sciendo

GESTALT THEORY, DOI 10.2478/gth-2022-0009
© 2022 (ISSN 2519-5808); Vol. 44, No. 1-2, 79–96

Original Contributions - Originalbeiträge

Alessandra Galmonte, Alessandro Soranzo, Mauro Murgia, Fabrizio Sors & Tiziano Agostini

Lightness Contrast Spatially Propagates on Perceptually Unified Elements

1. Introduction

The simultaneous lightness contrast phenomenon is the condition whereby a gray patch on a white background looks darker than an equal patch on a black background. In this condition, the induced gray surface perceptually acquires a complementary color than the inducing surrounding area.

Several theories have been advanced to explain the contrast phenomenon, which differ in terms of the importance credited to the perceptual processes involved. Some theories underline the role of the interactions of retinal neurons, while others focus on cognitive mechanisms (see Soranzo & Gilchrist, 2019). Theories based on retinal interactions, the so-called "low-level theories", have been called to question since several visual illusions have been found that contradict retinal interaction-based explanations and support the main role of perceptual belongingness, first advanced by Wertheimer (1923), in determining the lightness contrast phenomenon. Of relevance for this paper is the phenomenon advanced by Agostini and Proffitt (1993). These authors showed the importance of belongingness by using displays of black, white, and gray disks placed on a homogeneous background. Belongingness evoked by good continuation or common fate facilitated the emergence of contrast: gray disks perceptually grouped with black disks appeared lighter than those belonging to white disks, and vice versa.

The aim of the present research is to measure the strength of belongingness in the magnitude of the contrast phenomenon. To achieve this, in an Agostini-and-Proffitt-type configuration, we manipulated the numbers of inducing and induced elements and their relative positions.

The low-level explanation of the contrast phenomenon first advanced by Hering (1920/1964) received great attention after the physiological discovery of the lateral inhibition process in the limulus's retina (Hartline, Wagner & Ratliff, 1956). According to this explanation, a gray on a white background appears darker than an equal gray on a black background because the receptors stimulated by the white color inhibit the neighboring receptors stimulated by the gray color, causing, at the perceptual level, its darkening. The receptors stimulated by the black background, instead, send little inhibition to nearby receptors responding to the gray color, resulting in a weaker darkening effect (Jameson & Hurvich, 1964; Ratliff, 1965; Cornsweet, 1970).

Data seemingly supporting this theory come from Fry and Alpern (1953), which demonstrated that the contrast effect decreases as the distance between the inducing background and induced region increases, as well as from Diamond (1953), who noted a decrease of the effect when the induced and inducing regions, instead of surrounding the gray surfaces, just touch them on one side.

Several models originate from this low-level approach and an excellent review of them is outlined by Foley (2019). However, as anticipated, this account has been questioned by many, and the low-level interpretation is nowadays adopted mainly to account for phenomena occurring at an early stage of the visual process, i.e., for brightness (i.e., perceived luminance, rather than lightness phenomena; see Gilchrist, accepted). For example, the Contrast Sensitivity Function models (Campbell & Robson, 1968; Shapley & Tolhurst, 1973; Sullivan & Georgeson, 1977; Wilson & Bergen, 1979) well interpret perceptual effects such as the Craik–O'Brien–Cornsweet effect (COCE; Craik, 1940; O'Brien, 1958; Cornsweet, 1970), in which spatial frequencies play an important role. Moreover, edge detector models (Blakeslee & McCourt, 1997; Kingdom & Moulden, 1988; Moulden & Kingdom, 1991; Ratliff, 1972) originate from this low-level approach.

Lightness phenomena, instead, are much difficult to interpret within the low-level approach. One of the most compelling pieces of evidence against the low-level account was offered by Wolff (1933), who noted that moving the inducing region away in depth from the target causes the disappearance of the contrast effect. This manipulation does not modify local/retinal photometrical relationships between the part of the retina that is stimulated by the light reflected from the inducing background and that stimulated by the target region. Thence, this result implies that contrast can occur in relation to the apparent coplanarity and/or to belongingness. This effect is very robust as it received confirmation using different types of displays, as well as on using inducers of different shapes, sizes, and intensities (see Soranzo, Galmonte & Agostini, 2010; Soranzo et al., 2020; Nedimović & Zdravković, 2021; Acaster et al., 2021).

Benary (1924), picking up a Wertheimer (1923) observation, demonstrated the role of belongingness in determining the contrast effect. He proposed a figure in which a gray triangle lying on a bigger black triangle, to which it perceptually belongs, appears lighter than an identical gray triangle that lies on the arms of a black cross placed on a white background. In the latter case, the gray triangle perceptually belongs to the white background. Equivalent surrounds bound both the gray triangles: each gray triangle is adjacent to a white region beside the hypotenuse and to a black one beside the two catheti. According to Benary (1924), the belongingness of the target region to a whole figure defines which will be the reciprocal chromatic influences among the different regions of the display.

Further corroboration of the key role of belongingness in determining the contrast effect comes from Laurinen and Olzak (1994). These authors superimposed sinusoidal modulations on each of the four regions forming the simultaneous lightness contrast display with a white-and-black background encompassing a gray surface each. They found that the difference between the grays is weakened if the modulation frequency on the targets is different from that on the backgrounds.

Bonato and Cataliotti (2000) tested the importance of perceptual belongingness in the lightness contrast phenomenon by manipulating the texture of surfaces. They compared the lightness difference between two equal targets in two contrast displays. In the first, the targets had different textures relative to each other but equal to their own background; in the second, the targets shared the same texture, but it differed from that of their backgrounds, which shared the same texture. The lightness difference between the targets was larger in the first case, when the targets shared the same texture as their own backgrounds. In this case, their belongingness to their respective background was stronger.

Adelson (1993) presented another set of illusions that cannot be explained by models based on retinal interactions. The author demonstrated that simple geometrical changes of stimuli that should have little effect on low-level mechanisms greatly affect the strength of the contrast. Moreover, the same author maintained that midlevel mechanisms, involving contours, junctions, and grouping, appear to be critical in explaining many lightness phenomena (Adelson 2000).

Eagleman, Jacobson and Sejnowski (2004) presented a class of illusions in which temporal relations with spatially neighboring objects can modulate their lightness. The authors demonstrated that the lightness of an object depends on both its spatial context – which includes perceptual organization, scene interpretation, three-dimensional perception, shadows, and other high-level percepts – as well as its temporal context.

Agostini and Galmonte (2002) found that perceptual belongingness prevails over local factors in inducing contrast effects. Stimuli were provided by two gray dashed Necker cubes, having black or white inducer corners; these configurations were placed on a white or black background, respectively. According to the local mechanisms of lateral inhibition, the effect would be determined by the influence of the target's surrounding regions only, i.e., by the inducer background, especially because each single gray element is entirely surrounded by the background, and this fact would favor local contrast. According to a belongingness principle-based explanation, instead, perceptual organization principles should affect the contrast exerted by the inducer corners on the gray dashed lines. The results show that the gray dashed lines having (belonging to) the black inducers are perceived as lighter than those of the other cube. Therefore, when the two explanatory approaches are directly compared, belongingness can account for the occurrence of lightness contrast, while local accounts cannot.

Agostini and Galmonte (1999) investigated the changes in the simultaneous contrast effect as a function of a systematic manipulation of spatial articulation. They found that the contrast effect is large when the spatial articulation is low; the effect decreases by introducing a spatial relation of adjacency, and it is further reduced on introducing inclusion relations when there is clear figure/ground stratification and, hence, a higher degree of articulation. Moreover, *ceteris paribus*, the magnitude of contrast is weaker when the target is moved from the center of the inducing region to its border.

From the above-cited literature, it can be concluded that perceptual belongingness plays a central role in lightness perception. The importance of perceptual belongingness is at the core of two current leading approaches of lightness perception: the anchoring and the decomposition theories (Soranzo & Gilchrist, 2019).

2. The anchoring and the decomposition approaches

Both the anchoring and the decomposition approaches posit that the visual system parses the retinal images into different components. The anchoring approach parses the image into adjacent frameworks of luminances, while the decomposition approach splits the image into overlapping layers of illumination and lightness. Hence, for the anchoring approach, belongingness directly affects lightness as it dictates how surfaces are grouped within a framework; for the latter, it has an indirect effect as it first influences the perceived level of illumination. The two interpretations of the effects of belongingness on lightness contrast have been compared by Soranzo, Lugrin and Wilson (2013). The authors urged the need for integration between the two approaches as belongingness seems to have a dominant role in generating contrast effects.

As anticipated, the experimental part of this paper develops this line of research further to clarify the role of the inducers on the induced elements by keeping the local stimulation constant. To clarify the role of the inducers on the lightness of the induced elements, on Agostini–Proffitt display types, we manipulated their numerousness and relative spatial positions. Furthermore, to compare the two interpretations of the effects of belongingness on lightness perception, the intensity of the inducers was also manipulated.

3. Experiment 1

The aim of Experiment 1 was to assess whether the relative number and position between the induced and inducing regions affect the lightness of the induced elements. For this purpose, we created four displays, each composed of eight disks organized in a T-shaped form. The color of the disks was manipulated so that the relative number and position between the induced and inducing regions changed across the conditions. The rationale behind this manipulation was to assess the effects of belongingness: if belongingness generates contrast effects, then contrast effects must be recorded for all the induced elements, independently from the relative number and position of the inducers.

3.1. Method

3.1.1. Observers

Twenty observers volunteered for this experiment, all having normal or corrected-to-normal vision. They were naïve as to the purpose of the experiment.

3.1.2. Apparatus and stimuli

Stimuli were presented on a high-resolution CRT monitor (1280 × 1024 27 pixels), controlled by a PC. The monitor was already calibrated. Disks arranged to form the letter T constituted the stimuli presented to the observers. This kind of display has been chosen to manipulate the belongingness relationships determined by Gestalt laws. The background had homogeneous luminance and surrounded the disks that formed the experimental displays. The size of the stimuli and their luminances are reported in Figure 1. There were four experimental displays; in each of them, the relative numbers of induced and inducing elements and their relative positions were manipulated. The four experimental conditions are depicted in Figure 2.

3.1.3. Procedure

Observers were seated at a distance of 100 cm from the computer screen. In a forced choice paradigm, their task was to stare at a fixation point, placed at the center of the two displays, and to make a judgment in the lightness dimension, by indicating in which of the two displays the gray elements were lighter/darker (the direction of the question was counterbalanced). Observers participated in the experiment individually; vision was binocular, and each observer gave one judgment for each pair of displays once. The presentation order was randomized, and the left/right position was counterbalanced. The experiment was conducted in a darkened room.

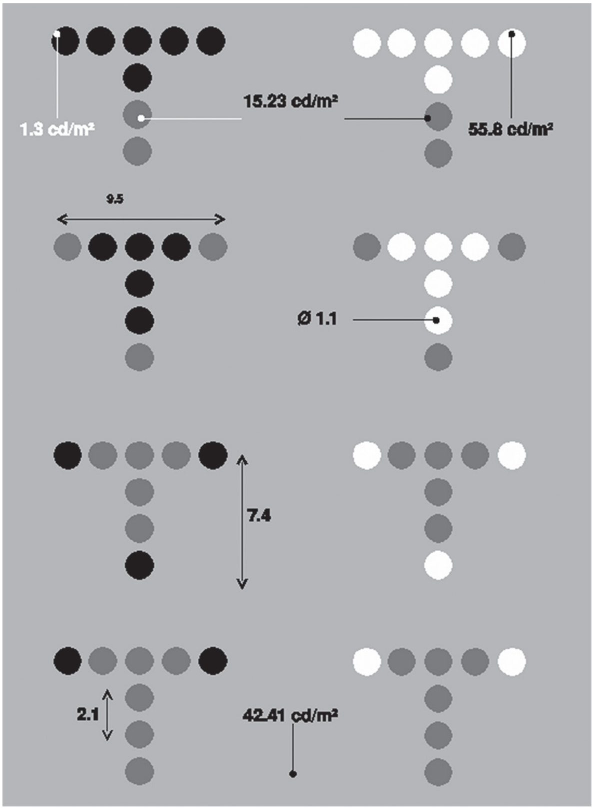


Fig. 1. Size and luminances of the stimuli; units of measurement are centimeters for size and candela per square metre (cd/m^2) for luminance.

3.1.4. Results and discussion

A binomial test was used to analyze the data. Results were statistically significant at an alpha level of 0.05. Moreover, it can be noted that increasing the number of induced elements while decreasing the number of inducing elements, the observers' confidence decreased. This suggests that contrast induction elicited by belongingness decreases as the number of inducers decreases.

To further investigate the effect of the number of inducers, we conducted Experiment 2.

4. Experiment 2

To further investigate the effects of the relative number and position between the inducing and inducer elements, a parametric study was conducted in Experiment 2. The displays were similar to those used in Experiment 1 but were

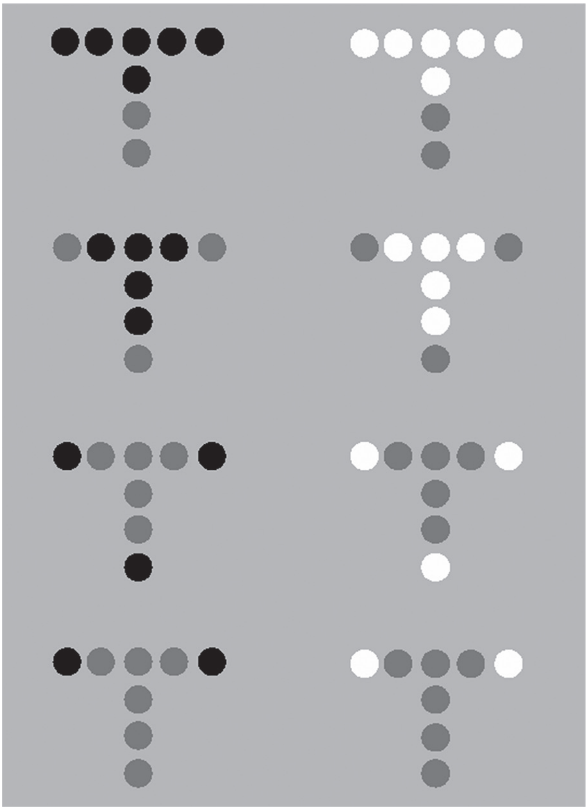


Fig. 2. Experimental displays used in Experiment 1.

simplified in a way that all inducing and induced elements were aligned to form a single line (e.g., without the horizontal line of the T as in Experiment 1).

4.1. Method

4.1.1. Observers

Since the results that emerged in Experiment 1 with naïve observers highlighted an effect of belongingness even when the number of inducers was small, for the present experiment, we decided to use two expert observers (authors AG and TA), having normal and corrected-to-normal vision, respectively.

Another reason to use experts for this experiment is that the task required a large number of observations and a high degree of accuracy. In fact, it has been noted that adjustment tasks, particularly when sustained, produce highly variable results (Arend & Spehar, 1993a, 1993b; Spehar, Gilchrist & Arend, 1995; Spehar & Zaidi, 1997).

For a statistical analysis to be powerful enough to detect an effect, a small number of participants must be compensated by a high number of repetitions. An *a priori* power analysis was conducted to establish the number of repetitions needed to get a power of 0.9 with two participants. The analysis indicated that number of repetitions per participant had to be 20 for α=0.05, power =0.90, and effect size f=0.8 (estimated based on the results of Experiment 1).

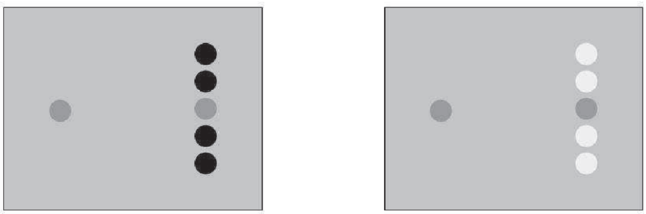
4.1.2. Apparatus and stimuli

The apparatus was the same as in Experiment 1. Five disks aligned along the vertical axis made up the stimuli. The background, having homogeneous luminance, surrounded the disks forming the experimental displays.

There were eight standard displays (four with black and four with white inducers); in each of them, the relative number and position of the induced and inducing elements were manipulated. The adjustment method was used in two different experimental situations. In the first situation (nulling task **a**), the color of the gray elements of the standard display was matched against the corresponding grays lying on the background. In the second situation (nulling task **b**), the target gray elements were embedded in the display that was similar to the experimental display but the inducer elements were of the opposite intensity (see Figure 3).

The rationale of nulling task **a** is to measure the effects of belongingness on the lightness of both the white and black inducers separately.

A



B

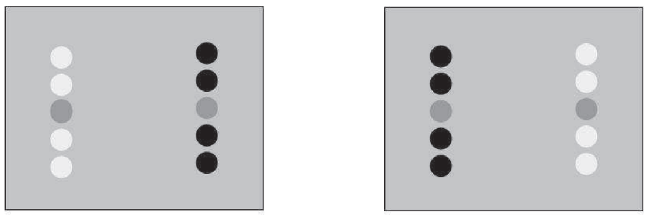


Fig. 3. (**A**) Nulling task **a**. The lightness of the gray disk on the left was adjusted until it was perceived equal to that of the aligned gray target embedded in the standard display. (**B**) Nulling task **b**. The lightness of the gray disk on the left was adjusted until the illusion was canceled out.

To validate this theoretical assumption, it was decided to take a baseline for each of the experimental conditions described previously, comparing each condition to itself.

The rationale of nulling task **b** was to obtain a relative measure of the simultaneous lightness contrast effect, wherein the measured effect is made up of both the induction effect in the direction of white exerted on the gray elements belonging to black inducers and the induction effect in the direction of black due to the influence of the white elements collinear to the gray elements.

Finally, it should be noted that in both nulling tasks, the surroundings of the standard and the test grays are of the same luminance. This means that if contrast effects emerge, they must be exclusively due to belongingness. Figure 4 shows the size and luminances of the stimuli.

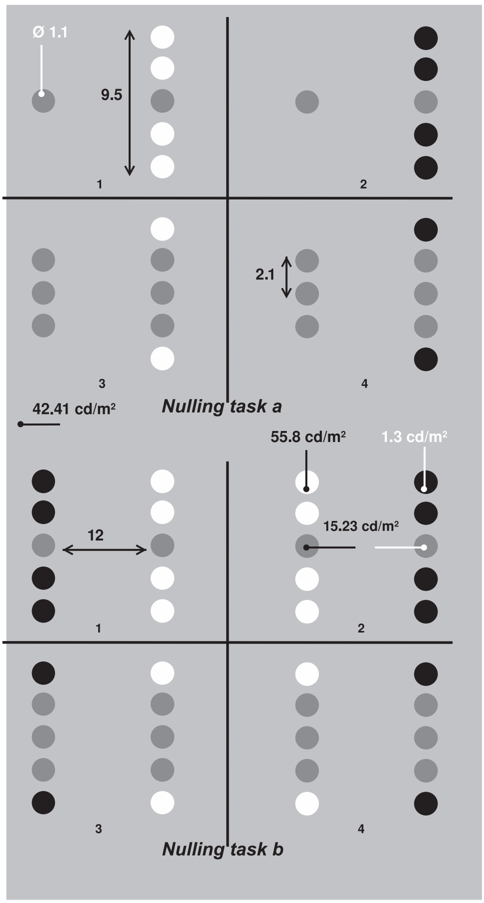


Fig. 4. Size and luminances of the stimuli of Experiment 2; size is reported in centimeters, luminance in candela per square metre (cd/m²).

4.1.3. Procedure

Observers were seated 100 cm away from the monitor. Their task, in both experimental situations, was to use two keys of the computer keyboard to adjust the lightness of the test grays to match the perceived lightness of the standard grays. With regard to the nulling task **a**, each of the eight standard displays (four having white inducers, and four having black ones), was presented 20 times. The luminance of the test grays on which the adjustment was made was 10 times lower and 10 times higher than that of the standard grays, in random order. In addition, the position factor on the screen was controlled for (standard on the right and test on the left, and vice versa), obtaining an overall experimental design of 8 × 8 × 2. The baseline was obtained as follows: eight experimental displays by 20 presentations by two positions on the screen (right/left).

Observers took part in the experiment individually; vision was binocular. The experiment was conducted in a darkened room. Figure 5 shows the stimuli and the task of Experiment 2.

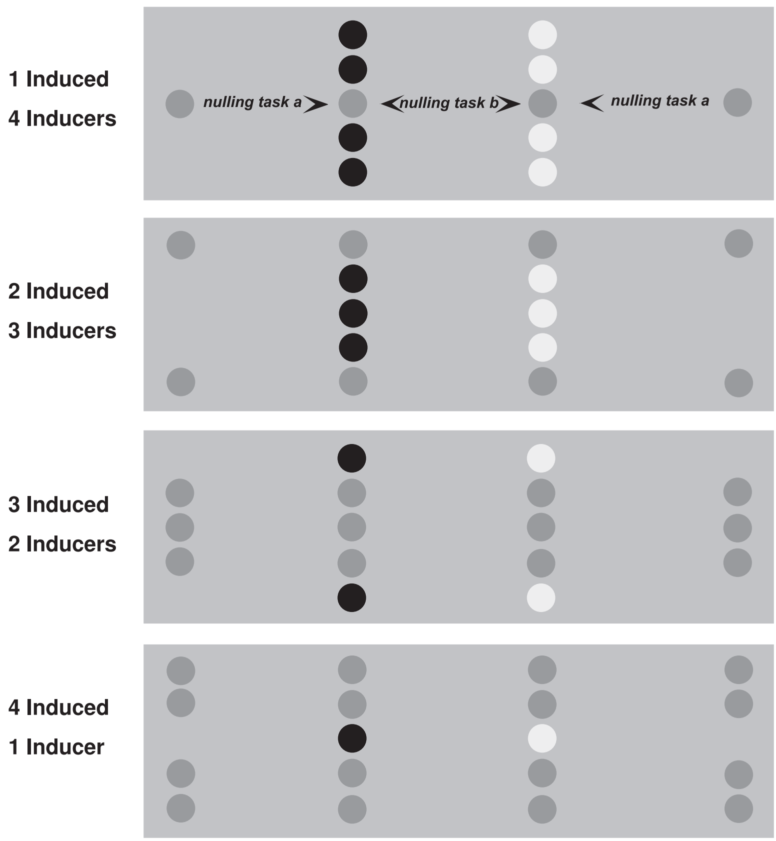


Fig. 5. Stimuli and task of Experiment 2.

4.1.4. Predictions

Based on the hypothesis that lightness contrast is generated by belongingness, rather than proximity, of the inducing elements to the induced elements, it is expected that the contrast increases with the number of inducing elements.

4.1.5. Results

The results are depicted in Figure 6. Luminance values have been transformed into log units. The relative baseline has been subtracted from the mean value of each condition.

Despite the gray targets being surrounded by the same background, the color of the inducers aligned with the targets determined the contrast effect [AG: $F(9,1)=9{,}991.84$; $p<0.0001$; TA: $F(9,1)=1{,}940.04$; $p<0.0001$].

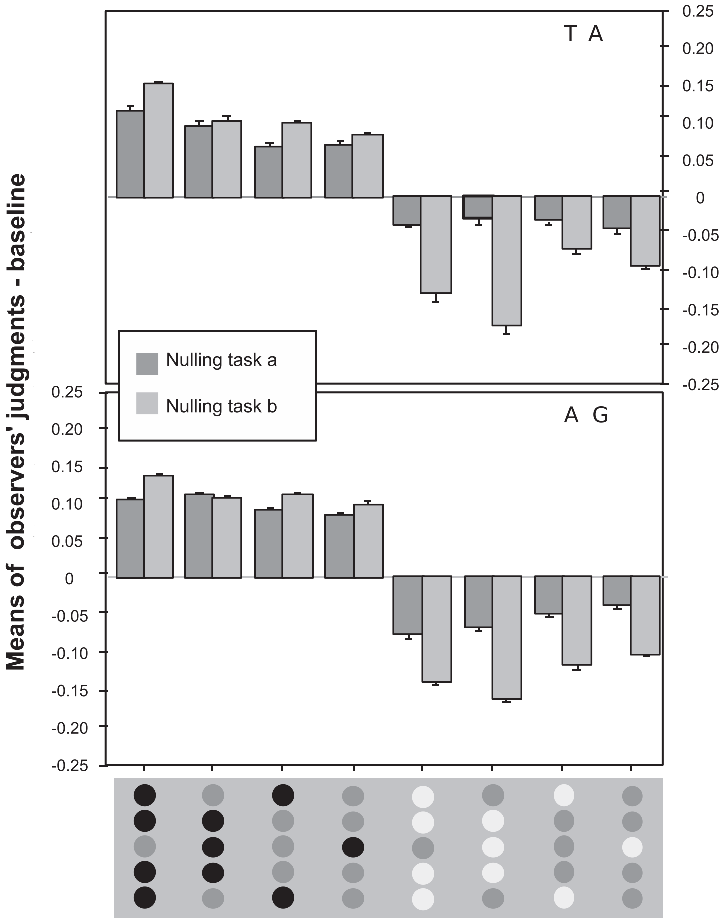


Fig. 6. Results of Experiment 2. Note: TA and AG are the authors Tiziano Agostini and Alessandra Galmonte in this paper.

Contrast effects were recorded also with just one inducer. However, an analysis of variance for repeated measures showed an effect of the number of inducers for both the observers [AG: $F(9,3)=7.19$; $p<0.005$; TA: $F(9,3)=21.994$; $p<0.0001$].

It seems that lightness contrast decreases as the number of inducers decreases and the number of induced elements increases, regardless of their position.

Not surprisingly a statistically significant difference emerged between nulling tasks **a** and **b** [AG: $F(9,1)=280.7$; $p<0.0001$; TA: $F(9,1)=90.833$; $p<0.0001$] with contrast being stronger in nulling task **b**. In nulling task **b,** both inducers generated a contrast effect, while in nulling task **a,** there was only one inducer type at the time.

Posthoc analysis performed on each pair of conditions resulted in statistically significant values for both observers ($p=0.008$ after Bonferroni correction), except for the following pairs:

- **Observer AG**

Nulling task a

- Black inducers: 3 vs. induced elements: 4;
- White inducers: 2 vs. induced elements: 3

Nulling task b

- Black inducers: 2 vs. induced elements: 3.

- **Observer TA**

Nulling task a

- Black inducers: 1 vs. induced elements: 2;
- Black inducers: 3 vs. induced elements: 4
- White inducers: 1 vs. induced elements 3;
- White inducers: 1 vs. induced elements 4;
- White inducers: 2 vs. induced elements 3;
- White inducers: 2 vs. induced elements 4;
- White inducers: 3 vs. induced elements 4

Nulling task b

- Black inducers: 2 vs. induced elements 3;
- Black inducers: 2 vs. induced elements 4;
- Black inducers: 3 vs. induced elements 4

A one-sample *t*-test applied on each of the eight experimental conditions, for both nulling tasks **a** and **b**, always showed a statistically significant difference with respect to the target objective value, with a probability <0.008 (again after Bonferroni correction).

By subtracting the adjustment mean value in nulling task **a** from that for nulling task **b** for comparable conditions, it was possible to determine the magnitude of the effect of inducers with opposite polarity. An asymmetry emerged with this analysis; black inducers generate stronger effects than white inducers.

4.1.6. Discussion

The principles of perceptual organization determine the spatial propagation of the contrast effect on all the unified elements. This happens also when the number of the inducers is reduced to one. Nevertheless, the data seem to show a tendency to a reduction of the contrast effect as the number of induced elements increases and the number of inducers decreases.

Relative position has no effect, indicating once more that local effects (e.g., retinal interactions) play a scarce role in lightness perception.

Simultaneous lightness contrast is induced by both white and black elements. In addition, nulling task **a** led to a stronger contrast effect for grays grouped with black elements, while nulling task **b** seemed to lead to a symmetrical distribution of the effect.

What is observable from these data is that the overall contrast is not the result of the sum of the effects measured separately on white and black inducers.

Moreover, it is quite important to once more underline that these kinds of displays, where elements are surrounded by the same background, allow one to measure the contrast effect independently from the background, since under these conditions, the local induction factors are the same.

5. General Discussion

The present work was inspired by the research of Agostini and Proffitt (1993) demonstrating that lightness contrast can be induced by perceptual organization principles in the absence of spatial contiguity. We used new displays in which the relative number of inducing and induced elements and their relative spatial positions were manipulated. In this way, we were able to verify the extent of the simultaneous lightness contrast that is related to perceptual belongingness.

From the two above-reported experiments, it emerged that the perceptual organization principles determine the spatial propagation of the contrast effect on all the unified elements. This happens also when the number of inducers is reduced to one. It seems, however, that the contrast effect decreases as the number of induced elements increases and that of the inducers decreases.

Contrast induction is instead independent of the spatial position of elements. Most importantly, for the purpose of this research, it should be noted that contrast effects were recorded although the surrounding area of the target elements was the same. This phenomenon once more challenges low-level theories based on retinal local interactions.

Interestingly, we recorded a simultaneous lightness contrast with both white and black elements. The two adjustment tasks tested in Experiment 2 led to different results: when the adjustable elements were not subject to any induced effects, stronger contrast effects were recorded with black inducers; when, instead, the adjustable elements were subjected to inducing effects by inducers of the opposite polarity than the target elements, contrast effects were symmetrical for both the inducer types.

It is relevant to note that the overall contrast effect is not the result of the sum of the effects measured separately on white and on black inducers configurations

5.1. Interpretative approaches

Our results, apart from challenging the retinal-based approach once more, are useful to evaluate the anchoring and decomposition approaches of lightness perception (see Introduction section). According to the anchoring approaches, only black inducers should generate contrast effects, while the decomposition approach predicts contrast effects with both inducer colors.

To conclude, the results of these experiments suggest the way that neurophysiology and visual science should follow to identify the structures of the visual system that are responsible for the assignment of surface color in spatially articulated contexts.

In fact, in the present as well as on many other occasions reported in the literature, low-level models based on lateral inhibition mechanisms turned out to be inadequate to explain the functioning of the perceptual system in extracting, classifying, and integrating detectable edges in complex scenes and in the subsequent assignment of surface colors.

Therefore, it is extremely important to manage to provide apt operational definitions for theoretical concepts such as perceptual belongingness, which can serve as guidelines for both psychology research and neurophysiology.

Acknowledgment

This research was supported by the Ministero dell'Istruzione, dell'Università e della Ricerca (MIUR) Grant 2005115173_001 (A.T.).

Commercial relationships: none.

Abstract

In 1993, Agostini and Proffitt showed that perceptual belongingness (the subsumption of some sets of elements into a perceived whole) causes simultaneous lightness contrast to be seen in configurations in which the inducing elements are not adjacent to the target. The aim of the present research was to measure the strength of belongingness in determining the contrast phenomenon when the numbers of the inducing and induced elements and their relative positions are manipulated in Agostini-and-Proffitt-type configurations. In the first experiment, by using a forced choice paradigm, naïve observers indicated which gray disks arranged to form the letter T in two rows (organized with black/white inducers) appeared lighter/darker. In the second experiment, expert observers performed two nulling tasks: 1) the lightness of gray disk(s) was adjusted until it was perceived equal to that of gray target(s) aligned with white/black inducers; 2) the lightness of target(s) organized with white/black inducers was adjusted to match the target(s) organized with black/white inducers. We found that also when there are few inducers, perceptual belongingness causes the contrast effect to propagate spatially on all the induced elements. Spatial position does not influence the induction effect. Low-level theories cannot account for these phenomena, but higher-level processes must be factored in to explain them.

Keywords: lightness, simultaneous contrast, perceptual belongingness, grouping.

References

Acaster, S., Taroyan, N., Reidy, J., & Soranzo, A. (2021). Behavioural and electrophysiological correlates of lightness contrast and assimilation. *Experimental Brain Research, 239*, 3205-3220. https://doi.org/10.1007/s00221-021-06197-3

Adelson, E. H. (1993). Perceptual organization and the judgment of brightness. *Science, 262*, 2042–2044.

Adelson, E. H. (2000). Lightness perception and lightness illusions. In M. Gazzaniga (Ed.), *The New Cognitive Neuroscience* (2nd ed., pp. 339–351). Cambridge, MA: MIT Press.

Agostini, T., & Galmonte, A. (1999). Perceptual articulation affects lightness. *Perception & Psychophysics, 61*(7), 1345–1355.

Agostini, T., & Galmonte, A. (2002). Perceptual organization overcomes the effect of local surround in determining simultaneous lightness contrast. *Psychological Science, 13,* 88–92.

Agostini, T., & Proffitt, D. R. (1993). Perceptual organization evokes simultaneous lightness contrast. *Perception, 22*, 263–272.

Arend, L. E., & Spehar, B. (1993a). Lightness, brightness and brightness contrast: 1. Illuminance variation. *Perception and Psychophysics, 54***,** 446–456.

Arend, L. E., & Spehar, B. (1993b). Lightness, brightness and brightness contrast: 2. Reflectance variation. *Perception and Psychophysics, 54*, 457–468.

Benary, W. (1924). Beobachtungen zu einem experiment über Helligkeitskontrast [Observations concerning an experiment on brightness contrast]. *Psychologische Forschung, 5,* 131–142.

Blakeslee, B., & McCourt, M. E. (1997). Similar mechanisms underlie simultaneous brightness contrast and grating induction. *Vision Research, 37*, 2849–2869.

Bonato, F., & Cataliotti, J. (2000). The effects of figure/ground, perceived area, and target saliency on the luminosity threshold. *Perception & Psychophysics, 62*(2), 341–349.

Campbell, F. W., & Robson, J. G. (1968). Application of fourier analysis to the visibility of gratings. *Journal of Physiology, 197*, 551–566.

Cornsweet, T. N. (1970). *Visual Perception*. New York: Academic Press.

Craik, K. J. W. (1940). *Visual Adaptation*. Ph.D. Thesis. Cambridge University.

Diamond, A. L. (1953). Foveal simultaneous brightness contrast as a function of inducing- and test-field luminances. *Journal of Experimental Psychology, 45,* 304–314.

Eagleman, D. M., Jacobson, J. E., & Sejnowski, T. J. (2004). Perceived luminance depends on temporal context. *Nature, 428*, 854–856.

Fry, G. A., & Alpern, M. (1953). The effect of peripheral glare source upon the apparent brightness of an object. *Journal of the Optical Society of America, 43*, 189–195.

Gilchrist, A. (accepted). Toward a Materialistic Theory of Perception. Gestalt Theory - "Colour and Space in Perception and Art".

Hartline, H. K., Wagner, H. G., & Ratliff, F. (1956). Inhibition in the eye of Limulus. *Journal of General Physiology, 39*, 357–673.

Hering, E. (1920/1964). *Outlines of a Theory of the Light Sense* (Jameson, L. M. H. D., Trans.). Cambridge, MA: Harvard University Press. (Original work published 1920).

Jameson, D., & Hurvich, L. M. (1964). Theory of brightness and color contrast in human vision. *Vision Research, 4*, 135–154.

Kingdom, F., & Moulden, B. (1988). Border effects on brightness: A review of findings, models and issues. *Spatial Vision, 3*, 225–262.

Laurinen, P. I., & Olzak, L. A. (1994). Spatially remote, frequency-tuned mechanism can control apparent lightness. *Perception, 23*, 18.

Moulden, B., & Kingdom, F. (1991). The local border mechanism in grating induction. *Vision Research, 31*(11), 1999–2008.

Nedimović, P., & Zdravković, S. (2021). Lightness contrast & assimilation: Testing the hypotheses. *Primenjena psihologija, 14*(3), 253–275.

O'Brien, V. (1958). Contour perception, illusion, and reality. *Journal of the Optical Society of America, 48*, 112–119.

Ratliff, F. (1965). *Mach Bands: Quantitative Studies on Neural Networks in the Retina*. San Francisco: Holden-Day.

Ratliff, F. (1972). Contour and contrast. *Scientific American, 226*, 91–101.

Shapley, R. M., & Tolhurst, D. J. (1973). Edge detectors in human vision. *Journal of Physiology, 229*, 165–183.

Soranzo, A., Acaster, S., Taroyan, N., & Reidy, J. (2020). Depth plane separation affects both Lightness Contrast and Assimilation. *Frontiers in Psychology, 11*, 2114. https://doi.org/10.3389/fpsyg.2020.02114

Soranzo, A., Galmonte, A., & Agostini, T. (2010). Von Bezold effect reverses under stereoscopic conditions. *Perception, 39*, 592-605. http://dx.doi.org/10.1068/p6462.

Soranzo, A., & Gilchrist, A. (2019). Layer and framework theories of lightness. *Attention, Perception & Psychophysics, 81*(5), 1179-1188. https://doi.org/10.3758/s13414-019-01736-1

Soranzo, A., Lugrin, J. L., & Wilson, C. J. (2013). The effects of belongingness on the Simultaneous Lightness Contrast: A virtual reality study. *Vision Research, 86*, 97–106.

Spehar, B., Gilchrist, A. L., & Arend, L. E. (1995). The critical role of relative luminance relations in White's effect and grating induction. *Vision Research, 35*, 2603–2614.

Spehar, B., & Zaidi, Q. (1997). New configurational effects on perceived contrast and brightness: Second order White's effects. *Perception, 26*, 409–417.

Sullivan, G. D., & Georgeson, M. A. (1977). The missing fundamental illusion: Variation of spatio-temporal characteristics with dark adaptation. *Vision Research, 17*, 977–981.

Wertheimer, M. (1923). Untersuchungen zur Lehre von der Gestalt II [Laws of organization in perceptual forms]. *Psychologische Forschung, 4*, 301–350. Translation published in Ellis, W. (ed.) (1938): A Source Book of Gestalt Psychology, 71-88. London: Routledge & Kegan Paul.

Wilson, H., & Bergen, J. R. (1979). A four mechanism model for threshold spatial vision. *Vision Research, 19*(1), 19–32.

Wolff, W. (1933). Über die kontrasterregende wirkung der transformierten farben [Concerning the contrast-causing effect of transformed colors]. *Psychologische Forschung, 18*, 90–97.

Alessandra Galmonte, b. 1970, is Associate Professor at the Department of Medical, Surgical and Health Sciences at the University of Trieste (Italy). Her main interests range from basic research in the domains of colour perception, perceptual organisation, and movement learning to health and medical psychology, methodology and psychophysics, and to applied domains such as sport psychology, cognitive ergonomics, and usability.
Address: Department of Medical, Surgical and Health Sciences, University of Trieste, c/o ITIS - Via Pascoli, n.31 - 34129 - Trieste (Italy)
E-mail: agalmonte@units.it
ORCID: 0000-0003-2927-8965

Alessandro Soranzo, b. 1967, is currently employed at Sheffield Hallam University as Associate Professor of Cognitive Psychology. His main fields of interest are colour perception, visual attention, experimental aesthetics and research methods.
Address: College of Social Sciences and Arts | Sheffield Hallam University Sheffield | S10 2BP
E-mail: a.soranzo@shu.ac.uk
ORCID: 0000-0002-4445-1968

Mauro Murgia, b. 1982, is a Psychologist and Ph.D. in Neuroscience and Cognitive Sciences. He is a member of the "Perception, Cognition and Movement" research group of the Department of Life Sciences of the University of Trieste. He is interested in movement perception, cognitive training, numerical and spatial cognition, sport psychology, motor rehabilitation. He has conducted his studies in many universities and research institutes in Italy, Spain, Germany, and USA.
Address: Department of Life Sciences, University of Trieste, Via Weiss 21 – Building W – 34100 Trieste (TS), Italy.
E-mail: mmurgia@units.it
ORCID: 0000-0002-8450-1157

Fabrizio Sors, b. 1988, is an Assistant Professor at the Department of Life Sciences of the University of Trieste. He teaches General Psychology and Methodology of Scientific Communication. His research activity is mainly focused on perceptual-cognitive processes related to multisensory stimuli, on the complex movements deriving from these processes, as well as on the effects of social influence on the same processes and movements.
Address: Department of Life Sciences, University of Trieste, Via Weiss 21 – 34100 Trieste, Italy
E-mail: fsors@units.it
ORCID: 0000-0002-3803-1772

Tiziano Agostini, b. in 1961, is a Full Professor at the Department of Life Sciences of the University of Trieste. He teaches Introductory Psychology and Methods of Investigation and Intervention Applied to Sport and Health. He is interested in visual perception, methodology of psychological research, history of psychology, experimental psychology of sport, and cognitive ergonomics. He is the coordinator of the Bachelor's degree in Psychology.
Address: Department of Life Sciences, University of Trieste, Via Weiss 21 – Building W – 34100 Trieste (TS), Italy.
E-mail: agostini@units.it
ORCID: 0000-0003-0105-2999