# Spatial organization affects lightness perception on articulated surrounds

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**The articulation effect refers to a change in lightness contrast induced by adding small patches of different luminances to a uniform background surrounding a target in a lightness contrast display. This study investigated how local luminance signals are integrated to generate the articulation effect. We asked whether spatial organization due to perceptual grouping can influence the articulation effect even when the spatially averaged luminance of the surrounds is held constant. Grouping factors used were common-fate motion (Experiment 1), similarity of orientation (Experiment 2), and synchrony (Experiment 3). Results of all experiments consistently showed that the articulation effect was larger when the target was strongly grouped with the articulation patches. These findings provide converging evidence for the effects of spatial organization on the articulation effect. Moreover, they suggest that lightness computation underlying the articulation effect depends on a middle-level representation in which perceptual organization is at least partially established. The changes in lightness perception due to spatial organization could be accounted for by the double-anchoring theory of lightness (Bressan, 2006b).**

## Introduction

When a uniform field surrounds a small gray patch (target), the lightness of this target can be affected by the surrounding field. The target appears lighter on a dark surround than on a light surround (lightness contrast). Although lightness contrast has been traditionally investigated using spatially uniform surrounds (Wallach, 1948; Heinemann, 1955), lightness perception under natural viewing conditions commonly involves complex inhomogeneous fields. Thus, the investigation of lightness contrast has been extended to more complex displays in which the surrounding field contains stimuli of different luminances. As a result, the *articulation effect* was discovered. The articulation effect refers to a change in lightness contrast when the surround is articulated (i.e., small patches of different luminances are added to the uniform field) (Gilchrist et al., 1999; Adelson, 2000; Bressan & Actis-Grosso, 2006). Moreover, articulating the surround can reduce as well as enhance lightness contrast depending on the target luminance in the stimulus display (Schirillo & Shevell, 1996; Spehar, Debonet, & Zaidi, 1996; Bressan, 2006a; Sawayama & Kimura, 2012). These effects occur even if the spatially averaged luminance is held constant (Bressan & Actis-Grosso, 2006). These findings suggest that effects of the articulated surrounds cannot be reduced to those of a spatially-uniform equivalent surround. Although the articulation effect has long been investigated, its underlying mechanisms are not well understood.

One important issue that may further elucidate underlying mechanisms involves identification of spatial factors that are critical to mediating the articulation effect. Previous studies have identified several factors that play important roles in this effect. One of these is the numerosity of the small patches (Schirillo, 1999a, 1999b; Gilchrist & Annan, 2002). For example, Schirillo (1999a, 1999b) showed that increasing the number of the patches could produce a correspondingly larger articulation effect. He concluded that articulating the surround enhances the inference that the luminance edge between a light and a dark surround is caused by a change in illumination rather than in reflectance. Another factor is spatial arrangement of the patches (Schirillo & Shevell, 1997, 2002; Soranzo & Agostini, 2006a, 2006b). Schirillo and Shevell (1997, 2002) showed that certain spatial arrangements of the patches altered the interpretation of luminance edges

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from reflectance to illumination edges and produced a larger articulation effect. These spatial factors have been investigated in view of lightness constancy or illumination estimation. This approach is based on a major theoretical view that addresses the articulation effect. The view assumes that articulation of an area surrounding a target in a lightness contrast display facilitates the inference that light and dark surrounds are in different illuminations (Lotto & Purves, 1999; Schirillo, 1999a, 1999b; Soranzo & Agostini, 2006a, 2006b). Although previous studies have established that the processing of illumination contributes to the articulation effect, the two factors mentioned here may not exhaust all spatial factors critical for the articulation effect.

Another line of studies suggests that lightness computation underlying the articulation effect can be dissociated from the processing of illumination (Bressan, 2006b; Economou, Zdravkovic, & Gilchrist, 2007; Sawayama & Kimura, 2012). For example, Sawayama and Kimura (2012) introduced the perception of transparency over the dark articulated surround in a lightness contrast display and investigated its effects on lightness perception of a target on the surround. Transparency was induced by manipulating global stimulus configuration while keeping local configuration constant within the articulated surround. They found that the target lightness on the articulated surround did not change with the perceived transparency, while that on the uniform surround did. This result suggests that lightness on the articulated surround was determined locally depending on luminance samples within the articulated surround. This finding is also consistent with another theoretical view which asserts that articulating the surrounds facilitates local lightness computation (Gilchrist et al., 1999; Adelson, 2000).

The notion that local lightness computation is separable from the processing of illumination invites an examination of other spatial factors that might mediate the articulation effect. In this respect, scene segmentation is worth considering. Ample precedents show that perceptual scene segmentation affects lightness of a target (Gilchrist, 1977; Agostini & Proffitt, 1993; Laurinen, Olzak, & Peromaa, 1997; Bressan, 2001, 2006a; Agostini & Galmonte, 2002; Bressan & Kramer, 2008). For example, Agostini and Galmonte (2002) demonstrated that when several elements were perceptually grouped to form a distinct entity (an object), the lightness of the elements was more strongly affected by other elements belonging to that object than by the immediate surround. However, in these studies, grouping greatly changed the effective surround luminance; e.g., a gray target appeared darker when it was grouped with white than with black contextual patches. It remains to be seen whether grouping can influence lightness by changing not the effective luminance, but the strength of articulation in the surrounding region.

Thus, the present study investigated whether the articulation effect can be influenced by spatial organization due to perceptual grouping. Specifically, we asked if the strength of the articulation effect changes depending on whether the target is grouped with or segregated from articulation patches. We investigated effects of three different grouping factors: common-fate motion (Experiment 1), orientation similarity (Experiment 2), and synchrony (Experiment 3). Regardless of grouping manipulation, the articulation patches are placed in the close vicinity of the target.

# Experiment 1

In the first experiment, we manipulated the grouping between the target and articulation patches as well as the grouping between the target and background by varying common fate relations, and investigated how the manipulations affected the articulation effect.

## Methods

### *Observers*

Four observers (including the first author) participated in Experiment 1. They had normal or corrected to normal visual acuity. The three observers other than the first author were naïve to the purpose of the experiment.

### *Apparatus*

The stimuli in the present experiments 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 color monitor (CV921X) driven by an NVIDIA video card with a pixel resolution of 1280 $\times$ 1024 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.

### *Stimuli and procedure*

A light or dark surround of $7° \times 7°$ was used in Experiment 1. Each surround was articulated (Figure 1, left and center) or uniform (Figure 1, right). To construct articulated surrounds, $1° \times 1°$ patches of different luminances were added to the uniform background while preserving the spatially averaged

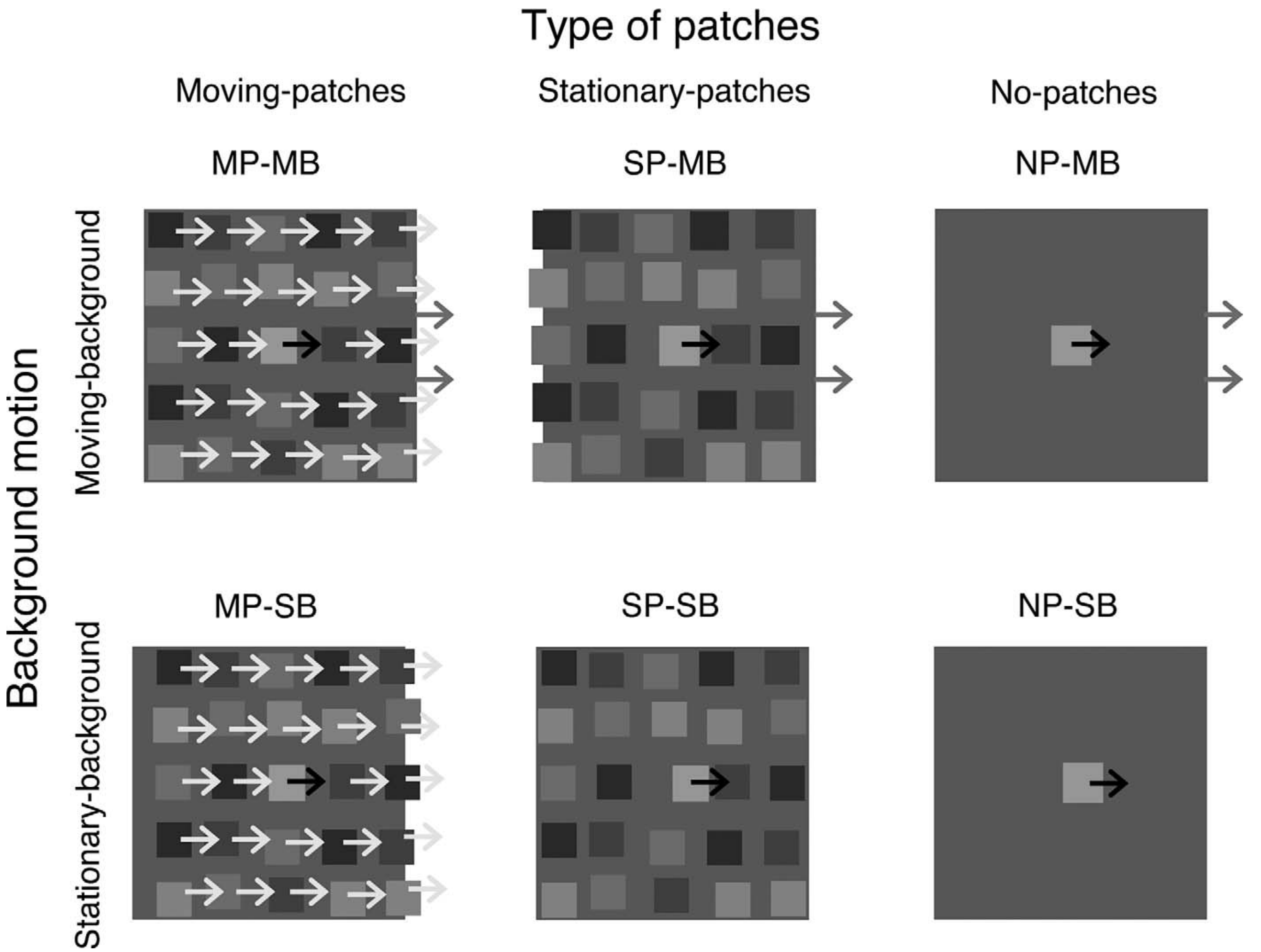


Figure 1. Stimulus conditions in Experiment 1. The target was a moving patch at the center of a light or dark surround (the examples of the dark surround were shown here). By varying the type of the articulation patches and the motion of the background, spatial organization of the stimulus display was manipulated. The stimulus condition was defined by a combination of the type of patches and background motion. The motion of a region was schematically illustrated by an arrow. The type of patches was either moving-patches (MP), stationary-patches (SP), or no-patches (NP). The background motion condition was either moving-background (MB) or stationary-background (SB). In the moving-patches and/or the moving-background condition, the articulation patches and/or the background moved coherently with the target at the same speed and timing and in the same direction. See Supplementary Movies 1 and 2 for the moving version of the stimulus.

luminance of the surround. In all conditions, the target was a moving patch, with a size of $1° \times 1°$, located at the center of the surround. It was moved alternatively, up and down, and right and left, with a speed of 2.25°/sec. Horizontal or vertical displacement of the target was $\pm 0.25°$.

Each stimulus condition was defined by a combination of the type of patches and background motion conditions (Figure 1). Three types of patches were used: moving-patches (MP), stationary-patches (SP), and no-patches conditions (NP). The moving-patches condition (Figure 1, left) was produced by moving the articulation patches together with the target at the same speed and timing and in the same direction. In the stationary-patches condition (Figure 1, center), patches were stationary. It should be noted that, because of the small displacement of moving patches, spatial closeness of the patches to the target was changed only slightly between the moving- and stationary-patches conditions. In the no-patches condition (Figure 1, right), there were no patches within the surround.

Two types of background motion were used: a moving-background condition (MB) and a stationary-background condition (SB). In the moving-background condition (Figure 1, top), the background was moved with the target at the same speed and timing and in the same direction. In the stationary-background condition, the background was stationary (Figure 1, bottom).

The luminance of the articulation patches ranged from 0.83 to 1.36 log cd/$m^2$ on the light articulated surround and from 0.05 to 0.58 log cd/$m^2$ on the dark articulated surround. The spatially averaged luminance of the articulated light and dark surrounds was 1.16 and 0.38 log cd/$m^2$, respectively, which was identical to that of the background. The luminance of the target was 0.80 log cd/$m^2$. A matching stimulus was also a moving patch with a size of 1° × 1° placed on a checkerboard surround with a size of 7° × 7° which was composed of 1.16 and 0.38 log cd/$m^2$ checks. A detailed description of the checkerboard surround is presented in our previous study (Sawayama & Kimura, 2012). The matching stimulus was moved in the same way as the target.

The procedure required observers to engage in two different tasks: a lightness matching task and a grouping rating task. The lightness matching task required observers to match the achromatic color of the target on the light or dark surround by adjusting the luminance of a matching stimulus. The grouping rating task required observers to rate the degree of perceived grouping between the target and articulation patches, or between the target and the background using a 5-point scale. A score of five meant that the target was definitely grouped with the articulation patches (or the background) and a score of one meant that the target was not grouped with these regions at all.

Lightness matching and grouping rating tasks were performed in different sessions. At the beginning of each daily session, observers dark adapted for at least 5 min and then preadapted to the uniform background for 2 min. Within a session, either the dark or light surround was used for the matching. Each stimulus condition was tested in a pseudo random order within each session. The session was repeated twice on different days, and each stimulus condition was tested 10 times in total for each observer.

After all sessions of lightness matching were finished, grouping rating was carried out. The same stimulus conditions as in the lightness matching were tested in a pseudo random order. Within one session, observers had to judge grouping between the target and articulation patches throughout, whereas in another session they had to judge grouping between the target and background. Each condition was tested 10 times in total for each observer.

## Results and discussion

Figure 2 displays the PSEs (Points of Subjective Equality) of target lightness averaged across different observers in different stimulus conditions. The PSEs

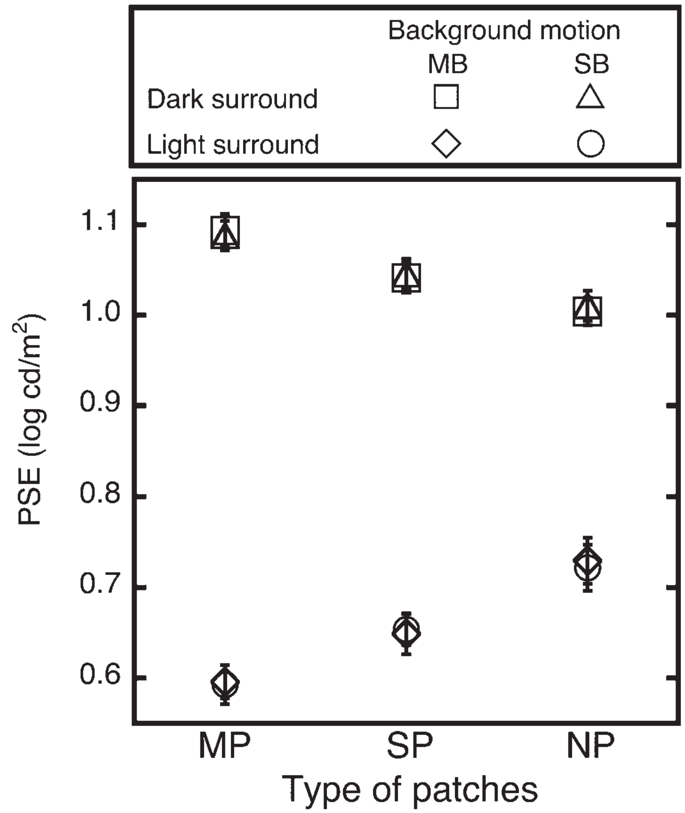


Figure 2. Results of lightness matching in Experiment 1. The PSEs of target lightness were plotted as a function of the type of patches (i.e., MP, SP, and NP). Different symbols indicate the results in different stimulus conditions as shown in the legend. Squares and triangles denote the results on the dark surround. Diamonds and circles denote the results on the light surround. Error bars indicate ±1 *SEM* across observers.

were analyzed with a three-way repeated-measures ANOVA, with surround luminance (light or dark), type of patches (moving-, stationary-, or no-patches), and background motion (moving- or stationary-background) serving as the within-subject variables. The main effects of the surround luminance and the type of patches were statistically significant, $F(1, 3) = 89.89$, $p < 0.005$ and $F(2, 6) = 6.82$, $p < 0.05$, respectively, but the main effect of the background motion was not, $F(1, 3) = 1.27$, *ns*. In addition, the interaction between the surround luminance and the type of patches was statistically significant, $F(2, 6) = 102.64$, $p < 0.001$, whereas the other interactions were not.

The post hoc analysis of the interaction between the surround luminance and the type of patches showed that, for both the light and dark surrounds, perceived target lightness changed with the type of patches, $F(2, 12) = 84.08$, $p < 0.0001$ and $F(2, 12) = 33.95$, $p < 0.0001$, respectively. The multiple comparison tests using Ryan's method ($\alpha = 0.05$) showed that when the surround was dark (squares and triangles in Figure 2) the target lightnesses in the moving- and stationary-

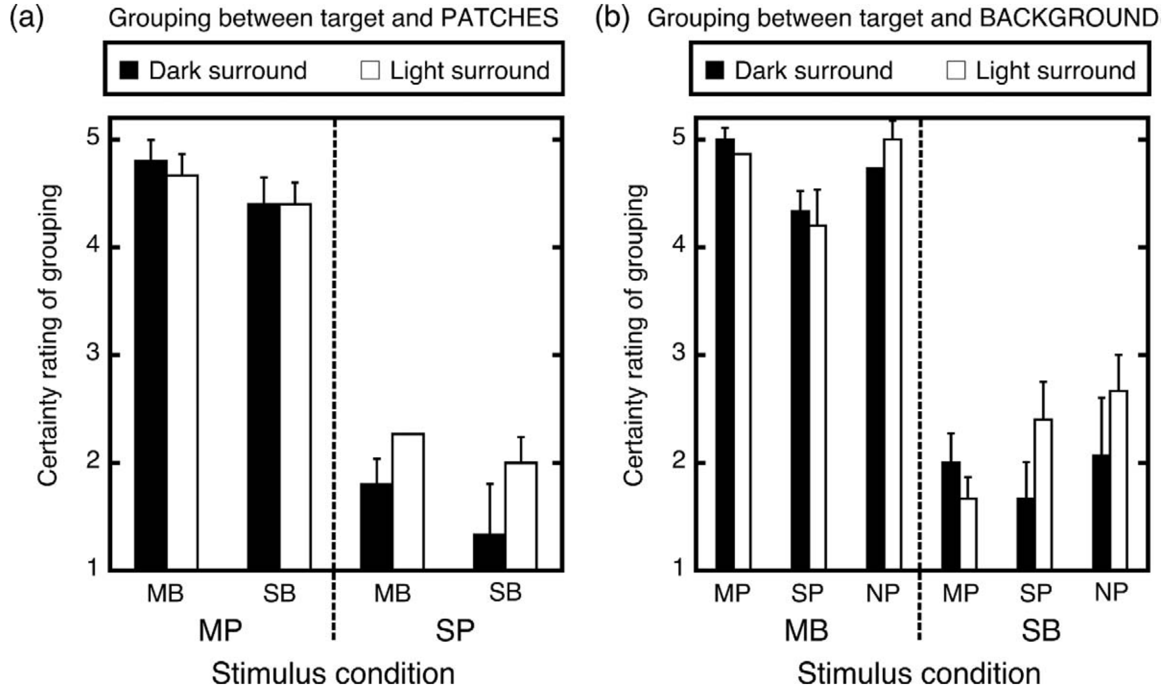


Figure 3. Results of grouping rating in Experiment 1. (a) Grouping rating between the target and patches and (b) grouping rating between the target and background. Rating values were shown for the combination of the type of patches (MP, SP, and NP) and background motion (MB and SB) conditions. Black bars denote the results on the dark surround, while white bars denote those on the light surround. Error bars indicate +1 *SEM* across observers.

patches conditions were statistically higher than that in the no-patches condition. Conversely, when the surround was light (diamonds and circles in Figure 2), the target lightnesses in the moving- and stationary-patches conditions were statistically lower than that in the no-patches condition. The difference between the target lightness on the light and dark surrounds confirmed the articulation effect in the present study.

Importantly, these multiple comparisons also showed the influence of common-fate motion on the articulation effect. Specifically, on the dark surround, target lightness was statistically higher when the articulation patches were moved with the target (MP in Figure 2) than when they were stationary (SP in Figure 2), despite the fact that patches were in close vicinity of the target in both conditions. Conversely, on the light surround, target lightness was statistically lower when the patches were moved with the target (MP in Figure 2) than when they were stationary (SP in Figure 2).

The results of grouping rating confirmed that the stimulus manipulation changed which regions were grouped with the target, as intended (Figure 3). When the articulation patches moved with the target, they were grouped with the target (Figure 3a). In contrast, when the patches were stationary, they were not grouped with the target. Thus, manipulating common-fate motion changed spatial organization of the stimulus and also modulated the articulation effect. These results suggest that spatial organization due to common-fate motion affected the articulation effect.

Furthermore, the difference in target lightness between the stationary- and no-patches conditions suggests that there is some contribution of retinal proximity to the articulation effect as well. This difference was found even though the target was not grouped with the articulation patches in the stationary-patches condition (SP in Figure 3a). It seems that mere existence of the surrounding patches can produce the articulation effect.

Although the results of grouping rating showed that grouping between the target and background changed with background motion (Figure 3b), the results of lightness matching changed little, if any. This finding is consistent with the interpretation that immediate surrounds contribute to lightness computation of the target, regardless of whether or not those surrounds were strongly grouped with the target. This may be another contribution of retinal proximity to lightness contrast, although it appears separable from the articulation effect.

One might argue that moving the articulation patches, rather than spatial organization due to perceptual grouping, produced the changes of the articulation effect. However, in an additional experiment using a stationary target, we confirmed that static common fate (Palmer, Brooks, & Nelson, 2003) modulated the articulation effect. When the target was

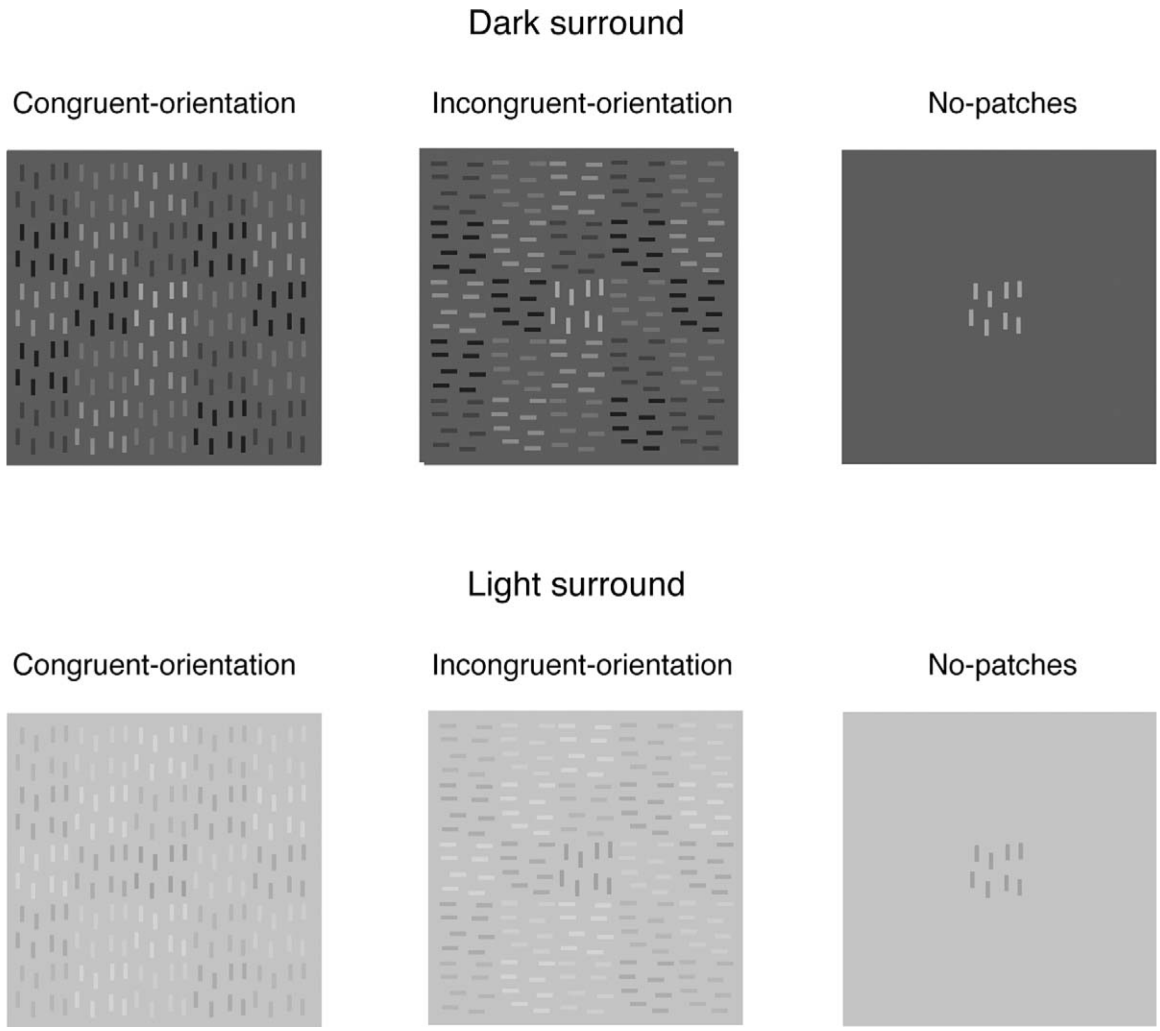


Figure 4. Stimulus conditions in Experiment 2; examples on the dark (top) and light (bottom) surrounds. The target was a texture patch composed of eight vertical line segments and centered on the surrounds. The orientation of the surrounding elements was either vertical (congruent-orientation condition, left) or horizontal (incongruent-orientation condition, center). In the no-patches condition, the surround was spatially uniform (right).

stationary, moving articulation patches now worked to segregate them from the target. Then, observers reported that the target was more strongly grouped with the patches when they were stationary and the articulation effect also became larger. Therefore, regardless of whether the patches were moving or not, when the target was strongly grouped with the patches due to common fate, a larger articulation effect was found.

## Experiment 2

We manipulated the grouping between the target and articulation patches by varying similarity of orientation, and investigated how this manipulation affected the articulation effect.

### Methods

#### *Observers*

Four observers (including the first author) participated in Experiment 2. The three observers other than the first author were naïve to the purpose of the experiment and also participated in grouping rating.

#### *Stimuli and procedure*

The target used in Experiment 2 was a texture patch composed of eight vertical line segments of $6 \times 24$ min of arc, with all line segments having the same luminance (Figure 4). Three types of the surround condition were used: congruent-orientation (Figure 4, left), incongruent-orientation (Figure 4, center), and no-patches conditions (Figure 4, right). In the congruent- and incongruent-orientation conditions, similar texture patches to the target were placed on the surround. The segment orientation of the articulation patches was set to vertical in the congruent-orientation condition but to horizontal in the incongruent-orientation condition. In the no-patches condition, the surround was spatially uniform.

The segment luminance of the articulation patches ranged from 0.83 to 1.36 log cd/m$^2$ on the light articulated surround and from −0.13 to 0.64 log cd/m$^2$ on the dark articulated surround. The spatially averaged luminance of the articulated light and dark surrounds was 1.16 and 0.38 log cd/m$^2$, respectively, which was identical to that of the background. The luminance of the target was 0.68 log cd/m$^2$. A matching stimulus was the same texture patch as the target. It was placed on a uniform background, because when placed on a checkerboard background, as in Experiment 1, lightness matching was very difficult due to low visibility of the line elements. Luminance of the uniform background was equated to the spatially averaged luminance of the light and dark surrounds, respectively, on which the target was presented.

As in Experiment 1, both lightness matching and grouping rating tasks were carried out. In grouping rating, observers rated the degree of perceived grouping between the target and articulation patches using a 5-point scale. Otherwise, the methods were identical to those of Experiment 1.

### Results and discussion

Figure 5 shows the PSEs of target lightness averaged across different observers in different stimulus conditions. The PSEs were analyzed with a two-way repeated-measures ANOVA, with surround luminance (light or dark) and surround type (congruent-orientation, incongruent-orientation, or no-patches) serving as the within-subject variables. The main effects of the surround luminance and the interaction were statistically significant, $F(1, 3) = 15.77$, $p < 0.05$ and $F(2, 6) = 31.48$, $p < 0.001$, respectively, but the main effect of the surround type was not, $F(2, 6) = 0.17$, *ns*.

The post hoc analysis of the interaction showed that, on both the light and dark surrounds, target lightness changed with the surround type, $F(2, 12) = 18.28$, $p < 0.001$ and $F(2, 12) = 18.72$, $p < 0.001$, respectively. The multiple comparison tests, using Ryan's method ($\alpha = 0.05$), showed that on the dark surround (Figure 5a), the target lightness in the congruent-orientation condition was higher than that in the incongruent-orientation condition and that in the no-patches condition. Conversely, on the light surround (Figure 5b), the target lightness in the congruent-orientation condition was lower than that in the incongruent-orientation condition and that in the no-patches condition. These results indicate that varying similarity of orientation between the target and articulation patches modulates the articulation effect. Both on the light and dark surrounds, the target lightness in the incongruent-orientation condition was slightly shifted in the direction of increased lightness contrast, but these changes were not statistically significant.

The results of grouping rating (Figure 5c) confirmed that the articulation patches were grouped with the target in the congruent-orientation condition, whereas they were segregated from the target in the incongruent-orientation condition. Thus, taken together with the results of lightness matching, the present results suggest that spatial organization induced by similarity of orientation affected the articulation effect.

## Experiment 3

In Experiment 3, we investigated the effects of spatial organization by synchrony (Lee & Blake, 1999; Blake & Lee, 2005). Synchrony grouping can be induced when stimulus changes are synchronized, but those changes can be dissimilar (Lee & Blake, 1999; Blake & Lee, 2005).

### Methods

#### *Observers*

Seven observers (including the first author) participated in Experiment 3. The six observers other than the first author were naïve to the purpose of the experiment and also participated in grouping rating.

#### *Stimuli and procedure*

The target and articulation patches were presented in two-frame apparent motion displays (Figure 6). The motion direction and displacement size of the target differed from those of the articulation patches; they were also randomly varied among different articulation patches. Their spatial displacements were within a range from 0.1° to 0.65°. The two frames of the displays were irregularly alternated, and thus the target and the articulation patches were displaced back and forth in a stochastic fashion. The mean alternating frequency was 4.3 Hz and the standard deviation was 0.7 Hz. The temporal alternation sequence of the target was the same as that of the articulation patches, but temporal phase was manipulated. In the in-sync condition, the timings of all stimulus alternations were synchronized (Figure 6a). In contrast, in the out-of-sync condition, the temporal phase of the target alternation was delayed by 200 ms relative to that of the patches

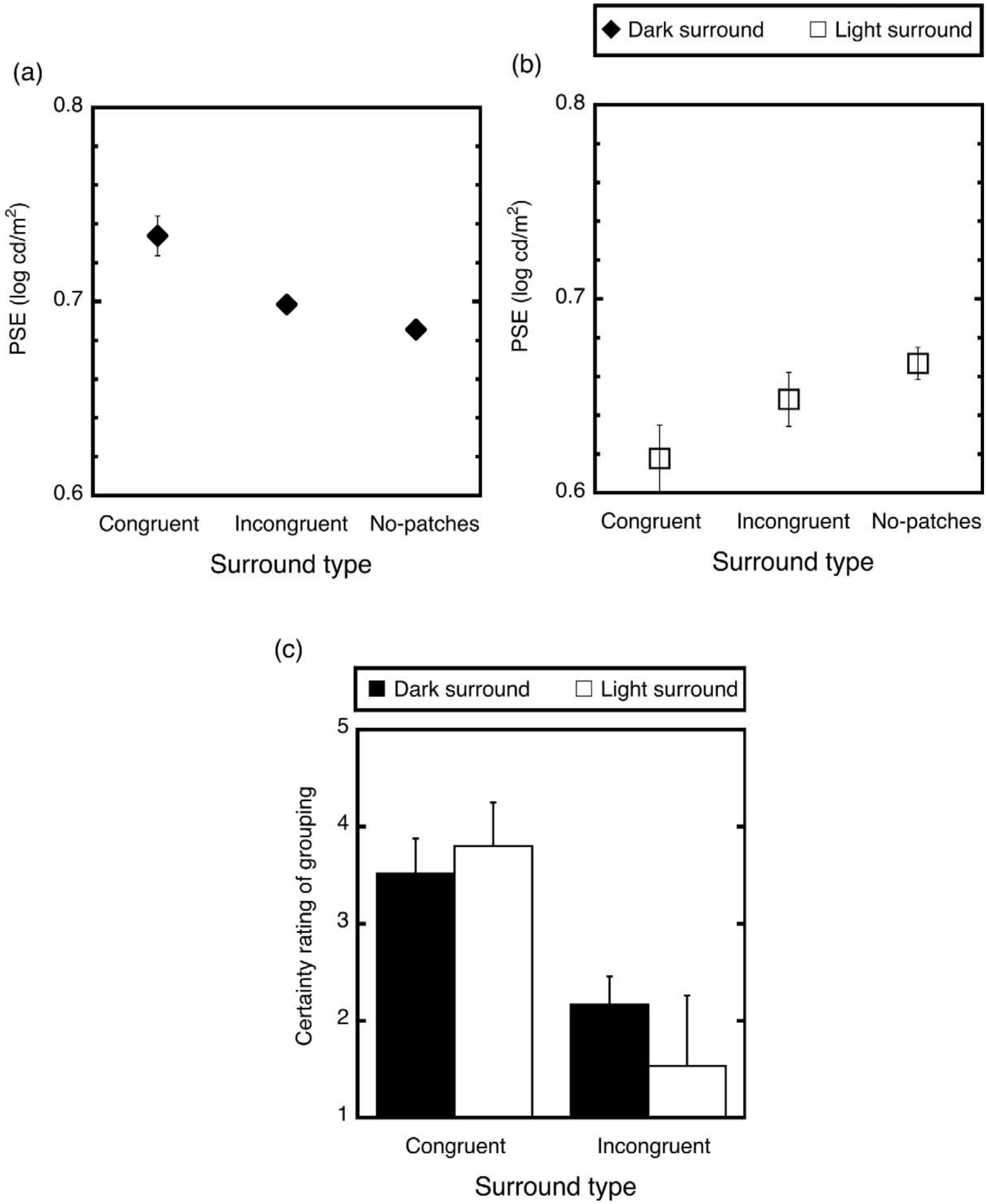


Figure 5. Results of Experiment 2. The results of lightness matching on the dark (a) and light (b) surrounds. The PSEs of target lightness were plotted as a function of the surround type (congruent-orientation, incongruent-orientation, and no-patches conditions). Error bars indicate $\pm 1$ *SEM* across observers. In Experiment 2, the matching stimulus was presented on the uniform dark or light background with a luminance equated to the spatially averaged luminance of the dark or light surround, respectively, on which the target was presented. Thus, the results were separately shown for the dark and light surrounds. (c) The results of grouping rating. Rating values were shown for the congruent- and incongruent-orientation conditions. Black and white bars indicate the results on the dark and light surrounds, respectively. Error bars indicate $+1$ *SEM* across observers.

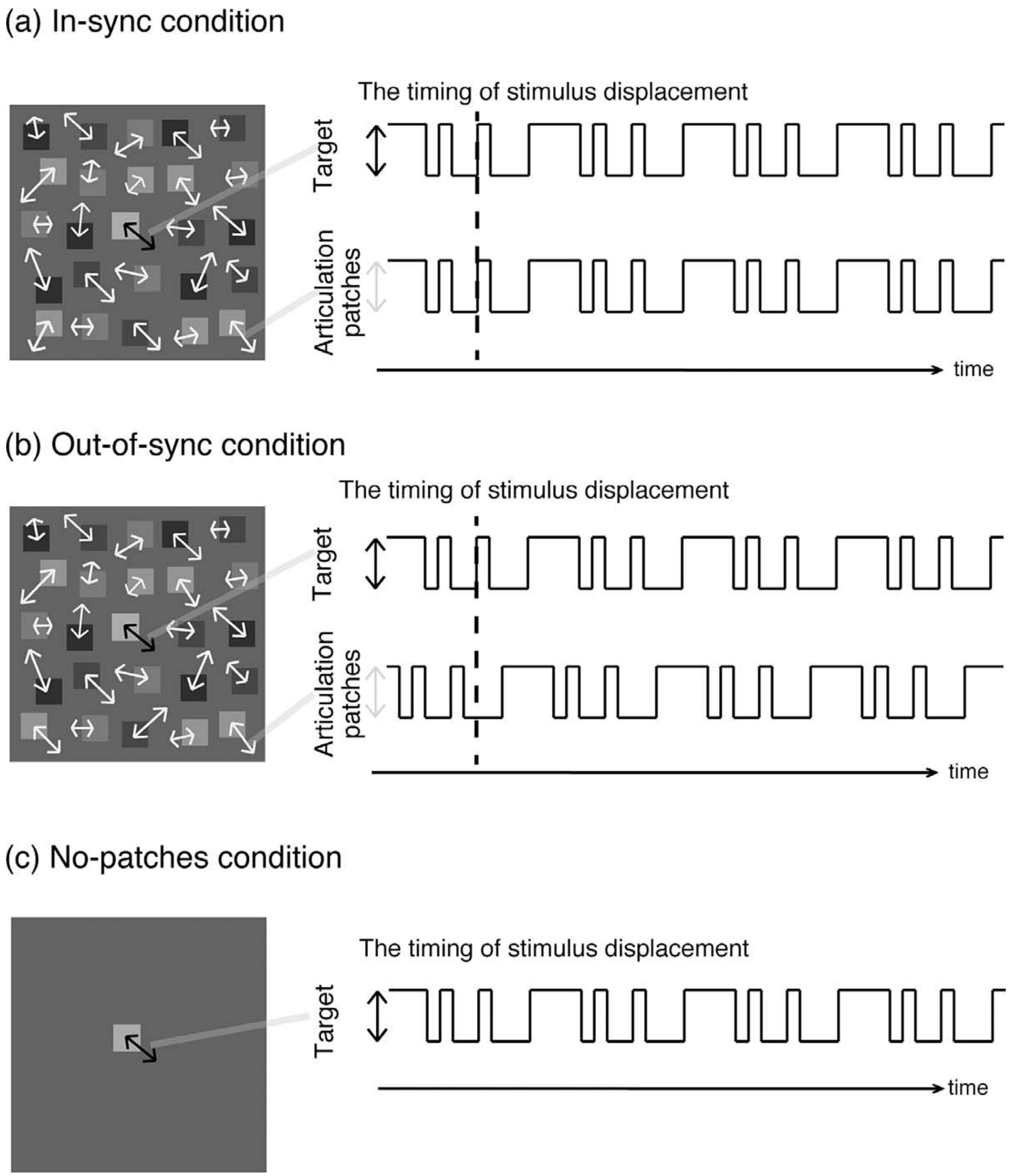


Figure 6. Stimulus conditions in Experiment 3. The target and articulation patches were presented in two-frame apparent motion displays, with their motion direction and displacement size being randomly varied among each other. The two frames of the displays were irregularly alternated so that the target and articulation patches were respectively displaced back and forth in a stochastic fashion. In the in-sync condition (a), the timing of the target displacement was synchronized with the displacement of the articulation patches, whereas in the out-of-sync condition (b) the target displacement was delayed by 200 ms relative to the displacement of the patches. In the no-patches condition (c), the surround was spatially uniform. See Supplementary Movies 3 and 4 for the moving version of the stimulus.

(Figure 6b). The no-patches condition was also tested. The size of the dark and light surrounds was 10° × 10°. As in Experiments 1 and 2, lightness matching and grouping rating were carried out. The other methods were the same as in Experiment 1.

## Results and discussion

Figure 7a plots the PSEs of target lightness averaged across different observers in different stimulus conditions. The PSEs were analyzed with a two-way

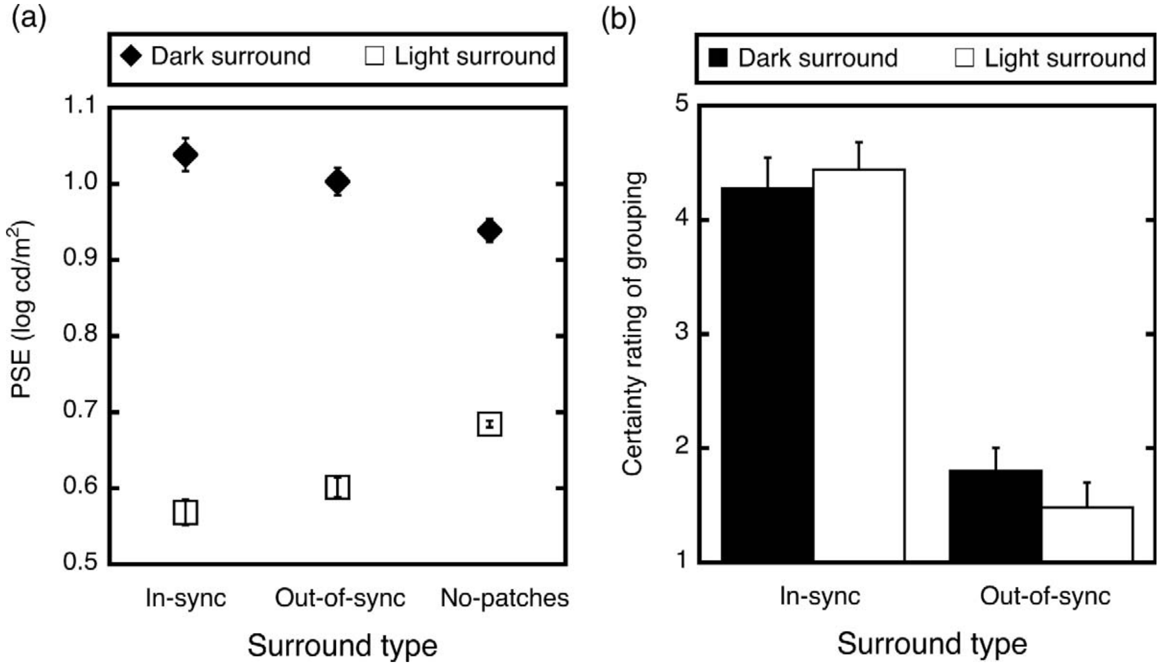


Figure 7. Results of Experiment 3. (a) The results of lightness matching. The PSEs of target lightness were plotted as a function of the surround type (in-sync, out-of-sync, and no-patches conditions). Diamonds and squares denote the results on the dark and light surrounds, respectively. Error bars indicate $\pm 1$ *SEM* across observers. (b) The results of grouping rating. Rating values were shown for the in-sync and out-of-sync conditions. Black and white bars indicate the results on the dark and light surrounds, respectively. Error bars indicate $+1$ *SEM* across observers.

repeated-measures ANOVA, with surround luminance (light or dark) and surround type (in-sync, out-of-sync, or no-patches) serving as the within-subject variables. The main effects of the surround luminance and the interaction were statistically significant, $F(1, 6) = 197.96$, $p < 0.0001$ and $F(2, 12) = 50.65$, $p < 0.0001$, respectively, but the main effect of the surround type was not, $F(2, 12) = 1.27$, *ns*.

The post hoc analysis of the interaction showed that, on both the light and dark surrounds, target lightness changed with surround type, $F(2, 24) = 44.29$, $p < 0.0001$ and $F(2, 24) = 31.30$, $p < 0.0001$, respectively. The multiple comparison tests, using Ryan's method ($\alpha = 0.05$), showed that the articulation effect was stronger when the target was synchronized with the articulation patches than when the target was not. That is, on the dark surround (filled diamonds in Figure 7a), the target lightness in the in-sync condition was significantly higher than that in the out-of-sync condition. In contrast, on the light surround (open diamonds in Figure 7a), the target lightness in the in-sync condition was significantly lower than that in the out-of-sync condition. Furthermore, the results of grouping rating confirmed that the stimulus manipulation changed how the target was grouped with the articulation patches, as intended (Figure 7b). These findings suggest that spatial organization induced by synchrony affects the articulation effect.

In addition, the effect of retinal proximity was suggested by the results that even when the target displacement was not synchronized with the displacement of patches, a small but significant articulation effect was still found (Figure 7a).

## General discussion

The way in which local luminance signals are integrated to generate the articulation effect is an important problem for understanding lightness computation within complex heterogeneous stimuli. The present study aimed to investigate whether the articulation effect could be affected by spatial organization of a stimulus display. We manipulated how a target and articulation patches could be perceptually organized, while holding nearby patches in close vicinity of the target and also ensuring that the spatially averaged luminance of patches was identical to background luminance. The results showed that different grouping factors such as common-fate motion, orientation similarity, and synchrony modulated the articulation effect. Specifically, the articulation effect was larger when a target is strongly grouped with articulation patches. These findings provide converging evidence for the effects of spatial organization on the articulation effect. Overall, they suggest that lightness computation underlying the articulation effect depends, at least partially, on a middle-level spatial representation where some retinal elements are spatially organized according to grouping factors.

The type of perceptual organization investigated in this study has been discussed in only a few theories of lightness perception. One prominent theory is the double-anchoring theory of lightness (Bressan, 2006b), which is a development of the anchoring theory proposed by Gilchrist et al. (1999). This model is discussed in detail in Appendix A. Basically, the model assumes that multiple frameworks exist that link a target to the other regions in a given scene. The frameworks are determined by spatial and photometric grouping factors. A lightness value of a target, called the "territorial" lightness, is then computed within each of the multiple frameworks to which the target belongs. Specifically, the territorial lightness is determined as the weighted average of two intermediate lightness values that are computed at respectively two anchoring steps, called highest-luminance and surround steps. These intermediate values are determined by the luminance ratio of the target to the different anchors, i.e., the highest luminance within the framework and the surround luminance, respectively. All territorial lightnesses computed in different frameworks are averaged with weights given to each framework to establish the final lightness of the target.

In this model, stronger grouping between the target and articulation patches works to increase the relative weight of the framework to which the articulation patches belong. This can explain changes in the target lightness depending on the manipulation of spatial organization of the stimulus display. According to the model, the fact that the spatially averaged luminance of the articulation patches was kept identical to that of the background field played an important role in the present study in showing effects of spatial organization. With this type of stimulus, photometric grouping factors such as luminance polarity and luminance similarity do not favor the grouping of the target with the articulation patches or that with the background field. This situation allowed weaker grouping factors (such as common-fate motion, orientation similarity, and synchrony) to be effective (Bressan, 2007). In addition, this model (Bressan, 2006a) can also explain how relative target luminance drives the direction of the articulation effect (Schirillo & Shevell, 1996; Spehar, Debonet, & Zaidi, 1996; Sawayama & Kimura, 2012), a finding that other theories have difficulty in explaining.

Retinal proximity of the articulation patches also played an important role in the articulation effect, i.e., significant articulation effects were found in Experiments 1 and 3 even when the observers reported that the target was not grouped with the articulation patches. These results can be interpreted as suggesting that the articulation effect is also mediated by low-level processing operating on an early 2-D representation tightly associated with the retinal image (See also Laurinen et al., 1997; Blakeslee & McCourt, 1999, 2001; Shapiro & Lu, 2011). However, the effect of the mere presence of articulation patches may be explained at the same processing level at which the effects of grouping are explained, because in the double-anchoring theory of lightness retinal proximity is another grouping factor (Bressan, 2006b).

In summary, the present study showed that spatial organization due to common-fate motion, orientation similarity, and synchrony could affect the articulation effect. These findings suggest that grouping processing involving object formation is relevant to lightness computation for articulated objects in natural scenes.

*Keywords: lightness perception, articulation effect, spatial organization, perceptual grouping*

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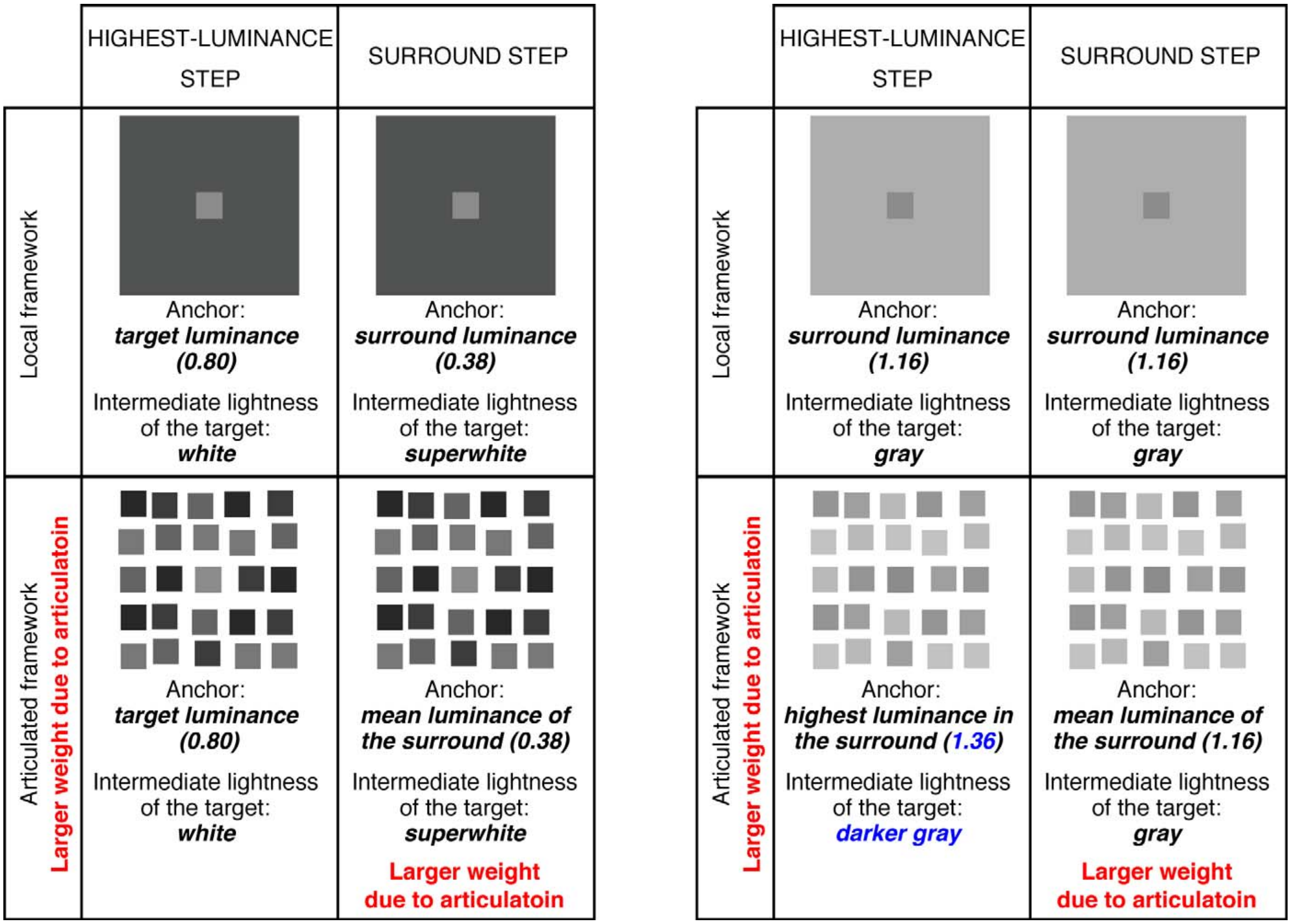


Figure A1. Application of the double-anchoring theory of lightness to the stimuli used in Experiment 1; the dark (left) and light (right) articulated surround conditions. For each stimulus, local (top) and articulated (bottom) frameworks are considered. The local framework consists of the target and its immediate surround. The articulated framework consists of the target and articulation patches. Within each framework, the highest luminance within a framework is assigned the highest lightness value (i.e., white) at the highest luminance step, whereas the (spatially averaged) surround luminance is assigned white at the surround step. These values serve as the anchors for lightness computation at each step. The intermediate lightness of the target at each step is determined by the luminance ratio of the target to the anchor at the step. Note that four different cells in the figure describe lightness computation for a single stimulus in different contexts, and they are separately presented just for the purpose of illustration. The numerical values shown in the parentheses indicate the log luminances of the anchors. See text for how the weightings are determined between different frameworks and between two anchoring steps.

## Appendix A

According to the double-anchoring theory of lightness (Bressan, 2006b), a target belongs to multiple frameworks; for the present, these are treated as local and articulated frameworks for the present stimulus configuration. A local framework consists of the target and its immediate surround, while the articulated framework consists of the target and the articulation patches (Figure A1). The model assumes that articulating the surround produces two effects (Bressan, 2006a, 2006b): an increase in the relative weight of the articulated framework (bottom cells in Figure A1) and an increase in the relative weight of the surround step in the articulated framework (bottom right cell for the light and dark surround conditions, respectively).

In the dark articulated surround condition (Figure A1, left), the intermediate lightness of the target is white at the highest luminance step within both local (top left) and articulated (bottom left) frameworks, because the target has the highest luminance. At the surround step, the intermediate lightness of the target is "superwhite" within both local (top right) and articulated (bottom right) frameworks, because the target has a higher luminance than the surround defined as white. Surround articulation increases the relative weight of the superwhite component at the surround step in the articulated framework (bottom right). In short, surround articulation makes the target lighter.

In the light articulated surround condition (Figure A1, right), the intermediate lightness of the target is gray at both the highest luminance (top left) and surround (top right) steps within the local framework, because the surround has the highest luminance. Within the articulated framework, it is gray at the surround step (bottom right), while it is darker gray at the highest luminance step (bottom left), because some articulation patches have the highest luminance. One of the effects of surround articulation is to increase the relative weight of the articulated framework (bottom), which in turn makes the final target lightness darker due to a larger contribution of the darker gray component at the highest luminance step (bottom left). Thus, surround articulation darkens the target.

The present findings that spatial organization affects the articulation effect can be explained by changes in the relative weighting between different frameworks (Bressan, 2007). That is, when the target is grouped with the articulation patches, the weight of the articulated framework relative to the local one is increased. This change in weighting produces a lightening effect in the dark articulated surround condition and a darkening effect in the light articulated surround condition. This explanation applies to the results of all experiments in this study. A similar scheme has been applied to account for lightness contrast on checkerboard surrounds (Bressan, 2006a) and the dungeon illusion (Bressan, 2007; Bressan & Kramer, 2008).