UNIVERSITY OF CRETE
SCHOOL OF SOCIAL SCIENSES

ELEFTHERNA

SCIENTIFIC JOURNAL
DEPARTMENT OF PSYCHOLOGY

VOLUME VIII
RETHYMNO 2016

Changes in highest luminance of the backgrounds do affect the lightness of targets in Simultaneous Lightness Contrast

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Abstract

The Anchoring theory of lightness account for Simultaneous Lightness Contrast is based on calculations performed within the local groups of the targets with their respective backgrounds. Because the highest luminance is different in those groups, the illusion emerges. However recently Maniatis (2015) has claimed that equalizing the highest luminance in the two groups does not affect the illusion.

We tested this claim by having observers match the lightness of the targets in a standard and 3 variants of the SLC illusion in which we placed lines of different width on the two backgrounds (white stripes on the black background and black stripes on the white).

Our results strongly suggest that changing the highest luminance of the backgrounds in SLC defines the size of the illusion. These results are taken to support the explanation provided by Anchoring Theory.

Keywords: lightness perception, Simultaneous Lightness Contrast, Anchoring theory, grouping, visual illusions

Introduction

Simultaneous Lightness Contrast (SLC) (Figure 1) has been the source of great debate in color vision since the beginning of the previous century. The main reason for this is that SLC violates the (still highly regarded) "constancy hypothesis", according to which equal stimulations in the retina produce equal percepts[32]. Hering (1874/1964)

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[32] For a detailed discussion of this see Gilchrist (2006).

discussed SLC as the best manifestation of the aforementioned doctrine. He forecasted a neural mechanism that was responsible for affecting the two targets in SLC differently, thus causing them to differ in lightness. This mechanism was later shown to be lateral inhibition (Hartline et al., 1956) and all current low-level theories of lightness are rooted in its operation.

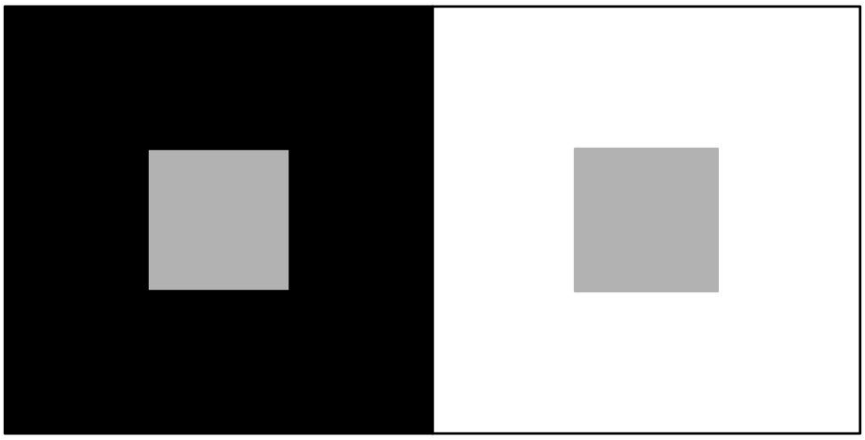

Figure 1: The Simultaneous Lightness Contrast illusion. The square on the black background appears lighter than the one on the white background although both have the same luminance.

The generic explanation of SLC according to these theories is as follows; the receptors corresponding to the gray square on the white background are relatively more inhibited than those corresponding on the gray square on the black. Benary (1924) emphatically contested this claim early on. He designed an illusion in which lateral interactions for the two targets were equal but nevertheless an illusion emerged, probably as a result of gestalt organizational principles (Figure 2). Many followed this line of research and showed that lateral inhibition cannot account for a score of "contrast" illusions (Economou et al., 2015; Adelson, 2000; White, 1981).

Still lateral inhibition was seen as the best explanation for the basic SLC illusion and the rest of the contrast effects that could not be accounted for where deemed to manifest higher order effects on the visual system.

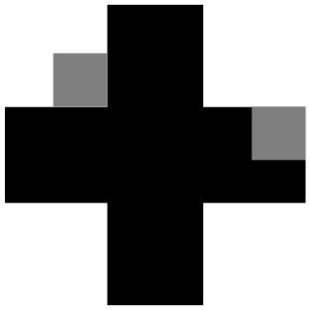

Figure 2: The Benary illusion. Although lateral interactions on the gray squares are equal, the target appearing to rest on the black cross appears lighter than the target appearing to rest on the white background.

Gilchrist and his colleagues (1999) published a theory that was based on several computations performed by the visual system within surface groups following certain rules of gestalt organization. According to this account surfaces are grouped together in groups following traditional gestalt organizational principles. For each group the surface with the highest luminance is axiomatically assigned the value of white. All other surfaces are assigned color values depending on their luminance ratio with the highest in the group.

It is possible that a surface belongs simultaneously to more than one group. Indeed, in most complex scenes this is the case more often than not. It follows that one surface will have as many lightness computations for as many groups as it belongs to. Its final lightness value is an average of all those computations, weighted for group coherence, meaning that computations within stronger groups carry more weight.

This scheme applies to SLC as well. The gray targets belong to their respective backgrounds (local frameworks) but at the same time to the whole display (global framework). Their computations within the global framework come out equal. Both targets stand in a 5:1 luminance ratio with the anchor of this group, which is the white background (highest luminance). So their value is 5 times lower than white, namely middle gray. The target on the white background is also computed locally to be middle gray as the anchor in this local group is also the white background. So the final value of the target on the white background will be middle gray[33]. However the target on the black background is the highest luminance in that group so is automatically computed white. Its final value will be between middle gray and white, but closer to middle gray as this computation comes from a stronger group (more surfaces, larger area).

The anchoring account of SLC has held up pretty well against testing with both novel displays and variations of the SLC (for a full review see Gilchrist, 2006). Recently however Maniatis (2015) showed that placing a small white square inside the black background and a small black square inside the white background does not seem to change the illusion. This display is shown in Figure 3. Maniatis goes on to claim that since changing the highest luminance in the group does not produce a difference in the illusion, the anchoring account of SLC is false.

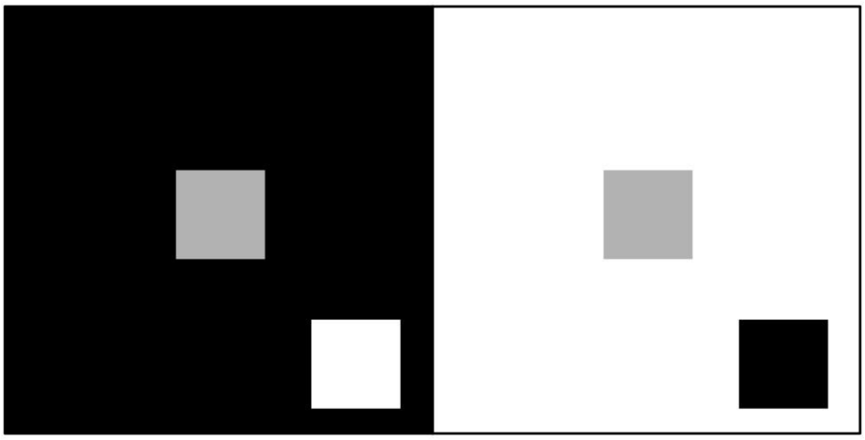

Figure3: Variation of SLC by Maniatis. The claim is that the two targets should look identical now because of the smaller squares inserted in the backgrounds.

[33] Actually the local value of this target is somewhat lower than middle gray due to scaling effects not discussed here. For a more comprehensive view see Economou et al., 2007.

There are several problems with this view and a theoretical response has already been given by Gilchrist (2014). First of all this criticism does not solely concern Anchoring Theory but virtually every lightness theory that exists today, as all should predict some change in the illusion when white area is added to the black background. Second, the criticism is based on accepting a null hypothesis, namely that the illusion does not vary (dependent on the manipulation), instead of producing a positive effect that is not predicted by Anchoring Theory. This is even worse in this case as Maniatis provides no empirical data in support of her observation.

We decided to test Maniatis' central claim directly. We created variants of the SLC illusion shown in Figure 4. We overlaid the black background with white stripes varying in thickness, and the white background with respective black stripes. Doing that should successfully change the highest luminance in the framework with the black background and reduce the illusion. The thickness of the stripes was varied in order to see if changing the area of the highest luminance in the black framework affects the illusion. Anchoring theory clearly predicts that a reduced illusion will be obtained as the thickness of the stripes increases.

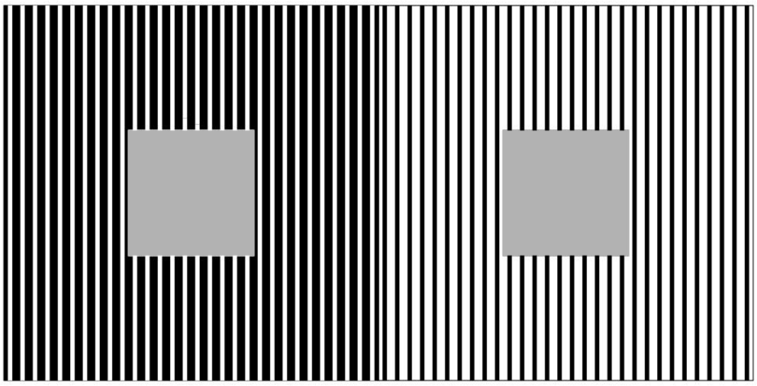

Figure 4: Variation of SLC used in our experiment. The black background is overlaid with thin white stripes and the white background is overlaid with thin black stripes.

Method

Participants.

Forty observers were randomly assigned in one of four groups (between Ss design). The participants were recruited through the Psychology Department's observer pool and were compensated for their participation in the experiment with credit towards a course in cognitive psychology. Participants had normal or corrected to normal vision.

Stimuli.

The generic stimulus used in the experiment is shown in Figure 3. Targets measured 4x4cm and backgrounds 12x12cm. The stripes had a width of 0.75mm, 2mm and 3mm in the respective conditions.

The targets had a luminance of 41.4 cd/m^2 corresponding to a 5.0 on the Munsell scale. The black and white backgrounds had luminance values of 6.53 cd/m^2 and 188.5 cd/m^2 corresponding to Munsell values of 2.0 and 9.5 respectively.

Directly below the illusion a standard Munsell scale with 16 chips of varying luminance was simulated. Room lights were turned off and the only ambient illumination in the room came from the computer screen.

The stimuli were presented on an LG flatron 23 inch monitor powered by an Intel® Core™ i5 computer. Observers viewed the display from a distance of 70cm with their heads resting on a chin rest.

Procedure.

Each observer gave two lightness matches for the two gray squares. The order of the matches was counterbalanced. Observers were instructed that there were no right or wrong answers in this experiment and their unbiased perceptual response was required. There were no time limitations for the match.

Results

All data were analyzed using SPSS v22. Munsell values were transformed into log reflectance units. We subtracted the value of the targets on the white background from the values of the targets on the black background and considered the difference to be the size of the illusion that each observer estimated. Positive numbers mean that the target on the black background was seen lighter and negative numbers mean that the target on the white background was seen lighter. The mean illusion sizes for all conditions are presented in Figure 5.

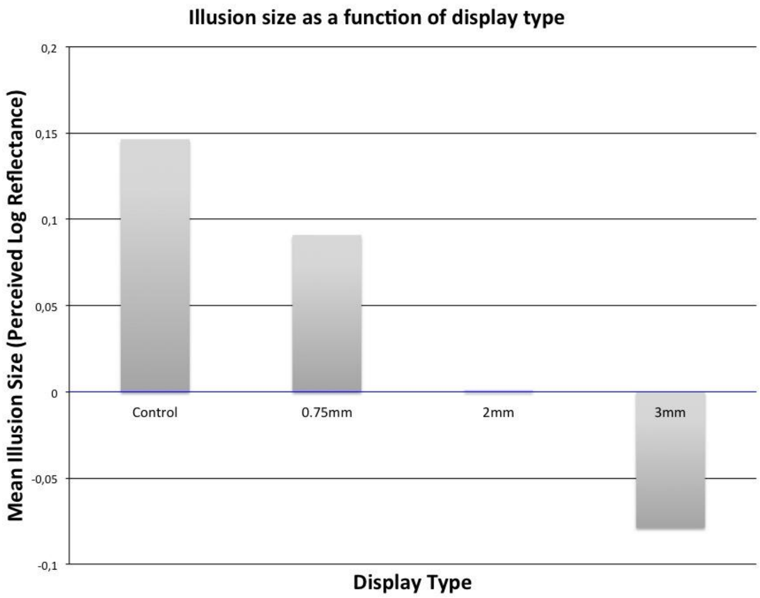

Figure 5: Mean illusion size across the four conditions used in our experiment. As the thickness of the stripes increases, illusion strength decreases. Bars above the line indicate illusions in the regular direction and bars below the line indicate reversed illusions.

We used a simple One-way ANOVA to compare the illusion sizes across conditions. The analysis revealed a significant effect of background type on illusion size $F(3, 36) = 3{,}08$, $p = .04$. Subsequent post-hoc two tailed T-tests revealed significant differences between the standard display and the 3mm display ($p < .01$), and between the 0,75mm display and the 3mm display ($p < .05$). Also the difference between the standard and the 2mm display approached but did not reach significance ($p = .07$). Had we tested with a one tailed T-test this difference would probably be significant as well.

The results show that increasing the thickness of the stripes in our display reduces the strength of the SLC illusion, contrary to Maniatis' claim and in accordance with Anchoring Theory predictions.

Discussion

The results presented here cannot be misinterpreted. They clearly show that changing the highest luminance relationships in SLC affects the size and indeed even the direction of the illusion. This strongly supports Anchoring Theory against the Maniatis critique. When the backgrounds in SLC are overlaid with the thinnest stripes some reduction in the effect is observed albeit not statistically significant. Thickening the stripes further however produces a reduced effect at 2mm (almost zero illusion) and a slight reversed effect with the 3mm lines.

This was not surprising as there have already been empirical data in accordance with ours. Economou et al. (2007) had created a variation of SLC to test the belongingness relationships in the illusion and they found that placing rings around the targets in SLC that had opposite colors from the backgrounds reverses the illusion. The same authors systematically varied several grouping parameters in SLC using their Reverse Contrast illusion (Economou et al., 2015) and found strong dependence of the size and direction of the illusion to grouping relationships in the display.

So why don't we see a reduced effect in the Maniatis display? While her display is not detrimental to the anchoring account, the aforementioned question still warrants an answer. First of all let us mention that her display is essentially a de-articulated variant of the Dungeon illusion created by Bressan (2006) and shown in Figure 6. In that display adding more squares around the target reverses the illusion as predicted by anchoring theory. If one combines this with the results from the Reverse Contrast study by Economou et al., will realize that there are several possible reasons why there is not an observable reduction in the SLC illusion with the Maniatis display.

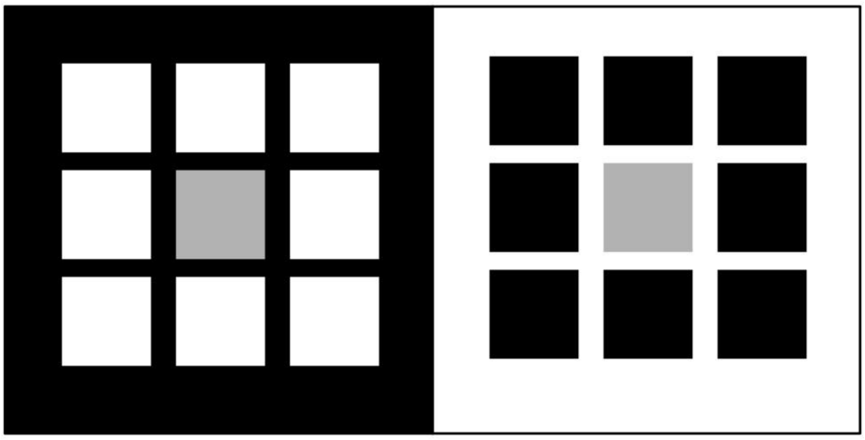

Figure 6: Bressan's Dungeon illusion. A reversed contrast effect caused by the squares that group with the gray targets.

First area might be low, so that the small white square in her display cannot anchor the whole group. Second, articulation is low. Third, grouping with the target is weak. Let us examine those in turn.

Area is central to Anchoring theory and effects of area on lightness have been presented regularly in literature (Guclu, & Farell, 2005; Bonato & Gilchrist, 1999; Diamond, 1953). In our display, increasing the area of the stripes seems to be related with observable illusion changes. So it is possible that making the squares larger in the Maniatis display would produce a reduced effect.

Articulation has been also shown to exert strong influence on lightness (Radonjic & Gilchrist, 2013; Zdravkovic & Gilchrist, 2010; Bressan & Actis-Grosso, 2006; Giotaki et al., 2005; Gilchrist & Annan, 2002; Adelson, 2000). In their Reverse Contrast study Economou et al. varied the articulation of the context bars in the illusion and observed a decrease in illusion strength. In their most de-articulated version with just two context bars for each target (which is also comparable with the Maniatis display) they obtained essentially a zero illusion, exactly as Maniatis claims should be the case with her display. So adding a couple of more squares in her display might also produce a reduction in the illusion.

Grouping between the two squares in the Maniatis display relies solely on one principle, size similarity (note that the squares in her original display do not have the same size with the targets). All the other grouping principles do not exist in her display. Proximity is low, there is no good continuation or border alignment and shape similarity is not unique to the targets and the small squares but is shared by the backgrounds as well. All these are critical in order to group two surfaces together. And in order for a surface to be affected (lightness-wise) by the luminance of another surface, they have to share some degree of belongingness.

All these three factors might contribute to the null result with the Maniatis display, however this study cannot enlighten us with respect to which of the three factors is responsible or the degree of their contribution to the effect. At this point we should also remind that there are no data published on Maniatis' display. Although we consider it improbable to find an effect a proper study with her original display should be conducted in the future.

A final point concerns the low-level account of our results. We did not create this study to test between theories of lightness perception. As we mentioned in the introduction we believe all theories would predict the pattern of results obtained in our study. However we did not test our displays on simulations of theories like ODOG (Blakeslee & McCourt, 2004) so we cannot argue strongly on this point.

In conclusion, we show that adding white stripes on the black background and black stripes on the white background of the SLC illusion affects the strength and its direction, contrary to the critique by Maniatis based on her display. Our study strongly indicates that anchoring within perceptual groups is a valid model of Simultaneous Lightness Contrast.

Acknowledgments: We would like to thank Alan Gilchrist and Suncica Zdravkovic for our discussions on the display used in the experiment and Andreas Kastellakis for providing very helpful input on the manuscript.

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Αλλαγές στην υψηλότερη φωτεινότητα των φόντων στην πλάνη της Ταυτόχρονης Χρωματικής Αντίθεσης επηρεάζουν το χρώμα των στόχων.

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Περίληψη

Η ερμηνεία της Θεωρίας του Σταθερού σημείου για την πλάνη της ταυτόχρονης χρωματικής αντίθεσης βασίζεται σε χρωματικούς υπολογισμούς που πραγματοποιούνται σε τοπικό επίπεδο ανάμεσα στους στόχους και το φόντο τους. Η πλάνη δημιουργείται διότι η επιφάνεια με την υψηλότερη φωτεινότητα είναι διαφορετική ανάμεσα στις δύο αυτές ομάδες επιφανειών. Ωστόσο πρόσφατα η Μανιάτη (2015) υποστήριξε ότι η εξισορρόπηση των επιφανειών με την υψηλότερη φωτεινότητα στα δύο πεδία δεν επηρεάζει την πλάνη.

Ελέγξαμε αυτόν τον ισχυρισμό με ένα πείραμα όπου παρατηρητές ταύτισαν χρωματικά τις επιφάνειες στόχους της πλάνης στην κλασική της μορφή και σε τρεις παραλλαγές στις οποίες τοποθετήσαμε ένα πλέγμα κάθετων γραμμών (που είχαν διαφορετικό πλάτος σε κάθε συνθήκη) σε κάθε φόντο (λευκές γραμμές στο μαύρο φόντο και μαύρες στο λευκό).

Τα αποτελέσματά μας ξεκάθαρα δείχνουν ότι τυχόν αλλαγές στις υψηλότερες φωτεινότητες των πεδίων στην ταυτόχρονη χρωματική αντίθεση καθορίζουν το μέγεθος της πλάνης. Τα αποτελέσματα αυτά είναι απολύτως συμβατά με την ερμηνεία της Θεωρίας του Σταθερού σημείου.

Λέξεις κλειδιά: αντίληψη ουδέτερων χρωμάτων, Ταυτόχρονη Χρωματική Αντίθεση, θεωρία του Σταθερού Σημείου, ομαδοποίηση, οπτικές πλάνες.

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