



Brief article

People cannot locate the projection of an object on the surface of a mirror

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ABSTRACT

People cannot veridically perceive reflections of objects as projections on the surface of mirrors. People tried to locate an object's projection on a flat mirror. The observer stood at the opposite end of a long mirror to the experimenter. They were told to remember the location of the projection of the experimenter's face. The experimenter then moved and the observer stuck a card onto the mirror at this remembered location. The actual location was midway along the mirror between the experimenter and the observer. However, cards were placed much too close to the experimenter. Repeated testing with feedback reduced, but did not eliminate, errors. Our perception of mirrors is dominated by what appears to be visible *through* the mirror, not what is projected onto its surface. In contrast, if the experimenter stuck a card onto the mirror then removed it, observers remembered this physically-specified location accurately.

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1. Introduction

Flat mirrors are commonplace in our everyday environment, but people make striking errors when asked about reflections projected onto their surface. For example, they overestimate the size of projections of objects. Most people believe that a mirror must be about face-sized to see all of their face reflected in it, when in fact it need only be half that size (Bertamini & Parks, 2005; Lawson & Bertamini, 2006). People also think that they can see more of themselves in a mirror as they move away from it, when actually the size of their projection remains the same (Lawson, Bertamini, & Liu, 2007). Many people believe that they will be able to see their face reflected in a mirror from a wide range of angles. However, you need to be directly in front of a mirror to see yourself. People also often incorrectly think that they will see their face reflected simultaneously in multiple mirrors which are mounted flat on the same wall (Lawson, 2009).

These examples of errors in understanding the optics of mirrors relate to the visibility and size of projections of objects. They led to a new prediction: if people only accu-

rately perceive the virtual world through a mirror, not projections on the surface of a mirror, then people should be unable to locate *where* an object is projected on the mirror surface, see Fig. 1. Informal observation supports this hypothesis. It is surprisingly hard to point to the projection of an object when standing to the side of a mirror.

In two experiments, an observer and an experimenter stood at fixed, initial positions and the observer was told to remember the location of the projection of the experimenter's face on a mirror, see Fig. 2. The experimenter then moved away and the observer stuck a card onto the surface of the mirror at this remembered location. The experimenter then returned to their initial position to allow the observer to check the accuracy of their response. Children and adults readily understood this task but, nevertheless, made large, systematic errors. This is because there is a compelling perception that projections *on* a mirror are located *through* the mirror. This illusion resulted in observers placing their cards much too far away, close to the experimenter's end of the mirror.

Few people notice their misperception of projection locations. This is likely due to three factors. First, we often use mirrors to look at ourselves. Here, our reflection is projected directly in front of us. Second, as an object approaches a mirror, the location of that object, its projection

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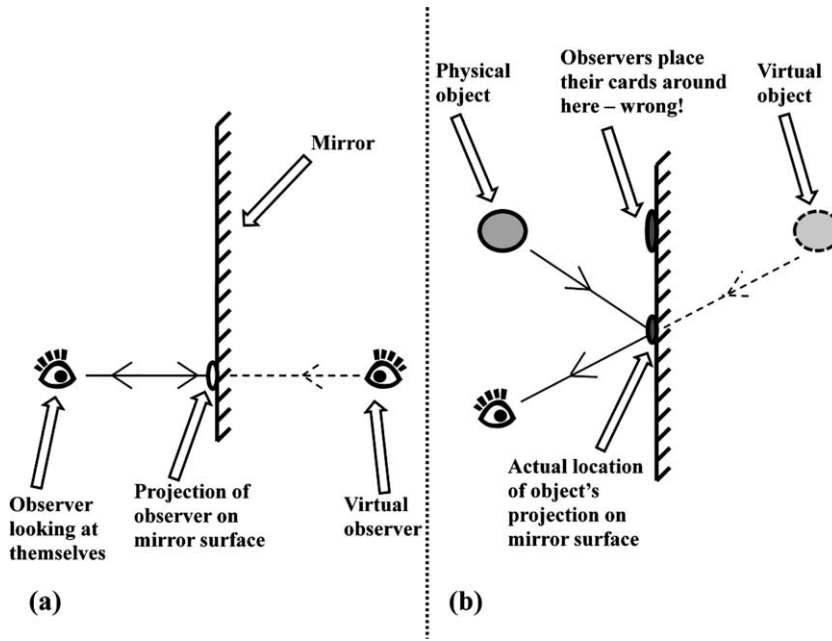


Fig. 1. Two bird's eye views of an observer looking at a mirror. (a) The observer looks at themselves. Here, the projection of the observer is directly inbetween the observer and the virtual observer. (b) The observer looks at another object which is as far away from the surface of the mirror as the observer. Here, the object is projected onto the mirror surface midway along it between the observer and the object. However, to the observer, the object's projection *appears* to be located *behind* the mirror surface. Therefore when asked to stick a card onto the mirror at the location of the projection of the object they put their card much too far away, approximately inbetween the physical object and the virtual object. In fact, relative to both the physical and virtual objects, projections are *always nearer* to the observer along the plane of the mirror surface unless, first, the virtual object is directly in front of the observer (as in (a) here) or unless, second, the physical object is placed right against the mirror.

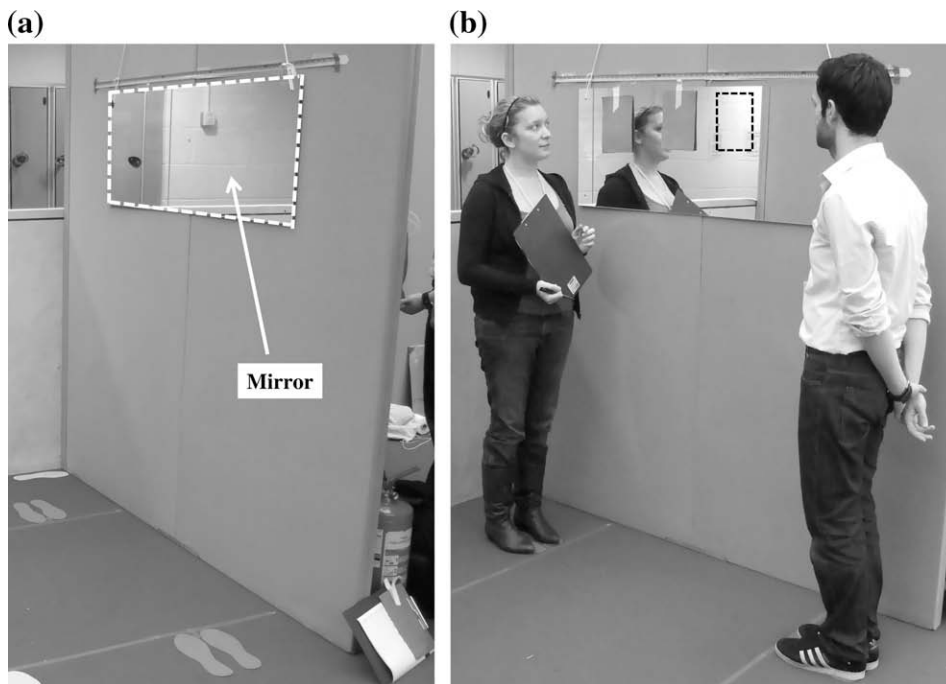


Fig. 2. The set-up for Experiment 1. The general set-up was identical for Experiment 2. (a) The mirror with the tape-measure above it and the two pairs of footprints on the floor beneath. (b) An experimenter (on the left, with a clipboard) and an observer (on the right) standing on their respective footprints. The left and right cards stuck on the mirror show typical responses on the first and second trials respectively for the projection location task. The dotted box shows the correct position of a card for it to cover up the observer's view of the projection of the experimenter's face on the surface of the mirror.

and the virtual object all converge to the same point. Only in these two special cases is the object's projection directly inbetween the physical and the virtual object; usually the projection is nearer to the observer, see Fig. 1. Finally, mirrors are generally used to gain information about physical objects by perceiving virtual objects. Information about the projections themselves is not usually useful.

2. Experiment 1

An observer and experimenter stood equally far away from a long, flat mirror, with the observer near its right end and the experimenter at its left end (see Fig. 2). The study examined the observer's ability to remember the location of the projection of the experimenter's face on the mirror.

2.1. Method

2.1.1. Observers

Schoolchildren, teachers and visitors to a week-long science exhibition (74 male, 61 female, aged 9–72) volunteered to participate.

2.1.2. Procedure

The experiment was conducted in a semi-screened area of a large hall. A mirror (120 cm wide \times 45 cm high) was hung onto a screen with the top 172 cm above the floor. Two pairs of 28 cm long footprints marked the standing position for the experimenter and the observer. The midpoint of each pair was 35 cm away from the screen with the mirror. The experimenter's footprints began 25 cm inside the left mirror edge. The observer's footprints began 10 cm outside the right mirror edge, so observers could not see their own reflection. This avoided confusion about whose face reflection they should cover. A tape-measure was fixed above the mirror. It extended 15 cm beyond each end of the mirror. There were two cards (15 cm wide \times 21 cm high) with sellotape on their top edge.

With the experimenter and observer standing on their footprints, the observer was told to remember where the experimenter's face appeared on the mirror.¹ The experimenter then walked away from the mirror and handed a card to the observer. The observer tried to stick the card onto the mirror at the remembered projection location, stepping away from their footprints if they wished. Some observers moved their card after returning to their footsteps to check its position. Once the observer was satisfied with the card's position, the experimenter recorded its location using the tape-measure above the mirror. The experimenter and observer then returned to their footprints and the observer was asked if the card covered the projection of the experi-

menter's face. If they said no the trial was repeated with the first card remaining stuck on the mirror.

The front of the two pairs of footprints were 105 cm apart so the midpoint between the experimenter's and observer's feet (and their eyes) was about 42 cm from the right mirror edge. This location, 42 cm along the mirror from its right edge, was taken as the correct response since the centre of the projection of the experimenter's face should have been located at this point, see Fig. 3. However, the projection location would alter somewhat if the experimenter or the observer moved from their footprints or did not stand up straight. Most observers could easily reach this projection location without moving from their footprints.

2.2. Results

Observers overwhelmingly (126 of 135; 93%) placed their first card beyond the actual projection location. Their mean response was 34 cm (SD = 21 cm) too near to the experimenter's end of the mirror. This large, initial error was not fully corrected on the second trial (20 cm error; SD = 17 cm). Indeed, 18 of the 118 observers who did a second trial made a greater error. Responses on both trials differed from the correct response on one-sample *t*-tests ($p < 0.001$).

ANOVAs were conducted for each trial with sex (male, female) and age (9–13, 14–17, 18 and older) as between-subjects factors. On the first trial, females (39 cm error; $N = 61$) were 9 cm worse than males (30 cm; $N = 74$), [$F(1, 129) = 6.89, p = .01$]. There was no effect of age [$F(2, 129) = 0.90, p = .4$]. There was a marginal sex \times age interaction [$F(2, 129) = 3.05, p = .051$] with the female disadvantage occurring mainly for adults. Young females (32 cm error; $N = 21$) performed similarly to young males (31 cm; $N = 22$). For 14–17 year olds, females (38 cm; $N = 20$) were 6 cm worse than males (32 cm; $N = 18$). Adult females (47 cm; $N = 20$) were 20 cm worse than adult males (27 cm; $N = 34$). On the second trial, females (24 cm error; $N = 55$) were still worse than males (16 cm; $N = 63$), [$F(1, 112) = 6.80, p = .01$]. There were no effects of age [$F(2, 112) = 0.10, p = .9$] or sex \times age [$F(2, 112) = 1.34, p = .2$]. These sex differences were reflected in the percentage of accurate responses (within 10 cm of correct): 5% versus 9% on the first trial and 18% versus 27% on the second trial for females versus males respectively.

2.3. Discussion

Observers systematically mislocated the projection of the experimenter's face on the surface of the mirror. They strikingly overestimated the distance of the projection from themselves. Accuracy improved on the second trial but most observers still placed their card significantly beyond the actual projection location. Children responded like adults but females made larger errors than males.

3. Experiment 2

Before concluding that the results from Experiment 1 demonstrate people's inability to locate projections,

¹ The verbal instructions given by the experimenter to the observer were as follows (italics indicate emphasis): "Can you see the reflection of my face in the mirror? ... I am going to give you this card and I want you to stick it onto the mirror so that it *covers up the reflection of my face*, so that you *can't see my face in the mirror any more*. However, to make life harder for you, I am going to move away from where I am now before I give you the card, so you will have to *remember where my reflection is now*. Have you remembered where you are going to put the card? ... OK, I'm going to move now, and give you the card".

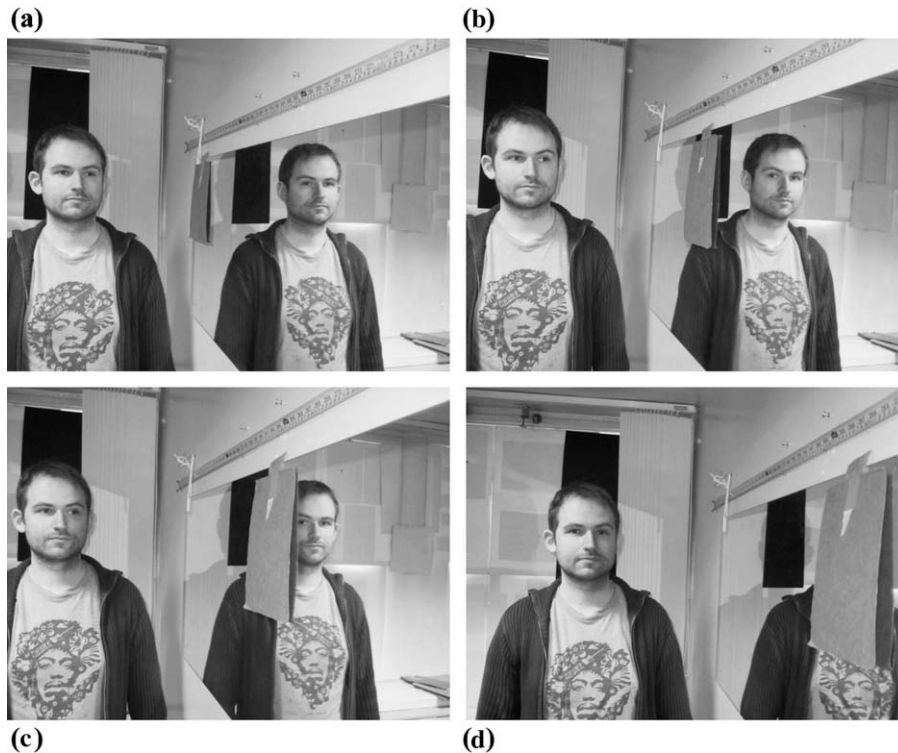


Fig. 3. Four photographs taken from the viewpoint of the observer in Experiment 2. The view of the scene was similar in Experiment 1. In each case, the observer could see the experimenter directly (on the left) and also the projection of the experimenter on the surface of the mirror (on the right). (a) The card is 58 cm beyond its correct location, and it is as far from the observer along the plane of the mirror as the experimenter (as in Fig. 1b). (b) The card is at the mean first trial location in Experiments 1 and 2, at 35 cm beyond its correct location. (c) The card is 9 cm beyond its correct location, still slightly too near to the experimenter. (d) The card is at about the correct position. It is 2 cm beyond the correct response assuming perfect placement of the observer and the experimenter.

alternative explanations were examined in a laboratory-based study. Experiment 2 tested two groups on extra tasks as well as the same projection location task as in Experiment 1.

First, to assess whether observers can accurately remember any location on a mirror, one group (the Physical-Before-Projection-Task group) did a physical location task before the projection location task. Here, the experimenter and observer stood on their footprints as the experimenter stuck a card onto the mirror. The observer was told to remember this card's location. The experimenter then removed their card and gave it to the observer to stick onto the mirror at the remembered location. To increase the similarity between this task and the projection location task, the experimenter's card covered the projection of the experimenter's face from the observer's viewpoint, so the correct response was identical in both tasks.

Second, many in the Physical-Before-Projection-Task group were expected to spontaneously use the tape-measure above the mirror in the physical location task. This might encourage them to use the tape-measure in the subsequent projection location task and this, in turn, could improve their performance. To check whether the tape-measure was useful for locating projections, at the end of the experiment observers were asked to report the number on the tape-measure above the centre of the projection of

the experimenter's face. The Physical-Before-Projection-Task group might also benefit from noticing that the experimenter's card covered the projection of the experimenter's face in the physical location task. If so, they could simply repeat their response in the projection location task. These two possibilities were tested by comparing the Physical-Before-Projection-Task group's performance on the projection location task to that of a second (Projection-Task-Only) control group who did not do the physical location task.

Third, in Experiment 1 the projection location was calculated as midway between the observer and experimenter's footsteps. This assumed that the observer and experimenter stood up straight and exactly on their footsteps. This assumption was tested in Experiment 2 by checking the actual projection location for each observer individually.

3.1. Method

3.1.1. Observers

Undergraduate students (18 male, 70 female, aged 18–42) from the University of Liverpool participated for course credit. Half (nine male) were assigned to the Physical-Before-Projection-Task group and half to the Projection-Task-Only group.

3.1.2. Procedure

The experiment was conducted in a small room using the same materials in the same positions as in Experiment 1. The only difference between the Physical-Before-Projection-Task group and the Projection-Task-Only group was that the latter group did not do the physical location task.

First, the Physical-Before-Projection-Task group did the physical location task. As the experimenter and observer stood on their footprints, the experimenter stuck a card onto the mirror. The experimenter told the observer to remember the card's location then they walked away from the mirror, removed their card and handed it to the observer. The observer then tried to stick the card onto the mirror at the remembered physical location. Once the observer was satisfied with this card's position this location was recorded. In this task the experimenter stuck their card onto the mirror so that it covered the projection of the experimenter's face from the observer's viewpoint. Thus the correct location as well as the apparatus and method of testing was identical for the physical location task and the subsequent projection location task. Only the means of specifying this location differed. Observers were not told that the answer was the same for both tasks.

Second, all observers did the projection location task. This replicated Experiment 1 except that if observers said that their card still did not cover the projection of the experimenter's face after the second trial they were given a third trial.

Third, the correct response for the projection location task was checked. As the experimenter and observer stood on their footprints, the experimenter stuck a card onto the mirror to cover the projection of the observer's face from the experimenter's viewpoint. The observer was asked if the card covered the projection of the experimenter's face. If necessary, the experimenter adjusted the card's position until the observer agreed that they could no longer see the experimenter's face in the mirror. The card's location was then recorded and the card was removed.

Finally, as the experimenter and observer stood on their footprints, the observer was asked what number on the tape-measure was directly above the centre of the projection of the experimenter's face on the mirror.

3.2. Results

First, observers were accurate at the physical location task. The Physical-Before-Projection-Task group placed their cards on average just 1 cm from the experimenter's card ($SD = 3$ cm; maximum difference 7 cm). Most people (31 of 44, 70%) reported using the tape-measure to remember this location, but five used the scene reflected in the mirror and five remembered it relative to the mirror edge or their body position.

Second, in the projection location task all but one observer placed their first card too far away. Surprisingly, success at the preceding physical location task failed to benefit the Physical-Before-Projection-Task group: their mean response (34 cm beyond the actual projection location; $N = 44$; $SD = 15$ cm) was no more accurate than the Projection-Task-Only group (35 cm; $N = 44$; $SD = 16$ cm). These errors persisted on the second trial for both the

Physical-Before-Projection-Task group (18 cm error; $N = 43$; $SD = 20$ cm) and the Projection-Task-Only group (15 cm; $N = 44$; $SD = 20$ cm), although most (87%; 76 of 87) were more accurate on the second than the first trial. Third trial responses still generally overshoot for both the Physical-Before-Projection-Task (9 cm; $N = 32$; $SD = 20$ cm) and the Projection-Task-Only (12 cm; $N = 35$; $SD = 20$ cm) groups.

Third, these errors were not due to systematic discrepancies between the calculated and the actual projection location. When checked individually, the correct response for the projection location task was an average of only 1 cm from the calculated correct response, with a maximum difference of 10 cm.

An ANOVA was conducted on projection location responses, with one between-subjects factor (group: Physical-Before-Projection-Task, Projection-Task-Only) and one within-subjects factor (trial: 1, 2, 3, correct). The correct response was the location agreed by the observer to be correct when the experimenter placed the card in the third task. Empty cells (one on the second trial, 21 on the third trial) were filled with the response on the previous trial for that observer since missing values occurred when people said that their previous response was correct. There was an effect of trial [$F(3, 258) = 119.649$, $p = .000$]. Post-hoc Newman-Keuls tests confirmed that accuracy improved from the first trial (35 cm error) to the second trial (16 cm) and then to the third trial (9 cm). However, even third trial responses differed significantly from the correct response. Importantly, there was no effect of group [$F(1, 86) = 0.683$, $p = .9$] or trial \times group [$F(3, 258) = 0.703$, $p = .5$].

Using the tape-measure to locate projections would have improved initial performance. The mean response when using the tape-measure above the mirror to report the experimenter's projection was systematically biased away from the actual projection location for both the Physical-Before-Projection-Task (12 cm error; $N = 19$; $SD = 12$ cm) and Projection-Task-Only (13 cm; $N = 22$; $SD = 9$ cm) groups. Nevertheless, this error was much less than that for first trial responses in the projection location task (35 cm error).

As in Experiment 1, females were worse at locating projections than males: by 16 cm on the first trial (38 cm error versus 22 cm), 12 cm on the second trial (19 cm versus 7 cm), and 8 cm on the third trial (10 cm versus 2 cm). These sex differences were reflected in the percentage of accurate responses (within 10 cm of correct): 1% versus 11% on the first trial, 33% versus 53% on the second trial and 61% versus 91% on the third trial for females versus males respectively.

3.3. Discussion

People could accurately remember a physically-specified location on the mirror although the position was not visibly marked when they responded. However, this success did nothing to reduce errors on the subsequent projection location task. The Physical-Before-Projection-Task group overestimated the distance of projections just as much as the Projection-Task-Only group.

4. General discussion

The location of the projection of an object on the surface of a mirror was judged to be much too far away, and nearly as distant as the physical object generating the projection (see Fig. 4). This error persisted, though weaker, with repeated testing. In contrast, observers could accurately remember a physically-specified location on the surface of the mirror. However, this success did not then improve their performance on the projection location task. People’s typical reaction to their projection location errors was laughter and surprise. Nobody said that they had misunderstood the task.

Both adults and children initially responded as if the experimenter’s projection was almost next to the experimenter. Their mislocations were therefore strongly biased towards the experimenter’s apparent position in the virtual world inside the mirror (see Fig. 1b). People seemed unable to perceive projections as existing on the surface of the mirror. This misunderstanding of mirror optics is

consistent with other mistakes that people make about mirrors (Lawson, 2009; Lawson & Bertamini, 2006; Lawson et al., 2007).

It is important to contrast these deficits in extracting information about projections with examples of the successful and sophisticated use of mirrors to provide information about the physical world. For example, people are quite accurate at using projections on a flat mirror to estimate the physical size of objects (Higashiyama & Shimono, 2004). Most 4-year-olds can reliably locate a toy hidden behind one of two identical screens using the toy’s projection on a flat mirror (Field & Hogg, 1992). Mirrors can be successfully used to locate hidden objects by many 2-year-olds (Robinson, Connell, McKenzie, & Day, 1990), parrots (Pepperberg, Garcia, Jackson, & Marconi, 1995) and pigs (Broom, Sena, & Moynihan, 2009).

In comparison, locating projections of objects on the surface of mirrors is a much greater challenge. This seems surprising given the apparent ease with which young children overcome the illusion that mirrors show a world

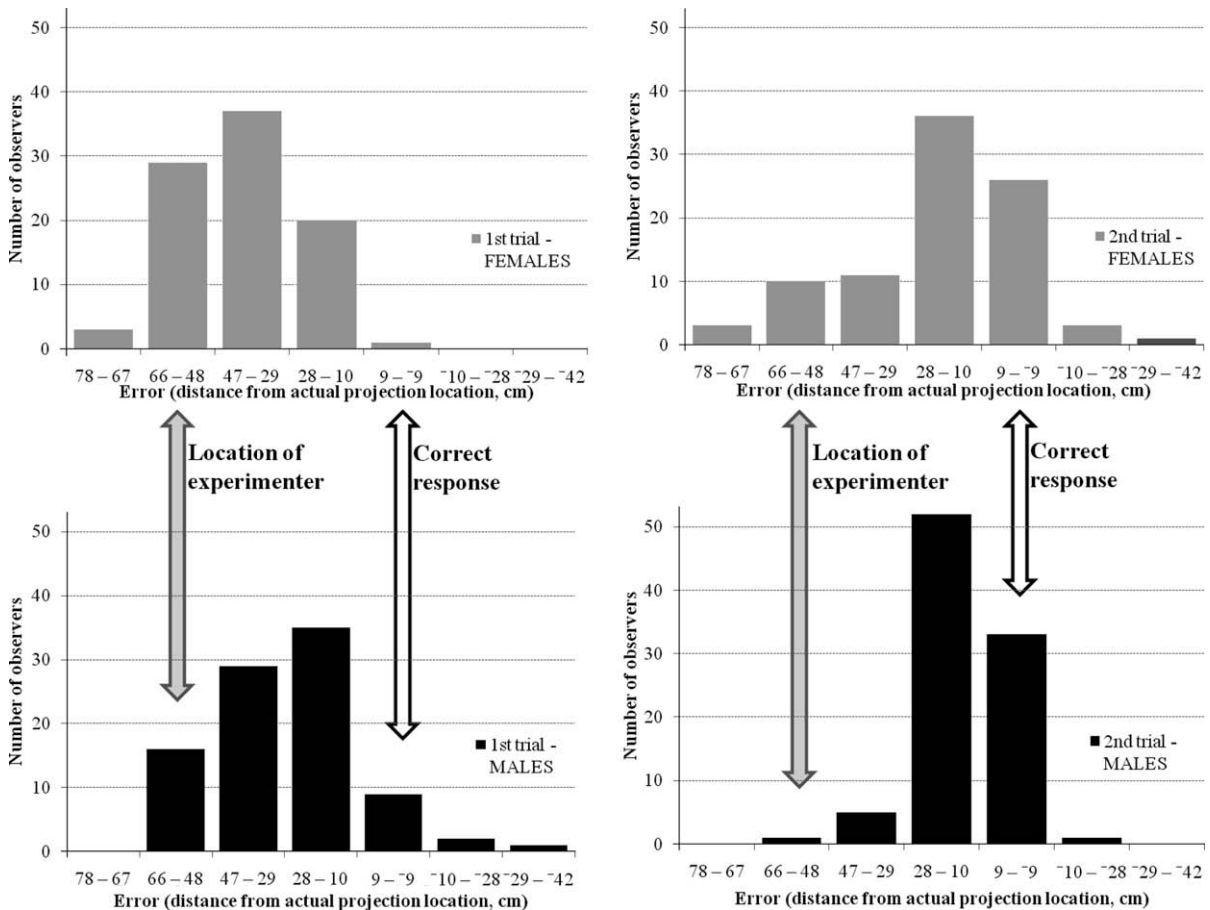


Fig. 4. Results for the projection location task for all 182 adults tested in Experiments 1 and 2. Responses are binned into seven adjacent strips (two narrower end strips and five 18 cm wide central strips) along the 120 cm wide mirror. The first strip starts at the left mirror edge, by the experimenter and includes all responses overshooting the correct location by 78–67 cm; the next strips are 66–48 cm; 47–29 cm; 28–10 cm; responses 9 cm either side of the correct location; –1 to –28 cm, so responses too near to the observer; and finally –29 to –42 cm so up to the right mirror edge, next to the observer. Results are reported separately for females (N = 90; upper graphs with grey bars) and males (N = 92; lower graphs with black bars) on the first trial (left graphs) and second trial (right graphs). White arrows show correct responses. Grey arrows indicate the distance of the experimenter along the plane of the mirror, about 58 cm beyond the location of the projection of the experimenter.

through the glass and, instead, realise that mirrors reveal another view of the physical world. However, it seems that even adults rarely extend this understanding to realise that projections on mirrors are usually much closer to them than the physical objects generating the projections.

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