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GROUNDING NAÏVE PHYSICS AND OPTICS IN PERCEPTION

ABSTRACT: Many adults hold mistaken beliefs concerning the behavior of mechanical motion and reflections. In the field of psychology this has been investigated in the areas of naïve physics and naïve optics. The interesting question regards where these false beliefs come from. Particularly thought-provoking is the case of errors which are at odds not only with (presumably or even actually) known physical/optical concepts, but also with what people would actually perceive. Some errors are in fact consistent with what people see in ecological conditions while others apparently are not. This has led to the former being referred to as *perceptual errors* and the latter as *conceptual errors* (Lawson & Bertamini 2006). We propose that many of these 'conceptual errors' are generalizations of what can be actually perceived under some conditions that are then incorrectly applied under others. In this sense, they can be thought of as a second way in which perception shapes naïve beliefs.

1. ERRONEOUS BELIEFS IN NAÏVE PHYSICS AND OPTICS

In psychology there has been a great deal of research on the naïve beliefs that people hold about motion as studied in traditional mechanics. This research covers a number of areas: the trajectory and speed of falling objects (Bozzi 1959; Kaiser et al. 1985; McCloskey et al. 1983; Runeson 1974; Shanon 1976) and thrown objects (Hecht & Bertamini 2000; McCloskey et al. 1980; Shaffer & McBeath 2005); the dynamics of pendulum oscillations (Bozzi 1958; Frick et al. 2005; Jansson & Runeson 1969; Pittenger 1990), objects in rotation (Proffitt & Gilden 1989; Proffitt et al. 1990) and objects released after being rotated (McCloskey 1983a; McCloskey et al. 1980). This field of studies has been called naïve or intuitive physics.

More recently a similar area of study has investigated naïve beliefs concerning the behavior of mirror reflections: naïve optics (e.g. Bertamini et al. 2003; Bertamini et al. 2010; Bianchi & Savardi 2012; Croucher et al. 2002; Savardi et al. 2010).

Both areas of research have revealed that people hold a surprising number of erroneous beliefs. For example McCloskey et al. (1980) used simple paper-and-pencil tasks to show that despite the fact that many people study physics at school, they still expect a ball exiting from a curved tube (Fig. 1a) or flying from a sling (Fig. 1b) to continue along a curved trajectory rather than move straight along a tangent. They also believe that a ball carried by a horizontally moving object and then dropped will fall straight down or even in the opposite direction, i.e. backwards (Fig. 1c). Moving to naïve optics, many people expect that a person entering a room and making a parallel approach to a plane mirror will start to see their reflection at the nearer edge before they actually do see it (Fig. 2a) or that they will see it appearing at the mirror's farther edge rather than the nearer edge (Fig. 2b) (Croucher et al. 2002). Moreover, a significant percentage of adults don't expect the reflection of objects moving at various angles with respect to a mirror to follow symmetrical patterns, but to move along the same line either in the same allocentric direction (which means that if the object is moving towards the mirror surface, in the reflection it will move away from it — Fig. 2c) or in the opposite direction but still along the same line (Fig. 2d) (Savardi et al. 2010).

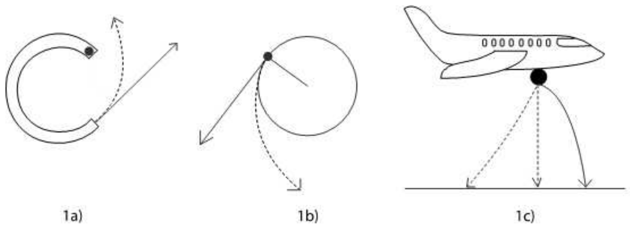

Figure 1: Many people expect the dashed trajectories represented in the figure rather than the correct continuous ones. McCloskey's tasks: 1a) C-tube problem: draw the path that the ball will follow on emerging from a curved tube if it is inserted into one end of the tube and then shot out of the other end; 1b) Sling problem: a ball attached to a string is twirled at high speed in a circle above a person's head — draw the path that the ball will follow after the string breaks (assume it breaks when the ball is at the point shown in the diagram); 1c) Airplane problem: an airplane is flying at a constant speed and altitude — draw the path that a ball dropped from the plane will follow until it hits the ground.

Furthermore, when asked to predict what part of the surrounding space an observer would see reflected in a mirror on a wall given various viewpoints, approximately 50% of adults for close viewpoints and up to 80% for greater distances expect the observer to see more or less the same field for both central and eccentric viewpoints — i.e. the space directly in front of the mirror plus a certain area beyond both its edges – represented, in Figures 2e and 2f by the gray areas delimited with dashed lines (Bianchi & Savardi 2012; Bertamini et al. 2010). However, although this is true for central viewpoints (in Fig. 2e the straight lines delimitate the correct area of visibility), for eccentric viewpoints one sees in reality an expansion at the father edge while part of the space in front of the mirror at the nearest edge is not visible (Fig. 2f — area between the straight lines).
Where do these false beliefs come from?

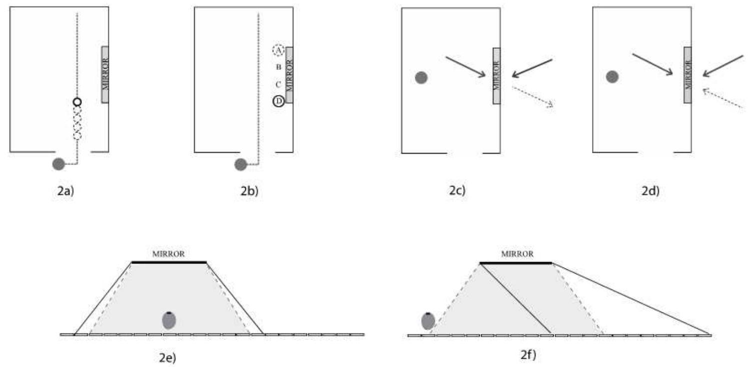

Figure 2: Some false beliefs concerning naïve optics — all are represented using aerial views. Many people expect a person entering a room and walking parallel to a mirror on the wall to see their reflection before reaching the near edge of the mirror (2a: dashed circles indicate where people expect their reflection to appear; the solid circle indicates where it would in reality appear). Alternatively they expect the person to see the reflection appear at the farther edge of the mirror (2b) in the position indicated by A (dashed circle); the solid circle indicates where it would in reality appear. Likewise a good number of people expect a person looking at an object moving towards a mirror along the path indicated by the arrow (Figures 2c and 2d) to see the reflection moving along the same trajectory with an identical orientation (2c: dashed arrow) or an opposite orientation (2d: dashed arrow). The reflection would in reality move as indicated by the solid arrow beyond the mirror. A person looking in a mirror from a central (2e) or eccentric (2f) position is expected to see more or less the same area reflected (gray area delimited by dashed lines) while the correct cone of view is very different (as delimited by continuous lines).

2. THE ORIGIN OF THESE ERRORS

2.1. An overview of the debate on the origins of errors in naïve physics

Right from the beginning of the debate on errors in naïve physics there were discussions about whether perception might be the cause of these errors, but the majority were inclined to look for other origins. For instance, Shanon, in his seminal study (1976) discovered that when asked about the speed of free falling objects, adults manifested the belief that objects fall with a uniform speed. This was as if they had totally forgotten the basic notions of Galilean-Newtonian physics that they had studied at school and were instead thinking in terms of the Aristotelian theory of motion. However, when these adults were questioned further, it seemed that there were no reasons to believe that their responses were based on actual knowledge of Aristotle's theory. Shanon wondered if the error was the result of what people perceive. He concluded however that this was not the case basing his decision on the results of an experimental study which, however, unfortunately included an error in the method used.[1]

The trend to attribute errors to naïve commonsense theories dominated the first decade of the debate. McCloskey suggested that people's false beliefs concerning the trajectories and speeds of objects in motion were founded on intuitive descriptive *theories* that people had in mind.

> "The interviews clearly indicated that at least 11 of the 13 subjects relied heavily upon a well-developed naïve theory of motion in order to find an answer to the problems. Remarkably, all 11 subjects held the same basic theory. This theory, which we will refer to as a naïve *impetus theory*, makes two fundamental assertions about motion. First, the theory asserts that the act of setting an object in motion imparts to the object an internal force or 'Impetus' that serves to maintain the motion. Second, the theory assumes that a moving object's impetus gradually dissipates (either spontaneously or as a result of external influences) and as a consequence the object gradually slows down and comes to a stop" (McCloskey 1983b, p. 306).

The concept of a descriptive propositional theory initially received a general consensus, despite McCloskey, Washburn and Felch's (1983) suggestion that the expectation that a falling object would not follow a parabolic trajectory (e.g. in the airplane condition in Fig. 1) might be based directly on perception:

> "because of a visual illusion, objects dropped from a moving carrier are often perceived as falling straight down. The straight-down belief may develop directly from this misperception" (McCloskey et al. 1983, p. 642).

Studies on induced motion had indeed shown that when an object is viewed against a moving frame of reference, the motion of the object *relative to the frame* is perceived as being *relative to the environment*. For example, given a stationary dot inside a rectangle which moves to the right, as the rectangle moves the dot is also perceived to move — not to the right, but to the left (Duncker 1929/1939; Wallach 1959). Similarly, when an object is dropped from a moving carrier and the latter remains visible while the object drops (which is usually the case), if the carrier moves with a speed perceived as constant, the dropped object is perceived as falling straight down with respect to the ground or as moving backwards (McCloskey et al. 1983, exp. 3). This was also found when realistic stimuli were considered, e.g. a video of a walking person dropping a ball from shoulder height, or a video of a ball pushed along the top of a filing cabinet until it falls off (McCloskey et al. 1983, exp. 4).

If one accepts that perception plays a role in the aforementioned errors and then looks at the literature on naïve physics between the late seventies and the late eighties from this perspective, one notices that researchers were divided into two camps: some defended the hypothesis that naive beliefs were manifestations of implicit theories, i.e. "general laws" (e.g. McCloskey 1983a,b; Proffitt & Gilden 1989; Proffitt et al. 1990) while others suggested that the errors were based on what people perceive (Bozzi 1958, 1959; McCloskey et al. 1983; Pittenger 1990; Runeson 1974). There were different sets of data supporting one or the other of these positions. Somewhere in between there was also a third point of view, which was interesting but did not receive the attention it deserved (at least in our opinion). Using a cleverly designed experiment, Yates and colleagues (1988) demonstrated that people change their responses when the superficial structure of a problem alters. This occurs despite the fact that the underlying physical laws remain the same. For example, in the C-shaped tube task (Fig. 1a), after responding to the traditional version of the problem, participants in the experiment were invited to focus on the path of the ball inside the cylinder instead of at the exit ("imagine being inside the ball moving through the C-tube along the outer wall…"); in the sling problem (Fig. 1b), they were encouraged to imagine the outward pull and relatively low velocity that would be felt by a person being swung around by the arms and think about the forces that that person would feel just before and just after being released. This change of "focus" led people to consider the effect of the spin of the ball in the C-tube (which was frequently ignored in the original formulation) and they thus more frequently predicted that the ball would follow a curved path (rather than moving straight along the tangent) or they exaggerated the curvature of the path. The change in focus in the sling problem meant that people were more likely to take the concept of centrifugal forces into consideration — something which was often disregarded in the traditional version of the problem.

This sensitivity to the superficial structure of a problem was at odds with the hypothesis that participants were following a general principle or a general theory. It was more compatible with the hypothesis that people were enacting prototypical mental models of situation-specific behaviors (Yates et al. 1988). Evidence that responses followed a concrete act of imagination (mental enactment) of a specific situation was not only confirmed by the reports made by participants, but their behavior also supported this: very often, before responding, participants closed their eyes and accompanied the motion that they were imagining with body movements (made with the hands, forearms or head).

Imagining prototypical mental models is thus to be considered a third potential source of the errors, but in this case the question regarding the role of perception is only reformulated, not resolved. Indeed, an urgent issue concerns the origins of these prototypical mental images. In other words, we need to understand the relationship between the simulated/imagined situation and the "corresponding" perceived situation. Yates and colleagues leave this question open. Later studies showed that visualization plays an important role in mental imagery

related to physical and mechanical motions (e.g. Frick et al. 2005; Hegarty 1992; Huber & Krist 2004; Schwartz 1999).

2.2. Hints from naïve optics

To date there have been no debates which specifically discuss the origin of the false beliefs regarding the behavior of reflections. The main aim of researchers into naïve optics seems to be to increase the database on which a theoretical discussion might be founded. A first attempt to categorize errors, however, has been put forward by Lawson and Bertamini (2006) who suggest distinguishing between perceptual and conceptual errors. Some errors in naïve optics are in fact consistent with what people see in mirrors in ecological conditions and these are called 'perceptual errors'. Other types of errors are not consistent and these are known as 'conceptual errors'. The critical point when distinguishing between the two is whether visual feedback makes the erroneous belief disappear or not. For instance, people greatly overestimate the size of the reflection of their face *on the surface* of a mirror. This is known as the overestimation error (Bertamini & Parks 2005; Lawson & Bertamini 2006) and this is a case of perceptual error. The reflection is exactly half the width and half the height (so quarter the area) of the observer's actual face, but people estimate the reflection to be around the same size as their real face. This happens because people do not see the mirror image *on the surface* of the mirror but *behind the plane* of the mirror. Gombrich (1960) was the first to suggest drawing the outline of the reflected face on the surface of the mirror with a felt-tip pen so that a contour which corresponds to the size of the reflection of the observer's head can be seen. People are usually surprised by how small this outline is but in ecological observation conditions we do not really see anything *on* the surface of a mirror: the mirror appears to be transparent (like a window) and the reflection seems to be *beyond* it. When we are asked to estimate the size of our face in a reflection, what we estimate is the size of the object visible "beyond" the surface of the mirror. We estimate what we see and the error we make demonstrates this.

Extending Lawson and Bertamini's classification to the phenomena studied in naïve physics, the errors people make when predicting the uniform motion of free falling objects are another example of perceptual errors: they *perceive* the motion of objects falling straight down or along inclined planes as uniform (Bozzi 1959; Runeson 1974) and therefore it is not surprising that they *predict* uniform motion when they are asked to imagine it (Shanon 1976). Similarly, when people look at liquid in an inclined container, they do not see the surface as being parallel to the ground but perceive it as slightly inclined (Sholl & Liben 1995). The container functions as a proximal frame of reference and induces this effect. Therefore it is not surprising that when people are asked to draw liquid in variously inclined containers, most of them predict that the surface will be inclined and not parallel to the ground (McAfee & Proffitt 1991).

We can be surprised by these errors because they contrast with elementary notions that we are supposed to *know*. Particularly thought-provoking, though, are the errors which are at odds not only with presumably or even actually known physical/optical concepts, but also with what people would in fact normally perceive. Nobody, when walking parallel to a plane mirror, has ever seen their reflection before reaching the nearer edge (Fig. 2a) and neither have they seen their reflection appearing at the farther edge of the mirror (Fig. 2b) or moving as represented in Figures 2c and 2d. And nobody has ever seen that a mirror reflects the same portion of a room independently of whether the observer is positioned centrally or laterally with respect to the mirror (Fig. 2e-2f). *Strictly speaking*, the origin of these latter errors has nothing to do with what people see and, in fact, when visual feedback is provided and they are asked to repeat the task while looking at reflections in a mirror, these errors disappear. These are, in Lawson and Bertamini's (2006) terms, 'conceptual errors'. By 'conceptual' the authors simply mean errors which are not due to behaviors that people have seen in ecological conditions. The authors, however, are not committed to any particular hypothesis about the origins of these errors. In one passage they seem to suggest that the problem might concern an incorrect memory of past experience ("many people fail to store readily accessible information from their past experience of mirrors", p. 1284), but in another passage they give credit to Bertamini, Spooner and Hecht's (2003) hypothesis that "it is difficult to generate the virtual world seen in a mirror from knowledge of the real world, because no rigid transformation in 3-D space can achieve that. People may resort instead to transformations that they can imagine, such as a rotation around a vertical axis"

(Lawson & Bertamini 2006, p. 1284). They go on to explicitly state that further research is needed to elucidate the origin and content of these incorrect beliefs (cit., p. 1284). What is certain (and this is what they want to emphasize when they compare the different classes of errors) is that these errors lack perceptual support: they are eliminated if people can see an uncovered mirror in which the reflection is visible.

In the next section, taking advantage of some results from experiments in naïve optics and gleaning from discussions on naïve physics, we will suggest a hypothesis to explain where these errors come from.

2.3. *A proposal: two ways in which erroneous beliefs can be grounded in perception*

We propose that the 'conceptual errors' discussed above are in any case shaped by what people see. These erroneous predictions are in fact based on generalizations of salient perceptual aspects *which have been perceived* in ecological conditions.

For example, when asked to predict the orientation of a reflection or its movement starting from the real object/movement, people recall the rule that 'a reflection does the same' and/or the rule that 'a reflection does the opposite' as their visual experiences have led them to believe. In fact, when looking at the reflection of their body in a plane mirror set vertically on the wall in front of them or set horizontally on the floor or ceiling, adults notice both the identity of the reflection with respect to their real body and its allocentric spatial opposition ("I'm facing this side of the room, the reflection is facing the opposite side"; or "I'm upright, the reflection is upside-down"). This allocentric opposition is constantly present in mirror reflections of one's own body and is noted by observers as a salient feature (Bianchi & Savardi 2008). It is even more evident than the egocentric left-right reversal that is also present and that psychological literature on mirror reflections has emphasized for years (e.g. Gregory 1996; Haig 1993; Navon 2001; Tabata & Okuda 2000; Takano 1998; Takano & Tanaka 2007). In the same way, reflected gestures that move in an opposite allocentric direction with respect to the real gesture are recognized as opposite, independently of whether the reflection is on a mirror in front of the observer, to the side, or under their feet (Bianchi & Savardi 2008).

Furthermore, a study investigating the relationship perceived between objects or movements and their reflections in a vertical frontal mirror (Savardi et al. 2010) proved two things. First, when asked to describe the movement of the reflection of a simple object with respect to the real movement, adults tend to choose the terms 'identical' or 'opposite' as being the most suitable; when observing objects moving parallel or almost parallel to a mirror (namely at 0° and 22.5°), they see the reflected movement as identical to the real one; an impression of opposition is instead associated with seeing something moving orthogonally (90°) or almost orthogonally (67.5°) towards the mirror. Secondly, with static objects, whether people describe the reflection as 'identical' or 'opposite' depends on which axis shows the most evident asymmetry: when the axis is parallel to the mirror surface, participants describe the orientation of the reflection as 'identical' to the real object; when the axis is orthogonal to the mirror surface, participants describe the orientation of the reflection as 'opposite' with respect to the real object.

All these results suggest that the best geometry for modeling what people have in mind when thinking about the spatial structure of reflections is not based on the geometrical transformations that are normally used to explain mirror symmetry, neither is it a rotational model. Rather, it concerns identity and opposition (Bianchi & Savardi 2009). The blatant error that people make when they approach a mirror from the side walking parallel to it and predict that their reflection will appear at the farther edge of the mirror moving towards them (Fig. 2b) is compatible with the heuristic that 'reflections do the opposite'. The same can be said for the error shown in Fig. 2d, whereas the error represented in Fig. 2c is compatible with a generalization of the rule that 'reflections do the same'.

Similar explanations work well for other errors in naïve optics, such as looking at a reflection and expecting to see the area beyond the left and right edges of the mirror (Figg. 2a, 2e, 2f). When people look in mirrors either intentionally or by chance in everyday life their eyes are not usually aligned with one of the mirror edges. It is certainly more common for observers to find themselves in different positions with respect to a mirror (either directly in front of it or beyond its edges) and thus the incidence of their line of vision is at different angles. In each case, large portions of the real world beyond the edges of the mirror are

visible: when an observer is positioned "inside" the mirror edges, this holds for all four edges; when he/she is displaced laterally, this holds for all the edges except the nearest. In other words, people normally perceive an expansion. If they do not carefully analyze what happens at the nearer as opposed to the farther edge of a mirror (or consider what will change depending on different viewpoints), they will easily generalize the experience that a mirror reflects the world beyond its boundaries, and hark back to this prototypical behavior in prediction tasks.

3. CONCLUSIVE REMARKS

The hypothesis put forward in these pages in a sense adds to the concept of 'imagination of prototypical events' suggested by Yates and colleagues (1988) with respect to naïve physics and also the idea of 'conceptual errors' introduced by Lawson and Bertamini (2006) in relation to naïve optics. It does so by proposing that there are at least two ways in which predictions about "how the world behaves" are shaped by perception.

When these predictions *reflect what people actually see*, the link is clear. But when they do not, before excluding the possibility that they are grounded in perception, it is worth wondering whether they manifest a *generalization to incorrect conditions* of the aspects which actually characterize some perceptual experience. In other words, the point is that only part of what people see (some local or global properties, some directly noticed relations) pops out as being salient to the event. This is basically decided by laws of perceptual organization, given various attentive conditions — which indeed characterize ecological perceptual experiences. The challenge for psychologists is to discover what becomes salient and why.

We have focused our analysis on a specific class of phenomena (the motion of objects and the behavior of reflections in plane mirrors) since this has allowed us to support our argument by making reference to specific experimental studies and the corresponding findings. However, the claim we put forward here has a wider field of application and a broader impact and indeed it sheds light on the ways in which cognition is grounded in perception (e.g. Barsalou 2010; Pecher & Zwaan

2005). Moreover, it has already been pointed out that a phenomenological investigation of the naive-physical realm and of the associated value-laden dimensions of the world of direct experience (in terms of the Gestalt-theoretical approach to external reality, e.g. Köhler (1976) as well as Gibson's (1979) ecological approach to perception and Bozzi's *Naive Physics*, 1990) would offer a unifying, realistic, theoretical account of a natural ontology (Smith & Casati 1994).

Notes

[1] He showed participants ten displays showing falling balls, but the duration of the fall on the screen was very brief and participants had difficulty in "seeing" what was going on in the short lapse of time. To overcome this problem, he thought that a reasonable solution was to slow down the motion. But he did not realize that participants were no longer seeing (and judging) the characteristics of motion of free falling balls, but wereinstead observing the motion of an object falling through dense jelly. (Observation reported by Bozzi, 1990).

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