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Differences between predictions of how a reflection behaves based on the behaviour of an object, and how an object behaves based on the behaviour of its reflection

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ABSTRACT

We studied adults' understanding of the relationship between objects and their reflections. Two studies investigated whether adults performed in a similar way when asked to predict the movement of a reflection in a flat mirror based on the movement of the corresponding object or, vice versa, predict the movement of the material object based on the movement of its reflection. We used simple movements in the experiments: movements in a straight line at various angles with respect to the mirror. Despite the simplicity of the task, some of the participants made incorrect predictions in a percentage of cases ranging from 0% to 54%, depending on the angle. Asymmetries between the two directions of prediction emerged, in particular in terms of types of error. Results confirmed a cognitive difference between deriving the reflected (virtual) world from the "real" (material) world and vice versa. In particular the expectation that something will be *opposite* in a mirror is more salient when people imagine *how a reflection will be with respect to the material world* rather than when they imagine how the material world will be with respect to a reflection.

1. Introduction

> "…there's the room you can see through the glass — that's just the same as our drawing room, only the things go the other way."
> [Lewis Carroll (*Through the Looking Glass and What Alice Found There*, 1871, p. 8)]

Mirror reflections are common phenomena in modern environments and the fascinating history of mirrors has been the subject of a number of popular books (Melchior-Bonnet, 2001; Pendergrast, 2003). We interact with mirrors on a daily basis, for instance when driving, in a gym or a dance class, or in the morning before leaving home when we glance in the mirror to see if we look alright. Interacting with mirrors requires some understanding of the *correspondence* between what we see in a mirror and the object that exists outside the mirror, but this understanding may be implicit or explicit. Some studies have documented the reasoning that people go through regarding the *correspondence* between material objects and reflections (see next section), but an issue that has not been systematically investigated is whether this correspondence is symmetrical or not: is the answer the same when people are asked to *predict one feature of a material object based on its reflection* or, vice versa, *predict one feature of a reflection based on its material counterpart*? From an optical and geometrical point of view the transformation is symmetrical and the question might sound silly. But studies on naïve physics (e.g. McCloskey, 1983a, 1983b; McCloskey, Washburn, & Felch, 1983; McCloskey, Caramazza, & Green, 1980) and naïve optics (e.g. Croucher, Bertamini, & Hecht, 2002; Lawson & Bertamini, 2006; Bianchi & Savardi, 2012) have clearly demonstrated that people do not necessarily reason in terms of the physical or optical laws which they were exposed to at school (and which in many cases they only recall as explicit knowledge) when they make predictions about the trajectory or speed of moving objects or about how reflections in mirrors behave. They base their prediction on what they imagine and imagining slightly different scenarios alters their prediction. A paper which epitomizes this is Yates et al. (1988) which shows how people radically change their prediction concerning the trajectory of a moving object in situations when small changes to the imagined scenario are suggested even if the scenarios are all subject to the same physical laws. Therefore, any differences discovered between predictions about movement in a reflection based on the imagined movement of the corresponding material object and, conversely, predictions about the movement of a material object based on its reflection would help us to understand how people think of mirrors from a cognitive point of view rather than in merely optical–geometrical terms. In the present paper we describe two experiments involving

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predictions of simple movements and analyse the results. In the first experiment we used a paper and pencil task, and in the second a real-life setting.

1.1. Predicting the correspondence between an object and its reflection

Memory for layouts is generally very good in humans (Simons, 1996). The layout of a scene is matched by the layout of a reflected scene. Various studies have directly or indirectly addressed the issue of how people understand this relationship, but they have never taken into consideration whether the perception of this relationship is identical in both directions, i.e. from a reflection to the material world or vice versa.

1.1.1. Correspondence of size

People are accurate when they make judgments about the size of a material object starting from the corresponding reflection (Bianchi, Savardi, & Bertamini, 2008; Higashiyama, 2004; Higashiyama, Shimono, & Zaitsu, 2005; Jones & Bertamini, 2007). The situation is very different when judging the size of an image on the surface of a mirror: predictions of the size of the reflection of one's own head, of another person's head, or the size of a simple figure are, for example, biased (Bertamini & Parks, 2005; Lawson & Bertamini, 2006; Lawson, Bertamini, & Liu, 2007). However, in this study we will not consider the information on the mirror surface and focus instead on the link between material and virtual objects.

1.1.2. Correspondence of location

Another aspect concerns the correspondence between *the position* occupied in space by an object or body and that of its reflection. It has been shown that people are reasonably accurate when they judge the orthogonal distance of an object from a flat mirror surface basing their assessment on its reflection (Higashiyama & Shimono, 2004). However, when lateral positions are involved they are less accurate. For example, 20%–40% of adults expect a person entering a room and moving parallel to a mirror surface to see their reflection appear at the far edge rather than the near edge of the mirror (Bertamini, Spooner, & Hecht, 2003). Similar errors are found with movements at various angles of incidence with respect to the mirror (Savardi, Bianchi, & Bertamini, 2010). Moreover, many adults expect to see what seems to be a slight expansion of the space directly in front of the mirror in a reflection, independent of the observer's viewpoint (Bertamini, Lawson, Jones, & Winters, 2010; Bianchi & Savardi, 2012; see also Croucher et al., 2002). This also holds for depicted scenes (Bertamini, Latto, & Spooner, 2003).

1.1.3. Correspondence of orientation

For decades psychologists have been discussing how reflections display a reversal of the left-right orientation (Corballis, 2000; Gardner, 1964; Gregory, 1987, 1996; Haig, 1993; Ittelson, 1993; Ittelson, Mowafy, & Magid, 1991; Morris, 1993; Navon, 1987; Tabata & Okuda, 2000; Takano, 1998). Recently, it has been demonstrated experimentally that this reversal – defined in terms of the intrinsic frame of reference of an object or body – is not the only reversal characterizing the structure of reflections and neither is it the reversal which adult observers notice first: what they notice and describe is the *opposite* orientation of reflections along the axis which is orthogonal to the mirror with respect to an *allocentric* frame of reference (Bianchi & Savardi, 2008; Savardi et al., 2010). It is also important to remember how mirrors are used in everyday life and in particular in relation to faces. People generally see their own face from a frontal view. As a consequence, self-recognition has been found to be superior for full-frontal views as compared to other viewing angles, but this pattern does not extend to the recognition of other people's faces (Laeng & Rouw, 2001; Troje & Kersten, 1999).

These three types of correspondence and people's expectations concerning them are also often used in depicted scenes or manipulated in artworks that make use of mirrors, as exemplified by Bertamini, Latto et al. (2003); Hockney (2006) and Savardi and Bianchi (2014).

1.2. Psychological models of the correspondence between material and reflected objects

In terms of optics, there is a simple principle underlying reflections in a planar mirror. The ray of light forms incidence and reflection angles that are equal and coplanar, and the distances of the corresponding points along these rays are also equal. However, cognitive scientists have shown that even when adults have explicit knowledge of this law, they do not use it to predict the behaviour of reflections. This was revealed when participants in an experiment were asked to predict when a person walking parallel to a mirror hanging on a wall would start seeing his/her reflection or the reflection of another object (Croucher et al., 2002). The same occurred when, in another experiment, the participants were requested to predict the extension and angle of a mirror's field of view, given various positions of the observer (Bianchi & Savardi, 2012). Beyond these two studies, which directly tested whether people possess an explicit knowledge of the physical rule of reflection even if they do not use it, one can in general maintain that all the errors reported in the literature on naïve optics are indirect proof that people do not apply the correct physical rule. If people were applying it, errors would be rare.

Psychologists have tried to understand how naïve subjects connect the reflected world with the material world. Some of the initial hypotheses, which resulted from the debate on the mirror question and the left-right mirror reversal (e.g. Corballis, 2000; Gregory, 1996; Tabata & Okuda, 2000; Takano, 1998), called into play viewpoint reversals, representational reversals and optic reversals. Recently, on the basis of various different types of errors made by adults (including left-right reversal), two further hypotheses have been put forward. We refer to these as the "rotational geometry hypothesis" and the "vector geometry hypothesis".

1) Rotational geometry: People may think of the virtual world in a mirror in terms of a rotation of the world through the surface of the mirror. This was first suggested by a localization error discovered when participants in an experiment were asked to predict in which part of a mirror a person walking parallel to it would see their reflection appear. Around 20–40% expected it to appear at the farther rather than the nearer edge (Croucher et al., 2002). This is compatible with the idea that they expected the virtual world to be rotated 180° with respect to the material world. However, when the participants were asked to identify the correct reflection from a series of pictures showing a room and its reflection in a mirror, they were able to say that the picture where the reflection showed a 180° rotation of the room was incorrect (Croucher et al., 2002). In another study participants were asked to look at reflections of simple objects and describe the relationship between the reflection and the object. Participants almost never described the reflection as being rotated with respect to the object (Savardi et al., 2010, exps. 4–5). These results suggest that although some data is compatible with the idea that people think of reflections in terms of a rotation (Hecht, Bertamini, & Gamer, 2005) this is not a heuristic that people consciously adopt. The rotational hypothesis has been re-proposed in a less radical version by Muelenz, Hecht, and Gamer (2010). They showed that the reconstruction of the virtual world is systematically rotated counter-clockwise by an average angle of two degrees. However, as pointed out by the authors, this rotational error accounts for small quantitative errors of localization but does not explain more blatant qualitative errors such as those previously mentioned.
2) Vector geometry: These more serious qualitative errors have led researchers to wonder whether the correspondence between material and reflected worlds is cognitively modelled in terms of identity and opposition (Bianchi & Savardi, 2008, 2009; Savardi et al., 2010). This