
The relationship perceived between the real body and the mirror image

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Abstract. We analyse here people's perception of their reflections in mirrors placed in different positions. In two experiments, participants looked at their mirror image, in a third experiment they looked at another person's image. In both cases they were asked to answer a series of questions about how the virtual body appeared relative to the real body, focusing on different aspects. In experiment 1, they were asked to decide whether the reflections were identical, similar, different, or opposite in terms of the global relationship, orientation, and lateralisation (left–right arm). In experiment 2 they were instructed to make simple gestures and to evaluate if the gestures in the reflection were identical, opposite, similar, or different from theirs. Results show that 'identity' was preferred when the mirror was in front, and 'opposition' was preferred when the mirror was below. When opposition was experienced, it was attributed mainly to the exocentric frame of reference. Egocentric left–right reversal was not a common experience, although it was reported more frequently when the mirror was in front. The different roles of the exocentric and egocentric frames of reference were further tested in experiment 3, in which the condition of an observer looking at another person's reflection was studied. Contrary to the emphasis on the egocentric frame of reference in the literature on the 'mirror question', results presented in this paper demonstrate the importance of the exocentric frame of reference in influencing how observers react to their reflections.

1 Introduction

Our aim here is to analyse the relationship that observers perceive between themselves and their reflected image, by means of descriptive tasks. Various conditions of reflection were studied: the 'canonical' reflection, with a mirror set vertically in front of the observer, and the less frequent, but nonetheless ecological, conditions of reflecting surfaces set vertically beside the observer (eg shop windows reflecting people walking on the street) or lying horizontally on the floor (eg puddles or lakes in natural environments, but also, occasionally, floors of buildings).

In previous research, the study of mirror reflections has been developed along two directions, naive optics and the 'mirror question'. Naive optics is a branch of 'naive physics' which concerns the study of common-sense beliefs about the way the world of physics works [see the historical note by Pittenger and Runeson (1990), about Bozzi's pioneering work in the late 50s and the definitions by McCloskey (1983) and Proffitt (1999)]. In particular, it concerns the naive beliefs that people hold about the way mirrors work. These studies showed significant errors in adults' prediction about what should be reflected in a mirror (Croucher et al 2002; Hecht et al 2005) and about size estimation of one's own head in mirrors (Bertamini and Parks 2005; Lawson and Bertamini 2006; Savardi and Bianchi 2005). Perceptual judgments were generally found to be more accurate than the explicit knowledge emerging from predictive tasks. In none of these studies is the role of the frame of reference (a central point in this paper) treated as an important variable.

Parallel to this literature is the main stream of discussion concerning mirror reflections which has developed over the last twenty years. It focuses on the so-called 'mirror question', ie on 'why mirrors reverse right and left but not up and down'. This debate has been basically addressed by means of speculative analyses. Many theories have been proposed to explain this phenomenon (for a brief critical review, see Navon 2001), invoking conventional descriptions (Bennet 1970; Corballis and Beale 1976), objects geometry (Ittelson 1993; Ittelson et al 1991), laws of optics (Gardner 1964; Haig 1993; Tabata and Okuda 2000), cognitive schemas (Corballis 2000; Morris 1993; Navon 1987, 2001; Takano 1998), and rotations needed to position the object in front of the mirror (Gregory 1987, 1996). In every case, egocentric left–right reversal produced by plane mirrors is used as the starting point. However, up to now researchers have never empirically investigated what observers do in fact perceive and how they would describe the relation between the real and the reflected object. This would make it clear whether left–right reversal is in fact an important feature of the perception of mirror images. In particular, by investigating the relationships that people perceive when looking at themselves in a mirror, we can understand the role of different frames of reference entailed in mirror-image perception of human bodies.

We decided to focus on people's reflections rather than on reflections of other objects, since the classic discussion on the 'mirror question' has been mainly developed with reference to the human body (Block 1974; Corballis 2000; Gardner 1964; Gregory 2001; Ittelson 1993; Locke 1977; Navon 1987; Tabata and Okuda 2000; Takano 1998), though different kinds of stimuli have also been studied, such as letters or words (Block 1974; Ittelson et al 1991; Locke 1977; Takano 1998), geometrical solids (Ittelson et al 1991; Takano 1998), and everyday objects like books (Gregory 1987). In this literature no distinction is made between the condition where the observer is also the target of the mirror reflection and where she/he is looking at another person's reflection. The lack of attention to this aspect was also highlighted by Bertamini and Parks (2005) with reference to how the problem of size perception in mirrors has been addressed in the literature (Gombrich 1960; Gregory 1996; Mackavey 1980; Parks 2001), even though these two conditions are optically relevant. In terms of the present paper, one might expect the condition of looking at one's own reflection or at another person's reflection to affect the relationship perceived between the real and the reflected body in two ways.

First, one could point out that past experience plays a different role in the two conditions. If we extend a recurrent leitmotif in the research on recognition of normally oriented and mirror-oriented faces (see, in particular, Bredart 2003; Rhodes 1986) to reflections of bodies, we might conclude that observers are extremely familiar with one's own mirror-oriented image while being extremely unfamiliar with another person's mirror-oriented image. Thus, they might be familiar with their left–right reversal in mirrors, while being unfamiliar with other person's left–right reversal in mirrors (in fact, we usually look at other people directly, not at their reflections). Therefore, one could predict that the relationship which is perceived between the virtual and the reflected body depends on the subject of the reflection (me or another person). On the other hand, it might be expected that, after a lifetime of looking at one's own reflected image, the familiarity with this perception would easily be generalised for any reflection. Therefore, we should expect naive observers to be familiar with the left–right reversal independently of who is the reflected person.

Second, there is a difference in the structure of comparison characterising the two conditions of looking at oneself or at another person's reflection. In fact, looking at another person's reflection is not very different from looking at letters or Shepard-like solids reflected in mirrors. With regard to the problem of left–right reversal, the only relevant variable distinguishing these two conditions is the object's degree of asymmetry,

which may or may not draw the observer's attention to the 'left–right but not up–down reversal phenomena'. On the other hand, as Gregory (2001, page 904) suggested, a really fascinating aspect of the 'left–right but not up–down reversal phenomena' as yet not investigated by psychologists arises from the uniquely puzzling condition of seeing oneself in a mirror. In fact, since one's own face is invisible without a mirror, as we can't take our eyes out and turn them around, the question is why it is that you look reversed to yourself in a mirror, when in fact you can't actually step into the mind of others around you and you do not see your own face except in the mirror. Is it possible that we don't see ourselves reversed? The first observation pointed out by Gregory, which focuses on the lack of the typical dual structure characterising comparisons when we consider our own faces reflected in a mirror, disappears when we look at another person's reflection (see Savardi and Bianchi 2005). The question whether we do or do not perceive a reflection reversed, holds in both conditions of looking at oneself or at another person's reflection. This cannot be answered other than by means of an examination of the relationships perceived by the observers.

In the following experiments, we addressed this second question by asking observers to inspect and describe a series of mirror images. When an imperfect identity is recognised, what are the differences noticed by the observer? Do observers perceive their reflections as reversed? Which reversal do they see? Is it the egocentric left–right reversal as described in the 'mirror question' or is it the exocentric reversal of body orientation (back to front or upside down, depending on the position of the mirror), which is in fact present in the scene as well as the left–right reversal? Does one recognise the gestures seen in the mirror as identical to one's own gestures or does one perceive the reflection to be moving in the opposite direction?

1.1 *A proposal for describing the 'observer–reflection' configuration analytically*

Since different positions of the mirror with respect to the body being reflected give origin to various 'observer–reflection' configurations, we propose to analyse the varying relationships characterising them using the following three variables:

- (i) the exocentric localisation of the reflection with respect to the observer;
- (ii) the exocentric orientation of the reflection with respect to the observer orientation;
- (iii) the identical or opposite *egocentric structure* of the reflected body with respect to the real body.

It can be easily shown that, by using these three variables, one can analyse the spatial structure of every possible 'object–reflection' configuration in plane mirrors. For instance, if we describe the 'observer–reflection' configurations in figure 1b using these three variables, we can see that:

(i) The reflections have different localisations with respect to the real body: they are localised north (N), west (W), or below (B) the observer, or they may be further identified by combining the former basic relationships (NW or BW).

(ii) There is an opposite sagittal orientation in the N and NW reflections (ie they are facing south while the observer is facing north) and an identical sagittal orientation in the B, W, or BW reflections (ie they are all facing north). In relation to the gravitational orientation, there is an opposite orientation in the B or BW reflections (ie they are upside down while the observer is upright), while there is an identical gravitational orientation in the N, W, or NW reflections (ie they are upright like the observer). It is important to notice that the exocentric coordinates north–south, east–west, up–down, as they are used here and throughout the present paper to describe both the localisation (variable i) and the orientation (variable ii), do not coincide with geographic coordinates. They define the exocentric space within a more 'local' system of coordinates, conventionally described and based on the orientation of the observer (as in the above description of figure 1b). Note that, even though this space is defined

with the observer's body as the origin of the spatial coordinates, it maps what is external to the observer and shared with other people or reflections. We could call the side of the room where the door is north, and thus call the other sides of the room east, south, and west, etc.

(iii) Only the third variable refers to the single-body schema and has two autonomous definitions for the observer's body and the body in the reflection. In the 'mirror question', the left–right lateralisation of the reflection and the real body is the aspect focused on. For instance, in figure 1b, the observer has his/her right arm extended as in the NW and BW reflections; all the remaining reflections have their left arm extended.

The analytical description of the relationships characterising each specific observer–reflection configuration, based on these three variables, can be addressed at a pre-experimental level. What needs to be empirically investigated are the relationships that observers perceive when looking at different observer–reflection configurations. While investigating this, the following experiments also aim to provide an answer to the second question posed by Gregory (2001) as mentioned above: "Is it possible that we actually don't see ourselves reversed?"

2 Experiment 1: The relationship perceived between oneself and one's reflection

In this study we explore whether observers perceive their reflection in a mirror as identical, similar, different, or opposite to themselves. Various observer–reflection configurations were studied, depending on the following three independent variables:

- position of the mirror in relation to the observer: reflections generated by mirrors set vertically on the wall (frontal reflections) versus reflections generated by mirrors lying horizontally on the floor (gravitational reflections);
- absence or presence of cues stressing left–right lateralisation: posture with both arms at the sides in a relaxed position versus posture with an extended arm;
- egocentric reflection lateralisation: inverted (in standard reflections) versus identical (in reflections generated by two adjacent mirrors positioned at a 90° angle).

The first variable was studied between subjects, the second and third within subjects.

Perception of one's reflection in a mirror was investigated with structured verbal reports produced by adults in front of mirrors (see apparatus). A series of questions was used to study the following aspects (dependent variables): (1) the global relationship perceived between the observer and his/her reflection; (2) the relationship perceived between the orientation of the observer and that of the reflection; (3) the local relationship perceived between lateralised body parts (eg the arm) of the observer and the reflection; and (4) the relationship perceived when looking at an egocentrically identical reflection versus an exocentrically identical reflection.

Four relationships were proposed to the subjects as sets of 'possible' descriptions: 'identical', 'similar', 'different', and 'opposite'. We used the concepts of 'identical', 'similar', and 'different' in the same naive sense as used by Goldmeier (1936/1972), Medin et al (1990), Palmer (1978), and Tversky (1977) when studying 'similarity' and 'difference' with reference to simple two-dimensional figures, and as they are intuitively used in classical same–different tasks. We used also the word 'opposite' in a similar naive sense (see section 2.2).

If the left–right reversal is a salient characteristic that people see when looking at their reflections, one could expect participants to refer to it frequently (when the observer–reflection configuration shows this), in particular when they are asked to focus on their arms [question (c)] or in the direct comparison between an egocentrically correct and an egocentrically opposite reflection [question (d)]. Moreover, since this reversal characterises all direct reflections, no difference should be found when the configuration is changed. On the other hand, if the egocentric left–right reversal is

an intriguing theoretical problem but not as important as the exocentric relationship between real and virtual bodies, one could expect participants' descriptions to be affected by the latter. Since these exocentric relationships vary in different observer–reflection configurations, different descriptions should arise for different configurations. Moreover, if these variations were recognised as oppositions, as they are in an analytical sense, we would expect them to transform the global experience of identity into a perception of either opposition or similarity. This would be consistent with previous findings showing that two objects, identical in all of their properties with the exception of one (which is opposite), will be perceived either as similar or opposite, depending on which property is transformed (Bianchi and Savardi 2007; Savardi and Bianchi 2000a, 2005). As a result of these findings, the opposition of the up–down orientation might be expected to be more suitable in giving rise to a general perception of opposition than the east–west or the north–south reversals.

By asking participants not only to choose which out of the four descriptions fit best, but also to state whether those excluded were 'possible' or 'inadequate', the study allows a more complete understanding of the relationships perceived in the observer–reflection configuration, at different levels of evidence.

2.1 Method

2.1.1 Subjects. Forty-six undergraduate students participated in the experiment. Twenty of them participated in the frontal condition (figure 1a, reflection N; figure 1b, reflections N and NW) and twenty-six in the gravitational condition (figure 1a, reflection B; figure 1b, reflections B and BW). In both cases they were divided into small groups of inter-observation, composed by three subjects (see Bozzi 1978, discussed in Kubovy 1999; see also Bozzi and Martinuzzi 1989; Savardi and Bianchi 2000b).

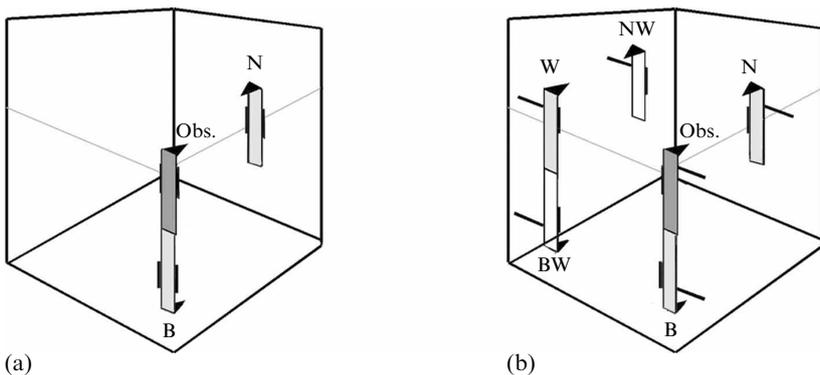


Figure 1. Representation of the experimental conditions, given the two postures analysed, arms against the sides (a) and right arm stretched out wide (b). Reflections formed on a single plane mirror are represented in light grey; reflections formed by two plane mirrors, in white. The observer (Obs.) is dark grey. The reflections being analysed are indicated by capital letters referring to the exocentric spatial location of the reflection (N = north, NW = north-west, B = below, BW = below-west) in relation to the observer. The reflection W, though not analysed, was left in the figure because it contributes to the formation of the two 90° reflections analysed (BW, NW).

2.1.2 Apparatus. A mirror room was set up for the experiment. It was composed of two $2.5 \text{ m} \times 2 \text{ m}$ plane mirrors, placed vertically and orthogonally to form two adjacent walls of the mirror room, and two $2 \text{ m} \times 2 \text{ m}$ mirrors, lying horizontally to form the ceiling and the floor of the room. The apparatus was built to allow participants to stand on the mirror on the floor.

2.1.3 *Stimuli*. For each of the two conditions, frontal (group 1) and gravitational (group 2), participants were asked to look at four different observer–reflection configurations, as described in table 1. In the first two configurations (I and II), the reflection under observation was a reflection formed in a single plane mirror. The third configuration (III) consisted of two reflections: one formed in a single plane mirror and one formed by two adjacent (90°) mirrors.

2.1.4 *Task*. A structured verbal descriptive task was used. Participants were asked four questions, each referring to one of the four dependent variables under study. Table 1 shows how the four questions relate to the scenes being analysed.

Table 1. Reflections observed during experiment 1 and relative questions, for the two different groups.

Observer–reflection configuration	Conditions		Questions
	frontal (group 1)	gravitational (group 2)	
I. Arms against the sides in a relaxed position: single plane mirror reflection	reflection N (see figure 1a)	reflection B (see figure 1a)	(1) general relationship question (2) orientation question
II. Right arm stretched out wide: single plane mirror reflection	reflection N (see figure 1b)	reflection B (see figure 1b)	(3) arm focused question
III. Right arm stretched out wide: single plane and 90° mirror reflections	pair of reflections (N, NW) (see figure 1b)	pair of reflections (B, BW) (see figure 1b)	(4) single plane versus 90° reflection question

The first question, subsequently referred to as the ‘general relationship question’, asked participants to focus on the global relationship perceived between their reflection and themselves. First, they were asked to choose the most adequate description: “If you had to describe the relationship that you perceive between yourself and your reflection, would you say that your reflection is ‘identical’, ‘similar’, ‘different’, or ‘opposite’ in relation to yourself?” (question 1a). Next, participants were asked to clarify if the excluded relationships were nevertheless ‘possible’ descriptions of the experience under observation, although not the best ones: “Could you say that you perceive your reflection as ... (one of the relationships excluded in 1a was cited, eg: ‘opposite’) to you?” (question 1b). Question 1b was repeated for every relationship, out of the four, that was excluded in 1a.

The second question, subsequently referred to as the ‘orientation question’, aimed at analysing which relationship participants perceived between their own orientation and that of their reflection: “With regard to your spatial orientation and the reflection’s spatial orientation, would you say that your reflection has an ‘identical’, ‘similar’, ‘opposite’, or ‘different’ orientation compared to yours?” (question 2a). Subjects were then invited to expand on the answer: “Why did you say that? What are you referring to?” (question 2b).

The third question, subsequently referred to as the ‘arm extension question’, was introduced to draw attention to the reflection’s left–right egocentric opposition. The question aimed to verify whether the influence of the egocentric coordinates (and thus the descriptions of opposition instead of identity) would increase when gestures emphasising body lateralisation, like arm movements, are involved. The researcher extended participants’ right arm into the position shown in figure 1b and then asked

participants to say whether the reflection was extending the ‘identical’ or ‘opposite’ arm in relation to their extended arm (question 3a). “Why do you say that it is the ... (chosen relationship in 3a) arm?” (question 3b). “Could you say that it is also the ... (excluded relationship in 3a) arm?” (question 3c).

The fourth question, subsequently referred to as the ‘single plane mirror versus 90° reflection question’ asked participants to compare two reflections: a reflection in a plane mirror, which presents the egocentric left–right reversal but keeps the exocentric east–west lateralisation invariant, and a 90° reflection, which keeps the egocentric left–right structure invariant but inverts the east–west exocentric lateralisation (see figure 1b: pair N–NW for the frontal condition group; pair B–BW for the gravitational condition group). Both left–right and east–west lateralisations were made particularly evident because of the posture of the observer (extended arm). Participants were asked: “Which one do you perceive as being identical to yourself?” (question 4a). “Why do you say that?” (question 4b).

The two independent groups of participants were asked these four questions in a fixed order. When, in the question, explicit reference to the four relationships (identical, similar, different, and opposite) was made, the order of these relationships was randomised between groups.

2.2 Procedure

Participants took part in the experiment in groups of three. They were told that they would be taken into a mirror room and asked to analyse the relationship perceived between themselves and their reflected image. The researcher then explained that they were going to participate in the experiment in groups and that they would be invited to engage in a discussion with the other members of the group during the experimental session, not necessarily to reach an agreement on a common description but to use the other participants’ descriptions in order to decide on a final personal choice which they felt best fitted what they perceived.

In order to avoid differences in the use of the terms ‘identical’, ‘similar’, ‘different’, and ‘opposite’, participants were invited to share their interpretation of the meanings of these words by indicating pairs of objects in the environment around them that they would consider identical, similar, different, or opposite. Participants were told to refer to the common use they made of these words in everyday life when comparing two objects. In this way the members of the group agreed on the use of these words before entering into the mirror room.

The sessions were video-recorded in order to facilitate data collection. The experimenter took part in the experiment by asking the standard list of questions and by asking for clarifications when required. The experiment lasted approximately 1 h.

2.3 Results and discussion

2.3.1 General relationship question. From the analysis of the ‘best-fitting’ descriptions (question 1) independently of the two reflection conditions, a difference between the frequency of the four relationships was found ($\chi^2_3 = 14.870$, $p = 0.01$). ‘Identical’ was the most frequently chosen (41.3%), ‘opposite’ and ‘similar’ were both described by 28.3% of responses, while ‘different’ was hardly ever used (2.1%). In addition to clarifying the specific kind of relationship perceived, these results also suggest that 58.7% of responses reported the presence of some variation in the reflection, at this level apparently equally describable in terms of similarity and opposition.

A $\lg \chi^2$ analysis was conducted on the frequency of the four relationships in the frontal and gravitational conditions (percentages are shown in figure 2). It revealed a significant difference between the two conditions ($\lambda_3 = 43.987$, $p = 0.001$): ‘identical’ was more frequently used in the frontal condition ($R = 5.9$), while ‘opposite’ ($R = 3.7$) and ‘similar’ ($R = 2.4$) in the gravitational condition.

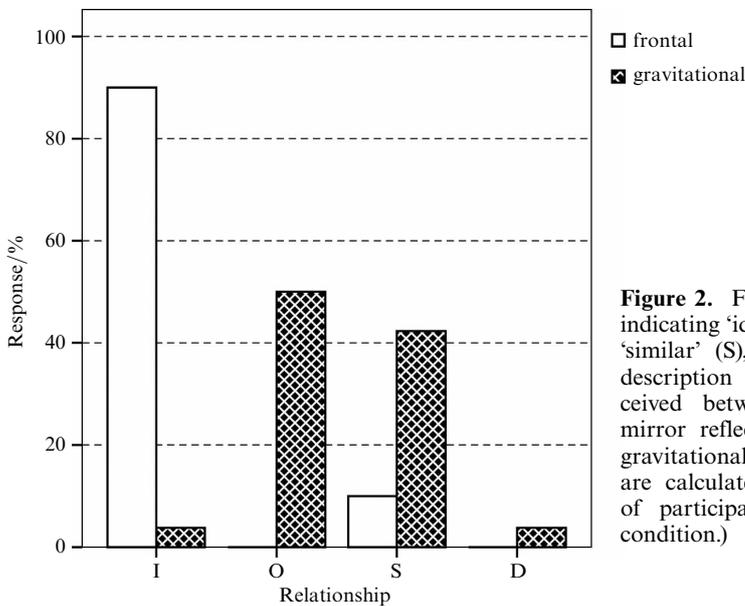


Figure 2. Frequencies of responses indicating ‘identical’ (I), ‘opposite’ (O), ‘similar’ (S), ‘different’ (D) as ‘best’ description of the relationship perceived between oneself and one’s mirror reflection in the frontal and gravitational conditions. (Percentages are calculated on the total number of participants for each reflection condition.)

By adding up the total number of frequencies of responses indicating each relationship as ‘best description’ (question 1a) or ‘possible description’ (question 1b), a unique value was obtained. This expressed the number of participants who judged ‘adequate’ (‘best’ or ‘possible’) a particular relationship. The analysis of these values showed that, independently of the reflection, the four descriptions are not considered to be equally adequate ($\chi^2_3 = 22.432$, $p = 0.001$); in particular, ‘different’ was judged to be less adequate than the others ($R = -4.0$). An effect of the reflection condition was also found ($\lambda_3 = 15.645$, $p = 0.001$). ‘Identical’ was said to be an adequate description only by 38% of the subjects in the gravitational condition ($R = -3.6$) and by 100% of the subjects in the frontal condition ($R = 3.6$). An inverted result emerged for ‘opposite’, which was described as adequate by only 25% of subjects in the frontal condition ($R = -2.8$) and by 88% in the gravitational condition ($R = 2.8$). No significant differences were found between the use of ‘similar’ (60%–81%) and of ‘different’ (2%–5%) in the two conditions.

To summarise the results from question 1, in particular regarding the recognition of some elements of variation in the reflected images, ‘different’ was found to be inadequate in describing the kind of variation perceived in both conditions (<12%). Participants preferred ‘similar’ or ‘opposite’ to describe the reflections. The high frequency of ‘similar’ in both frontal (60%) and gravitational (81%) conditions suggests that it has to be considered an adequate description for either kind of variation present in the frontal reflection (ie inversion of the exocentric north–south orientation and/or egocentric reversal of left and right) and in the gravitational reflection (ie inversion of the exocentric up–down orientation and/or egocentric reversal of left and right). ‘Opposite’ (88%) was more specifically linked to the gravitational reflection.

Given that egocentric left–right reversal is present in both frontal and gravitational reflections, does this preference for ‘opposite’ in the latter condition mean that this reversal is more noticeable with gravitational reflections, even though present in both conditions? Or is it the variation of the exocentric orientation, which has in fact different values in the two conditions (gravitational versus sagittal inversion) that our participants were describing? Questions 2, 3, and 4 were aimed at helping to find the answers to these points. Before looking at the data, let us reconsider Gregory’s dilemma on the basis of the above results: “Is it possible that we don’t actually see

ourselves reversed?” Results from question 1 suggest that different answers would be given to this question, depending on which kind of reflection we are looking at. People do not see themselves reversed in the frontal condition, where the reflection is described as ‘identical’ by the large majority of subjects. They do, however, see themselves reversed in the gravitational condition (given that the following analysis will confirm whether it is left–right reversal or gravitational inverted orientation that was actually described by subjects when choosing the term ‘opposite’).

2.3.2 Orientation question. The difference between the four relationships, independently of the two reflection conditions, turned out to be highly significant ($\lambda_4 = 62.455$; $p = 0.001$). Participants used ‘opposite’ (87%) as best fitting description of their reflected image orientation more frequently than expected; ‘similar’ and ‘identical’ were scarcely used (6.5%), while ‘different’ was never chosen.

No difference was found between the two reflection conditions ($\lambda_3 = 5.325$, $p = 0.07$)—see figure 3. Only a tendency to describe the virtual body as ‘identical’ more frequently in the frontal reflection ($R = 2$) emerged.

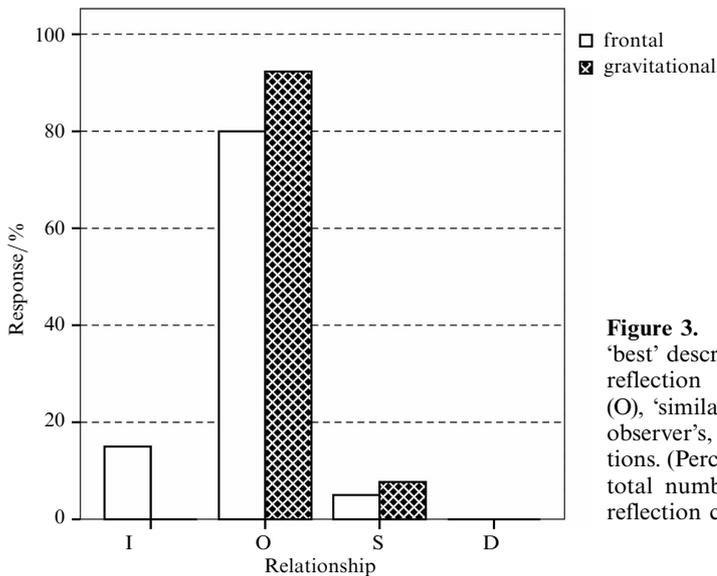


Figure 3. Frequencies of responses ‘best’ describing the orientation of the reflection as ‘identical’ (I), ‘opposite’ (O), ‘similar’ (S), ‘different’ (D) to the observer’s, in the two reflection conditions. (Percentages are calculated on the total number of participants for each reflection condition.)

When asked to specify which aspect of the scene participants were describing (question 2b), they never referred to the egocentric left–right reversal in the gravitational condition. All participants referred to the upside–down orientation of the mirror image. In the frontal condition, all the descriptions of opposition were explained by saying that, if their real body was facing north, the virtual one was facing south; only six of sixteen subjects who described the orientation as ‘opposite’ also referred to the egocentric left–right reversal.

On the basis of these data, Gregory’s question could be answered by saying that, when looking in a mirror, observers see themselves reversed both in the frontal and in the gravitational condition, but with respect to the exocentric orientation of the virtual body. Only for a minority of cases, and only in the frontal condition, did the recognition of an opposite orientation refer to the left–right reversal.

2.3.3 Arm extension question. Subjects were asked to focus on their arm and to choose whether they would consider ‘identical’ or ‘opposite’ to be the ‘best’ description of the relationship perceived between their own arm and the virtual one (question 3a). Participants answered with a significant preference (binomial tests) for ‘identical’ in both

frontal condition (observer proportions: ‘identical’ = 0.75; ‘opposite’ = 0.25; $p = 0.04$) and gravitational condition (observer proportions: ‘identical’ = 0.81; ‘opposite’ = 0.19; $p = 0.003$). As shown in figure 4, in both conditions, ‘identical’ was described as ‘adequate’ (‘best’ plus ‘possible’ descriptions) by 100% of subjects, ie also by those who chose ‘opposite’ as the ‘best’ description. ‘Opposite’ was described as ‘adequate’ more frequently than ‘inadequate’ in the frontal [observer proportions: ‘opposite’ (yes) = 0.80; ‘opposite’(no) = 0.20; $p = 0.012$], but not in the gravitational condition [observer proportions: ‘opposite’(yes) = 0.38; ‘opposite’(no) = 0.62; $p = 0.327$].

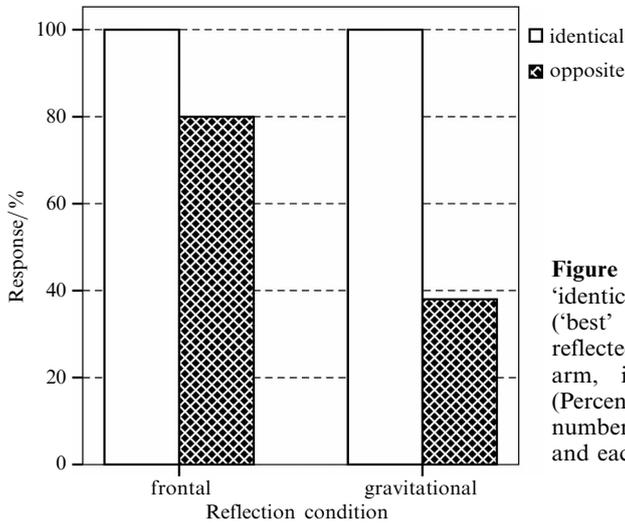


Figure 4. Frequencies of responses indicating ‘identical’ (I) or ‘opposite’ (O) as adequate (‘best’ or ‘possible’) descriptions of the reflected arm in relation to the observer’s arm, in the two reflection conditions. (Percentages are calculated on the total number of responses for each relationship and each reflection condition.)

Going back to Gregory’s question (which in this case would seem to be “Is it possible that we do not see egocentric left–right reversal?”) these data suggest that the majority of subjects (75% in the frontal condition, 81% in the gravitational condition) do not see any reversal, if we are referring to their immediate reaction when facing a mirror (‘best description’). On a more analytical level (as a ‘possible’ description) the left–right reversal is recognised by 55% of subjects in the frontal condition and only by 19% of subjects in the gravitational condition.

If the description of egocentric left–right reversal simply reflected the application of general knowledge about the inversion produced by mirrors, we would have found no difference between the two conditions. Interestingly, the recognition of left–right reversal was more frequent in the frontal reflection, which was described as ‘identical’ in question 1 by most subjects, and rarely noticed in the gravitational reflection, which was described as ‘opposite’ by the majority of subjects. This confirms that the global relationship perceived is independent of the recognition of egocentric left–right reversal.

2.3.4 Single plane mirror versus 90° reflection question. The participants identified the reflections showing egocentric left–right reversal and identical exocentric east–west orientation (ie reflections formed on a single plane mirror: N and B in figure 1b) as being identical to themselves in both the frontal (observer proportions: N = 0.85; NW = 0.15, $p = 0.003$) and gravitational (observer proportions: B = 0.73; BW = 0.27; $p = 0.003$) conditions. It is worth mentioning that in the gravitational condition the preferences for the egocentrically identical reflection (27%) were never justified by the participants by referring to the egocentric left–right structure, but to the fact that it was possible to see more of themselves in the 90° reflection than in the reflection located under their feet. On the other hand, participants referred to egocentric left–right identity when choosing the 90° reflection in the frontal condition.

In terms of Gregory's speculation, one might conclude that the lack of evidence of left–right reversal is also confirmed when observers are directly confronted with two alternative reflections showing different egocentric left–right orientations. In general, the results from experiment 1 seem to suggest that the egocentric left–right structure is not as important as the exocentric orientation in determining the relationship perceived with one's own reflected image. However, there may be an alternative explanation for the preference for the egocentrically inverted reflection as opposed to the 90° one. Because we are very familiar with the experience of looking at our own reflected image in single plane mirrors, any reflection showing no left–right reversal would appear to be not identical simply because it is not familiar. In other words, results from question 4 could be due to past experience rather than to the intrinsic ease of manipulating different perceptual frames of reference. Experiments 2 and 3 aimed to separate the role of these two factors.

3 Experiment 2: How does the reflection 'behave'?

The aim of this experiment was to investigate:

- (i) The relationship perceived by observers between their gestures and the reflected image, given different positions of the mirror and different gestures. In this experiment observers looked at themselves while making very simple and familiar gestures. If participants' responses were driven by a generic familiarity with the 'behaviour' of their reflected image, we would expect them in any case to describe the gestures in the reflection as 'identical', independently of the observer–reflection configuration. On the contrary, if participants' responses were dependent on the specific configuration under observation, then we would expect observers to notice differences.
- (ii) The role of egocentric and exocentric spatial frames of reference and, in relation to this, the role of lateralisation and direction gestures. On the basis of the results found in experiment 1, we hypothesised that observers would describe the gestures in the reflection as, respectively, 'identical' and 'opposite', according to the exocentric frame of reference. As part of this hypothesis, we expect direction to affect, in particular, the perception of identity and opposition, as it is a salient characteristic of visual configurations. That is, we expect that subjects would describe the reflected gestures as 'identical' when they had the same exocentric direction as the observer's gestures—eg in figure 5a, the pairs (Obs., 0N), (Obs., –1B)—and 'opposite' when they showed an opposite direction—eg in figure 5a, the pairs (Obs., 0W), (Obs., 0NW). No prediction was made regarding the structures perceived as 'similar' or 'different', other than expecting the latter to be rarely used, in line with the results of experiment 1.
- (iii) The effects of the presence or absence of motion. Motion may be expected to either increase the perceived identity between gestures by showing their simultaneous occurrence, or to emphasise the direction of the gesture and hence, for gestures with opposite pointing, their opposition.

3.1 Method

3.1.1 *Participants*. Fifty undergraduates at the University of Verona (aged 18 to 30 years) participated in the experiment.

3.1.2 *Apparatus*. The apparatus was the same as that used in experiment 1.

3.1.3 *Stimuli*. Participants were presented with eight sets of reflections resulting from the combination of four independent variables (see figure 5):

- Floor, two levels: floor 0 (where the observer and reflections 0N, 0W, 0NW stand); floor –1 (immediately under observer's feet, where reflections –1B, –1N, –1W, –1NW are).
- Location in relation to the observer, four levels: below (B), north (N), west (W), and north-west (NW). Each position is associated with a fixed pattern of relationships

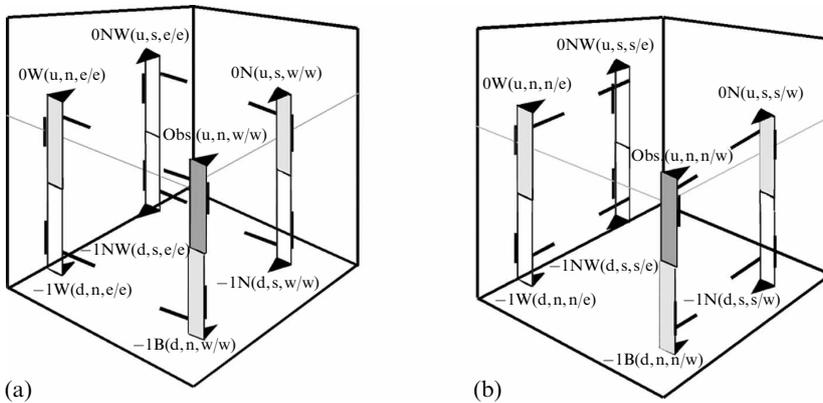


Figure 5. Representation of the sets of reflections analysed (four at floor -1 ; three at floor 0) for the two gestures: west arm towards west (a) and west arm towards north (b). For each reflection the following are specified: floor number (0 , -1); location (in capital letters; B = below; N = north, W = west, NW = north-west); and, in brackets, the exocentric orientation [gravitational orientation: up(u)–down(d); sagittal orientation: north(n)–south(s); the third and fourth letters, divided by the solidus, represent direction and lateralisation of gestures].

between the gravitational (up or down), sagittal (north or south), and coronal (east or west) exocentric orientation of the reflection and that of the observer. Each position is also characterised by a precise egocentric relationship, which consists of the presence or absence of the left–right reversal. In figure 5 these patterns are described, in brackets, for each reflection.

- Gesture, two levels: west arm towards west (w/w), or west arm towards north (n/w).
- Motion, two levels: dynamic condition (participants were invited to move their arm repeating the gesture in the same direction), static condition (subjects were asked to remain static).

All independent variables were studied within subjects. The eight sets of reflections consisted of the combination of all the levels of the variable location and one of the levels of the variables: floor, gesture, and motion:

- set a: figure 5a (static gesture: west arm toward west), reflections 0N, 0W, 0NW;
- set b: figure 5a (static gesture: west arm toward west), reflections $-1B$, $-1N$, $-1W$, $-1NW$;
- set c: figure 5b (static gesture: west arm toward north), reflections 0N, 0W, 0NW (static);
- set d: figure 5b (static gesture: west arm toward north), reflections $-1B$, $-1N$, $-1W$, $-1NW$;
- set e: set a (dynamic gesture);
- set f: set b (dynamic gesture);
- set g: set c (dynamic gesture);
- set h: set d (dynamic gesture).

The relationship that participants perceived between their gestures and the reflection (dependent variable) was studied on four levels (the same as used in experiment 1): ‘identical’, ‘opposite’, ‘similar’, and ‘different’.

3.2 Procedure

Participants took part in the experiment individually. Instructions regarding the task and the meaning of the terms ‘identical’, ‘opposite’, ‘similar’, and ‘different’ was the same as in experiment 1. The experimental session lasted about 40 min.

3.3 Task

Participants were invited to enter the mirror room and to stand on the mirror on the floor. They were then asked to do a certain gesture and to look at the set of reflections indicated by the experimenter. For each of the eight sets, the following questions were asked:

(1) “Look at these reflections: is any of these reflections making a gesture identical to yours?”

(2) “What are you referring to, when saying that?” The second question was asked only if a reason for the previous answer was not clearly stated spontaneously.

The same questions were repeated for the other three relationships (‘opposite’, ‘similar’, and ‘different’). The order of presentation of the eight sets and of the four relationships was randomised between subjects.

3.4 Results and discussion

(1) Frequency of the four relationships. A significant difference was found between the total frequency of the responses ‘identical’, ‘similar’, ‘opposite’, or ‘different’, independently of the levels of the independent variables ($\chi^2_3 = 324.749$, $p = 0.001$; $C = 0.45$). Only in a minority of cases (27.9%) did subjects say they perceived their reflected gestures as ‘identical’ to the gesture actually made. On the other hand, the presence of variation was recognised in around 76% of the responses and it was more precisely described as ‘opposition’ in 41.7%, as ‘similarity’ in 27.7%, and as ‘difference’ in 7.2% of the cases. The frequent recognition of not perfect identity in the reflected gesture is the first aspect to emphasise. The second is that the most frequent response was ‘opposite’. What exactly do observers perceive as being opposite in their reflected gestures?

(2) *Main effect of the analysed variables.* Table 2 summarises the data discussed below. Floor. The frequency of responses describing the reflected gestures as ‘opposite’ ($\lambda_1 = 0.266$, ns) or ‘similar’ ($\lambda_1 = 1.002$, ns) did not differ for the sets of reflections visible in floor 0 or floor -1. The description of gestures as ‘different’ more frequently referred to reflections seen in floor -1 ($\lambda_1 = 4.730$, $p = 0.05$). A tendency towards a more frequent use of ‘identical’ for reflections presented in floor 0 was found ($\lambda_1 = 3.436$, $p = 0.06$).

Gestures. None of the descriptions ‘identical’ ($\lambda_1 = 0.429$, ns), ‘opposite’ ($\lambda_1 = 0.759$, ns), ‘different’ ($\lambda_1 = 0.267$, ns), or ‘similar’ ($\lambda_1 = 3.211$, ns) were more frequent in either of the two gestures.

Table 2. Frequencies of the four relationships for each analysed independent variable.

	Identical	Opposite	Similar	Different	Total
Floor					
0	183 (29.1%)	255 (40.5%)	158 (25.1%)	33 (5.2%)	629 (100.0%)
-1	208 (24.9%)	329 (39.4%)	230 (27.5%)	68 (8.1%)	835 (100.0%)
Motion					
static	187 (25.6%)	318 (43.6%)	183 (25.1%)	42 (5.8%)	730 (100.0%)
dynamic	204 (27.8%)	266 (36.2%)	205 (27.9%)	59 (8.0%)	734 (100.0%)
Gesture					
west/west	201 (27.6%)	300 (41.2%)	179 (24.6%)	48 (6.6%)	728 (100.0%)
west/north	190 (25.8%)	284 (38.6%)	209 (28.4%)	53 (7.2%)	736 (100.0%)
Location					
N [0N, -1N]	144 (35.0%)	127 (30.8%)	115 (27.9%)	26 (6.3%)	412 (100.0%)
NW [0NW, -1NW]	80 (18.9%)	212 (50.0%)	95 (22.4%)	37 (8.7%)	424 (100.0%)
W [0W, -1W]	72 (17.0%)	203 (48.0%)	129 (30.5%)	19 (4.5%)	423 (100.0%)
B	95 (46.3%)	42 (20.5%)	49 (23.9%)	19 (9.3%)	205 (100.0%)
Total for each variable	391	584	388	101	1464
% of total ($n = 1400$)	27.9%	41.7%	27.7%	7.2%	104.6%

Motion. Movement or lack of movement in gestures did not affect the description of the reflection's gestures as 'identical' ($\lambda_1 = 1.026$, ns) or 'similar' ($\lambda_1 = 1.726$, ns) to the observer's gesture. These data disprove the hypotheses that motion increases the recognition of identity by introducing the perception of simultaneousness between observer's gestures and the reflected gestures. The second hypothesis about motion was that it might increase the perception of opposition by emphasising the opposite directions of gestures (in the exocentric space), when present. In order to verify this hypothesis, a subset of 'observer–reflection' configurations showing this kind of opposition was studied. A higher use of the description 'opposite' was found in the dynamic than in the static condition ($\lambda_1 = 3.187$, $p = 0.05$).

Location. In the following section, the location is expressed by the names of both reflections corresponding to the specified location on both floors (0 and -1)—see figure 5. The analysis was conducted by comparing (for each of the four relationships) the frequencies of responses in the three localisations: N, NW, and W. A separate χ^2 analysis was conducted on responses given to the reflection $-1B$, to prevent the different sample of responses for this location—consisting in fact of only one reflection—affecting the results of the analysis. For ease of understanding, in figure 6 results are represented near their respective locations.

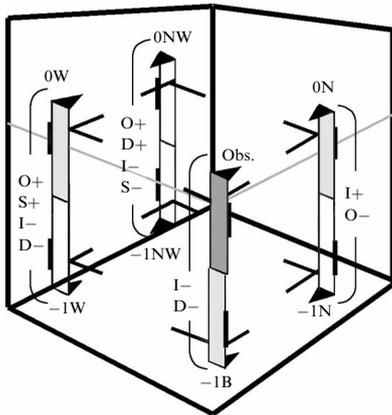


Figure 6. Representation of the use of the four relationships ('identical', I; 'opposite', O; 'similar', S; and 'different', D) to describe reflected gestures in the various locations. The sign '+' indicates that the relationship is used more than would be expected by chance, '-' that it is used less.

The results suggest that the perception of the reflected gestures is not independent of the specific location, ie the specific observer–reflection configuration:

- 'identical' ($\lambda_2 = 40.537$, $p = 0.001$) was used more frequently than expected with reflections N [0N/ $-1N$] ($R = 6.4$), less frequently with reflections NW [0NW/ $-1NW$] ($R = -2.7$), and with reflections W [0W/ $-1W$] ($R = -3.8$). From the analysis of the distribution of the four relationships within localisation $-1B$ ($\chi^2_3 = 59.410$, $p = 0.001$), 'identical' resulted less frequently than expected ($R = -7.5$) with this reflection too.
- 'opposite' ($\lambda_2 = 44.841$, $p = 0.001$) was used more frequently to describe the gestures in reflections W [0W/ $-1W$] ($R = 3.9$) and NW [0NW/ $-1NW$] ($R = 2.7$), while less frequently in N [0N/ $-1N$] ($R = -6.6$).
- 'similar' ($\lambda_2 = 7.263$, $p = 0.05$) was used more frequently to describe the gestures in reflection W [0W/ $-1W$] ($R = 2.2$) and less frequently in reflection NW [0NW/ $-1NW$] ($R = -2.4$).
- 'different' ($\lambda = 6.431$, $p = 0.05$) was more frequently used with reflections NW [0NW/ $-1NW$] ($R = 2.3$) and less frequently with reflections W [0W/ $-1W$] ($R = -2.0$) and $-1B$ ($\chi^2_3 = 59.410$, $p = 0.001$, $R = -4.1$).

In order to verify whether these results may be consistently explained in terms of exocentric or egocentric space and to study the role of lateralisation and direction,

a second analysis was conducted. Each reflection (of each gesture) was recoded by the experimenters depending on whether the direction and lateralisation were identical or opposite with respect to two frames of reference: egocentric and exocentric. The frequencies of 'similar', 'identical', 'opposite', and 'different' were then compared with the expected values based on these criteria. For example, if the response 'opposite' was consistent with predictions for the egocentric frame of reference, this response should occur more frequently for reflected gestures with egocentrically opposite lateralisation or direction.

The analyses of participants responses (see table 3) revealed that exocentric direction is predictive for the recognition of gestures in the mirror as 'similar' and 'identical' when they point in the same direction, and as 'opposite' when they point in two opposite directions. The responses 'identical' and 'opposite' are also consistent with the predictions for exocentric lateralisation. The only data consistent with predictions based on egocentric space concern the description of the reflected gesture as 'similar', when the gestures in the mirror have identical egocentric directions with respect to the participant's gesture.

Table 3. Consistency in the participants' use of the four relationships (in columns), in relation to egocentric and exocentric descriptions regarding the lateralisation and direction of the reflected gestures.

Frame of reference	Gesture component	Identical	Opposite	Similar	Different
Egocentric	lateralisation	contrary $\lambda_1 = 26.793$ $p = 0.001$ $R = -3.2$	contrary $\lambda_1 = 8.550$ $p = 0.01$ $R = -2.9$	non-dependent $\lambda_1 = 2.729$ ns	non-dependent $\lambda_1 = 1.947$ ns
	direction	contrary $\lambda_1 = 10.025$ $p = 0.01$ $R = -3.2$	non-dependent $\lambda_1 = 0.494$ ns	consistent $\lambda_1 = 8.584$ $p = 0.001$ $R = 2.9$	non-dependent $\lambda_1 = 0.039$ ns
Exocentric	lateralisation	consistent $\lambda_1 = 73.930$ $p = 0.001$ $R = 7.9$	consistent $\lambda_1 = 80.854$ $p = 0.001$ $R = 8.9$	non-dependent $\lambda_1 = 0.783$ ns	non-dependent $\lambda_1 = 0.128$ ns
	direction	consistent $\lambda_1 = 69.534$ $p = 0.001$ $R = 8.4$	consistent $\lambda_1 = 168.372$ $p = 0.001$ $R = 12.7$	consistent $\lambda_1 = 26.385$ $p = 0.05$ $R = 5.2$	non-dependent $\lambda_1 = 0.473$ ns

Note. The table summarises the results of a series of likelihood ratios (λ s).

4 Experiment 3

The absence of a systematic description of reflected gestures as 'identical' in experiment 2 suggests that participants were not simply describing the 'usual' behaviour of their reflected image. The gestures studied in experiment 2 are indeed familiar components of actions that we daily produce in front of the mirror (eg when moving our arm towards a shelf to reach a comb, or when looking at ourselves dressing in front of a mirror). Familiarity could explain why the gestures seen in reflections 0NW/-1NW (figure 6) were described as 'opposite' and 'different' more often than by chance.

These are, in fact, unfamiliar reflections. Familiarity, however, cannot be the explanation for many other results. For instance, it cannot explain why gestures in unfamiliar reflection (ie created by two mirrors meeting at 90°) were sometimes described as ‘identical’, while gestures in familiar reflections (ie created by a single frontal mirror) were sometimes described as ‘opposite’.

Experiment 3 was designed to further test the hypothesis of the importance of the exocentric frame of reference versus the hypothesis of familiarity, when looking at another person’s reflection. In this condition, the hypothesis of familiarity is partially weakened, first by the fact that we rarely see other people’s reflections and second by the fact that, in the case of other people, the pattern of normal encounters is egocentrically based. We all recognise, for example, that, when we shake hands, our egocentric right hand encounters the other person’s same egocentric right hand.

4.1 Method

4.1.1 *Participants.* Twenty undergraduates of the University of Verona (aged 18 to 24 years) took part in the experiment.

4.1.2 *Apparatus.* The same apparatus as in experiments 1 and 2 was used.

4.1.3 *Stimuli.* Six ‘gesture configurations’ were presented to the subjects. They resulted from the combinations of two levels of floor (0 and -1) and three levels of localisation (N, W, and NW). The configurations studied are represented in figure 5a by the pairs (Obs., 0N), (Obs., 0W), and (Obs., 0NW) for floor 0, and by the pairs (Obs., -1B), (Obs., -1NW), and (Obs., -1W) for floor -1. For both floors, the first two pairs showed egocentric left–right reversal, the third pair had the same egocentric left–right lateralisation as the real body.

4.2 Procedure

Participants took part individually in the experiment in the Department of Psychology laboratory at the University of Verona. A research collaborator participated as model standing in front of the mirror with her left arm stretched out sideways. Participants were asked to say whether they perceived the reflection making ‘opposite’, ‘identical’, ‘similar’, or ‘different’ gestures with respect to the model.

The experimenter pointed to the six target reflections one at a time (their order was randomised between subjects). After participants gave the ‘best description’, they were asked to say if the excluded relationships were in any case ‘possible descriptions’, using the same procedure as in experiments 1 and 2.

4.3 Results

A significant difference was found in the use of the four relationships ($\lambda_{15} = 36.172$, $p = 0.002$). If we consider, in general, the frequency of each relationship for all the reflections, we notice that 50% of participants described the reflected gestures as ‘opposite’, around 24% described them as ‘identical’, 20% as ‘similar’, and less than 1% as ‘different’. ‘Identical’ was the preferred description for the gesture shown by reflection 0N. Familiarity with the classic frontal reflection might be invoked to explain this. However, since this reflection is characterised by an identical east–west exocentric structure, an alternative explanation is exocentric identity. This second explanation seems to be supported by the finding that ‘opposite’ was the preferred description for reflections—1NW, 0NW, and -1W. In each of these three reflections, the gesture in the mirror has an opposite exocentric west–east orientation, while -1W and 0NW have identical egocentric left–right orientation with respect to that of the model.

The same distribution of preferences for ‘identical’ and ‘opposite’ was found when considering the judgments of ‘adequacy’ by adding together the frequency of ‘best’ and ‘possible’ descriptions ($\lambda_{15} = 50.601$, $p < 0.001$).

5 General discussion

In the experiments presented in this paper we studied naive observers' experiences when looking at their reflected image, by means of descriptive tasks. The problem of left–right reversal, discussed in the literature on the 'mirror question' as the most striking transformation produced by plane mirrors, is addressed by considering the observer's point of view when looking at his/her own reflection (experiments 1 and 2) or at another person's reflection (experiment 3). We sought, first, to understand whether and in what conditions egocentric left–right reversal affects the perception of self in mirrors and, second, to note if other oppositions which reflections do in fact show in relation to the observer in the exocentric frame of reference (namely transformations of south–north, east–west, up–down orientations) are more relevant in shaping the perceived relationship between the real and reflected body.

Before discussing how our findings impact on the left–right reversal debate (b, see below) and what they might add to previous studies on naive optics (c), we want to expand on our view (a) regarding the current discussion whether the left–right reversal is a real perceptual problem—as argued by Corballis (2000), Ittelson (1993), and Takano (1998)—or a pseudoproblem—as proposed by Gregory (1996), Haig (1993), and Tabata and Okuda (2000).

(a) *Egocentric left–right reversal is a perceptual datum, not a pseudoproblem.* It is clear from our experimental designs that we subscribe to the view that left–right reversal is a visual characteristic which may be seen in reflections of human bodies in plane mirrors (see also Savardi and Bianchi 2005). The purpose of the experiments described here was to test whether this characteristic is perceptually salient in shaping people's experience of their own or other persons' reflected images, not to demonstrate that reversal is absent. It is an undeniable perceptual fact that the virtual body (in the classic reflection formed by single plane mirrors) moves the left arm when the real body is moving the right arm and vice versa.

The explanation that a given object (or human body) is matched by its virtual image by means of appropriate geometric operations, such as a rotation through a fourth spatial dimension or a point-by-point correspondence with the reflected image (see Gregory 1996, and Tabata and Okuda 2000), does not make the psychological problem of left–right reversal disappear. We agree with Takano (1998, page 37) that "according to this line of argument ... one could maintain that the Müller-Lyer illusion, for example, is not worth investigating because the two compared lines are identical in length from a geometrical point of view. The mirror reversal problem arises from a discrepancy in recognised directions, just as the Müller-Lyer illusion arises from a discrepancy in recognised lengths. From a psychological point of view, it is undeniable that the former discrepancy as well as the latter exists in reality". In other words, egocentric left–right reversal exists in the domain of visual perception and is a problem independent of the physics of reflection. For this reason, we suggest that the classic form of the 'mirror question' ("why does the mirror reverse left and right?") is misleading, since left–right reversal refers to what the observer perceives and not to what the mirror does. If the question is approached from the observer's (not the mirror's) point of view, all the arguments regarding the physics of reflection are put to one side. The confusion between the optics of the phenomenon and the perceptual phenomenon itself offers a modern case of 'stimulus error' (Boring 1921; Bozzi 1972, 1998; Jameson et al 2007; Kanizsa 1979; Kohler 1929; Savardi and Bianchi 1999). Geometrical and optical explanations, apart from being misleading for psychologists investigating this phenomenon, are of no use to the observer. Knowing that the two parallel lines in the Müller-Lyer configuration are of equal length, does not help the observer to see them as equal. Similarly, knowing that a point-by-point transformation or a transformation into the fourth dimension would make the geometrical correspondence between virtual

and real body clear does not mean that these transformations can be 'perceived' or even 'imagined'.

(b) *Different frames of reference are involved in mirror-image perception.* A second kind of common criticism concerning the 'sense' of the 'mirror question' focused on the fact that the classic formulation ("why does a mirror reverse left and right but not up and down?") implies confusion between different frames of reference (Block 1974; Gardner 1964; Ittelson 1993; Ittelson et al 1991; Morris 1993). 'Left' and 'right' refer to an egocentric frame of reference, while 'up' and 'down' refer to the exocentric environmental orientation. The most common reaction to this observation has been to conclude that the 'mirror question' is actually a false problem: correcting the description would make the pseudoproblem disappear. We agree that eliminating linguistic ambiguity is very important, but we do not believe that the problem would thus disappear. On the contrary, the results of the experiments presented in this paper highlight the importance of considering that different frames of reference are involved in mirror-image perception. As regards the human body, our findings showed that frontal reflections (ie reflections formed on a single plane mirror set vertically on the wall in front of the observer) were strongly associated with recognition of identity on both levels of description ('best description', about 90% of responses; 'adequate' description, 100% of responses). However, these reflections were at the same time recognised by no less than 80% of subjects as having an opposite orientation, mainly owing to the opposite sagittal south–north exocentric orientation and, to a lesser extent (30%), to the recognition of egocentric left–right reversal. When looking at gravitational reflections, that is reflections formed on a single plane mirror set horizontally on the floor, participants more frequently reported a general perception of opposition (in experiment 1, 50% of subjects judged this to be the 'best' description of the perceived relationship, 88% as a 'possible' description). Only less than 5% did consider 'identical' to be the 'best description', and only 38% considered it an 'adequate' description. A higher number of subjects preferred to describe the perceived invariance in terms of similarity rather than identity (42% 'best description', 80% 'possible description'). Participants describing the orientation as 'opposite' (92.3% of the subjects, in experiment 1) exclusively referred to the reversed exocentric up–down orientation and never mentioned the egocentric left–right reversal.

This difference in noticing egocentric left–right reversal in frontal and gravitational reflections might be due to the difficulty in recognising egocentric orientation in bodies reflected upside down. This would be consistent with findings confirming that transverse self-rotations and ground plane rotations are more easily imagined than coronal self-rotations (see Carpenter and Proffitt 2001; Creem et al 2001; Parsons 1987a, 1987b). Whatever the reason for these results, they demonstrate that people do not simply apply explicit knowledge about left–right reversal in plane mirrors (this knowledge seems to be more significant in the psychological debate on mirrors than in naive observers' experiences of reflections). Results showed that exocentric, as opposed to egocentric, relationships were important in structuring the experience of identity and opposition to reflected bodies. This was the case even when direct comparisons between single plane reflections and reflections formed in two adjacent orthogonal mirrors were considered (experiment 1), as well as when other people's reflections, rather than one's own reflection, were considered (experiment 3). In all three experiments, in both frontal and gravitational conditions, the perception of identity was better associated with reflections having an identical exocentric east–west orientation but opposite egocentric left–right orientation (single plane mirror reflection), as compared to reflections having an identical egocentric left–right structure, but an opposite exocentric east–west orientation (90° mirror reflections).

Experiment 2 allowed us to go deeper into an analysis of the role of familiarity versus that of the ‘observer–reflection’ visual configuration by extending the investigation to the recognition of gestures. Participants’ familiarity with gestures made by single plane mirror reflections might lead us to predict frequent use of the response ‘identical’. In everyday situations observers often face their reflected image when making gestures or moving their arms into various positions. However, results from experiment 2 confirmed that people recognise that reflected gestures fail to correspond to the observer’s gestures in a very high percentage of cases (73% of the responses). They are more frequently considered to be ‘opposite’ (41%) rather than ‘similar’ (27.7%) or ‘different’ (7.2%). An analysis of these results in terms of egocentric versus exocentric frames of reference confirmed that, whatever the gesture, the reflection floor, and the specific location, responses of opposition were used with reflected gestures pointing in an opposite exocentric direction. Similarly, ‘identical’ responses—when used—tended to be associated with reflected gestures preserving an identical direction to the original one within the exocentric spatial coordinates.

At this stage of the investigation one cannot predict precisely how perception of mirror images would change when considering reflections of various objects instead of reflections of the human body. If it is true—as our argument states—that perception of mirror images depends on the frame of reference implied by the object (and hence by its reflection), one should expect responses to vary accordingly.

An example will help to explain this. Consider a mirror hanging on the wall and, in front of it, a man with his right arm stretched out sideways (let’s say pointing towards the window) parallel to the mirror, a teacup with its handle pointing towards the window, and three T-shirts hanging in front of the mirror with “L”, “HUM”, and “AMBULANCE” respectively printed on them. If we look at the reflections of these objects, we will probably notice that the reflections of the body (as confirmed by the results in this paper) and of the cup look natural pointing in the same direction as the real objects do (ie towards the window). The same holds with the T-shirt with the L if I see the sign as a simple drawing of a right angle, while it seems to be opposite if I see it as a letter. The T-shirts with the words HUM and AMBULANCE will look quite odd and the latter more than the former. In this case, too, I can see that the exocentric orientation of the words in the reflected image is the same as that of the words in the real T-shirt: in fact, with HUM, both the real and the reflected H are towards the window, then comes the U while the M is the farthest from the window. But the image appears awkward, despite showing identity in the exocentric frame of reference. This ‘oddness’ of the reflection reveals that, in the case of text, the exocentric frame of reference has a secondary role, while it is the left–right frame of reference of the words which emerges. Furthermore, the increased ‘oppositeness’ perceived with AMBULANCE as compared to HUM suggests that the ‘local’ left–right orientation of the letters affects the perception of the reflection significantly, in addition to the ‘global’ left–right orientation of the entire word.

(c) *Possible impact of these results on previous studies on naive optics.* Before ending, we would like to propose a possible alternative interpretation of a finding regarding naive optics (Bertamini et al 2003; Croucher et al 2002), suggested by the results presented in this paper. We refer, in particular, to the fact that people who were not able to precisely predict when they would start to see themselves (or a target) in a mirror also tended to expect the reflection to appear on the opposite side of the mirror. Interestingly, people made this latter error only when pretending to approach a mirror set on the wall (not when it was placed on the ceiling or on the floor). Again, these findings cannot be explained by the application of explicit knowledge, since we would not expect varying responses. Neither can they be explained by familiarity, since people have a great deal of experience of approaching mirrors hanging on the wall,

walking horizontally towards them, while very few people experience climbing vertically up mirrors or walking over mirrors lying on the floor or under mirrors hanging on the ceiling. Moreover, the experience of seeing a reflection appearing on the opposite side of the mirror while approaching it from one side is certainly not familiar. That was, however, what subjects who made an error predicted. Bertamini et al (2003) explained their results by suggesting that some people may expect the transition from actual to reflected world to be a 180° rotation around a vertical axis and this false belief might explain the above set of results. However, they also found that people easily recognised the error in images where the mirror reflection had been reversed from left to right around its vertical axis, while revealing a surprisingly high level of tolerance to various other distortions in mirror reflections (expanded, compressed, or tilted images). The scenes studied showed a room and a mirror with the reflection of the room on the wall opposite the observer. The left–right reversal was applied to the whole scene; thus the distorted reflection showed exocentric left–right reversal, the same as in our 90° reflection condition. The results of our experiments showed that people easily recognise exocentric oppositions present in reflected scenes: the north–south, the up–down, and also the east–west opposition that is visible with some single plane mirror reflections (eg W in figure 5a) and in the 90° mirror condition (NW in figure 5a) that coincides with the kind of transformation used by Bertamini et al (2003) when rotating the scene. In this sense our findings agree with the expectation that opposition (reversal) would be recognised here. At the same time, we believe they suggest an alternative explanation to the idea that people confuse reflections with rotations. The mistaken expectation that the reflection would appear on the opposite side of the mirror could be explained as an erroneous generalisation of the exocentric structure of opposition that usually characterises our perception of reflections. When we look at ourselves or at any other person or object approaching a vertical mirror from various angles (see figure 7) we see that the reflection is moving either in an identical exocentric direction or in the opposite direction. These two components characterise any movement towards mirrors set vertically on the wall, with only two exceptions. The first is, when approaching it by walking orthogonally towards it (figure 7d). In this case the ‘opposition’ component is the only one present. The second is when approaching it walking parallel to the mirror (figure 7e)—as in the condition studied by Bertamini et al (2003)—where the ‘opposition’ component disappears in favour of the identity-of-direction component alone.

Our findings demonstrated that, when the observer–reflection gestures configuration were in opposite directions, people described the reflected gesture as opposite to

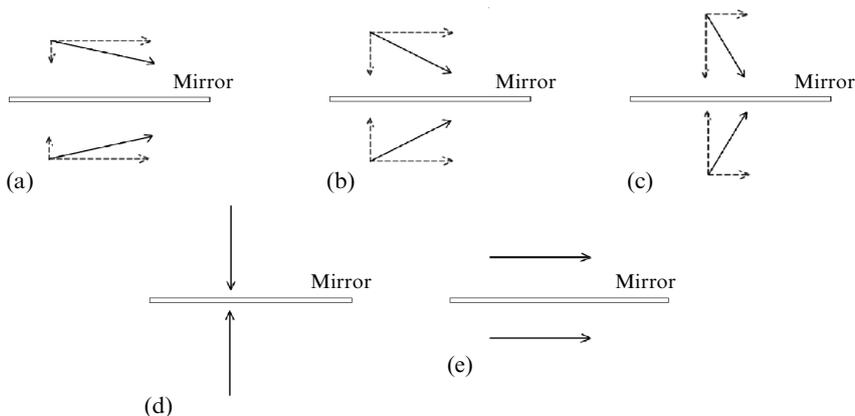


Figure 7. Exocentric components of the direction of the motion characterising mirror reflections in plane mirrors, given different angles of approach towards the mirror.

their own gestures, and that in the motion condition this perceived opposition was emphasised. We suggest that this component of ‘moving in opposite directions’ that reflections usually show, is a salient characteristic of our experience of mirror reflections. This is likely to be even more so when the entire person/object is in motion, and not only an arm movement is involved. That is, correct perceptual knowledge may lead to incorrect predictions if applied to the special condition of walking parallel to the mirror (figure 7e).

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References

- Bennet J, 1970 “The difference between right and left” *American Philosophical Quarterly* **7** 175–191
- Bertamini M, Parks T E, 2005 “On what people know about images on mirrors” *Cognition* **98** 85–104
- Bertamini M, Spooner A, Hecht H, 2003 “Naive optics: Predicting and perceiving reflections in mirrors” *Journal of Experimental Psychology: Human Perception and Performance* **29** 982–1002
- Bianchi I, Savardi U, 2007 *Contrariety in Perception* (Rome: Aracne) in preparation
- Block N J, 1974 “Why do mirrors reverse left/right but not up/down?” *Journal of Philosophy* **71** 259–277
- Boring E G, 1921 “The stimulus error” *American Journal of Psychology* **32** 449–471
- Bozzi P, 1972 “Cinque varietà di errore dello stimolo” [Five varieties of stimulus error] *Rivista di Psicologia LXVI* fasc. 3–4 (Istituto di Psicologia dell’Università di Trieste)
- Bozzi P, 1978 “L’interosservazione come metodo per la fenomenologia sperimentale” [Inter-observation as a method for experimental phenomenology] *Giornale Italiano di Psicologia* **5** 229–239
- Bozzi P, 1998 “Considerazioni eccentriche sull’errore dello stimolo” [Eccentric considerations about the stimulus error] *Giornale Italiano di Psicologia XXV* 239–251
- Bozzi P, Martinuzzi L, 1989 “Un esperimento di interosservazione” [An experiment of inter-observation] *Rivista di Psicologia LXXIV* 11–46
- Bredart S, 2003 “Recognizing the usual orientation of one’s face: the role of asymmetrically located details” *Perception* **32** 805–811
- Carpenter M, Proffitt D R, 2001 “Comparing viewer and array mental rotations in different planes” *Memory & Cognition* **29** 441–448
- Corballis M C, 2000 “Much ado about mirrors” *Psychonomic Bulletin & Review* **7** 163–169
- Corballis M, Beale I, 1976 *Psychology of Left and Right* (New York: Halsted Press)
- Creem S H, Wraga M, Proffitt D R, 2001 “Imagining physically impossible self-rotations: geometry is more important than gravity” *Cognition* **81** 41–64
- Croucher C J, Bertamini M, Hecht H, 2002 “Naive optics: Understanding the geometry of mirror reflections” *Journal of Experimental Psychology: Human Perception and Performance* **28** 546–562
- Gardner M, 1964 *The Ambidextrous Universe* (New York: Basic Books)
- Goldmeier E, 1936/1972 “Similarity in visually perceived forms” *Psychological Issues* **29** whole number
- Gombrich E H, 1960 *Art and Illusion* (Oxford: Phaidon Press)
- Gregory R L, 1987 “Mirror reversals”, in *The Oxford Companion to the Mind* Ed. R L Gregory (Oxford: Oxford University Press) pp 491–493
- Gregory R L, 1996 *Mirrors in Mind* (New York: Freeman Spektrum)
- Gregory R L, 2001 “Seeing oneself” *Perception* **30** 903–904
- Haig N D, 1993 “Reflections on inversion and reversion” *Perception* **22** 863–868
- Hecht H, Bertamini M, Gamer M, 2005 “Naive optics: Acting upon mirror reflections” *Journal of Experimental Psychology: Human Perception and Performance* **31** 1023–1038
- Ittelson W H, 1993 “Mirror reversals: real and perceived” *Perception* **22** 855–861
- Ittelson W H, Mowafy L, Magid D, 1991 “The perception of mirror rotated objects” *Perception* **20** 567–584
- Jameson K A, Bimler D, Dedrick D, Roberson D, 2007 “Considering the prevalence of the stimulus error in color naming research” *Journal of Cognition and Culture* **7** 119–142
- Kanizsa G, 1979 *Organization in Vision* (New York: Praeger)
- Kohler W, 1929 *Gestalt Psychology* (New York: Liveridge)
- Kubovy M, 1999 “Gestalt psychology”, in *The MIT Encyclopedia of the Cognitive Sciences* Eds R A Wilson, F C Keil (Cambridge, MA: MIT Press) pp 346–349

- Lawson R, Bertamini M, 2006 “Errors in judging information about reflections on mirrors” *Perception* **35** 1265–1288
- Locke D, 1977 “Through the looking glass” *Philosophical Review* **86** 3–19
- McCloskey M, 1983 “Intuitive physics” *Scientific American* **245** 114–119
- Mackavey W R, 1980 “Exceptional cases of pictorial perspective”, in *The Perception of Pictures* Ed. M A Hagen, volume 1 (New York: Academic Press)
- Medin D L, Goldstone R L, Gentner D, 1990 “Similarity involving attributes and relations: judgements of similarity and difference are not inverses” *Psychological Science* **1** 64–69
- Morris R C, 1993 “Mirror image reversals: Is what we see what we present?” *Perception* **22** 869–876
- Navon D, 1987 “Why do we blame the mirror for reversing left and right?” *Cognition* **27** 275–283
- Navon D, 2001 “The puzzle of mirror reversal: a view from clockland” *Psychology* **12**(17) 1–19
<http://psycprints.ecs.soton.ac.uk/archive/00000146>
- Palmer S E, 1978 “Structural aspects of visual similarity” *Memory & Cognition* **6** 91–97
- Parks T E, 2001 “The mirror- (and the moon-) illusion” *Perception* **30** 899
- Parsons L M, 1987a “Imagined spatial transformation of one’s body” *Journal of Experimental Psychology: General* **116** 172–191
- Parsons L M, 1987b “Imagined spatial transformations of one’s hands and feet” *Cognitive Psychology* **116** 178–241
- Pittenger J B, Runeson S, 1990 “Paolo Bozzi’s studies of event perception: a historical note” *International Society of Event Perception* **4**(3) 10–12
- Proffitt D R, 1999 “Naïve physics”, in *The MIT Encyclopedia of the Cognitive Sciences* Eds R A Wilson, K C Keil (Cambridge, MA: MIT Press) pp 577–579
- Rhodes G, 1986 “Memory for lateral symmetries in well-known faces: Evidence for configural information in memory representations of faces” *Memory & Cognition* **14** 209–219
- Savardi U, Bianchi I, 2005 “Looking at yourself in the mirror: structures of perceptual opposition” *Gestalt Theory* **3** 204–220
- Savardi U, Bianchi I, 2000a *L’Identità dei Contrari* [The identity of opposition] (Verona, Italy: Cierre)
- Savardi U, Bianchi I, 2000b “Metodo interosservativo ed eventi sotto osservazione: l’estensione dell’esperienza di spazio nella fenomenologia sperimentale della percezione” [Inter-observation method and events under observation: the extension of spatial experience in the experimental phenomenology of perception], in *Figura e Sfondo. Temi e Variazioni per Paolo Bozzi* [Figure and background. Themes and variations for Paolo Bozzi] Eds U Savardi, A Mazzocco (Padua, Italy: Cleup) pp 107–130
- Savardi U, Bianchi I (Eds), 1999 *Gli Errori dello Stimolo* [Stimulus errors] (Verona, Italy: Cierre)
- Tabata T, Okuda S, 2000 “Mirror reversal simply explained without recourse to psychological processes” *Psychonomic Bulletin & Review* **7** 170–173
- Takano Y, 1998 “Why does a mirror image look left–right reversed? A hypothesis of multiple processes” *Psychonomic Bulletin & Review* **5** 37–55
- Tversky A, 1977 “Features of similarity” *Psychological Review* **84** 327–352

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