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What Fits Into a Mirror: Naïve Beliefs About the Field of View

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Research on naïve physics and naïve optics have shown that people hold surprising beliefs about everyday phenomena that are in contrast with what they see. In this article, we investigated what adults expect to be the field of view of a mirror from various viewpoints. The studies presented here confirm that humans have difficulty dealing with the role of the viewpoint in reflections and consistently prove that predictions are dominated by two patterns and a frontal bias. The majority of adults correctly predict that, from a central viewpoint, the space reflected in a mirror expands beyond the orthogonal projections to both its edges. For eccentric viewpoints, half of the participants expected a different (correct) behavior, while the other half also predicted, in this case, expansion at both edges. This means that, contrary to what happens in reality, they expected the mirror to show the space that is orthogonally in front of it and also beyond it, whatever the position of the observer (frontal bias). The error also persisted after the observation of a real reflection. However, this was not found to be true with windows. Performance improved when participants were asked to recognize the correct answer out of a series of alternatives (in this condition, only a quantitative error persisted). In both tasks (production and recognition of the correct response), people relied on imagination or memory and not on the application of the optical rule that angle of reflection equals the angle of incidence.

Keywords: naïve optics, relationship between the observer's viewing position and the field of view of mirrors, mirrors versus windows, imagination and memory of reflections versus optical laws, opposition between real and reflected space

Research on naïve physics has demonstrated that adults hold surprising, erroneous beliefs about everyday phenomena concerning basic physical or mechanical laws (for a review, see Proffitt & Kaiser, 2003). Similarly, research on naïve optics has also shown that adults hold many surprising erroneous beliefs about the behavior of mirror images (for a review, see Lawson & Bertamini, 2006). What is surprising about these beliefs is not that they are inconsistent with established physical or optical theories but that what people predict is in contrast with what they perceive. For example, a false belief regarding reflections is to expect that a person entering a room and moving parallel to a mirror surface will see his or her reflection appear at the farther edge, rather than the nearer edge, of the mirror (Bertamini, Spooner, & Hecht, 2003). This error was also found for movements at various angles of incidence toward or away from the mirror (Savardi, Bianchi, & Bertamini, 2010). This error is more surprising than other errors described in naïve optics, such as, for example, the error of overestimating the size of one's own head on the surface of a mirror (Bertamini & Parks, 2005; Lawson & Bertamini, 2006; Lawson, Bertamini, & Liu, 2007). People do not see the reflection *on* the surface of the mirror, and unless one has specific knowledge of the projective laws of reflection or has spent time drawing the outline of objects and/or of one's own face on mirror surfaces (Gombrich, 1960, p. 5, invited readers to follow the outline of their face with their finger on a fogged-up mirror), this is not information we are familiar with. But errors like those mentioned here are more thought provoking: Nobody, when walking parallel to or obliquely toward a mirror, has ever seen his or her reflection appearing on the opposite side (the farthest side) of the mirror walking contrary to him/her. Strictly speaking, the origin of this error is not what people see. It has been suggested, however, that it might originate from an incorrect generalization of what they see (Savardi et al., 2010). When looking at their body in a large frontal mirror, participants describe the orientation of their reflection as opposite, more often than identical to, themselves ("I'm facing toward, e.g., north, while my reflection is facing the opposite direction, i.e., south"), and when they raise their arm to point in front, they say that the reflection is doing the same but pointing in the opposite direction (Bianchi & Savardi, 2008a). Adults describe in a similar way the movement of the reflection of a ball moving orthogonally toward a mirror or the orientation of the reflection of a puppet facing a mirror (Savardi et al., 2010, Experiment 5). The incorrect belief that the reflection would appear on the opposite side of the mirror and move contrary to the real person, even when he or she is walking parallel to the mirror, is in agreement with the hypothesis that people oversimplify the geometry of reflections, recalling and generalizing to whatever angle of incidence the prototypical model (Yates et al., 1988) that "the reflection moves contrary to the real person, in the opposite direction" (Savardi et al., 2010). Might a similar process of generalization also account for the errors that adults make when predicting the field of view of a mirror?

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The Field of View of a Mirror: The Early Error and the Frontal Error

A surprising percentage of adults—when asked to predict where an observer approaching a mirror from the side walking parallel to it would start to see herself/himself reflected in the mirror—make what has been called the "early error": They predict that he/she would start seeing the reflection before he/she actually does, that is, before reaching the near edge of the mirror (Bertamini, Spooner, et al., 2003; Croucher, Bertamini, & Hecht, 2002; Hecht, Bertamini, & Gamer, 2005; Lawson et al., 2006). The early error suggests that adults have incorrect beliefs regarding the field of view of mirrors, as they expect an expansion where this is not the case. These studies, however, do not provide a systematic investigation of (a) how people expect the space "captured" by a mirror to change depending on the position from which the observation is carried out (in the studies where the early error was discovered, participants were asked to predict only what happened at the *near edge* of the mirror; we do not know what they expect at the farther edge, nor how they expect the field of view to change in relation to changes in the viewpoint); (b) whether the errors made by adults follow a common pattern, and (c) what the source of this pattern or patterns might be. These are the questions addressed in this article.

A partial answer to the first question is offered by Bertamini, Lawson, Jones, and Winters (2010, Experiment 5). Diagrams showing a person standing in three different positions (in front, to the right, and to the left) with respect to a mirror hung vertically in the center of a room were presented to participants who were asked to predict how much of the room behind the person would be visible. The two main results emerging from this study concerned (a) a tendency to underestimate the extent to which the field of view is influenced by the observer's viewpoint (responses roughly overlapped in the three locations, and for eccentric positions, people only slightly shifted their response toward the correct direction), and (b) the emergence of a what we call a "frontal bias": In all three conditions, people expected the mirror to reflect the space in front of the mirror, although from the two lateral viewing positions, it did not.

However, since only two viewpoints were considered (one central and another eccentric—to the left or to the right, but at the same distance from the mirror), the study did not provide detailed information about how people expect the field of view to change when they progressively approach a mirror from one side. Moreover, at the farther edge, the field of view was necessarily limited by a corner of the room. We thus do not know how much space observers would think they would be able to see if the corner did not limit their visibility. In addition, the task was conceived so that participants had to indicate which tiles of the wall behind the back of the observer were visible in the reflection; but since the tiles were positioned far apart, we do not know exactly where they expected the field of view to end.

By removing these limits, focusing on various positions and distances from the mirror and changing the task conditions, we aimed to gain further insights into how much of the surrounding space people expect to be visible in a mirror set vertically on the wall, given various observer positions. We also wanted to look into what the origin of these beliefs might be. Starting from the errors found with a paper-and-pencil task in Study 1, in Study 2, we tested whether the accuracy of participants' predictions improved when they had the chance to observe a real reflection *before* doing the paper-and-pencil task. In Study 3, we investigated adults' understanding of the relationship between the field of view of a mirror and of a window. Studies 4 and 5 were designed to test whether the errors found in Studies 1–3 generalized to other conditions and tasks, and to understand the strategies used by participants in making their predictions. Results from Studies 1–3 had suggested, in fact, that participants were not simply applying the optical rule that the angle of reflection equals the angles of incidence.

Study 1

In the first study, a paper-and-pencil task was used. Participants were asked to predict what would be visible in a mirror from four different viewpoints: a central viewpoint (a person standing centrally in front of a mirror) and three variously eccentric positions. The objects to be reflected were positioned behind the observer. These were numbered adjacent tiles, and the proximity of the tiles allowed us to guarantee an accurate metric estimate of the expected field of view.

Method

Participants. Forty undergraduate students at the University of Macerata (mean age 22.7 years; 25 females) participated in Study 1.

Materials and Procedure. Participants received four diagrams representing a person standing to the left of the mirror (corresponding to tiles No. 7 and 9, which we will refer to as Pos. 7 and Pos. 9, respectively), in front of the mirror on the extreme left (Pos. 11), or in a central position (Pos. 13, as represented in Figure 1). On the wall behind the person represented in the diagram, there were 26 tiles numbered from left to right. The instructions invited participants to imagine the scene before giving their response:

> Imagine you are in front of a mirror hanging on a wall. In the diagrams (aerial view), your position is represented by the gray head. The thick line represents the mirror (which is 2m long). On the wall behind you there are a series of numbered tiles. Which tiles would you see reflected in the mirror from the position where you are? Mark the two limits in the series of tiles (putting a mark in between two tiles or inside a tile if you believe that you would not see it entirely but only a part of it), and write the corresponding numbers in the box.

The order of the four viewpoints was randomized between participants. The test was administered in a classroom at the beginning of a lecture. The instructions were verbally issued by the experimenter and were also printed at the bottom of each diagram.

Results

Participants' responses and correct responses have been coded in terms of angles, assuming the projection orthogonal to the mirror edges as corresponding to 0°, with positive angles indicating responses to the right of this point and negative angles indicating responses to its left.

Do participants predict a change in the field of view depending on the viewpoint? Participants partially understand that when changing the viewpoint, the field of view changes. However,

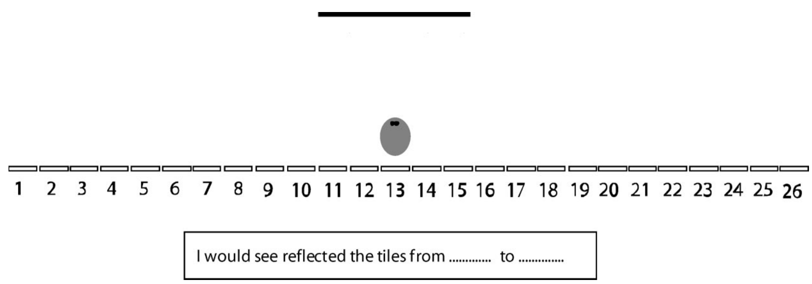

Figure 1. Example of one of the four stimuli used in Study 1, namely, the stimulus referring to the observer in a central position (Pos. 13).

they only have a rough understanding of this. This emerged from the results of a mixed analysis of variance (ANOVA) on the angles of response—with position and edge as within-subjects variables and sex as between-subjects variables—revealing the main effects of position ($F_{3,\ 114} = 10.549$, $p < .001$) and edge ($F_{1,\ 38} = 94.152$, $p < .001$), and an interaction between position and edge ($F_{3,\ 114} = 9.944$, $p < .001$). Sex was not significant ($F_{1,\ 38} = 2.202$, *ns*). Bonferonni post hoc tests clarified where the differences were: (a) with respect to position, a difference was found between the angle predicted when the observer was positioned centrally (Pos. 13) and all eccentric positions; (b) with respect to edge, the right edge was, on average, bigger than the left edge—this is correct given the positions studied (in three of them, the observer was positioned to the left of the mirror); (c) as shown by the interaction between position and edge (see Figure 2, top left graph), at the right edge, participants predicted a constant angle independently of the position of the observer, whereas they expected a change to occur at the left (near) edge. This change follows the trend of the correct angles, but in the extreme eccentric positions (Pos. 9 and 7), the average response remains around zero (and is not a positive angle, as it is in reality). This is apparently consistent with the frontal error described in the introduction to this article.

Were participants' estimates more accurate in certain positions and less in others? To answer this question, we focused on the difference between participants' predictions and the correct angle of reflection: the bigger the difference, the more inaccurate the response, while the positive or negative sign of the difference indicates whether the error consisted of an overestimation of the field of view (i.e., expecting it to show more than it would in reality) or an underestimation (i.e., expecting it to show less). A second ANOVA was carried out, using the mismatch between predicted and correct angles as a dependent variable. A main effect of position ($F_{3,\ 114} = 66.952$, $p < .001$) and edge ($F_{1,\ 38} = 5.436$, $p < .025$) was found, together with an interaction between position and edge ($F_{3,\ 114} = 22.561$, $p < .001$). The interaction, in particular, indicates that the mismatch changes depending on where the observer is positioned and which edge is considered (Figure 2, top right graph). At the left (near) edge, the mismatch between estimated and correct angles changes for all four positions (Bonferroni, $p < .001$); at the right (far) edge, a greater error was found for the two extreme eccentric positions (Pos. 9 and 7) than for the central (Pos. 13) or slightly eccentric (Pos. 11) positions.

Different types of errors. As the scatterplot in Figure 2 (bottom graph) makes clear, in some conditions (Pos. 13, and for the right edge in all eccentric positions), responses were entirely or almost entirely on the same side, with respect to zero, where the correct response is—the correct angle is represented by the dark dot. This means that participants predicted the correct type of behavior (e.g., the reflection shows more than a view ending orthogonally with respect to the mirror edge, i.e., an expansion), and the error only concerned the width of the expansion. In contrast, in other conditions (namely, for the near edge in all eccentric positions), approximately half of the responses are on the opposite side as the dark dot, manifesting that participants predicted the opposite behavior (i.e., an expansion rather than a reduction) rather than being only inaccurate in terms of quantitative estimation.

In order to better analyze the type of error made by participants, responses at both edges were recoded into three categories: (a) predictions that the space visible in the reflection finishes *orthogonally* (O) with respect to the mirror edge, which is consistent with the belief that the mirror shows only what is directly in front of it; (b) predictions that the space visible in the reflection is *expanded* with respect to the mirror edge (E), or, in other words, the mirror shows more than the space directly in front of it; and (c) predictions that the space visible in the reflection is *reduced* with respect to the mirror edges (R), meaning that part of the space that is in front of the mirror is not visible in the reflection.

Average angles of expansion and reduction were computed for the last two categories. No average values were used for responses that had been classified as orthogonal, since this response corresponded to a clear-cut position, which participants could easily identify and mark in the diagrams—the orthogonal projection fell exactly in between two tiles, as shown in Figure 1.

The percentage of responses in each category is reported in Figure 3, together with participants' most frequent responses (thick gray lines). Responses are plotted using a diagram similar to that presented to participants in order to provide a direct comparison between the field of view drawn by participants (referred to in the text as αP) and the correct field of view (referred to as αR, and indicated in the diagram by the dark dashed line). The results can be summarized as follows. First, when the position of the observer was central with respect to the mirror (Pos. 13), almost all participants correctly predicted that the reflection would show an expansion of the space directly in front of the mirror (E = 85–90%), but the extent of this expansion was, on average, underestimated ($t_{\alpha P\text{-}\alpha R\ (Pos.\ 13far)} = -4.841$, $df = 35$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (Pos.\ 13near)} = 5.343$; $df = 33$, $p < .001$). Second, when the observer was close to one edge of the mirror (Pos. 11), almost all participants (90%) correctly predicted an expansion at the far edge,

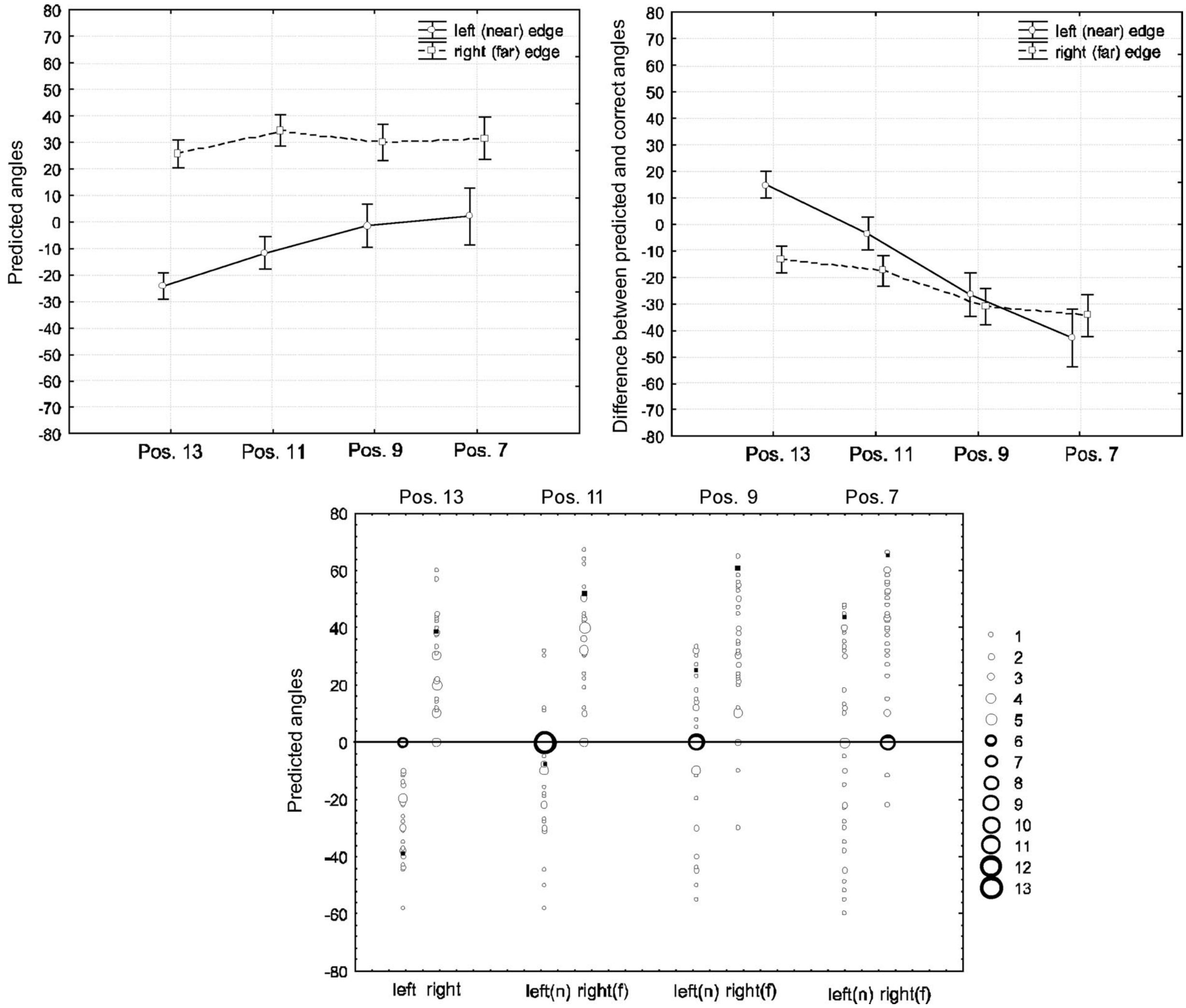

Figure 2. Top graphs: mean angles of response (graph on the left) and mean difference between predicted and corrected angles (graph on the right) for the two edges in the four positions in Study 1. Error bars represent a 95% confidence band. Bottom graph: frequency scatterplot of participants' responses (αP) for the two edges of the mirror (left/right, which, for the eccentric positions, correspond to the near/far edges, respectively) in the four positions in Study 1. The dark dots represent the correct responses (αR).

but also underestimated it ($t_{\alpha P\text{-}\alpha R\ (Pos.\ 11far)} = -6.139$, $df = 35$, $p < .001$). At the near edge, almost 60% of participants predicted an expansion of the space shown (which is correct, in terms of type of response), but predicted that it was wider than it would be in reality ($t_{\alpha P\text{-}\alpha R\ (Pos.\ 11near)}$: $t = -22.521$, $df = 22$, $p < .001$), whereas 32% of participants predicted that the space visible in the reflection would be limited orthogonally with respect to the mirror edge (O). Third, when the observer was positioned eccentrically, to the left of the mirror (in both Pos. 9 and Pos. 7), participants predicted an expansion of the space visible at the far edge of the mirror but underestimated it ($t_{\alpha P\text{-}\alpha R\ (Pos.\ 9far)} = -10.015$, $df = 34$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (Pos.\ 7far)} = -8.512$, $df = 29$, $p < .001$). Two different types of predictions were instead made for the near edge. Approximately 40% of responses for both positions predicted that the reflection would show more of the space that is directly in front (i.e., an expansion). A similar percentage of responses (45% in Pos. 7; 40% in Pos. 9) correctly predicted a reduction, that is, that part of the space in front of the mirror would not be visible in the reflection, but they underestimated the extent ($t_{\alpha P\text{-}\alpha R\ (Pos.\ 9near)} = -2.080$, $df = 15$, $p = .055$; $t_{\alpha P\text{-}\alpha R\ (Pos.\ 7near)} = -4.575$, $df = 17$, $p < .001$). This means that, in both cases (expansions and reductions), participants expected to see more than would be the case in reality.

Emergent patterns. Reponses represented in the diagrams in Figure 3 suggest two considerations. First, people have in mind two different models of the field of view of a mirror in a similar percentage of cases (approximately 40–50% of responses). One model oversimplifies the geometry of the field of view of reflections to the shape of the visual field that is experienced when the observer is positioned centrally in front of the mirror (forming, approximately, an isosceles trapezoid). This model emerges from responses predicting an expansion at both edges of the mirror, not only for the central position (Pos.

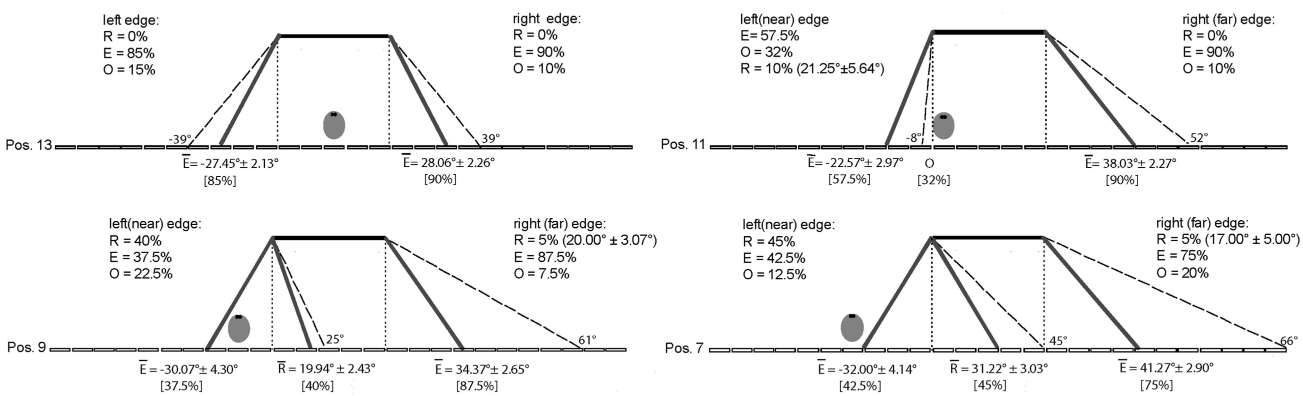

Figure 3. Percentages of the three types of response (expansion, E; reduction, R; orthogonal to the mirror edge, O) and mean angle and standard error within the category for the four positions studied and the two edges of the mirror in Study 1. The dashed lines represent the correct angle of reflection (αR); the dotted lines represent the orthogonal projection of the mirror edges. The thick gray lines represent the average angle (αP) of the more frequent category (or categories) of response.

13), where this is correct, but also for all the eccentric positions (Pos. 11, 9, and 7). Another subset of responses revealed a more articulated geometry of the field of view, according to which, from a central viewpoint, the reflection would show an expansion at both edges (trapezoidal field of view), whereas for eccentric viewpoints, the reflection would show an expansion at the farthest edge and a reduction at the nearest edge (this corresponds to the parallelogram-shaped fields in Figure 3).

The second consideration is that even those who were correct in applying two different patterns, depending on the viewpoint, underestimated the expansion or reduction (in Figure 3, the mean angles of expansion and of reduction indicated by the thick lines are systematic underestimations of the geometrical angles indicated by the dashed lines). This can be thought of as a bias toward a shrinkage of the predicted field of view in the direction of the physical edges of the mirror, thus revealing the persistence of a frontal bias in adults.

Study 2

How can incorrect predictions, such as those described thus far, coexist with our daily experience of mirrors? Study 2 was designed to understand whether prior observation of a real scene that corresponds to that represented in the paper-and-pencil task would be enough to correct participants' predictions, at least with respect to the observer positions.

Method

Participants. Forty undergraduates at the University of Macerata participated in Study 2: 20 (mean age 21.3 years; 11 females) participated in Condition 1, and 20 (mean age 21.6 years; 13 females) participated in Condition 2.

Procedure. A mirror (200 × 90 cm) was hung horizontally on a wall. The wall opposite the mirror consisted of a large window facing a garden (this choice was made in order to create an environmentally rich reflection). A series of numbered cards were hung on the window 1.5 m from the floor. The size of the cards and their distance from the mirror was determined in order to exactly represent the scene in the paper-and-pencil task: The farthest tiles that participants could see standing in the four positions marked on the floor (corresponding to Pos. 13, 11, 9, and 7) were the same as those that the observer could see in the paper-and-pencil task.

Participants were invited to stand for 5 s in the position marked on the floor and were then invited to move to the next position, where they stayed for another 5 s. The observation was carried out in Condition 1 from only two positions (Pos. 9 and Pos. 13) and in Condition 2 from all four positions. In each position, participants were invited to assess how much of the surrounding environment was reflected in the mirror.[1] The order in which participants occupied the various positions was fixed, from the most eccentric (Pos. 9 in Condition 1, Pos. 7 in Condition 2) to the central position (Pos. 13), which is the order that naturally occurs when a person approaches a mirror, walking toward it. After this observational phase, participants were invited to sit at a table positioned away from the setting and to complete the paper-and-pencil task. At the end of the session, they were told to stand, once again, in the four positions and were then asked, for each position, to tell the experimenter which of the extreme tiles they could see. This was done to check that they had understood the task and to verify that their responses would be as expected.

Results

Do participants predict a change in the field of view depending on the viewpoint? As in Study 1, the analysis of the angles of response revealed that participants have only a rough understanding that the field of view changes depending on the observer's viewpoint. The mixed model ANOVA conducted on the angles of response revealed a main effect of position ($F_{3,\ 108}$ =

[1] Of course, if participants were explicitly asked to focus on the numbers of the extreme tiles that they could see in the reflection from the various positions, the task would have simply been a memory task, which was not of interest to us. For this reason, we used a less specific instruction to guide their observation.

5.172, p = .002)—post hoc tests showed that the difference was between the angle indicated in the central position (Pos. 13) compared with the two most extreme eccentric positions (Pos. 7 and 9, $p \leq .05$)—and a main effect of edge ($F_{1,\ 36} = 51.403$, $p < .001$). The angle indicated for the far right edge was on average bigger than that on the left edge. However, as found in Study 1, the interaction between position and edge was also significant ($F_{3,\ 108} = 3.418$, $p < .05$). The mean responses for the far edge did not vary depending on the observer's viewpoint (see Figure 4, left graph), whereas, at the left (near) edge, a significant difference emerged between the central position (Pos. 13) and the two most eccentric positions (Pos. 7 and 9, $p < .001$); no difference was found between Pos. 13 and 11, or between Pos. 7 and 9.

No effects of sex or condition were found. This latter result means that having observed the reflection from four or only two of the positions before completing the paper-and-pencil task did not lead to different responses.

Different types of errors. The scatterplot (Figure 4, on the right) showed a pattern very similar to that found in Study 1. Responses were thus recoded in terms of type of behavior predicted: limited *orthogonally* (O), *expanded* (E), or *reduced* (R) with respect to the mirror edges. Mean angles and standard errors were then computed within each category of response. Average responses within categories (E, R, O) are summarized in Figure 5. The two conditions (observation from four or two positions) were kept distinct. This was done—despite the fact that the ANOVA discussed previously suggested no differences between the two conditions in terms of average angles of response—in order to potentially avoid masking differences in terms of frequency of responses falling in the three categories, and of average responses within each category.

Overall, prior observation of the reflection from two or all four positions did not reduced the number of participants who predicted incorrect behavior. A difference emerged only concerning Pos. 13 (likelihood ratio = 10.259, df = 4, $p < .05$), where incorrect responses (i.e., R and O projections)—although less frequent than the correct responses (i.e., E)—turned out to be more frequent for the left edge in Study 2 than in Study 1. No significant differences were found for any other position. Therefore, the observational phase did not improve the frequency of correct responses. However, it partially improved the precision of the angles estimated when the correct type of behavior was identified, as discussed below.

When the position of the observer was central with respect to the mirror (Pos. 13), in the majority of cases, participants correctly predicted that the reflection would show more than the space that is orthogonally in front of the mirror (E = 70%–85%), and also correctly estimated the extent of the expansion (Condition 1: $t_{\alpha P\text{-}\alpha R\ (Pos.\ 13far)} = -1.553$, $df = 16$, $p < .13$; $t_{\alpha P\text{-}\alpha R\ (Pos.\ 13near)} = 1.891$; $df = 13$, $p < .08$; Condition 2: $t_{\alpha P\text{-}\alpha R\ (Pos.\ 13right)} = -1.225$, df = 9, $p < .23$). The only exception was the underestimation of the field of view at the left edge in Condition 2 ($t_{\alpha P\text{-}\alpha R\ (Pos.\ 13left)}$ = 3.909, df = 13, $p < .001$).

When the observer was close to one edge of the mirror (Pos. 11), almost all participants correctly predicted an expansion of the space at the far edge of the mirror, but, as in Study 1, they underestimated it (Condition 1: $t_{\alpha P\text{-}\alpha R\ (Pos.\ 11far)}$: $t = -5.730$, df = 15, $p < .001$; Condition 2: $t_{\alpha P\text{-}\alpha R\ (Pos.\ 11far)}$: $t = -7.956$, df = 17, $p < .001$). At the near edge, two different types of behavior were predicted: Approximately half of the participants (40–60%) correctly predicted that the observer would be able to see beyond the orthogonal limit of the mirror (i.e., E), but expected this expansion to be wider than it actually was (Condition 1: $t_{\alpha P\text{-}\alpha R\ (Pos.\ 11near)}$: t = −4.230, df = 11, $p < .001$; Condition 2: $t_{\alpha P\text{-}\alpha R\ (Pos.\ 11near)}$: t = −3.050, df = 7, $p < .02$). The remaining participants either predicted that the mirror would show less than the space in front of it (R) or exactly what was in front (O), and in both cases, the angle predicted was obviously different ($p < .001$) from the correct angle.

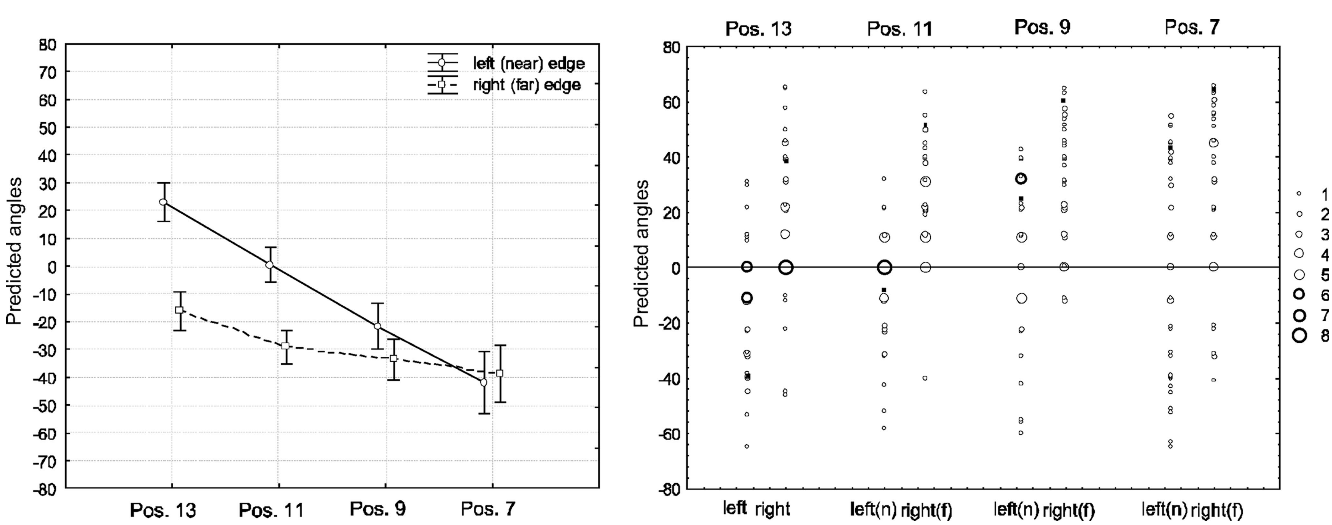

Figure 4. Graph on the left: mean angles in responses (error bars represent 95% confidence band) for the two edges in the four positions in Study 2. Graph on the right: scatterplot of participants' responses (αP) in Study 2 for the two edges of the mirror (left/right, which, for the eccentric positions, correspond to the near/far edges, respectively) in the four positions. The dark dots represent the correct responses (αR).

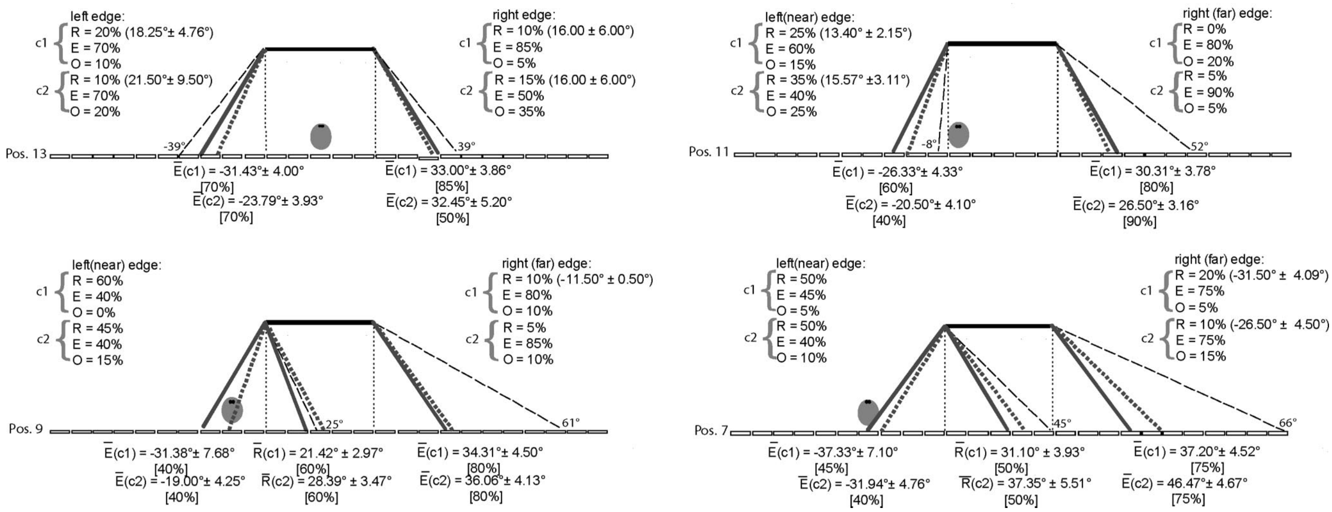

Figure 5. Percentages of the three types of response (expansion, E; reduction, R; orthogonal to the mirror edge, O) and mean angle and standard error within the category for the four positions and the two edges of the mirror in the two conditions (c1, c2) studied in Study 2. For an explanation, see the procedure. The dashed lines represent the correct angle of reflection (αR); the dotted lines represent the orthogonal projection of the mirror edges. The thick gray lines represent the average angle (αP) of the more frequent category (or categories) of response.

When the observer was positioned eccentrically, in line with what found in Study 1, in both Pos. 9 and Pos. 7, participants correctly predicted an expansion of the space visible at the far edge of the mirror (75%–85%), but underestimated it (Condition 1: $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 9far})} = -5.929$, $df = 15$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 7far})} = -6.362$, $df = 14$, $p < .001$; Condition 2: $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 9far})} = -5.957$, $df = 15$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 7far})} = -4.148$, $df = 14$, $p < .001$). With regard to the near edge, the same two types of responses as those that emerged in Study 1 were found. Approximately 40% of participants in both positions and both conditions incorrectly predicted that the reflection would expand beyond the orthogonal projection to its edge (E), whereas a percentage of participants, ranging from 50%–60%, correctly estimated that the reflection would not reflect a part of what is in front of the mirror. For the positions from which the observation was carried out (i.e., Pos. 9 in Condition 1 and both Pos. 7 and 9 in Condition 2), participants also correctly estimated the extent of the reduction (Condition 1: $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 9near})} = -1.203$, $df = 11$, $p = .25$; Condition 2: $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 9near})} = 0.944$, $df = 8$, $p = .37$; $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 7near})} = -1.354$, $df = 9$, $p = .20$).

To summarize, exposure to a real reflection before completing the pen-and-paper task improved the precision of estimates, to some extent, but did not influence the frequency of correct responses. The two patterns of response that emerged in Study 1 were confirmed. This proves that the erroneous belief held by half of the participants that the reflection shows beyond its edges at both edges, not only for central but also for eccentric viewpoints, is quite robust.

These findings also suggest that the participants responded neither by applying the basic optical law that angle of reflection equals the angle of incidence (this is incompatible with the errors found) nor by accessing a correct recall of what they see when normally interacting with plane mirrors (all participants, when positioned in front of the mirror, at the end of the session, confirmed to see the correct field of view). They rather seemed to apply a kind of prototypical model of the field of view of mirrors that they have in mind and which is compatible with a generalization of what can be seen when the observer is positioned centrally with respect to the mirror.

Study 3

The third study was designed to test whether the two models found in Studies 1 and 2 are specific for mirrors or also hold for windows. A possible explanation accounting for the early error is that people might be driven by a vague memory that, for windows as well as for mirrors, what is visible is a space that is larger than the scene that is cut orthogonally by the frame (Bertamini & Wynne, 2009). This is, however, in contrast with the fact that, with windows, adults make a "late" rather than "early" error, since they expect targets walking parallel to the window to be visible slightly after they, in fact, would be (Croucher at al., 2002). As shown in Figure 7 (where the correct angles of responses are represented by dashed lines), both mirrors and windows allow the same tiles to be visible, but the field of view is "straight" in the window condition and "folded back" in the mirror condition (this will be returned to in the final discussion). Are people aware that the field of view is the same for windows and mirrors? The study by Croucher et al. (2002) provides initial hints that people are not aware of this. The study did not, however, investigate how people expect the shape of the field of view visible through a window to change when an observer approaches a window walking parallel toward it, nor did it offer a direct comparison with mirrors in the same conditions.

In Study 3, people's predictions regarding the field of view of mirrors and windows were studied using the same paper-and-pencil task used in Studies 1 and 2. A within-subject design was preferred in order to have a direct match of responses. If participants think of the space visible in mirrors in analogy to the space outside, visible through a window, then similar results—and similar errors—will emerge in both cases. If the errors found with mirrors have no correspondence with the window task, then they can be considered to be specific to the believed geometry of reflections.

Method

Participants. Thirty-two undergraduate students at the University of Verona (mean age 23.1 years; 19 females) participated in Study 3.

Procedure. A paper-and-pencil task similar to that used in the previous studies was presented to participants. The only differences were that a second series of numbered tiles was shown "reflected" on the opposite side of the mirror and that participants were asked to make two different predictions. The first concerned the mirror: The instructions were the same as those used in Studies 1 to 2, except that it was specified that the series of numbered tiles opposite the mirror represented the "reflected tiles." The order of the four viewing positions was randomized between participants. After they had finished the mirror task (and the response sheets were collected by the experimenters), they were presented with another four identical diagrams but were told to consider the thick line as a window. They were asked to mark which of the tiles represented "beyond the window" they could see from each of the four positions (the order of the four viewpoints was randomized).

Results

Participants in Study 3 did not deal with mirrors and windows in the same way. They expected the visibility of mirrors to expand less beyond their orthogonal edges than windows. This emerged from a mixed model ANOVA carried out to study the effects of type of surface (i.e., window or mirror), position (Pos. 13, 11, 9, and 7), edge (left, right), and sex on the angle of response. The analysis revealed a main effect of surface ($F_{1,\ 30} = 42.246$, $p < .001$) and a significant interaction between surface, edge, and position ($F_{1,\ 30} = 42.246$, $p < .001$). As shown in the top graph of Figure 6 (and as confirmed by Bonferroni post hoc tests), only for the central position (Pos. 13) was the field of view predicted for mirrors and windows the same. From all other positions and at both edges, windows were associated with wider angles than mirrors.

A further difference between mirrors and windows emerged from the scatterplots used to explore the variability of responses, as in studies 1 and 2: Participants basically predicted the correct type of behavior for windows, and the error concerned only the width of the angle (in Figure 6, scatterplot on the right, the dispersion of responses is almost entirely on the same side with respect to zero as the correct responses are). Conversely, for mirrors, a certain amount of participants predicted the wrong type of behavior (in Figure 6, the scatterplot on the left is similar to those presented in Studies 1 and 2, with responses also on the opposite side with respect to the dark dots).

More analytically, after recoding responses in terms of type of behavior predicted (E, R, and O), responses in the mirror task follow the two patterns found in Studies 1 and 2 (see Figure 7). First, when the viewpoint was central (Pos. 13), most participants correctly predicted an expansion at both edges, but they underestimated it ($t_{\alpha P\text{-}\alpha R\ (\text{Pos. 13right})} = -4.011$, $df = 18$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 13left})} = 3.314$, $df = 18$, $p < .01$); almost 37.5% of participants predicted that the space fitting into the mirror would be exactly what is directly in front of it.

Second, when the viewpoint was eccentric (Pos. 11, 9, 7), participants mostly predicted an expansion of the space visible at the far edge of the mirror (50–60%), but they also underestimated it ($t_{\alpha P\text{-}\alpha R\ (\text{Pos. 11far})}$: $t = -5.430$, $df = 18$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 9far})} = -7.239$, $df = 15$, $p < .001$; $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 7far})} = -6.671$, $df = 17$, $p < .001$). At the near edge, in the two eccentric positions (Pos. 7 and 9), 30–40% of participants correctly estimated a reduction of the space shown in the reflection (in Pos. 7 they underestimated the reduction, $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 7near})} = -6.430$, $df = 11$, $p < .001$, whereas, in Pos. 9, they did not, $t_{\alpha P\text{-}\alpha R\ (\text{Pos. 9near})} = -2.084$, $df = 9$, $p = .06$). A similar percentage (34%–38%) predicted an expansion, confirming the two different types of behavior found in the previous studies. In Pos. 11, some participants (50%) correctly predicted that the observer would see beyond the orthogonal limit of the mirror (i.e., an expansion), but they expected this expansion to be wider than in reality ($t_{\alpha P\text{-}\alpha R\ (\text{Pos. 11near})}$: $t = -3.147$, $df = 15$, $p < .01$); 40% of participants predicted that the mirror would show exactly what was in front of it (i.e., orthogonal limit). Orthogonal responses were also produced for more eccentric viewpoints by approximately 30% of participants.

In the window task, the two pattern of responses found for mirrors was not found, and in all positions, the majority of participants (approximately 90%) predicted the correct behavior: When the position of the observer was central (Pos. 13), almost 90% of the responses correctly predicted at both edges that the window would show more than the space that is orthogonally in front of it. However, they underestimated the expansion ($t_{\alpha P\text{-}\alpha W\ (\text{Pos. 13right})} = -6.124$, $df = 27$, $p < .001$; $t_{\alpha P\text{-}\alpha W\ (\text{Pos. 13left})} = 6.182$, $df = 27$, $p < .001$). When the observer was positioned eccentrically, in Pos. 9 and Pos. 7, in 87%–97% of cases, participants correctly predicted an expansion at the far edge and a reduction at the near edge. The expansion at the far edge was underestimated in both Pos. 9 and 7 ($t_{\alpha P\text{-}\alpha W\ (\text{Pos. 9far})} = -6.331$, $df = 29$, $p < .001$; $t_{\alpha P\text{-}\alpha W\ (\text{Pos. 7far})} = -6.351$, $df = 29$, $p < .001$), as was the reduction at the near edge in Pos. 7 ($t_{\alpha P\text{-}\alpha W\ (\text{Pos. 7near})} = -3.552$, $df = 29$, $p < .001$). When the observer was close to one edge of the window (Pos. 11), again, 90% of the participants correctly predicted, but underestimated, an expansion at the far edge ($t_{\alpha P\text{-}\alpha W\ (\text{Pos. 11far})}$: $t = -4.944$, $df = 28$, $p < .001$). Only in Pos. 11, at the near edge, were responses more uncertain, with 62.5% of participants predicting that visibility would be limited orthogonally to the edge of the window, with half of the remaining responses correctly predicting an expansion ($t_{\alpha P\text{-}\alpha W\ (\text{Pos. 11near\_expansion})}$: $t = -0.254$, $df = 5$, $p = .80$) and half predicting a reduction ($t_{\alpha P\text{-}\alpha W\ (\text{Pos. 11near\_reduction})}$: $t = 3.407$, $df = 5$, $p < .05$).

In conclusion, Study 3 showed that people do not think of mirrors as homologous with windows, except for the central position where they predicted that mirrors and windows would have a similar field of view. When eccentric viewpoints were considered, two differences clearly emerged. First, participants expected the field of view of reflections to be less extended at the farthest edge and less reduced at the nearer edge than would be the case for windows (suggesting that the frontal bias is more characteristic of

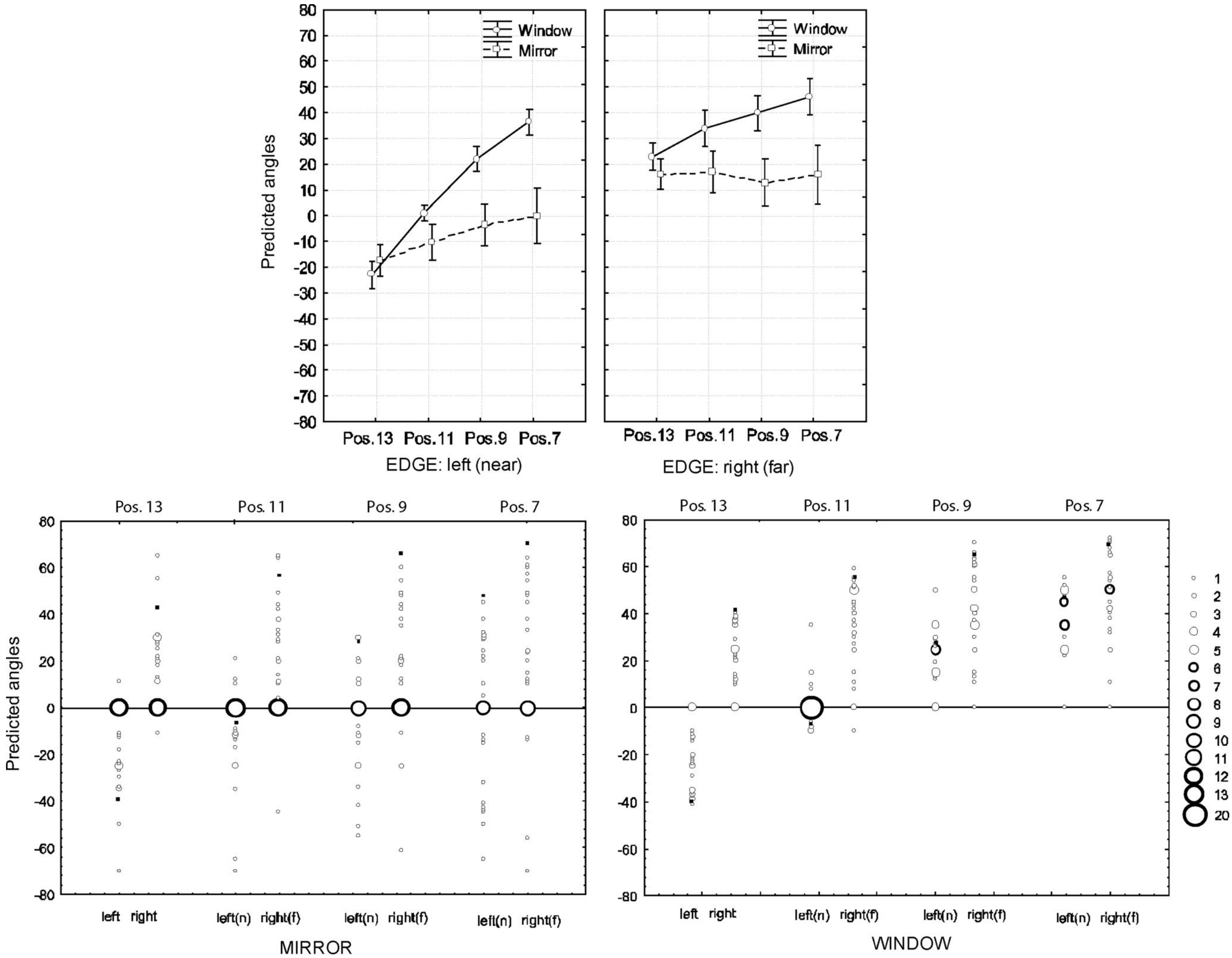

Figure 6. Top graphs: mean angles in responses in the mirror and window conditions for the two edges in the four positions in Study 3. Error bars represent 95% confidence band. Bottom graphs: frequency scatterplots of participants' responses in the mirror (scatterplot on the left) and window (scatterplot on the right) tasks in Study 3 for the two edges of the mirror (left/right, which, for the eccentric positions, correspond to the near/far edges, respectively) in the four positions. The dark dots represent the correct responses (αR).

mirrors than windows). Second, approximately half of participants predicted a different behavior at the near edge for mirrors and windows—an expansion for mirrors and a reduction for windows.

Study 4

Study 4 aimed to test whether the results found thus far generalize to the case of an observer positioned farther away from the mirror (twice as far) than in the previous studies. If the two patterns found in the paper-and-pencil task of Studies 1–3 are not related to the specific condition presented, but are general patterns concerning adults' beliefs about the field of view of mirrors, we expect to find the same two patterns when an increased distance between mirror and observer is considered. Conversely, if responses depend on the distance of the observer from the mirror, then changes in the emergence of the two patterns mentioned or in the distribution of responses might occur.

The study also aimed to understand how many participants based their response on the application of optical rules, independently of whether correctly remembered or not (i.e., an "optical law driven geometry of reflections") and how many instead imagined what might be visible from the given viewpoint and based their response on this (a "qualitative geometry of reflections").

Method

Participants. Thirty undergraduate students at the University of Verona (mean age 24.5 years; 21 females) participated in Study 4.

Procedure. Participants received four diagrams similar to those used in Studies 1–3 for the mirror condition, but the scenes represented in the paper-and-pencil task differed with respect to the distance of the observer position from the mirror (twice as far with respect to Studies 1–3). The order of the four viewpoints was

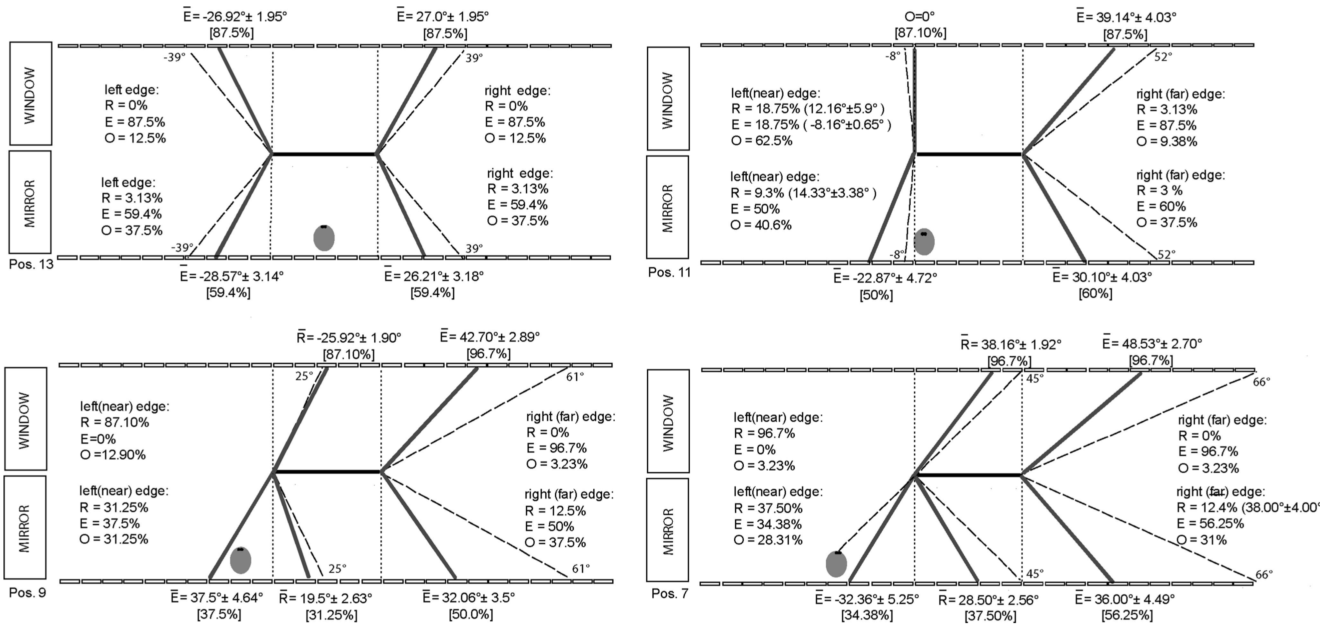

Figure 7. Percentages of the three types of response (Expansion, E; Reduction, R; orthogonal to the mirror edge, O) and mean angle and standard error within the category for the four positions studied and the two edges of the mirror in Study 3. Mirror and window conditions for each position are plotted together to emphasize the match of responses. The dashed lines represent the correct angle of reflection (αR); the dotted lines represent the orthogonal projection of the mirror edges. The thick gray lines represent the average angle (αP) of the more frequent category (or categories) of response.

randomized between participants. The test was administered in a classroom at the beginning of a lecture. The instructions were verbally issued by the experimenter and were also printed at the bottom of each diagram.

After they had compiled the paper-and-pencil task, a short questionnaire was presented, where participants were asked to explain on what bases they had responded. Three alternatives were offered in addition to a fourth free response: (a) I (physically or mentally) constructed/drew the angle of incidence and the angle of reflection according to the laws of optics; (b) I imagined myself in the same position as the observer represented in the diagram and I tried to mentally visualize what I would see from that standpoint; (c) I tried to remember what I usually see when I look in a mirror, and (d) something else.

Results

Predicted angles of response. In agreement with what found in the previous studies, participants did not gradually modify the angles delimiting the field of view but differentiated the field of view associated to the central position from that associated to the most eccentric viewpoint. This emerged from a mixed model ANOVA carried out to study the effect of position (Pos. 13, 11, 9, and 7), edge (left, right), and sex on the angles of response. A main effect of edge ($F_{1,\ 28} = 81.492$, $p < .001$, with the angle at the far edge bigger than that at the near edge) and the interaction between edge and position ($F_{3,\ 84} = 9.120$, $p < .001$) turned out to be significant. As post hoc tests revealed, participants did not gradually modify the field of view, but the difference was only between what they predicted from the central position (Pos. 13) and what they expected could be seen from the most eccentric viewpoint (Pos. 7).

Comparing the angles of response provided in Studies 1 and 4, we noticed that, for most of the positions, the angles describing the field of view were different for the shorter and larger distances of the observer, except for the central position (this was confirmed by a mixed model ANOVA with study and sex as between-subjects variables, and position and edge as within-subjects variables, and where the interaction between study and position turned out to be significant in the direction indicated, $F_{3,\ 198} = 4.409$, $p < .001$). This suggests that adults might have in mind a constant angle of expansion (approximately 26°–28°) characterizing the field of view of a mirror for central viewpoints, which holds independently of how far away from the mirror the observer is. Further research is needed to test whether in fact this is also the case beyond the two distances studied in this article.

The classification of responses in terms of type (E, R, and O) and the analysis of average angles within each class proved that the incorrect prediction of an expansion for the near edge when the observer occupied eccentric positions (Pos. 9 and 7), which was found in approximately half of the participants in Studies 1–3, was not only present but represented the most frequent response in Study 4. As shown in Figure 8, the percentage of responses of this type (E) range from 67% in Pos. 7 to 90% in Pos. 11.

Strategy used to make the prediction. Responses to the questionnaire helped us to clarify on what bases participants responded (and thus what the source of the error was). Only 13% of participants relied on the application of the optical law to resolve the task: 60% imagined the scene from the position of the observer

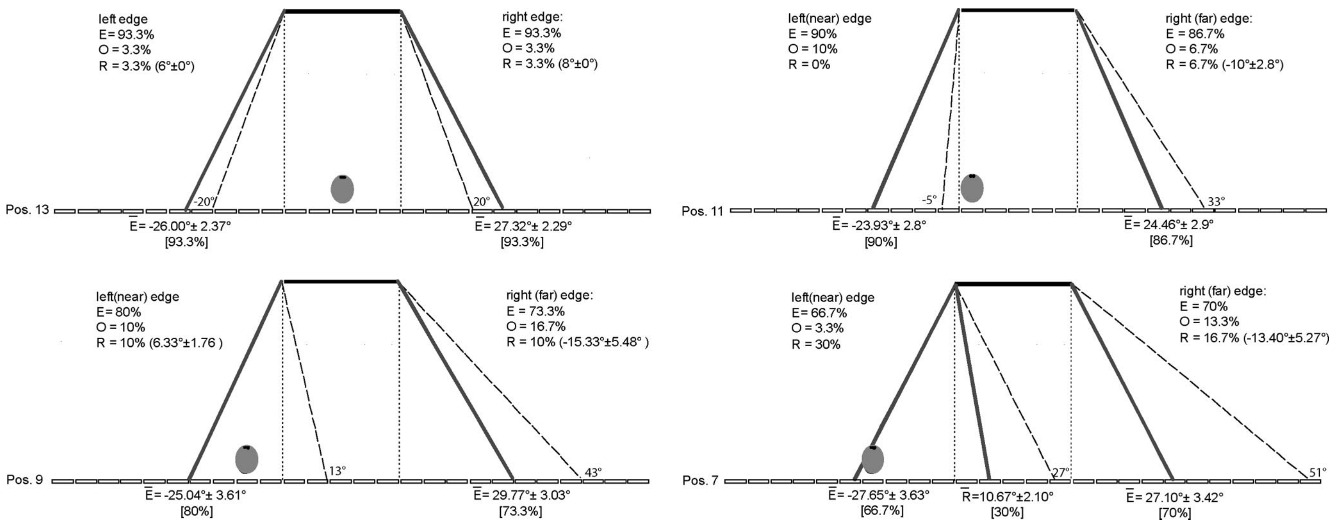

Figure 8. Percentages of the three types of response (expansion, E; reduction, R; orthogonal to the mirror edge, O) and mean angle and standard error within the category for the four positions studied and the two edges of the mirror in Study 4. The dashed lines represent the correct angle of reflection (αR); the dotted lines represent the orthogonal projection of the mirror edges. The thick gray lines represent the average angle (αP) of the more frequent category (or categories) of response.

and 23% resorted to trying to remember what they usually see in domestic mirrors.

Relying on one or the other strategy did not influence the predictions made. This was found both when analyzing the angles of response (an ANOVA carried out to study the effect of strategy, position, and edge revealed no significant effect of strategy, neither as main effect nor an interaction), and when considering the frequency of correct and incorrect responses at the near edge in Pos. 7 and 9. The distribution of correct responses (reduction) and errors (predictions of an expansion or that the field of view would end orthogonally with the edge of the mirror) was not affected by whether participants had applied an optical rule, had tried to remember what they usually see in mirrors, or had constructed a mental image of the scene (likelihood ratio $= 1.336$, $df = 4$; $p = .855$).

Study 5

In Studies 1–4, participants were involved in production tasks. One of the results described in literature about erroneous naïve beliefs concerning physical movements or reflections is that the errors are frequently made in paper-and-pencil or real-life production tasks but not when participants are asked to recognize the correct behavior among various alternatives, where the erroneous behavior they had predicted is also present. In Study 5, we investigated whether the errors found in Studies 1–4 using a production task (i.e., field of view expanded at both edges, whatever the viewpoint; underestimation of the field of view also when the shape of it is correct) were confirmed even when adults could choose their response among a set of alternatives where the correct response was also present. As in Study 4, we also asked participants to clarify on what bases they made their choices.

Method

Participants. Thirty undergraduate students at the University of Verona (mean age: 24.6 years; 24 females) participated in Study 5.

Procedure. Participants received four sheets, each referring to one of the four viewing positions (Pos. 13, 11, 9, 7). Four diagrams were printed on each sheet. The observer was in the same position in all four diagrams, while the field of view that the diagrams represented as being visible (tiles colored in black) changed. Participants were asked to choose which of the four diagrams represented what the observer could, in effect, see in the mirror from that viewpoint. One of the four alternatives consisted of the correct response. The other three alternatives represented the three most frequent incorrect responses produced by participants in Studies 1–3, that is, (a) that the field of view would be limited orthogonally to the mirror edges, (b) that the field of view would show an expansion at both edges, and (c) that the field of view would show a reduction at the near edge and an expansion at the farther edge (for the eccentric positions) or a reduction at both edges (for the central position). The width of the field of view used in alternatives b and c was defined by the mean angles of response in Study 1.

The order of the four viewing positions and of the four alternatives was randomized between subjects. The test was administered in a classroom at the beginning of a lecture. The instructions were verbally issued by the experimenter and were also printed at the bottom of each diagram. After participants had compiled the paper-and-pencil task, a short questionnaire was presented to participants, asking them to explain on what bases they had responded (the question and the alternative responses were the same as used in Study 4). They were also asked if, when solving the task, they had thought of the space reflected in the mirror as being opposite to the real space (yes/no) and to explain their answer.

Results

Preferred alternative. Responses were not randomly distributed among the four alternatives ($\chi^2 = 3.967$, $df = 9$; $p < .001$; see Figure 9). The percentage of participants who chose the correct response was lower than one might expect, ranging from 13% in Pos. 7 to 30% in Pos. 11, without significant difference. Many participants chose the response that was correct in terms of type, but where the expansion (and the reduction for the eccentric positions) was underestimated. In other words, in agreement with what was found in the previous studies, most participants preferred patterns that showed a field of view more constrained toward the mirror edges (frontal bias) than the correct pattern. Thus, for example, in addition to the 20% of participants who chose the correct width of expansion at both edges in Pos. 13, another 56.7% chose the diagram that also showed an expansion at both edges but that was less wide than it was in reality. Similarly, in Pos. 9 and 7, the correct type of behavior (reduction at the near edge and expansion at the far edge) was predicted not only by those who also chose the correct width (17% in Pos. 9 and 13% in Pos. 7) but also by another 60% of participants who expected the reduction at the near edge and the expansion at the far edge to be smaller than they would in fact be. Only in Pos. 11 were responses more uncertain (distributed among correct response, incorrect expansion, or incorrect reduction).

Strategy used to select the response. It was confirmed that the majority of participants (63%) relied on imagination, then on memory of how familiar mirrors behave (26%); only in a very small percentage (10%) relied on the application of optical laws ($\chi^2 = 20.800$, $df = 2$; $p < .001$). These percentages coincide almost perfectly with those found in Study 4.

Fifty-four percent of participants confirmed that, in responding, they thought that the space visible in the mirror is spatially opposite to the real space. This seems to be an idea about spatial organization in mirrors that half of the participants have, but (as confirmed by the results of a chi-square test, $\chi^2 = 4.800$, $df = 2$; $p = .09$) this does not seem to be specifically related to one of the three processes used (imagining the field of view, remembering it, or applying an optical notion).

Final Discussion

The studies presented in this article investigated how much of the surrounding space adults predict will be visible in a mirror, given various eccentric or central viewpoints. Five main findings emerged overall from the studies. First, participants were quantitatively inaccurate when estimating the width of the field of view, even when they correctly identified its shape. They underestimated the extension at the far edge and the reduction at the near edge for eccentric viewpoints, and underestimated the extension at both edges from a central viewpoint (the latter, only when the observer was a short distance from the mirror). This indicated that in general participants expected the field of view to be closer to the orthogonal projections relative to the mirror edges than it would be in reality.

Second, many participants mistook the shape of the visual field when the observer was eccentrically positioned. They expected the reflection to show all of what was in front, and even beyond the mirror edges, not only at the far edge (where this is true) but also at the near edge, where, in reality, the reflection would leave out part of the space which is in front of it (what we have indicated in the article as a "reduction"). This incorrect pattern was predicted by almost 50% of participants when the observer was a short distance from the mirror, and by 70%–80% of participants when the observer was farther away. This error was not made with windows and is therefore specific to mirrors.

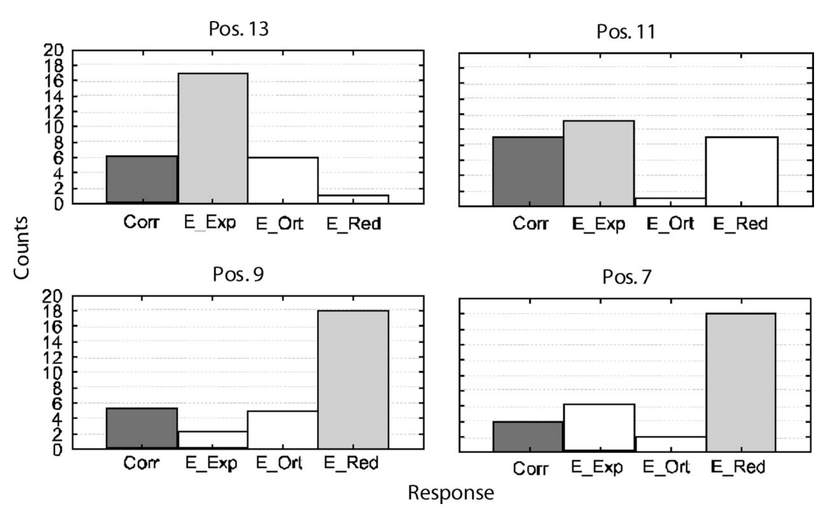

Figure 9. Distribution of responses for the four alternatives presented in Study 5 for each position: correct response (Corr); erroneous (underestimated) expansion at both edges (E_Exp); erroneous (underestimated) reduction at the near edge and expansion at the far edge (E_Red); and orthogonal field of view (E_Ort). Bars corresponding to the correct responses are in dark gray. Responses correct in terms of type, but incorrect in terms of width (underestimations) are in light gray.

Third, the opportunity to observe a real mirror while changing the viewpoint before compiling the paper-and-pencil task did not reduce the percentage errors described in the second point, but it partially corrected the quantitative inaccuracy described in the first point.

Fourth, when participants were asked to recognize the correct response among various patterns (rather than drawing the visual field), the majority of them predicted the shape of the field of view correctly (i.e., the error described in the second point reduces to less than 30%). However, they still underestimated it, in agreement with the bias described in the first point.

Finally, in both the production and recognition tasks, participants in a very small percentage of cases (10%–13%) recalled and applied the optical rule that the angle of reflection equals the angle of incidence. They more frequently imagined what they might have seen from the viewpoint of the observer in the diagram (this occurred in more than 60% of cases) or tried to remember what they usually perceive in mirrors (approximately 25%).

Difficulty in Dealing With the Role of the Viewpoint in Reflections

Three findings confirmed that participants have only a rough idea that what is visible in a mirror varies with the position of the observer: (a) the error of expecting an expansion at the near edge when the observer was localized eccentrically, (b) the fact that even those who made only a quantitative error when predicting the width of the field of view did not change responses in a systematic way for the four positions but only for very eccentric versus central viewpoints, and (c) the fact that the space that participants expected to see in the reflection from a central viewpoint turned out to be the same independently of whether the observer was a short distance away from the mirror or at twice that distance.

These results add to previous findings demonstrating the difficulty that adults have in acknowledging the role of the viewpoint in determining what is seen in a mirror. Adults generally claim that the projected size of their heads decreases when the viewpoint moves farther away from the mirror, whereas, in fact, it does not (Bertamini & Parks, 2005; Lawson et al., 2007). They are uncertain about whether the field of view of mirrors reduces (correct response) or becomes bigger when the distance of the observer from the mirror gets bigger (Bertamini, Lawson, & Liu, 2008). Moreover, as brought to the foreground by the Venus effect (Bertamini, Latto, & Spooner, 2003; Bertamini et al., 2010) and the early error (Bertamini, Spooner, & Hecht, 2003; Croucher et al., 2002), they have difficulty in predicting what the mirror shows when the viewpoint is eccentric. In general, the difficulty of predictive tasks when an observer is present also emerged in research carried out by Langley, Ronen, and Eylon (1997).

It has already been suggested that the reluctance to accept the role of the viewpoint in naïve optics can be explained by the fact that, in general, the visual system works to make the outside world constant despite continuous changes in observer position (Bertamini & Parks, 2005; Croucher et al., 2002). In the case of mirrors (and similarly for windows and looking through "holes" in general), the viewpoint is crucial in determining what the observer will see.

Two Patterns and a Frontal Bias

Our results suggest that, when asked to predict what of the surrounding space would fit into a mirror, adults have in mind two geometrical patterns and a frontal bias. Approximately 50% of responses for close observer viewpoints and up to 80% of responses for greater distances generalize a single pattern, that is, extension at both edges, independently of the position of the observer. The remaining participants manifested a twofold expectation that when the viewpoint is central with respect to the mirror, the space reflected will be extended at both edges of the mirror, whereas when the viewpoint is eccentric, the space reflected will be expanded at the farthest edge and reduced at the nearest edge.

The findings that the angles of expansion or reduction predicted were, on average, underestimations of the real angles (and smaller than for windows) and that half of participants expected the observer, even when positioned eccentrically, to see the space in front of the mirror as well as beyond both its edges suggest that an attenuated version of the frontal error found in children (Bertamini & Wynne, 2009) persists in adults. This is consistent with the hypothesis (put forward by Bertamini & Parks, 2005, and also discussed in Bertamini et al., 2010) that mirrors are treated as devices that capture an image (or, in our case, a space) and, therefore, what fits into a mirror depends mainly on what is near it rather than on the location of the observer, which is, to a large extent, disregarded.

Differences Between Mirrors and Windows

As Study 3 showed, both the frontal bias and the simplified pattern (extension at both edges, whatever the viewpoint) are specific to mirrors, since these effects were not found when a window was considered. With the exception of the central position where the visual field of mirrors and windows was estimated to be of a similar width, for all other positions, participants expected the field of view of mirrors to expand less beyond their edges than the field of view of windows.

These results add to the existing evidence that people are more accurate at predicting how the visual field changes in windows, when the viewpoint changes, than in mirrors. The early error was found for mirrors but not for windows (Croucher et al., 2002). In the majority of cases (approximately 70%), adults were able to predict that the field of view of a window reduces as the observer moves farther away, but in only 45% of cases were they able to predict the same when mirrors were involved (the remaining participants expected the opposite).

What makes the geometry of mirrors more difficult than that of windows? Or, given the results of Studies 4 and 5, why is imagining what fits into a mirror more complicated than imagining what fits into a window? It has to be acknowledged that if mirrors, on the one side, are familiar objects, on the other side, they only comply in part with the general rules of perceptual spatial organization, and in this sense, they are not "easy" objects. A fundamental characteristic of reflections is that reflected objects and spaces are oriented and located opposite to the real objects and spaces.[2] We mentioned in the introduction to this article that adults perceive (and describe) their own reflection, other people's reflections, and the reflection/movement of oriented objects as having an opposite orientation compared with the real body/object (Bianchi & Savardi, 2008a; Bianchi & Savardi, 2009; Savardi et al., 2010). Evidence that opposition is primal in direct space perception and categorization has been provided in various studies (e.g., Bianchi & Savardi, 2008b; Bianchi, Savardi, & Kubovy, 2011; Casasola, 2008; Hespos & Spelke, 2004; Savardi & Bianchi, 2009). With regard to the field of view, the opposition between real and reflected space is clearly shown in Figure 7. Both mirrors and windows allow the same tiles to be visible. However, in the case of windows, understanding the geometry of the field of view simply requires understanding that the frame of the window limits the view to what is inside the "hole." In the case of mirrors, the virtual world extends beyond its frame, but if it is recognized as a mirror, the scene on the other side of the frame is recognized as not physically located *there*. The fact that reflected objects and spaces are spatially perceived beyond the frame of the mirror, exactly as in the case of the window, but are, at the same time, localized on the opposite side of the mirror, makes the geometry of reflections complicated. The two patterns of response found in our studies might manifest two different solutions to explain this "folding back" of the ecological field of view that occurs in windows. As the results of Study 3 proved, when the observer stood in a central position with respect to the mirror, no significant differences emerged between the average angles drawn for mirrors compared with windows: The field of view is the same but folded back toward the observer. From the central position, this is relatively easy to understand. Participants who predicted an expansion at both edges of the mirror, whatever the viewpoint, generalized this folding to other positions. Participants making two different predictions, depending on whether the observer was centrally placed or not, seemed to take into account that the bending is different when the observer is in front of or laterally placed with respect to the mirror.

More research is needed to explore the relevance of the idea that the reflected world is opposite of the real world in naïve beliefs concerning mirrors. In Study 5, more than 50% of participants self-reported that they had thought of this, but it is not clear if this affected their response. The errors found in the studies presented in this article (both quantitative and qualitative) are also compatible with a mental rotation of the "folding line" (i.e., the line representing the mirror) toward a condition of orthogonality to the observer's line of sight (that is, toward the condition where the simpler pattern holds). If and how this might be consistent with the rotational hypothesis put forward by Muelenz, Hecht, and Gamer (2010) is another aspect that deserves more investigation.

Imagining What One Would See Rather Than Applying an Optical Rule

Finally, the finding that participants in our studies in a very small percentage of cases responded by applying the rule that the angle of incidence equals the angle of reflection may appear surprising. However, this is consistent with the results of a previous work, where it was found that adults who make typical errors in naïve optics, namely, the early error or expecting the reflection to appear on the opposite side of the mirror with respect to where it would in fact appear, made these errors despite the fact that they knew the optical rule stating that the angle of incidence equals the angle of reflection (Croucher et al., 2002). It is as if people are unable to apply this latter explicit knowledge to predictive tasks. This result is also generally more in line with the overall picture emerging from studies on naïve physics: The errors made by participants when predicting mechanical or dynamic behavior are often inconsistent not only with general and basic physical laws but also with the hypothesis that they are applying some kind of "general law" (as initially hypothesized by Shannon, 1976, and McCloskey, 1983). They rather seem to follow prototypical models of situation-specific behaviors (Cooke & Breedin, 1994; Hecht & Bertamini, 2000; Yates et al., 1988). Mental visualization is crucial in this process (Frick, Huber, Reips, & Krist, 2005; Hegarty, 1992; Huber & Krist, 2004; Yates et al., 1988; Schwartz, 1999). Our results are in agreement with this.

[2] It has already been stated that describing the objects/spaces reflected as spatially opposite is not an error, as some literature on the mirror reversal has implied (e.g., Gregory, 1996; Haig, 1993; Tabata & Okuda, 2000), but is instead a correct description of the perceived spatial structure of reflections (Savardi & Bianchi, 2005).

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