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Original Contributions - Originalbeiträge

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1. Introduction

The general theory of transparency perception states that transparency is perceived when certain conditions are satisfied, regardless of whether a surface is physically transparent (Kanizsa, 1979). What is required for transparency perception is that two separate surfaces are seen along the same line of sight, one of which is, of course, the surface that appears transparent. This intriguing aspect of transparency, which connects many problems of visual organization (such as color, form, and belongingness), is probably the reason why the perception of transparency has attracted visual researchers since Helmholtz (1866/1962), who spoke about seeing one color through another.

Within the theoretical framework of Gestalt Psychology, several authors were interested in solving the problem of transparency perception—i.e., in defining those conditions that should be satisfied in order for transparency to be perceived, given that physical and perceptual transparency do not necessarily coincide—starting from Koffka (1935), who referred to the issue in terms of phenomenal scission. While there are several types of phenomenal scission, transparency concerns the splitting of the physical intensity of a stimulus to generate multiple impressions (in our case *surfaces*) coexisting perceptually in a same spatial location. However, we owe to Metelli (1970, 1974), Metelli, Da Pos, & Cavedon (1985) and to Kanizsa (1955, 1979) the answers to crucial questions concerning perceived transparency.

Metelli developed the *episcotister* model that explained how the visual system assigns surface properties (such as transmittance and lightness) to a transparent layer when transparency occurs. This model was derived from a specific physical context that elicits a percept of transparency, and hence it works in terms of inverse optics, that is with the inverse of the equations derived from the physical model (Singh & Anderson, 2002; Gerbino, 2015). 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 speaking, these may be classified into two kinds: The first condition (dubbed by Kanizsa "topological") requires continuity of the contour on the underlying bipartite surface, while the second (called "figural") requires continuity of the boundary of the putative transparent layer at the locations where these two sets of contours intersect (Figure 1A).

Thus, according to Kanizsa (1980), there are three basic conditions that underlie the perception of transparency: (i) the "topological condition" (Figure 1B); (ii) the figural condition (Figures 1C and 1D); and (iii) the "chromatic" condition (defined by Metelli's model).

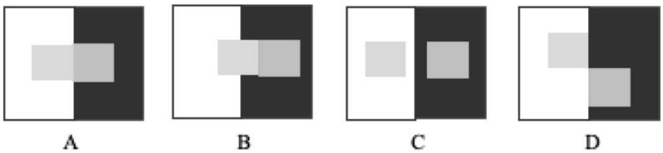

Fig. 1. Figural conditions for transparency by Metelli and Kanizsa. **(A)** Figural conditions are optimal. **(B)** Violation of the topological condition. The contour dividing the bipartite background must not undergo discontinuous jumps at locations where it meets the boundary of the putative transparent layer. **(C)** and **(D)** Violations of the figural condition. The two grey 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.

While the three conditions are indeed critical in the perception of so-called "balanced transparency" (Metelli et al., 1985), there are cases in which transparency is perceived when such conditions are not met: these situations could be considered as "anomalous" transparency (Bozzi, 1975; see also Soranzo & Agostini, 2004). A peculiar case of anomalous transparency is represented by a group of perceptual effects that are often referred to as *visual phantoms*. The term *phantom* is used to describe a variety of brightness effects, not all of which are limited to transparency. For instance, the phantom illumination illusion is a brightness effect determined by luminance gradients (Zavagno, 2005; Zavagno & Daneyko,2008), and Galmonte, Soranzo, Rudd, and Agostini (2015) called phantom illusion a simultaneous lightness/brightness effect induced by subliminal gradients. The word phantom, therefore, indicates a stimulation condition in which a key factor seems to be physically missing (e.g., a luminance discrepancy) or subliminal in the visual scene. In our study, we shall focus our attention on those phantom effects related to the perception of transparency, which are basically all variations of the first case of anomalous transparency, the Rosenbach effect (1902).

For the Rosenbach effect (see Figure 2), 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).

Fig. 2. The classical Rosenbach effect.

Rosenbach noticed that this phenomenal transparency is enhanced by the motion of the occluded surface. This observation evidenced the relationship between perceptual transparency and depth stratification. As stated above, according to Koffka (1935), transparency is one of the most striking examples of scission, which is better understood with chromatically homogeneous surfaces: in Figure 3, 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 seen in front of the other, and why. Petter described several rules that allow predicting the hierarchical depth stratification of chromatically homogeneous surfaces (for an extensive description of Petter's laws and of their validity in reference to perceptual transparency, see Masin, 2002). One of these rules is particularly relevant with reference to the Rosenbach effect: according to the so-called "motion rule," if one of the two rectangles in Figure 3 is moving, it would always be perceived in front of the other.

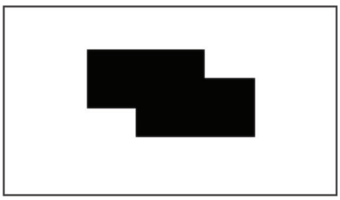

Fig. 3. The problem of scission with chromatically homogeneous surfaces becomes the problem of depth stratification.

Variations of the Rosenbach effect have been reported several times: Tynan and 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 "flickering phantoms" and Gyoba (1983) rediscovered the effect in a display such as the one reported in Figures 4A and 4B. 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

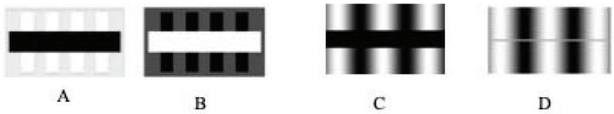

Fig. 4. The photopic **(A, B)** and scotopic stationary phantoms **(C, D)**, and the brightness grating induction **(D)**. Adapted from Gyoba (1983) and McCourt (1982).

stationary phantom illusion" as opposed not only to moving phantoms, but also to scotopic stationary phantom (Figure 4C). Photopic stationary phantoms have been analyzed by Kitaoka, Gyoba, Sakurai, and Kawabata (2001) and Kitaoka, Gyoba, and Kawabata (1999) with regards to depth stratification (being dependent on two of Petter's rules, i.e. (i) the length of intersecting borders and (ii) the relative dimensions of the grid and the horizontal band and to lightness contrast and assimilation. In this perspective, the "brightness grating induction" (McCourt, 1982, Figure 4D) is discussed as another example of the "big family" of phantoms effects.

The fact that the Rosenbach effect is stronger when the *occluded* surface is moving, as often reported (Zanforlin, 2003), agrees with the motion rule reported by Petter (1956). This may appear counterintuitive, but as Gerbino noticed (2015), transparency supports the modal completion of partially occluded contours, while occlusion requires their amodal completion. Thus, the motion of an occluded surface "brings" this above the occluding surface, hence facilitating the perception of the occluded margins through the transparency of the occluding surface, or, in other words, their modal completion.

However, in another variation of the Rosenbach effect, we observed (Uras, Actis Grosso, & Vicario, 2008) 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 & Sekuler, 1975). Indeed, the motion of an occluding surface should weaken the effect of anomalous transparency, or at least it should not have any influence on it.

In the following sections we are presenting an experiment aimed at investigating this observation. Our variation of the effect is fully described in the Methods section.

2. The Experiment

2.1. Participants

Twelve participants (six females; mean age = 28.6 years, Standard Deviation = 6.4), all studying or working at the University of Milano-Bicocca, participated in the experiment. All participants had normal or corrected-to-normal vision and none were aware of the purpose of the experiment. Experimental procedures were in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.2. Stimuli

Stimuli were presented on a notebook Packard Bell Easy Note S4930 equipped with a 15.4-in. color monitor (Wide extended graphics array with a resolution of 1,280 px × 800 px). Stimuli were created by modifying—according to the experimental factors described below—the following animation (see Figure 5): a rectangle (from here on *target*, which measured 2.3 cm × 1.2 cm, corresponding to 2.19° × 1.14°) was moving on a background divided into three sections (i.e., A, B, and A1, see Figure 5). The luminance value of section B was either a decrement or an increment (Figure 6) with respect to the luminance value of Sections A–A1, which shared the same luminance. At its appearance, the rectangle, which appeared at 1 cm from the screen border, started to move horizontally from left to right. The trajectory length measured 22.4 cm.

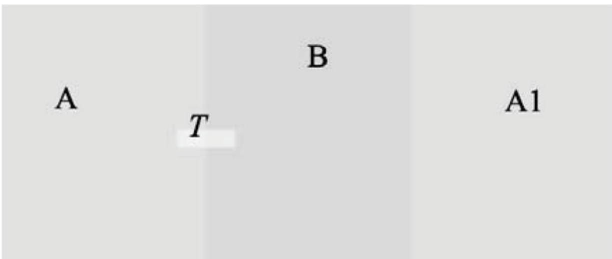

Fig. 5. One of the 24 stimuli. The background is divided in three sections: **(A)** left area, (where the rectangle T appears while moving in the moving stimuli); **(B)** a central band; **(A1)** right area (where the rectangle T disappears while moving in the moving stimuli). The figure corresponds to the static version.

A repeated measures experimental design was employed with the following within factors

(1) *target transparency* (from here on dubbed *transparency*): two levels, with the transparency index α set either at 100% (opaque) or at 75% (slightly transparent). The degree of transparency was created by using Flash MX 2004, in which α is an index that could assume a value comprised between 0 (totally transparent and therefore invisible) and 100 (totally opaque). The opaque target could have a luminance of either 11.43 cd/m^2 or 0.30 cd/m^2.
(2) *Target speed* (from here on dubbed *speed*): three levels, static, slow (3.7 cm/s), and fast (12.4 cm/s). In the condition *static* (Figure 5), the target appeared half on background A and half on background B.

(3) *Target and background contrast* (from here on dubbed *contrast*; Figure 6): two levels, low and high. Luminance background portions A–A1 and B were the following: 11.43 cd/m^2, 11.26 cd/m^2, 9.34 cd/m^2, 1.32 cd/m^2, and 0.30 cd/m^2. These luminance values were combined to obtain two conditions of high luminance contrast between the background regions and between target and regions (A–A1 = 11.43 cd/m^2, B = 1.32 cd/m^2, and T = 0.30 cd/m^2; A–A1 = 0.30 cd/m^2, B = 1.32 cd/m^2, and T = 11.43 cd/m^2), and two conditions of low luminance contrast (A–A1 = 11.26 cd/m^2, B = 9.34 cd/m^2, and T = 11.43 cd/m^2; A–A1 = 9.34 cd/m^2, B = 11.26 cd/m^2, and T = 11.43 cd/m^2).

(4) *Background polarity* A–B–A1 (from here on dubbed *polarity*; Figure 6): two levels, with region B as either an increment or a decrement to regions A–A1.

The combination of the four factors (*transparency* * *speed* * *contrast* * *polarity*) resulted in 24 stimuli.

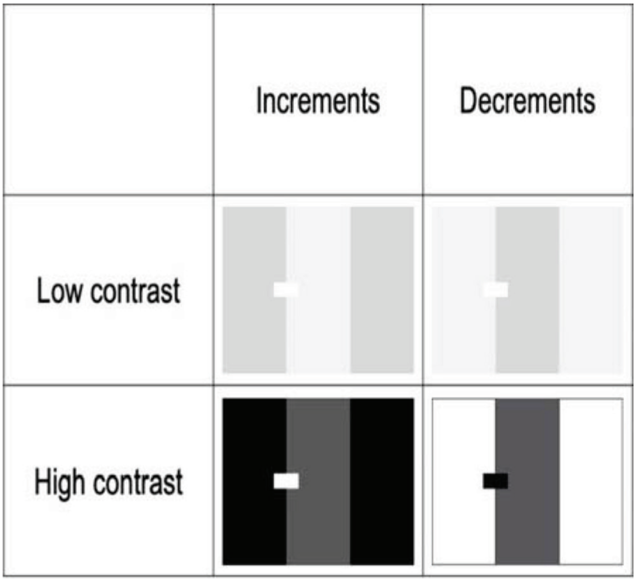

Fig. 6. The four possible combinations of lightness contrast and polarity.

2.3. Procedure

Stimuli were presented in a dim room and were viewed at a distance of 60 cm. Participants' task was to report the degree of transparency of the targets T (see Figure 5) using a 7-point Likert scale, in which 1 = opaque and 7 = transparent.

Participants were individually tested and no time restrictions were imposed for giving the responses: the animations were shown in loop and only after a response was given the experimenter started the next trial. The experiment lasted approximately 20 min.

2.4. Results

An Analysis of Variance for repeated measures was carried out on the data, with *transparency*, *speed*, *contrast*, and *polarity* as within factors. Except for *polarity* ($p = 0.3$), all factors determined significant main effects: *transparency* [$F(1, 11) = 306.886$, $p < 0.001$, $\eta2_p = 0.965$]; *speed* [$F(2, 22) = 9.054$, $p < 0.001$, $\eta2_p = 0.451$]; *contrast* [$F(1, 11) = 125.268$, $p < 0.001$, $\eta2_p = 0.919$]. Factor *speed* interacted significantly with *contrast* [$F(2, 22) = 6.969$, $p = 0.005$, $\eta2_p = 0.388$], *polarity* [$F(2, 22) = 23.599$, $p < 0.001$, $\eta2_p = 0.682$], and *transparency* [$F(2, 22) = 13.373$, $p < 0.001$, $\eta2_p = 0.549$]. The interaction *contrast* * *transparency* was also significant [$F(1, 11) = 205.330$, $p < 0.001$, $\eta2_p = 0.949$].

On each stimulus, a one-sample *t*-test was performed, to verify whether the mean score was different from 1 (which in the Likert scale corresponded 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 agrees with both Kitaoka et al. (2001) and Zanforlin (2003): with a high contrast between the three areas, the effect of anomalous transparency disappears. However, *contrast* significantly affected the degree of perceived transparency for both transparent and opaque targets. As seen in Figure 7, high contrast determined a rather strong impression of transparency for the transparent target, with means in the range of 4.9–5.9 (SD 1.0 ± 0.1). With low-contrast conditions, instead, the degree of perceived transparency of the transparent target drops significantly, with means in the range of 1.9–2.2 (SD 0.4 ± 0.1). This means that physically transparent targets are judged as highly transparent only with a high lightness contrast.

Opaque targets are instead perceived as transparent only in the low lightness contrast condition. What is interesting to notice is that when lightness contrast is low, the degree of perceived transparency does not change for transparent and opaque targets. In other words, physically transparent and physically opaque targets are perceived as equally transparent in the low-contrast condition, both because of a reduction of the perceived degree of transparency of the physically transparent targets and an increase in the degree of perceived transparency of the physically opaque ones.

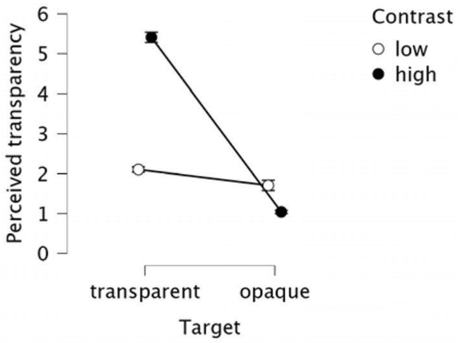

Fig. 7. Mean ratings for transparent and opaque targets displayed as a function of *contrast*.

The effect of speed is shown in Figure 8, where it is distinguished for the factor *contrast.* While speed had a marginal effect on the high contrasted transparent target, what is interesting here is the effect of perceived transparency in the low-contrast condition. As one can see, opaque targets gain in transparency with fast speed, whereas speed does not affect the degree of perceived transparency of the transparent target. Thus, opaque targets are perceived as even more transparent than the physically transparent one when moving at high speed in the low-contrast condition, while the effect of perceived transparency is drastically diminished (and significantly different from the physically transparent target) with static target.

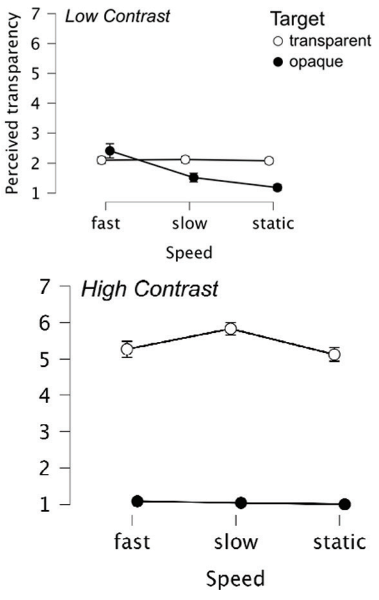

Fig. 8. Mean ratings for transparent and opaque targets displayed as a function of *speed* and distinguished for the factor *contrast*.

Figure 9 shows the effect of speed distinguished for the factor *polarity*. With regard to the opaque target, this gained a particularly strong transparent quality (mean 3.2, SD 0.7) when region B was an increment to region A and the target moved fast. However, one-sample *t*-tests confirmed that the mean rating for the fast opaque target in a low-contrast condition when B was a decrement was significantly different from 1, meaning that the target gained a weak transparency appearance [M = 1.58, SD = 0.7, $t(11) = 2.755$, $p < 0.05$, $d = 0.79$]. Moreover, the target that moved slow within a low-contrast condition was also seen as slightly transparent when B was a decrement [M = 1.70, SD = 0.7, $t(11) = 3.137$, $p < 0.01$, $d = 0.90$].

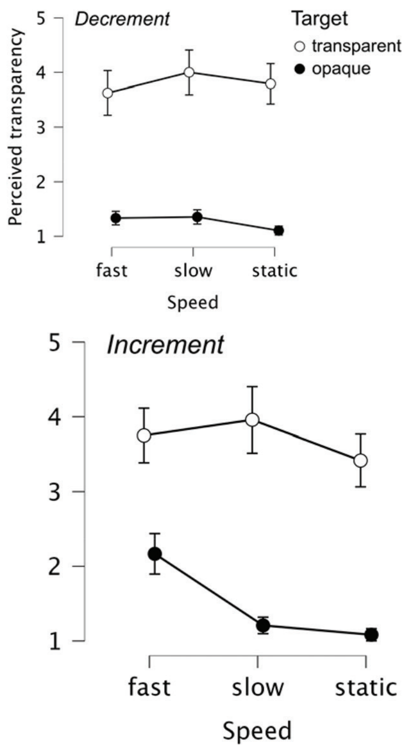

Fig. 9. Mean ratings for transparent and opaque targets displayed as a function of *speed* and distinguished for the factor *polarity*.

2.5. Discussion

We presented an experiment aimed at clarifying the combined role of (i) lightness contrast and (ii) motion on the perceived transparency (defined as anomalous transparency) of a physical opaque target. To this aim we also manipulated the lightness polarity of the background on which the target was moving.

Regarding lightness contrast, we confirmed the findings of both Kitaoka et al. (2001) and Zanforlin (2003): with a high lightness contrast between the three areas, the effect of anomalous transparency disappears. Our results add information on the influence of high contrast on the perceived transparency of physically transparent surfaces, which appear as drastically more transparent with high contrast than with low contrast.

The effect of anomalous transparency is thus present only in the low lightness contrast condition, with physically transparent and physically opaque targets perceived as equally transparent, due both to a reduction of the perceived transparency for the physically transparent targets and to an increase of the perceived transparency for the physically opaque ones. The effect of contrast on physically transparent surfaces was unexpected and calls for further investigation. Differently, the fact that anomalous transparency is present only with low-contrast conditions has been observed several times (e.g., Tynan and Sekuler, 1975; Kitaoka et al., 1999; Kitaoka et al., 2001), although in different displays.

Motion had a strong effect on the degree of perceived transparency. This somewhat counterintuitive finding is the main result of our study. While the increase in perceived transparency with motion of the occluded surface agrees with Petter's laws on depth stratification, a moving opaque occluding surface should not appear transparent. The motion of the occluding surface should actually weaken anomalous transparency. What we found instead is that motion of the occluding surface enhances the effect of anomalous transparency, with fast moving targets perceived as more transparent than slow moving ones, which in turn are perceived as more transparent than the static ones.

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 sections A and B (Figure 5) of the background (which differ in luminance), 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.

Interestingly, contrast polarity between sections A and B influenced the degree of perceived transparency when combined with motion. Thus, the opaque target gained a particularly strong transparent quality when region B was an increment to region A (see Figure 5) and the target moved fast across a low-contrast background. This last result, which calls for further investigation, could be related with the "brightness rule" (Morinaga, 1952; Morinaga, Noguchi, & Ohishi, 1962; Petter, 1960) described below.

Our study follows a long tradition of studies conducted in the mainframe of Gestalt psychology. With low contrast, by varying the contrast between the three areas (i.e., section A, section B, and the target), we also wanted to check how the effect of perceptual transparency is related to both one of Petter's rules and to the "brightness rule." According to Petter's rule, when two chromatically homogeneous surfaces are partially overlapping (as in Figure 10A), in order to see the whole configuration as two different figures, it is necessary to see a border that separate the two figures. Given that this border is not present, the perceptual system creates an "anomalous" border (defined as "quasi perceptual" by Kanizsa, 1979) following the minimum principle: between several possible alternatives, the system tends to minimize the formation of interpolated contours. Thus, the anomalous border is the shortest among those possible and, given that this border "gives rise" to a figure, this figure will be seen in front and the other behind.

The relation between the Petter's rule and perceptual transparency was already studied by Kanizsa (1969), who demonstrated (see Figure 10) that the effect of the rule itself is weaker than the effect of another rule, dubbed "brightness rule" (Morinaga, 1952; Petter, 1960).

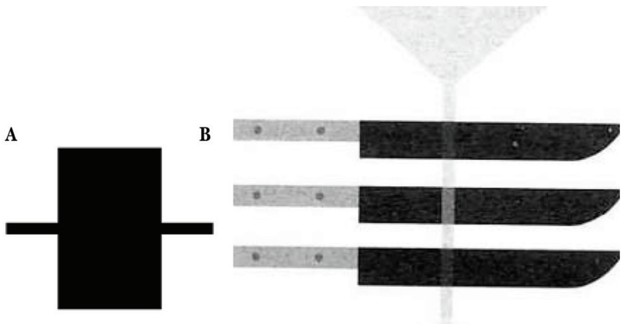

Fig. 10. **(A)** An example of "quasi perceptual" borders with chromatically homogenous surfaces. **(B)** The knife is seen alternatively in front or behind the glass, according to the brightness rule. Adapted from Kanizsa (1969).

As for chromatically homogeneous surfaces, also for perceptual transparency the problem of which surface is in front and which is behind should be dependent on the interpolated contours, but, according to the brightness rule, these contours are not necessarily the shortest ones; on the contrary, the surface that appears in front (i.e., the one to which the interpolated contours "belongs") is the surface whose lightness is closest to the lightness of the intermediate area. In Figure 10B, it is possible to see the effect of this rule: the knife and the glass are seen in front or behind, depending on the fact that their lightness is closer to the lightness of the intermediate area.

What we show in our study is that the effect of lightness contrast interacts not only with the figural condition but also with the motion of the surface that could be seen as transparent (and not as occluded by a transparent layer, as in other studies on phantom effect).

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.

Acknowledgments

This work is dedicated to the memory of Giovanni Bruno Vicario and Mario Zanforlin, who both worked at an early stage of this project (Actis-Grosso, Vicario, & Zanforlin, 2010), of which we here present a small portion.

Summary

We report an effect of anomalous transparency that is similar to other phantom effects. In an experiment aimed at testing the combined role of (i) motion of the occluding surface and (ii) lightness contrast and polarity on the perception of anomalous transparency, we found that transparency is perceived only with low contrast, and enhanced when the occluding surface is moving. A tentative explanation is suggested, based on simultaneous lightness contrast as a segregation factor and on motion as an integration factor, and discussed in light of previous studies conducted in the theoretical framework of Gestalt theories in perception.

Keywords: Anomalous-Transparency, Rosenbach-effect, Visual-phantoms, Petter-effect.

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