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Stereokinetic shapes and their shadows

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Abstract. The visual space of phenomenal appearances has a complex geometry which cannot be reduced strictly to Euclidean or projective geometry. The distinctive nature of this space and its objects is evidenced paradigmatically by stereokinetic phenomena, which are perceptual objects in actual three-dimensional coming into being. Stereokinetic phenomena produce the appearance not only of corporeality but also, in certain circumstances, of shadows. By altering certain components of his experiments on the three-dimensional appearance of a truncated cone, in fact, Musatti discovered that on its white base floats some sort of shadow obscuring stretches of the white lines. These shadows are connected to phenomena of amodal presentations successively analysed by Kanizsa. The continuity of the unfolding in visual space of stereokinetic transformations produces a diversified series of percepts coming into being, shadows included, and highlights the role of configurational movement as a factor of formal unification, thereby proposing once again the hypothesis of assimilative factors as responsible for the field organisation of past experience.

1 Premise

The debate in the cognitive sciences is bedevilled, although practitioners are aware of it to varying extents, by an underlying ontological problem which is sometimes neither thematised nor even noticed. I refer to the problem of *reductionism*.

Many linguistic and conceptual misunderstandings—ones, for example, concerning the concept of *mental image* or *representation*—derive from the habit of absolutising the results of particular investigations conducted according to a specific point of view or a particular methodology of analysis.

A way out of the problem may be the adoption, as an ontological option preliminary to the inquiry, of a *theory of the levels of reality* (Hartmann 1935; Albertazzi 2001d; Poli 2001), which is in contrast to the epistemological assumption of numerous disciplines, that there exists *only one reality*, devoid of *emergent categorial features*, which is *described differently by different sciences*.

A theory of the levels of reality proves especially useful in the analysis of cognitive processes, and in particular the *analysis of the structure of visual space*, which has a complexity that cannot be reduced to physical, psychophysical, or neurophysiologic ones, despite the *presence* and *reciprocal dependence* of these (and other) levels in the organisation of the visual field.

The debate on the boundary between the physical and the psychic marking the *onset of perceptions* still lacks a satisfactory categorical classification. For example, definition is almost never given to the difference between the *objectual quality* of perceived objects and their *conditions of perceptibility* (Benussi 1925a, 1925b; Musatti 1964, chapter 4, § 23; see below, section 3ff).

The distinctive feature of psychic processes, as Koffka pointed out in his time, is that they display a *direct access to information*, albeit at a differently conscious level of representation. This access is problematic, however, because it is one of the *levels of emergence* of new categories (Albertazzi 2003). Cognitive processes, in fact, comprise automatic processes and subjective ones, as well as processes acquired from past

experiences (Helmholtz 1867/1962; Kanizsa 1980; Rock 1983; Gregory 1998). To use Hartmann's terminology, the stratum of psychic phenomena is more correctly described as that of the *building-above* relationship, that is where the birth of a new categorial level takes place, as opposed to the more ordinary *overformation* relationship whereby new categories are added to ones already given (as happens in the relationship between physics and chemistry) [Hartmann (1935); for Hartmann's influence in neuroscience see Jung (1973); for reductionist conceptions see, for example, Quine (1974) part I; Churchland (1981)].

Moreover, each level has internal *layers*, of which examples at the psychic level are the various types of modal, amodal, and mental perception corresponding to the diverse forms of completion that Kanizsa analysed and made classic (Musatti 1964, page 315; Kanizsa 1980, chapter 3; Kanizsa 1991, chapter 2; Albertazzi 2003).

One of the potentially most fruitful fields of application of a theory of levels is *analysis of the intuited visual space and its objects*, given that the perceptive organisation is intrinsically stratified.

2 The structure of visual space

Aspects that make the objects of visual space especially interesting are the following:

1. The *characteristics of their visibility* during the act of seeing.
2. The *complex construction* of their phenomenal appearance.
3. Their intrinsic *processuality*, which makes them structurally dynamic objects.
4. The *continuity* of their unfolding in the intuitive space of vision.
5. The problem of their *identity*.

A striking example of this complexity is provided by *stereokinetic objects*. These were among the first phenomena studied which showed that the perceptive system is able to abstract three-dimensionality from two-dimensional stimuli in movement (Musatti 1924, 1955, 1975). These objects display the above features to the maximum extent. In fact:

1. They do not exist at the level of physical stimulation but are endowed with perceptive *evidence*.
2. They have the property of *visibility*, even with aesthetic quality (cf Duchamp's rotoreliefs, or Duncan's 'Leaning Tower').
3. They have intrinsic processuality (they are objects in *actual three-dimensional coming into being*).
4. They raise the problem of the *displacement* of objects in the phenomenal field.
5. They evidence the role of *movement as a factor of formal unification*.
6. They highlight the processes which constitute the *various structures of the phenomenal field as a whole*.
7. They are an example of the *coincidence of boundaries* in the phenomenal field.
8. They display the *whole*'s different degree of internal complexity with respect to its *parts*.
9. They are objects that *produce the appearance* not only of *corporeality* but sometimes also of *shadow*.

Stereokinetic objects exemplify the tendency for slowly rotating *complex planes* (here I use the term complex/*Komplex* as defined by Ameseder 1904, page 72) to change into *solid bodies moving in three-dimensional space*. In particular, they evidence the nature of the continuous common-fate movement that characterises a large part of *perceived movement*. Common-fate movement, in fact, reflects the tendency for a *single constantly moving figure* to be seen, rather than a complex of distinct elements in relative movement. In other words, common-fate movement induces the components involved to *assume the role of figure* and makes some sort of *general improvement* to the perceptive situation on the basis of the components involved.

In *Physics* Aristotle distinguished among the concepts of 'consecutive', 'contiguous', and 'continuous', affirming that:

> "Continuous [...] is a particular determination of the contiguous [...] when the limits of two things, by means of which the one and the other touch, become one alone [...]" (1980, *Physics*, V:3, 227a: pages 11 – 12) (on this point cf Albertazzi 2002a).

A continuous whole is therefore not an aggregate composed of the sum of its parts, which may have no connection with each other; rather, it is a whole constituted by *contiguous parts arranged in a certain structure that makes them continuous* (cf also 1977, *Metaphysics* 1052a, page 35. For a modern insight in mathematics cf Bell 1998, 2000, and unpublished).

Aristotle's above definition highlights the following features of stereokinetic objects:

1. Their *continuous on-going transformation* in *successive phases*.
2. The *role performed by the parts in reciprocal building-above* and *unfolding* as the whole is constituted.
3. The *non-independence* of the parts from the whole (see below, section 3).
4. These features produce the *visual quality* of the three-dimensional corporeality of the stereokinetic *whole*.

3 Coherence of the part/whole structure

Stereokinetic movements were first analysed (and also named) by Benussi, and subsequently by Musatti. They are therefore the legacy of a markedly philosophical tradition, that of Meinong's school of Graz (Albertazzi et al 2001; in part, Albertazzi 2001a, 2001b, 2001c).

Musatti, in particular, analysed the *structure* of stereokinetic objects in terms of both stroboscopic and other types of apparent movement. Examples of the former are the following:

> "Take two equal rectangles *contiguous* on one of their sides and *alternating at optimal rhythm*. One gains the impression of a single rectangle which slides from the position of the first figure to that of the second, and vice versa, on the same fronto-parallel plane.
>
> At a certain point this movement may change into that of a single rectangle which, still pivoting on the side in common, rotates in three-dimensional space presenting its two opposite faces *as if it were a sheet of paper or cardboard*. The movement may be backwards or it may be a rotation through 360 degrees. The rotation of the figure is in fact the only perceptive solution that satisfies the tendency to see *a single constant figure moving according to common fate* (Musatti 1955, § 1, pages 4 – 5).

(See figure 1.)

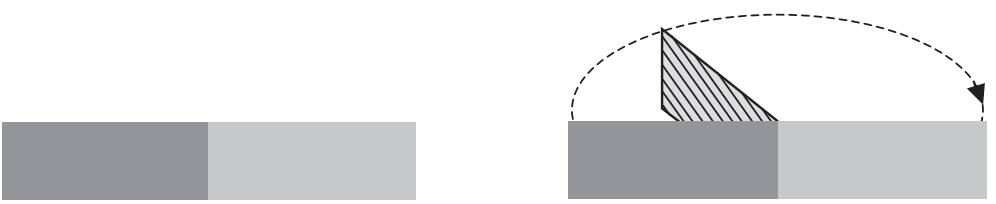

Figure 1.

If, instead, *a long and narrow rectangle is alternated with a long rectangle but broader than the previous one*, situated alongside the former, one gains the impression of:

> "1. A single rectangle that shifts in the plane from the first to the second position and which expands and contracts as it changes position to and from.
> 2. A block (a brick or a book), a solid body that shifts from one position to another and which rotates through 90 degrees, so that in the first position it presents its narrow side (the spine of the book) and in the second position its broader side (the cover)" (Musatti 1955, page 5).

(See figure 2.)

Figure 2.

If *two squares of different sizes* are then alternated, one has the impression of:

"1. A single square that slides in the plane from one position to the other, and vice versa, and simultaneously grows larger and smaller.
2. A single square of constant size which slides *not only sideways* but *depthways*, moving first towards and then away from the observer (the most frequent situation)" (Musatti 1955, page 5).

(See figure 3.)

Figure 3.

Stereokinetic transformation progressively acquires dominance in the three examples given. It is therefore favoured in cases in which its consequence should be a distortion of the single moving figure seen. This happens whilst *maintaining a certain constancy with the body seen*, and it comes about both when the alternating figures are seen as parts of a single body presenting different faces to the observer, and when the single figure perceived is seen at different distances, ie in different spatial positions, but maintaining constant shape and size. From this Musatti concluded that in stereokinetic movements there occur not only a *tendency to constancy*, but also a *resistance against shifting in depth*, and in this case the object tends to distort (growing smaller or larger) (Musatti 1955, page 6; Weiss and Adelson 2000).

By working also on the production of stereokinetic movements on other types of apparent movement—and in particular on so-called illusions of figure identity (Musatti 1928; 1955, §2)—Musatti found that these situations highlighted two components of the phenomenon (see figure 4):

1. A *kinematic doubling* of the movement of the lines in certain visual patterns (complexes).

2. An interactive dynamic between the *tendency to the minimum trajectory* and the *role of the parts in the continuous common-fate movement* (Musatti 1955, page 10; notice that these are functional parts, cf Kanizsa 1994, page 151).

One of the most interesting results of Musatti's experiments concerns stereokinetic phenomena with the rotation of *curvilinear figural complexes with variable curvature*, in particular the rotation of black cardboard disks with curved white lines drawn on them (Musatti 1955, § 3, pages 13 – 19). Suppose that the drawing is an ellipse.

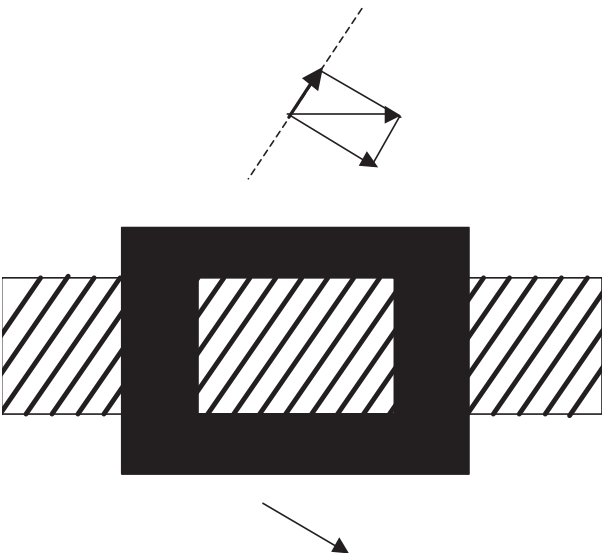

Figure 4.

"In this case too, the movement splits into two movements, one along the ellipse, which is not seen, and another which moves in a radial direction. The figure no longer rotates (the rotational movement disappears), but all its points move radially towards the perimeter or towards the centre. Apparently, therefore, every point of the ellipse maintains its direction towards the centre of the disk, only changing its distance.

In this case, the *stability of orientation* is at the expense of the figure's rigidity. What one sees is an elastic ring which changes shape because each of its points is constantly in movement with respect to the others (it writhes).

The stability of orientation is not perfect. It stretches for each element in the figure in a manner difficult to describe because it changes according to the point of observation. Together,

1. Stability of orientation, and
2. Continuous deformation

give rise to a *libration of the figure in space* (stereokinetic transformation) which also loses the property of deformability. One now sees a disk or a rigid ring which librates in three-dimensional space, constantly oblique and oscillating without rotating.

In the case of the ellipse that distorts into a ring, the tendency to the minimum trajectory holds. In the case of the ring or disk positioned obliquely in three-dimensional space, the tendency to constancy holds. Thus we have:

1. Rotating ellipse, constant shape, on a single plane.
2. An elastic ring or self-distorting figure on the plane and stably oriented.
3. A disk or constant figure, stably oriented and shifted in space" (Musatti 1955, pages 16 – 19; Zanforlin 2000).

(See figure 5.)

The stereokinetic phenomena displayed by the rotating ellipse are therefore doubly interesting because they give rise to more than one outcome, thereby revealing the *potentially hierarchical building-above structure of perceptive objects.*

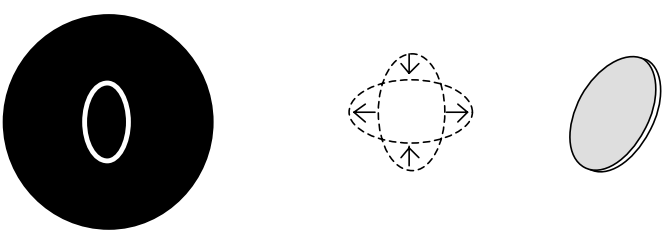

Figure 5.

If the ellipse is not placed at the disk's centre but on its perimeter, one obtains the same phenomena, but with greater difficulty.

The results of these experiments showed that there is *tendency to improvement* in stereokinetic phenomena consisting of a complex construction due to the *successive modification of the parts* of the moving complex in order to achieve greater *homogeneity* of the *whole*.

Musatti, in particular, believed that the general principle of homogeneity governed all perception, and it was to this principle that he ultimately related all the various factors analysed by Wertheimer (Musatti 1931). Specifically, according to Musatti:

> "1. Shapes constitute themselves in the perceptive world in a manner such that the elements unified in a formal complex have a specific qualitative homogeneity.
> 2. This homogeneity does not exist independently of the self-constitution of shapes, but it is a homogeneity which pertains to those elements only in as much as they are unified into the formal whole; it is therefore *not a property of the parts* but *a property of the whole*.
> 3. One may therefore say that self-constitution of particular forms of the complex in the perceptive field, or in other words the structurality itself of the perceptive world, is a mode whereby the elements of that field follow a natural tendency to realize their homogeneity.
> 4. This tendency of perceptive elements to render themselves homogeneous continues to act upon elements already unified into formal complexes, so that, purely because they have already been unified in those complexes, these elements tend to render themselves homogeneous in all their other qualitative aspects.
> 5. This tendency may be obstructed by the external or physical conditions of perception, but it can in particular cases overcome the obstacle, so that there arise particular qualitative homogeneities in the perceptive field to which correspond heterogeneities in the corresponding complexes of stimuli" (Musatti 1938, pages 163 – 164).

The stereokinetic phenomenon of the rotating ellipse is particularly important for analysis of the corporeality of the objects of visual space, because it produces a *diversified series of percepts coming into being*.

In this regard, Zanforlin has observed a further transformation of the rotating ellipse projectively compatible with the rotating ellipse, to wit:

> "The oblate *spheroid*, the solid produced by rotating an ellipse around its *minor* axis" (Zanforlin 2000, page 159).

Potentially there are therefore at least *four* percepts that *unfold processually* from the first configuration in movement.

Musatti observed with regard to the phenomenon of the rotating ellipse that it increased in complexity and interest in the case of the rotation of *figural complexes with constant curvature* (Musatti 1955, § 4, pages 19 – 22). Specifically:

> "1. If a concentric circle is drawn *at the centre* of the disk, it appears to be immobile.
> 2. If the circle is instead located *on the periphery* of the disk, the revolving movement of the disc is visible, but the circle remains stably oriented, turning always the same point in a particular absolute direction in space, upwards for example.
> 3. If a *large dot is drawn on the disk near the circle*, while the circle revolves maintaining its stable orientation, *the dot seemingly detaches itself*, and its distance from the circle does not remain stable; it tends to move away or to leave it" (Musatti 1955, page 19).

> "In the situation in which the point is situated in eccentric position within the circle, *the dot detaches itself from the plane of the disk* and *moves towards* the observer. It thus becomes part of the circle and appears as *the vertex of a small cone pointing at the observer*, librating in space as it revolves around the centre of the disk. It maintains its inclined axis, and, because it oscillates, the inclination of the axis constantly changes. The oscillation is soft and undulating, not mechanical. In this case, too, a stereokinetic transformation has occurred" (Musatti 1955, pages 21 – 22).

> "*The shifting of the dot in three-dimensional space causes the relative movement to disappear, so that dot and circle become a single solid body*. The rigidity of the dot and circle complex obeys the *tendency towards constancy*, rigidity and common fate movement" (Musatti 1955, page 22).

(See figure 6.)

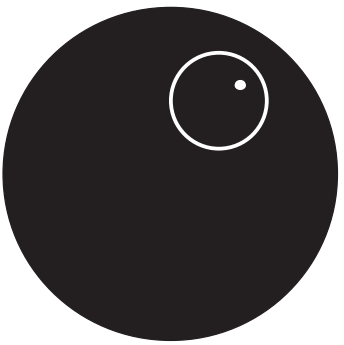

Figure 6.

On the basis of the experimental observations just described, Musatti concluded that the transition to three-dimensionality in stereokinetic transformations is due to *orientation maintenance by complexes in common-fate movement* which excludes relative movements and distortion.

The most important aspect of Musatti's analysis of stereokinetic phenomena concerns their *constitution in phases*, and in particular the passage from the second to the third phase. As we have seen, the second phase consists in *perception of distortion* of the complex, which corresponds to the projection onto a frontal plane of a particular solid: namely that moving solid which in the third phase appears as a perceptive object. Musatti believed that this passage was due to the influence of *empirical* factors connected with *our past experience* of solid objects. These latter are modified, moreover, by a restructuring brought about by the *organisation of assimilative phenomena* (Benussi 1922 – 1923, § 38; Musatti 1964, pages 39 – 41).

This is an important point because it is still debated in cognitive science, with reference to the problem of the cognitive integrations of primary processes. For example, Kanizsa, a pupil of Musatti, severely criticised the role that his teacher attributed to empirical factors in actual perception (on Kanizsa's distinction between 'perceptual' and categorical assimilation cf Kanizsa 1994, page 160). When he referred to assimilative phenomena, however, Musatti was not envisaging the role of past experience as it is generally conceived in the contemporary debate [a position similar to that held by Musatti is Gottschaldt's (1926, 1929)].

Assimilative conditions (which, once again, were first analysed by Benussi, cf Benussi 1922 – 1923; Musatti 1926, 1931) are those perceptive factors that operate when, for example, we see shapes in clouds, wall cracks, or ink blots. According to Benussi and Musatti, they give some sort of formal unity to the percept by *integrating its basic elements*. They act in two ways:

1. They determine the formation of *certain structures rather than others* on the basis of our past experience of distinct objects.
2. *They perceptively modify the aspect of particular structures* so that they correspond more closely to elements of our past experience.

In their tendency to improvement, *assimilative phenomena are analogous to the general principle of the homogeneity* of the elements of a shape whereby that shape constitutes itself as such; and, likewise, the property that derives is a *property of the whole* and not of the parts (Musatti 1938, pages 169ff). The action of assimilative phenomena enriches objects with corporeality on the basis of *organised systems of experiences* comprising the actual elements of the complex which find there location (for the concept of 'location' cf Musatti 1931; reproduced in Musatti 1964, pages 255 – 256). These are not simply mnestic traces or past experience in the classic Helmholtzian sense of the presence, in our past, of *an experience specifically complying* with the current conditions of a particular perception. According to Musatti, the assimilative

processes *activate themselves before and independently of properly mnestic factors, which in a particular situation may also be entirely absent* (Musatti 1931; reproduced in Musatti 1964, page 243).

On the basis of these considerations, Musatti asserts *identity* between *processes of formal unification* during an actual perception and the *processes unifying elements of past experience and actual perceptive elements* which lie at the basis of assimilative processes. As Benussi pointed out, these processes, as particular *conditions for the formation* of stereokinetic objects (for example, the '*hingebendes Schauen*', the rotation of the base disk), should not be confused with the *characteristics of visibility* of objects (perspective apprehension of what is seen, a circle and a dot for example) (cf above, section 1).

4 Fantasmatic shadows

By altering certain components of his experiments on the three-dimensional appearance of a truncated cone, Musatti discovered a further perceptive phenomenon (Musatti 1955, § 9).

> "If *dashed lines* rather than two circles are used to draw a truncated cone, the following perceptive rendering is obtained. The observer sees:
> 1. A truncated cone on whose black base the white dashes float.
> 2. A truncated cone on whose white base floats *some sort of shadow* which obscures stretches of the white lines.
>
> If the smaller circle is in front, the shadows, rather than appearing distinct for both circles, merge together, and in their rotating motion appear as shadows covering not only the base but also the mantle of the cone. In this case, the shape of the truncated cone is distorted so that it looks like a skull-cap or the segment of a sphere, across which these shadows slide.
>
> The tendency to sphericalization appears as the consequence of an interplay of shadows and lights sliding with relative movements on the solid bodies produced by the stereokinetic transformation" (Musatti 1955, page 36).

The eccentric circles appearing to complete behind the shadows are amodally completed in Kanizsa's sense (see figure 7).

Figure 7.

Musatti noted that the shadow effect occurs even if—in the case of a disk with an ellipse on its perimeter and a radially oriented minor axis (Musatti 1955, page 18), which is the situation in which stereokinetic transformations are most difficult to see—the *ellipse is coloured*, for example red or yellow, so that the colour is intense at the edges and attenuates towards the centre. In this case, it is not the distortion of the ellipse that is seen but its stereokinetic transformation (Musatti 1955, page 36). Since the chromatic continuous variations are generally seen as characteristics of illumination, they provoke the perception of diverse inclinations of the surface in relation to the light source, giving the perception of depth. In fact, Musatti observed that:

> "In this case, too, the *colouring appears to be something that floats on the solid body*, oblique and oscillating in space, like the *reflection of a light emitted by the axis on which*

the disk rotates. Moreover, the solid body is no longer transformed into a disk but assumes the shape of a *skull-cap or the segment of a sphere*.

Once again, the *sphericalisation* derives from the tendency to see the illumination as due to a *constant light source*: that is, to a *tendency to constancy* for both the surface and the light source.

If the colouring is inversely intense, the spherical skull-cap shape appears to be lit *from outside the field constituted by the rotating disk*" (Musatti 1955, pages 36 – 37).

As regards the *sphericality produced by the shadow*, Musatti explains its appearance as due to the scission of the light reflected by the objects between *surface colour* and *illumination*. In the case of a gradient of reflectance produced by a shadow, there occurs, with simple surfaces, the simultaneous interaction between the object's surface colour and that of the directional illumination, and the gradient is seen as being produced by the curvature of the surfaces.

The phenomenon becomes even more striking in a variation of Musatti's situation where the smaller circle is eccentric with respect to the larger one so that they intersect.

The situation was studied by Metzger who produced stereokinetic phenomena endowed with *transparency*, and, in some cases, once again the phenomenal appearance of *shadows* (Musatti 1953; Musatti 1955, § 11, pages 40 – 41):

"The experiment consists in giving a different colour to the zone where the two circular surfaces, both of them opaque, intersect: for example, yellow – green with a yellow disk and a green one (fusion colour), or purple with a red disk and a blue one. In this case, during the rotation, the zone common to the two disks *splits into two surfaces, one of which is seen as lying behind the other*. This produces one of the most evidence cases of 'double representation' highlighted by *illusory transparency*. More specifically, the following perceptive rendering is obtained:

1. There seems to be a difference of level between the disks. One of them appears to protrude slightly from the other, and the rest appears to be transparent.
2. The fusion colour is decomposed into its components: the green is seen behind the yellow, the blue behind the red.
3. The entire surface is transparent, and the observer also sees the base disk made of cardboard."

(See figure 8.)

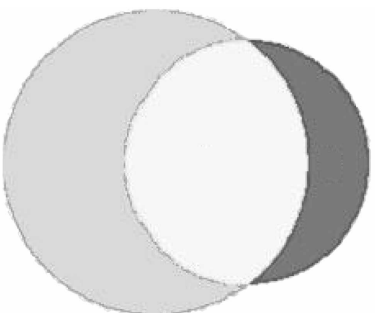

Figure 8.

In this situation, therefore, a certain number of *conditions* operate to produce the phenomenon of perceptive transparency (protrusion of one shape with respect to another, chromatic heterogeneity between the shared zone and their adjoining zones, a difference in level between the surfaces). Moreover, these conditions are significant because they concur in a *general tendency towards the best overall structure* (cf also Kanizsa 1955, pages 5ff). Musatti's explanatory hypothesis that the *colours of parts are unified into a single formal complex, depending on the conditions of the overall field*, was endorsed by Koffka and then confirmed also by Heider.

According to Heider, in fact, if a grey surface is perceived as split into two surfaces relating to two different shapes, one of which is transparent, the colour of the two components depends on the figural organisation of the field. Specifically, if the first

layer is incorporated perceptively into a blue surface, the one behind is seen as yellow. In this case, the colours separate according to the field conditions while their relationship remains unchanged (Heider 1933; see also Kanizsa 1955).

Once again, therefore, assimilative phenomena and the tendency towards the best form act in a twofold manner: (i) by favouring one particular type of formal unification rather than another, and, especially, (ii) by favouring what confers three-dimensionality on the visual field, *continuous common-fate movement*, in particular.

Musatti also observed that, if non-fusion colours are used in this experiment (for example, a major green disk, a minor red disk, and a blue intersection zone), the red seen behind the green is blue. This experiment shows that we can perceive transparency without colour constancy, since the colour of the uncovered region appears different from the colour of the covered region, although both pertain to the same object and are therefore expected to be constant. With certain combinations of colour, moreover, besides transparency, once again produced is *the appearance of a shadow*. Specifically, the observer sees the following:

> "A shadow sliding over the rear disk, in correspondence to the zone seen as transparent, as if the first disk makes the second one transparent but simultaneously projects its shadow, altering its colour" (Musatti 1955, page 41).

What happens is that, as the difference in brightness is equalised, a shadow is formed which makes the surfaces appear curved. The effect is probably due to both (i) the absence of constancy and (ii) a significant perceived diversity between the two superimposed figures.

In this case, there seems to occur some sort of ontological reinforcement of the stereokinetic corporeality—on the basis of the doubling of a single sensory process into two perceptive objects characteristic of the transparency phenomenon—with the *visibility* of the apparent shadow of one of the two objects, the one on top, being projected onto the object beneath.

Also, this phenomenon, according to the Benussi–Musatti theory, is due to the likening of the phenomenon to prior experiences of illuminated bodies, of the shadows that they produce, and in particular of the relationships between a source of light, the objects that intercept that light, and the shadows projected by those objects. Specifically, one may hypothesise that changes in brightness on the surface of an object in *visual space* are usually due to changes in illumination rather than to changes in the reflectance properties of its different parts.

Of particular interest in this area of research is the definition of a surface due to the rotational movement of other surfaces, a phenomenon subsequently analysed from 1940 onwards by Metelli, who gave it the name of "totalisation", and whose experiments were the prelude to large part of later studies on amodal perception (Metelli 1940, 1975).

Tommasi, Zavagno, and Vallortigara have recently described a variation of the rotating ellipse, reporting that rotation of a *grey shaded ellipse* on a white or a black background produces the compelling illusion of a uniformly tilting disk which presents the following characteristics:

> "1. A *dark smoke* appearing to slide independently in front of it, when rotated on a black background.
> 2. A *dazzling fog* moving independently in front of it, when the colour of the background is white. In this case the source of the dazzling light appeared to be located behind the disk.
> 3. An *attached shadow* when the background is grey. Here the shadow appears to be produced by a light source which seems to continuously change its position with respect to the object" [Tommasi et al 2001. (On these different stereokinetic objects cf also Bressan and Vallortigara 1986.)]

There has been no further theoretical analysis or experimentation since Musatti, however, apart from Metzger's above-mentioned variation on a particular aspect of the stereokinetic transformations which occurs in cases of sphericalisation: namely the *visual presence of shadows* in the experiment involving a truncated cone with dashed lines.

5 What theory of stereokinetic objects?

Musatti's experiments were originally based, as I have said, on the theory of the Graz school, which sought to explain so-called optical-geometric illusions, not as illusions but as particular perceptions of shape and therefore endowed with a specific *structure* (Benussi 1904, 1905, 1906, 1911, 1914; Albertazzi 1999, 2001a, 2001b, 2001c).

More generally, *inadequate presentations* specifically concern *qualitative change in the contents*, owing to the fact that when the elementary presentations are comprised in real complexes they give rise to contentual and/or objectual *changes* in what is presented.

In particular, according to Benussi and Musatti, psychic phenomena display the characteristics of *presence* and *absence* (Musatti 1964, page 40), and specifically:

Presence	localisable	perceptive data
	non-localisable	introspective data
Absence	indeterminate	fantasy
	determinate	memory

According to this grid, stereokinetic phenomena pertain to the domain of *presence*, ie they are *localisable, perceptive data* which constitute the *empirical reality* [on the four kinds of reality construction in Musatti (cf Musatti 1964, chapter 1)].

In general, Benussi's theses exerted a theoretical influence on Musatti. The 'Grazer' side of Musatti's theory consists in its assumption that *perceptive data* can be subsumed in various ways and at various levels under diverse cognitive or *perspective* constructions which give rise to different types of *objects*.

As regards the *corporeality* of stereokinetic phenomena in particular, Musatti drew on the teachings of Benussi, as we have seen, to explain such phenomena on the basis of processes of the assimilation of rigid objects drawn from *organised systems of sensory experience* which operate in actual perception as the *place* where those phenomena are *located*, ie as *field phenomena*.

Subsequent experimentation has confirmed the results of Benussi and Musatti, but it has led to the formulation of new hypotheses in explanation of stereokinetic phenomena. In general, however, the *philosophical* connotation of the context of analysis *has been lost*.

The various explanations put forward [for a critical review and bibliographical information see Zanforlin (2000); see also Fineman (1981, chapter 8); Robinson (1998, pages 179 – 188)] generally split up between those that refer to the 'rigidity assumption' and those that refer to theories based on the velocity of the 'local structure' of the surface [on the rigidity assumption hypothesis cf Ullman (1984a, 1984b)]. Metzger has emphasised the role performed by the conservation of the identity of figures in movement, while Wallach and O'Connell have likened it to the *kinetic depth effect*, in which movement between the various points of the pattern is also present [in particular, the phenomenon should be due to the action of two components: (i) variation in the direction of the lines and borders of the figure in motion, and (ii) variation in size (Wallach and O'Connell 1953)]. On discussing the latter aspect, Tampieri (1968) suggested that all that is necessary to explain the phenomenon is the change in size of the figures due to modification of the areas marked out by the lines. In order to explain the apparent height of the stereokinetic cone, Zanforlin refers to a process which minimises the differences

in relative velocity (VDM) among all the points of the moving pattern (ie all the stimuli in movement) and which derives from the 'minimum principle' formulated by Koffka (Koffka 1935; Zanforlin 1988a, 1988b). The important consequence of this hypothesis is that the impression of depth may occur even in the absence of variations in the magnitude of the stimulus, as long as it varies in velocity (Zanforlin 1988b, 2003). The VDM hypothesis would thus explain, besides the stereokinetic transformation of the rotating ellipse into an elastic and rigid disk, and into an egg-shaped object, also the fact that the spheroid in question does *not* appear because it does not constitute a minimum solution, unless several appropriate semi-elliptical lines are added to the ellipse's uniform surface (Zanforlin 2000, page 167).

Zanforlin has also examined the difference between Kanizsa's anomalous contours and other types of anomalous contours, as well as stereokinetic ones, which do not occur in stationary or translational movement but appear only in the third dimension—which once again highlights the complexity of the visual corporeality of such objects [Zanforlin (2003); other kinds of anomalous contour have been described, among others, by Purghé and Coren (1992) and Bruno and Gerbino (1991)].

No further analysis has been conducted on the nature of assimilative phenomena as field phenomena in the theoretical sense, but Koenderink's proposal of *homology fields* [Koenderink (2002); from an experimental point of view, cf Taya et al (1995); and with regard to neurophysiology of colour assimilation, Spillmann and Werner (1996), and Kelly and Grossberg (2000)].

6 Towards a theory of visual space

Independently of the individual hypotheses formulated, and which have been very briefly summarised here, all the explanations put forward on the corporeality of stereokinetic objects emphasise certain characteristics of visual space:

1. Strictly speaking, visual space is neither Euclidean nor projective in nature, and there is still no 'geometry' with which it can be described. The fact that continuous movement is a cause of the perception of depth, in fact, cannot be deduced by geometric calculation [on this point cf Perkins (1976); Perkins and Cooper (1980); and Proffit et al (1992)].
2. The boundary, velocity, direction, and movement of visual space are primitives endowed with a structure different from physical space and cannot be reduced to it (Albertazzi 2002a).
3. Continuous common-fate movement is one of the primary sources of the impression of corporeality of the objects in this space.

Benussi's and Musatti's experiments in analysis of the perception of the corporeality of the objects of visual space are therefore of particular *theoretical* interest to the current debate, because they offer suggestions for a number of important problems in the theory of perception. Their main points of relevance to the debate can be summarised as follows.

1. The problem of the relationship between *natural* factors and *empirical* factors.
2. The presence of *phases* in actual perception.
3. The difference between *perceptive presence* and *mental presence*.
4. The *structure of visual space*.
5. The *identity* of perceptual objects.
6. The problem of the *shadow*.

As regards the first point, analysis of assimilative phenomena—which Musatti believed to be responsible for stereokinetic objects—is an *alternative* to the theory of perception as inference based on mnestic traces, or of perception as hypothesis (Gregory 1998). Assimilative phenomena, in fact, are *field organisations of past experience*, not individual representations.

Assimilative phenomena therefore belong among the first-level *subjective integrations* in that they arise during the perceptive duration (Musatti 1964, page 262). They tend towards the homogeneity or improvement of form in similar manner to the classic laws of Gestalt, in the sense that if the perceptive element fits imperfectly with the system of experiences in which it is *located*, it undergoes a transformation that tends towards a general improvement of the complex as an assimilative gradient (Musatti 1931; reported in Musatti 1964, pages 255 and 262). Assimilative phenomena are particularly powerful in common-fate renderings.

As regards the second point, the one concerning the presence of *phases in actual perception*, also this aspect is currently a matter of debate, as it was at the beginning of the 1900s among the Gestalt experimentalists, and in particular between Koffka and Benussi (cf Benussi 1912; Koffka 1915). Following his polemic with Koffka, Benussi made some changes to the original theory but, as evidenced by his later writings, he never abandoned the idea of a *time of the formation of the percept*. The distinctive feature of Benussi's work was precisely that of investigating the *presence of phases in actual perception*, ie of layers internal to the act of perception able to explain, for example, the *unfolding corporeality of stereokinetic objects*. Visual space, in other words, is defined by *spatiotemporal fields* strictly *connected to the observer's interaction* (Lappin and van de Grind 2002).

As to the third point, the difference between *perceptive presence* and *mental presence*—which was originally formulated by Benussi and inherited, via Musatti and Metzger, by Kanizsa—concerns precisely the corporeality of stereokinetic objects. The aspect of a cone undergoing three-dimensional transformation may vary (from a cone to a bowl) but it remains an object seen stereoscopically; and corporeality, shape, and colour are likewise experienced with perceptive evidence. Benussi showed the difference between this situation of *evidence* and another situation, prior to the rotation of the disk, in which the cone, bowl, etc, may be *thought*, ie given in mental presence. The late Benussi hypothesised that stereokinetic phenomena are due to the transformation of mental presence into perceptive presence, because the idea of a corporeality given by a perspective shape is transformed into a seen corporeality (Benussi 1925a, 1925b; Musatti 1955, § 13, page 44).

As regards the fourth point on the nature of visual space, the contemporary debate comprises a variety of perspectives (neurophysiological, psychophysical, computational theories). In general, all these perspectives, even when they assume a dynamic position, focus on visual *states*, that is on the 'seen' rather than on the *process* of 'seeing'. Less analysed—but only by scholars dealing with attentional phenomena (for a review cf Scholl 2001)—therefore, is the *morphogenesis of seeing in actual perception*, which raises the question of the intrinsic processuality of visual objects as they form themselves within the field [ie the representation of the perceptual field into discrete units; on formation of perceptual objects cf Kanizsa (1994, page 153)]. Stereokinetic phenomena are paradigmatic examples of this process, for the reasons stated at the outset (section 2). They are not 'veridical' objects in standard sense, in fact, but in some way objects *operating on the representational structures of vision*, and the laws of their unfolding furnish the best understanding of the dynamics of actual perception. More in general, the *complexity of their corporeality* in the various transformations to which they give rise evidences the nature of perceptive objects as *field objects*.

The fifth point concerns the identity of perceptive objects (Michotte et al 1921; Metzger 1934; Albertazzi 2002b). Perceptive objects should not be reduced to or confused with physical objects, which are produced by a different, and in certain respects more complex, kind of cognitive completion and with respect to which constitute themselves independently on the basis of their own laws of organisation. Their identity is constituted by all the forms of stability, tendency to the minimum, continuity,

smooth change, and configurational movement. From this point of view, stereokinetic objects are a paradigmatic example of this type of identity. The images that remain on the retina are always the same in every phase of the movement, before and after the three-dimensional transformation, and this shows that the set of stimuli gives rise to two distinct perceptive solutions: (i) the relational aspect, which remains constant (distance, for example), and the objectual aspect (the shape), which changes until it assumes the solution which it stably maintains (Musatti 1964, page 314). In particular, as shown by transparency phenomena, in the double representation—to which the general law of figure/ground applies—we can see one object on top of the other or one object beneath the other.

Finally, as concerns the problem of shadows, Musatti's experiments prompt further considerations on the corporeality of perceptive objects, in that the shadow, as *fantasmatic appearance*, emerges in the phenomenal field even independently of a modally given object.

The shadow may make its appearance as a higher-order object *on the basis of assimilative conditions applying to the entire complex in movement* (as happens in stereokinetic phenomena), and which this thus further increases its homogeneity.

To conclude, we may say that the specific characteristic shadows are not objectual, because they refer to illumination, but they sometimes assume a certain degree of perceptual reality. With reference to Michotte's ideas (Thinès et al 1991), shadows can be thought as *located along a continuum* characterised by different degrees of reality: at one extreme the maximum shadow/light appearance devoid of any surface characteristics (a cast shadow of a flying object), at the other end the minimum shadow appearance which coincides with the surface appearance, passing through different stages in which a shadow looks like a transparent film, varying in darkness and density; analogously, in the phenomenon of fluorescence a surface is seen at about midway between reflecting and emitting light (I owe this reference to Da Pos).

All these aspects presented by stereokinetic objects shed light on the particular and complex geometry of visual space and its multiple and multifarious appearances, shadows included.

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