APPARENT TRANSPARENCY IN MOTION: VISUAL PHANTOMS AND THE ROSENBACH EFFECT.

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Abstract

When a stripe is partially overlapping a figure of different colour, it is possible to see the stripe as apparently transparent (i.e. the Rosenbach effect). This effect has also been dubbed phantom effect and referred to other effects of "anomalous transparency". An experiment is presented, aimed at testing the role of motion of the occluding surface on the perception of transparency in the Rosenbach effect. Results show that the perception of transparency is enhanced when the occluding surface is moving; a possible explanation is suggested, based on simultaneous lightness contrast.

Physically transparent surfaces allow the transmission of a certain amount of light rays through them. However, as Kanizsa (1955) underlined, physical transparency is neither a sufficient nor a necessary condition for perceptual transparency. The crucial question for understanding perceived transparency has been answered by Metelli (1970, 1974, 1985), who, with its *episcotister* model, explained how the visual system assigns surface properties (such as transmittance and lightness) to a transparent layer when such decomposition (i.e. transparency) occurs. This model was developed within a specific physical context that elicits a percept of transparency. Metelli used the model to motivate a perceptual theory of transparency that identified perceptual scission with the inverse of the equations derived in this physical model. In addition to these conditions on reflectance values, Metelli (1974) and Kanizsa (1979) also pointed to the role of figural conditions in the perception of transparency. Broadly, these may be classified into two kinds: The first (dubbed by Kanizsa "topological" condition) requires continuity of the contour on the underlying bipartite surface, while the second (called figural condition) requires continuity of the boundary of the putative transparent layer—at the locations where these two sets of contours intersect.

Thus, according to Kanizsa (1980), there should be three conditions for transparency to be perceived: (i) the "topological condition" (Figure 1B); (ii) the figural condition (Figure 1 C and D); (iii) the "chromatical" condition (defined by Metelli's model).

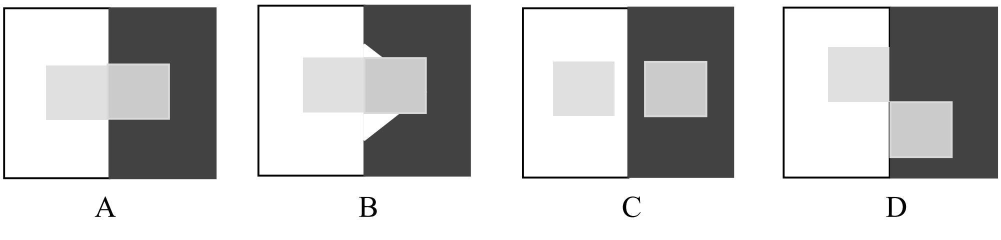


Figure 1 Figural conditions for transparency by Metelli and Kanizsa. (a) Figural conditions are optimal. (b) The contour dividing the bipartite background must not undergo discontinuous jumps at locations where it meets the boundary of the putative transparent layer. (c) and (d) The two gray regions must unite into a coherent surface: if they are separated (c) or shifted vertically relative to each other (d) resulting in discontinuities on the boundary of the putative filter, the percept of transparency is again weakened.

The perception of transparency has intrigued visual researchers since Helmholtz (1866/1962), who spoke of seeing one color through another, and Koffka (1935), who referred to the problem as one of *scission,* or splitting image intensities into multiple contributions. According to Koffka transparency is one of the most striking examples of scission, which is basically the problem of understanding how the visual system decompose a single intensity value at each location on the retina in the pattern of light intensities from separate contributions (such as illumination, shadows and depth) responsible for the image data. The problem of scission is better understood with chromatically homogeneous surfaces: in Figure 2, even if the figure is that of a single form, the observer sees two rectangles, alternatively one in front of the other. With chromatically homogeneous surfaces the problem of scission has been addressed as a problem of depth stratification (Petter, 1956), that is the problem of identifying the conditions under which one of the two *perceived* surfaces is perceived in front of the other, and why.

These conditions have been identified by Petter (1956), who described several rules for depth stratification with chromatically homogeneous surfaces: the collection of these rules has been later dubbed as "Petter's law" (for an extensive description of the law and of its validity for perceptual transparency see Masin, 2002). One of these rules is particularly relevant here: according to the so called "motion rule", if one of the two rectangles in Figure 2 is moving, this rectangle will be always perceived in front of the other.

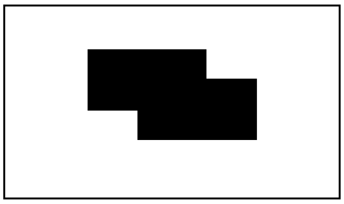


Figure 2 The problem of scission with chromatically homogeneous surfaces becomes the problem of depth stratification.

Anomalous transparencies and the family of phantoms effects

According to the general theory for the perception of transparency we perceive transparency when certain conditions are satisfied, regardless the fact that the perceived surfaces are physically transparent or not. However, there are some situations in which transparency is perceived when there are no such conditions: these situations could be considered as "anomalous" transparency.

One of the most intriguing effects of anomalous transparency is the Rosenbach effect: When a stripe is partially overlapping a figure of different color, it is possible to see the stripe as apparently transparent (i.e. the border of the figure occluded by the stripe is visible in transparency behind the stripe itself, Rosenbach, 1902). This phenomenal transparency is enhanced by the motion of the occluded surface.

The Rosenbach effect has been re-discovered several times: Tynan e Sekuler (1975) dubbed it "moving visual phantoms", underlying in this way the strong dependence of the effect on the motion of the occluding surface. Genter and Weisstein (1981) obtained the same effect of anomalous transparency with a "flickering phantoms" and Gyoba (1983) rediscovered the effect in a display such as the one reported in Figure 3A-B; even though Gyoba was aware of the Rosenbach effect, he considered this phenomenon as an example of visual phantoms: being not dependent on motion, he dubbed the phenomenon "photopic stationary phantom illusion" as opposed not only to moving phantoms, but also to scotopic stationary phantom (Figure 3C). Photopic stationary phantom has been analyzed in two following papers by Kitaoka, Gyoba, Sakurai e Kawabata (1999, 2001), where it is discussed in light of depth stratification (being dependent on two Petter's rules, i.e. (i) the length of intersecting borders and (ii) the relative dimensions of the grid and of the horizontal band) and of lightness contrast and assimilation: in this perspective the "brightness grating induction" (McCourt, 1982, Figure 3D) is discussed as

another example of the “big family” of phantoms effects.
The Rosenbach effect has been re-discovered again by Zanforlin (2003) and Uras, Actis-Grosso and Vicario (2008), in two independent researches focused on motion. Zanforlin (2003) has suggested a possible explanation for the effect, based on figure-ground distinction as an additional rule to Musatti’s (1953) minimum principle. Uras et al. (2008) observed that the motion of the ***occluding*** surface apparently strengthens the effect, and underlined that this observation is opposite to the effect of motion often reported in the literature (e.g. Tynan e Sekuler, 1975).

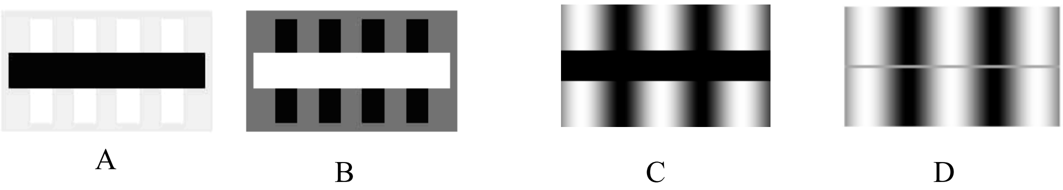


Figure 3. The photopic (A and B) and scotopic stationary phantoms, and the brightness grating induction (D).

The fact that the Rosenbach effect is stronger when the ***occluded*** surface is moving, as often reported, is in agreement with the motion rule reported above (Petter, 1956): the motion of the occluded surfaces “brings” it above the occluding surface, thus facilitating the perception of the occluded margins through the transparency of the occluding surface. In contrast, the motion of the occluding surface should not influence the perception of its transparency. The experiment here reported is aimed at testing this observation.

The Experiment

Subjects. Twelve subjects (six females, average age 28.6) volunteered for the experiment. They had normal or corrected-to-normal vision, and were naïve as to the purpose of the research.
Stimuli. Stimuli were created by and presenting on a notebook Packard Bell Easy Note S4930 equipped with a 15.4-in. color monitor (WXGA with a resolution of 1280 x 800 pixel). Stimuli were created by modifying – according to the experimental factors described below - the following animation (see Figure 5): a rectangle (2.3 x 1.2 cm) was moving on a background divided in three sections (i.e. A, B and C, see Figure 5). The luminance value of section B was different (either darker or lighter, see figure 6) from the luminance value of Sections A and C. The rectangle, which appeared at 1 cm from the screen border, started to move from left to right at its appearance. The trajectory length was 22.4 cm, and the rectangle disappeared while moving. The speed of motion was an experimental factor (see below).

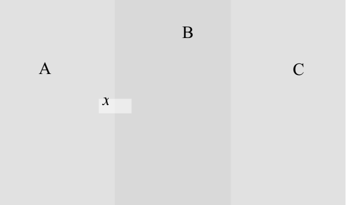


Figure 5 One of the 48 stimuli. The background is divided in three sections: A) left area, where the rectangle appears while moving; B) central band or “screen”; C) right area, where the rectangle *x* disappears while moving.

Experimental factors were:
A. Dynamicity (3 levels: fast, slow and static). This factor is crucial for testing our hypothesis (i.e. motion of the occluding surfaces enhances the perception of transparency). Stimuli were

presented both as animations and as simple static images. The images were created with the 120th frame of the animation, that is the frame were the area of the moving rectangle was half on the background and half on the central band, as in Figure 5. Furthermore, in the animations the rectangle could move with one of two different velocities: (a) 3.7 cm/s ("slow") or (b) 12.4 cm/s ("fast").

B. Lightness Contrast (two levels: "high" vs. "low"). To generate stimuli six different shades of grey were used, whose luminance was respectively 11.43 cd/m2 (white), 11.26, 9.34, 1.32 and 0.30 (black) cd/m2. All luminances were measured with a Minolta Luminance Meter LS100 photometer. By combining these grey values, four different situations were obtained (see Figure 6): two with a "low" lightness contrast and two with a "high" lightness contrast. Lightness contrast, calculated using Weber (1834) formula (i.e $\Delta L/L_b$, where ΔL is the difference in luminance between the moving rectangle and area B and L_b is the luminance of the background) was 0.02, 0.22, -1 and 1 for each situation respectively.

C. Lightness Polarity (two levels: positive vs. negative). In Figure 6 the four experimental displays, sorted by lightness contrast and polarity, are shown. Lightness polarity is defined as negative when the background (i.e Areas A and C in Figure 5) is lighter than the central band (i.e Area B in Figure 5) and as positive when the background is darker than the central band.

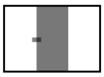
	Negative polarity	**Positive polarity**
"Low" contrast		
"High" contrast		

Figure 6. The four possible combinations of lightness contrast and polarity.

D. Transparency (4 levels, from transparent to opaque). The moving rectangle could assume one out of four different levels of physical transparency. This choice was made for two reasons: (i) asking participants to give a judgment on perceived transparency only to surfaces which are opaque in fact, could give raise to some sort of bias: we hope in this way to prevent participants from realizing the aim of the experiment; (ii) we wanted to investigate whether lightness contrast and lightness polarity interact with physical/perceived transparency. We then assigned to the moving rectangle different levels of α, where α is an index of transparency given by the software Flash MX 2004. This index could assume a value comprised between a minimum of 0 (totally transparent and therefore invisible) to a maximum of 100 (totally opaque): in our stimuli this value ranged from 25 to 100 with steps of 25.

Thus, experimental design was: Dynamicity (3 levels) x Lightness Contrast (2 levels) x Lightness Polarity (2 levels) x Transparency (4 levels), for a total of 48 stimuli. Each stimulus had two repetitions, for a total of 96 trials, randomized between subjects.

Procedure. Participants sat in a dimly lit room facing the computer screen 60 cm in front of the monitor. Before starting the experiment, participants were presented with two animations, where the moving rectangle was physically transparent (α=25) and physically opaque (α=100) respectively. Instructions were referring to the transparency of the moving rectangle, asking participant to judge, on a seven points Likert scale (1 for opaque and 7 for transparent) the perceptual transparency of the rectangle. Then the experiment starts: participants were individually tested and responded verbally; no time restriction was imposed for giving the response: the animations were shown in loop and only after the response was given the experimenter started the next trial. Each session lasted approximately 50 minutes.

Results. A repeated measures Analysis of Variance (ANOVA) 3x2x2x4x2 (Dynamicity x Contrast x Polarity x Transparency x Repetition) revealed a main significant effect of Dynamicity (F (2,22) = 3.7; $p < 0.05$), Contrast (F (1,11) = 127; $p < 0.0001$), and Transparency (F (3,33) = 235.67; $p < 0.0001$). Furthermore, only the following interactions were significant: dynamicity x contrast (F (2, 22) = 3.83; $p < 0.05$), dynamicity x polarity (F (2, 22) = 4.38; $p < 0.05$), dynamicity x transparency (F (6, 66) = 5.51; $p < 0.001$) and contrast x transparency (F (3, 33) = 89.88; $p<0.0001$).
As expected, scores for perceptual transparency are higher for animations than for static images, and for slow animations as compared with fast animations. Furthermore, perceived transparency was higher for high lightness contrast. However, by limiting the present discussion to the situations, which are not physically transparent (α values 75 e 100), another ANOVA 3x2x2x2x2 on these situations has been conducted. Here the significant factors are Dynamicity (F (2,10)= 6.5; $p <0.05$), Contrast (F (1,11) = 141; $p <0.0001$), and Transparency (F (1,11) = 433.78; $p<0.0001$). Only the following interactions were significant: dynamicity x contrast (F (2, 10) = 7.47; $p<0.05$), dynamicity x polarity (F (2, 22) = 5.92; $p<0.01$), dynamicity x transparency (F (2, 22) = 4.39; $p<0.05$) and contrast x transparency (F (1, 11) = 137.62; $p <0.0001$).
On each stimulus a one sample t-test was performed, to verify whether the mean score is different from 1 (which in the Likert scale was corresponding to an area perceived as opaque). Six stimuli were not perceived as transparent (all ts > 0.05) and were the ones with high contrast and $\alpha = 100$. This is a first result, which is in agreement with both Kitaoka et al. (2001) and Zanforlin (2003): with a high lightness contrast between the three areas, the effect of anomalous transparency disappears. However, it is interesting to notice that with that situations in which the α value was "almost" opaque (i.e. 75) and lightness contrast is low, the perceived transparency is not significantly changing, whereas the situations with an α value of 75 and high lightness contrast are perceived as extremely transparent. This implies that lightness contrast has a different role on the situations in which physical transparency is weak (and in this case a high contrast facilitates the perception of transparency) as compared to the situation in which there is no physical transparency but the perceptual outcome is that of transparency (and in this case a low contrast facilitates the perception of transparency).

Discussion

Results confirmed the observation reported in Uras et al. (2008): the motion of the occluded surface enhances the perception of its transparency. The effect of lightness contrast and polarity here reported is in agreement with both Kitaoka et al. (1999, 2001) and Zanforlin (2003). We suggest an explanation for these results based on three factors (i) the figural condition by Kanizsa; (ii) simultaneous lightness contrast and (iii) motion as a "factor of integration". In fact, according to the figural condition, the putative transparent layer should be perceived as a single surface. In contrast, for simultaneous lightness contrast, the lightness of the moving rectangle is continuously changing as long as its surface is partially on the background (surface A in Figure 5) and partially on the central band (surface B in Figure 5), being lighter on the darker surface and darker on the lighter one. Thus there are two opposite tendencies: on the one hand there is the tendency, due to simultaneous lightness contrast, to "split" the moving rectangle into two separate surfaces of different lightness; on the other hand there is a tendency, due to motion, to perceive the moving rectangle as a single surface. The perceptual system should thus "justify" a change in lightness of contiguous sections of the occluding surface (due to simultaneous lightness contrast) *together with* the motion of the whole figure. The solution of seeing a single transparent rectangle would thus be a good compromise: the line behind the occluding surface becomes visible as a sort of "border line" from which the rectangle starts to change its lightness. In this way motion would be the factor of *temporal* integration, while transparency would be the factor of *spatial* integration. The result for which transparency is better perceived with slow motion could thus be explained with the longer time of contact between the moving rectangle and the central band.

More experiments are needed to clarify the role of motion in the perception of transparency. At present, we think that our results suggest that researchers should be at least cautious in associating different effects within a larger group – such as the “family” of phantoms – and in generalizing results for one single effect to all the other supposed members of the family.

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