THE EFFECT OF NON-ADJACENT LUMINANCE GRADIENTS ON SIMULTANEOUS LIGHTNESS CONTRAST

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Abstract

In this work we revisit a phenomenon presented by Agostini & Galmonte (2002), who showed an enhanced effect of simultaneous lightness contrast (SLC) by embedding targets within the glare effect and its photometric negative (Zavagno 1999). In our study we employed 3 manipulations of SLC with targets surrounded by non-adjacent positive luminance ramps (these determine the glare and dark hole effects), negative ramps (the vector of the gradient is inverted 180 deg), and solid black (white background) and white (black background) squares. Configurations with positive ramps show a strong contrast enhancement on both backgrounds with respect to classic SLC (data collected in a similar setup but with different subjects), in line with findings reported by Agostini & Galmonte. The magnitude of the effect is more than halved with negative gradients and solid squares. Findings are consistent with the hypothesis that luminance gradients are relevant information for brightness perception (illumination, luminosity).

The phenomenon dubbed as simultaneous lightness (or brightness) contrast (from now on SLC) is somewhat of a benchmark test for theories that intend to explain how we perceive achromatic colours, i.e. those colours that belong to an ideal grey scale ranging from black to white. In its classic textbook form (Figure 1a), the phenomenon consists of two adjacent squares, one black the other white, which serve as backgrounds (or inducing fields) to two smaller grey squares (from now on targets) that are photometrically equal; in such a configuration, the target seen against the black background looks somewhat lighter than the target seen against the white background.

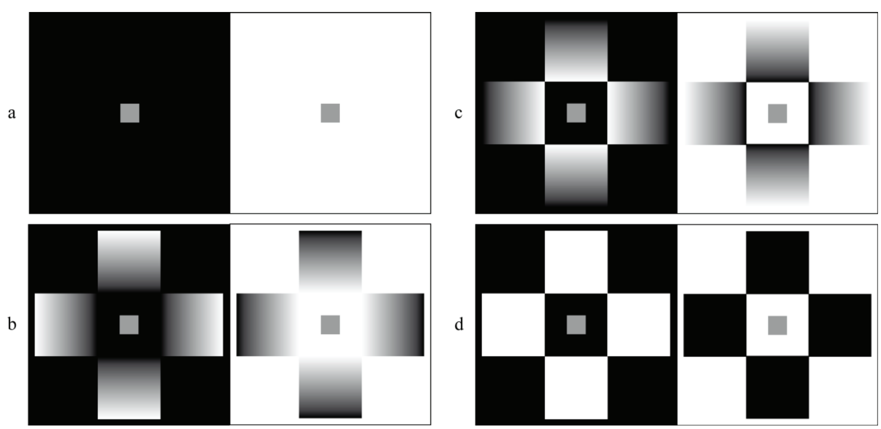

Fig. 1. a) Classic simultaneous lightness contrast; b) SLC with positive ramps; c) SLC with negative ramps; d) SLC with solid squares.

While SLC has been used and studied in many ways over the past 100 years, here we consider a configuration proposed by Agostini and Galmonte (2002), who combined the classic SLC configuration with the glare effect and its photometric negative (Zavagno 1999). They reported that targets equal in luminance surrounded by luminance ramps (as in Figure 1b) appear more different in lightness than similar targets surrounded by solid grey squares. Our experimental study stems from their research.

In particular, we wanted to verify how luminance ramps affected SLC by employing three types of modified SLC displays: with positive ramps (Figure 1b), with negative ramps (Figure 1c), and with flanking solid squares (Figure 1d). We define as positive ramps those linear luminance gradients in which the final luminance value facing a target is equivalent to the luminance of the target's background. Positive ramps determine relevant modifications in the brightness appearance of backgrounds (Zavagno 1999), inducing an impression of luminosity with white backgrounds (i.e. the glare effect), and a darkness enhancement with black backgrounds. Negative ramps are luminance ramps rotated by 180° with respect to positive ramps.

Method

Because many psychology students, i.e. our subject pool, are familiar with classic SLC, it is not rare to find participants reporting no contrast effect when they are presented with the illusion. This is a cognitive bias that goes by the name of "stimulus error" (Kanizsa 1979), according to which a participant to an experiment may want to report what he/she knows or assumes about the physical properties of a stimulus rather than what is actually perceived. In our attempt to avoid, or at least reduce, the occurrence of such a bias, we employed two reflectance values for our targets instead of one as usual. Hence in some configurations targets had the same reflectance, in others they differed in reflectance. This method was already used by Zavagno et al. (2011) and proved to be valid.

Participants

Participants were 35 students (12 male; age range 18-29) from the Psychology Department of the University of Milano-Bicocca. Participants were naïve to the purpose of the experiment.

Material

Stimuli consisted in modified SLC paper displays similar to those depicted in Figure 1b-d. Black and white backgrounds were squares (9.9 deg side); square targets (1 deg side) were inserted at the centre of each background in a square region (1.6 deg side) delimited by four squares (1.6 deg side) that could be either positive ramps, negative ramps, or solid black (on a white background) and solid white (on a black background) (from here on "solid ramps"). The luminance values of the white and the black backgrounds were respectively 2400 and 68.7 cd/m^2. The luminance of positive and negative ramps ranged from 68.7 to 2400 cd/m^2; the luminance of solid white and solid black squares measured respectively 2400 and 68.7 cd/m^2. Targets were cut from Neutral Value Munsell papers 6.0 (reflectance 30%; luminance 900 cd/m^2) and 6.5 (reflectance 36.2%; luminance 1090 cd/m^2). A modified SLC configuration could comprise two targets equal in reflectance (configurations *same*) or two targets different in reflectance (configurations *different*).

Summarizing, variables where: Background (*B*: black, white) × Ramps (*R*: positive, negative, solid) × Target (*T*: 6.0, 6.5) × Target Combination (*TC*: same, different). The combination of all factors determined 24 target-ramp-background combinations, which lead to 12 configurations structurally similar to those depicted in Figure 1b-d.

We employed a matching method with an achromatic Munsell scale, often used in lightness studies. The matching scale consisted in a 16 step Neutral Value Munsell scale ranging from 2.0 to 9.5 in Munsell values, placed on top of a black-white chequered background. Each step of the scale measured 3.01×1.1 deg; the chequered background measured 5.6×19.9 deg, with square checks measuring 0.78 deg per side. Munsell notations were placed under each step on a white stripe 0.4 deg below the row of Munsell steps.

Configurations were viewed one at a time, and were positioned 6 deg above the Munsell scale used for the lightness matching task. Stimuli and the scale were illuminated by the same spotlight (Spotlight Mini Profile ME with 20° objective, 250 W, colour temperature 5900 K), which was the only source of illumination inside the laboratory during the experiment. However, due to the geometry of the spotlight projection, targets and corresponding Munsell values on the scale were different in luminance (scale values: 6.0 = 791 cd/m^2; 6.5 = 980 cd/m^2). The resulting luminance differences between SLC targets and their corresponding Munsell values on the matching scale is, nevertheless, a negligible factor in this experiment because constant with all configurations.

Procedure

With factor *T* as a nuisance variable, we conducted a within subject experiment, while traditionally similar experiments are most often between subjects designs (e.g. Agostini & Galmonte, 2002; Economou, Zdravkovic, & Gilchrist, 2007) to avoid “learning” effects.

The participant entered the laboratory illuminated only by the spotlight, and was seated at a distance of 114 cm. Viewing distance was secured by a chinrest. The participant was informed that the task consisted in finding the grey match of each square target in a configuration. If a perfect match could not be found for a target, the participant was instructed to indicate the Munsell step that was closest to its grey appearance. The modified SLC displays were presented in random order once, with the black background either on the left or on the right side of the display. The position of the Munsell scale was instead fixed starting with 2.0 on the left side. There were no time constraints, however participants were instructed to perform matches as quickly as possible. When matches for both targets of one configuration were performed, the experimenter asked participants to close their eyes while a new configuration was positioned. The experiment lasted in average 20 minutes.

Results

Mean matching results for all targets are plotted in Figure 2. In all the analysis that follow, factors *B* and *T* always induced significant effects ($p<.0001$), as expected; we will therefore omit reporting such main effects when we illustrate the results. A 2×3×2×2 ($B\times R\times TC\times T$) ANOVA for repeated measures was conducted on the data; factors Ramp (*R*) and Target Combination (*TC*) produced both significant main effects: *R*, $F_{2,68}=7.31$, $p<.005$; *TC*, $F_{1,34}=7.52$, $p<.01$. Considering two way interactions, only $B\times R$ and $B\times TC$ were significant: respectively, $F_{2,68}=138$, $p<.0001$; $F_{1,34}=7.23$, $p<.05$. A series of one sample t-tests for all mean matches were carried out to verify in which cases mean matches were not statistically distinguishable from the actual reflectance of the target: a star in Figure 2 indicates that a matched reflectance was not statistically distinguishable from its actual reflectance on the Munsell scale.

To better visualize our data, we also grouped them on the basis of factors *TC* and *T*. This determines four groups of data: same targets 6.0, same targets 6.5, and two groups for different targets. Mean matching values for these data groups are graphed as matched reflectance in Figure 3; each graph also shows data for classic SLC displays collected within a different empirical study, however conducted with the same set-up employed here, including the use of targets 6.0 and 6.5, and *TC* as nuance variable (Zavagno et al., 2011).

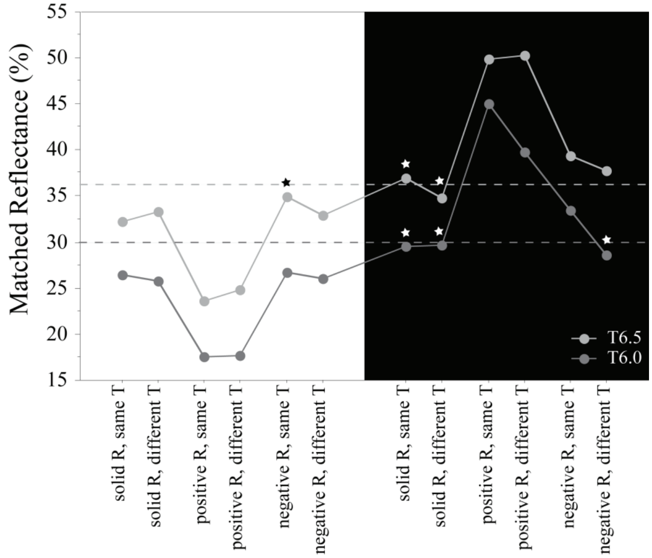

Fig. 2. Mean matching results plotted for each target in terms of matched reflectance. The split white-black background reflects the white-black backgrounds of the configurations. R stands for ramps (positive, negative, or solid, see Figure 1b-d). Same T stands for a configuration in which targets are photometrically equal. Dashed lines indicate the actual reflectance for targets 6.0 and 6.5. Stars above data points indicate mean matches not statistically distinguishable from actual target values.

In the ANOVA we conducted on all data, factor *TC* was found to produce significant effects. This came as a little surprise, since in experiments with 'classic' SLC displays (Figure 1a; data on the left side of the graphs in Figure 3), which purpose was to study the robustness of Achromatic Munsell scales with reference to background changes (Zavagno et al. 2011), the same experimental set-up was used and *TC* did not determine significant main effects. From Figure 2, however, the effects seem to be confined to targets 6.0 seen against a black background in same-different configurations. To test this intuition we ran two separate 2x3x2 ($B \times R \times TC$) repeated measure ANOVA's on the data distinguished by factor *T*. The analysis on data for T6.0 revealed a significant effect for *TC* ($F_{1,\ 34}=10.77$, $p<.005$), but not for *R* ($p=.098$), while the interactions $B \times R$ and $B \times TC$ are both significant (respectively $F_{2,68}=129.8$, $p<.0001$, and $F_{1,34}=8.43$, $p<.01$). The analysis on data for T6.5 show, instead, opposite results: factor *TC* did not induce significant effects ($p=.4$), while factor *R* did ($F_{2,68}=7.58$, $p<.005$); only the interaction $B \times R$ induced significant effects: $F_{2,68}=94.3$, $p<.0001$. Paired t-tests were therefore conducted between targets of identical reflectance, background and ramp, but different for *TC*. With reference to target 6.0, only means for targets on black backgrounds with positive and with negative ramps were statistically different: respectively $t_{34}=2.53$, $p<.05$ and $t_{34}=3.31$, $p<.005$ (see the dark grey curve on the black side of Figure 2). With reference to target 6.5, none of the paired t-tests revealed significant differences.

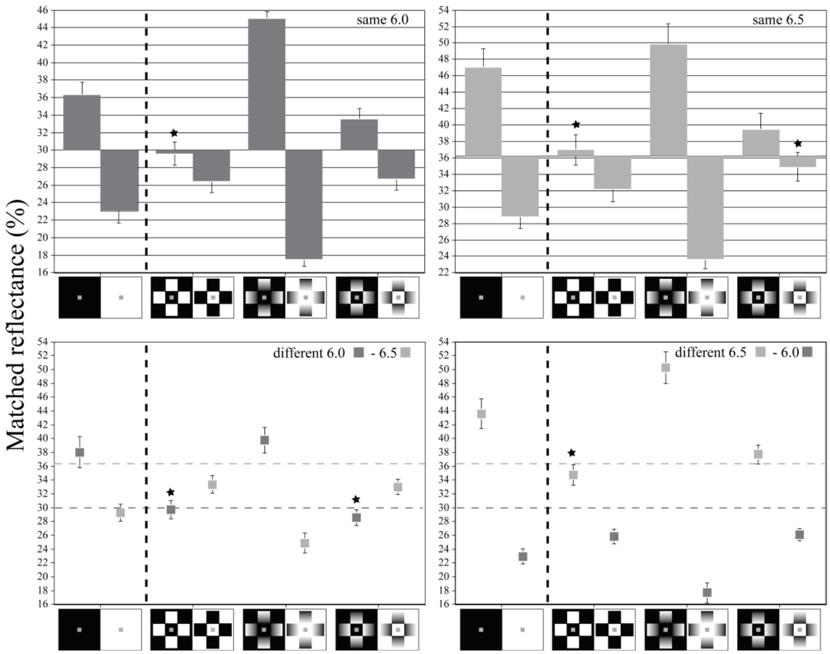

Fig. 3. Results grouped by factor *TC*. Top: results for configurations in which targets shared the same reflectance. Bottom: results for configurations with targets of different reflectance; dashed lines stand for the actual reflectance of targets 6.0 and 6.5. Stars indicate a non-significant difference between matched and actual reflectance (one-sample t-tests). On the left of each graph, separated by a vertical dashed line, are represented data for classic SLC collected within another study (16 observers) but with the same experimental set-up (Zavagno et al., 2011): such data is only used as baseline to understand how SLC increases or decreases in relation to the type of ramp.

On the two groups of data 'same targets' (Figure 3, top graphs) we conducted 3×2 (*R*×*B*) ANOVAs for repeated measures. For T6.0, the ANOVA showed that factor *R* induced significant effects ($F_{2,68}$=3.67, p<.05); also the interaction *R*×*B* was significant (F2, 68=109.6, p<.00001). For T6.5, the ANOVA showed similar results: *R*, $F_{2,68}$=3.13, p<.05; *R*×*B*, $F_{2,68}$=65.55, p<.00001. Finally, paired t-tests were carried out to compare all means respectively for T 6.0 and T6.5 within all same configurations. With regards to T6.0, only in two cases matches for targets were found to be statistically undistinguishable: *white B+solid R* and *white B+negative R* (p=.85), and *black B+solid R* and *white B+negative R* (p=.11). The same pattern of results was found with paired t-tests for T6.5: *white B+solid R* and *white B+negative R* (p=.1), and *black B+solid R* and *white B+negative R* (p=.36).

By comparing our data with the data collected by Zavagno et al. (2011) for classic SLC, we find that with configurations TC=same with T6.0, the magnitude of the effects measured as the mean distance expressed in Munsell units between target matches are approximately the following: 1.25 for classic SLC (Zavagno et al., 2011); 0.25 for solid ramps; 2.5 for positive ramps; 0.5 for negative ramps. With reference to configurations with TC=same with T6.5, the magnitudes of the effects are: 1.25 for classic SLC; 0.25 for solid ramps; 2.25 for positive ramps; 0.25 for negative ramps.

Discussion

By looking at the graphs displayed in Figure 3, a first consideration is that what ever you put inside a SLC display appears to affect the way targets appear, even if the additional elements are not adjacent to the target. In reality, for what we know, the story is a bit more complex. For instance, though global background sizes were equivalent across experiments, our cross configurations seem to limit a target's background to less than 1/6 of the total background. However, in spite of the literature that shows the effect of inducing field size on a target's lightness (the bigger the field, the stronger the induction: Diamond 1955), a target's lightness seems to depend more on the photometric characteristics of surrounding areas than on background size per se. When targets are surrounded by non-contiguous positive luminance ramps, the difference between targets is almost double the difference found with classic SLC. With negative ramps, instead, the effect of simultaneous lightness contrast is about half the effect found with classic SLC. In both cases, increments and decrements in the magnitude of simultaneous contrast are about equivalent for both backgrounds. The story is slightly different when it comes to the 'solid ramps' we used as control stimuli. These configurations share a common photometric feature with negative ramps: the contrast ratio between the edges of the squares facing the target and the target's background are the same. Nevertheless, on black backgrounds the contrast effect of the background on the target is statistically null, for both configurations same and different. This finding is predicted by the Anchoring theory (Economou et al., 1999), according to which the white squares surrounding the targets background become the anchor for lightness scaling, thus dethroning the target from its role of anchor in the local framework. However, it is not clear what the same theory would predict for configurations with luminance ramps (positive or negative). From our data, such ramps do not seem to be lightness features that can affect hypothesized anchoring processes. We believe, instead, that luminance ramps are key information for brightness perception (Zavagno & Daneyko 2008; Zavagno, Daneyko & Sakurai 2011), which in turn affects lightness computations. For instance, with negative ramps on the white background, luminance ramps would inform about a depression in illumination over the target; this in turn appears brighter than it does in classic SLC displays, thus reducing the contrast effect.

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