately from the processing of illumination at least in some situations, which may consequently help to maintain lightness constancy for the articulated objects.

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