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The tendency to overestimate what is visible in a planar mirror amongst adults and children

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Adults hold several mistaken beliefs about simple mechanical and optical phenomena. In particular, many adults believe that they would be able to see their own image in a mirror before they are in front of it. Similarly, they expect objects to become visible in mirrors before they actually do. This overestimation of what is visible is known as the early error (Bertamini, Spooner, & Hecht, 2003). It has been suggested that incorrect models about mechanics, and therefore erroneous beliefs, develop over time, as evidenced by good performance in young children (Kaiser, McCloskey, & Proffitt, 1986). With respect to knowledge about what is visible in mirrors we report the first developmental data. We confirmed an effect for prospective University students but found no evidence of any early error in children between the age of 5 and 11. This erroneous belief about mirrors develops during the later school years when people develop a system of beliefs based on experience.

Keywords: Naive physics; Mirrors; Developmental; Visual cognition; Perspective taking.

People fail to correctly answer simple questions about phenomena to which they had frequent exposure. For instance, a large proportion of people believe that an object dropped by a moving carrier (a walking person or an airplane) will fall along a straight line (McCloskey, 1983; Proffitt, 1999). Another example is the belief that if a glass is tilted the orientation of the liquid inside the glass will also be slanted (Hecht & Proffitt, 1995; Piaget & Inhelder, 1967).

More recently, Bertamini and colleagues have studied the answers to questions about planar mirrors. Mirrors are amongst the most common objects in the environment: They are in almost every house, car, or shop.

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Yet people find some questions challenging, and they make systematic mistakes. The errors can be classified in two groups.

1. *Early error*. In the typical setup, participants are told to imagine that they are approaching a mirror from the side, along a line parallel to the mirror. Many people claim that, as they approach the mirror, they would see their reflection before reaching the near edge. This error has been found with paper-and-pencil questionnaires, but it has been replicated with realistic simulations, and even with a positioning task in a real room (Bertamini, Spooner, & Hecht, 2003; Croucher, Bertamini & Hecht, 2002; Hecht, Bertamini, & Gamer, 2005). Psychology and physics students produce similar errors (Croucher et al., 2002).

   Closely related to the early error is the fact that if people see both a person and the reflection of that person in a mirror, for instance a painting of the toilet of Venus, they often believe that what they see in the mirror is the same as what the person sees (the Venus effect; Bertamini, Latto, & Spooner, 2003). In both cases the key issue is what is visible from where, and the responses demonstrate a poor understanding of the role of the viewpoint.
2. *Projection size*. Bertamini and Parks (2005) confirmed Gombrich's observation (1960) that people believe that if they were to outline their own face on a mirror this outline is the same size as their face (it is, in fact, half the size). People also believe that this outline gets smaller if they move farther from the mirror (in fact, the size on the mirror surface does not depend on distance) (Lawson & Bertamini, 2006; Lawson, Bertamini, & Liu, 2007). This type of error originates from the fact that the projection is an accidental cross-section rather than a distal object.

This paper will only focus on the first type of error. The available data comes mainly from undergraduate students. It is, therefore, important to explore how the tendency to overestimate what is visible in a mirror develops over the lifespan. With respect to mechanics, Kaiser, McCloskey, and Proffitt (1986) asked children (between 4 and 12 years) to draw the path a ball would take upon exiting a curved tube. Young children (below 6) performed as well as college students, whereas school-aged children were more likely to make errors, thus giving a U-shaped function. This trend suggests that the school-aged children are developing intuitive theories of motion that include erroneous principles. It is possible that at the same time they develop theories about mirror reflections.

We devised a paper-and-pencil task to test the early error with young children. In the task the scenario is described as a hide-and-seek game. In Experiment 1 we tested primary school children, comparing the data

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across the range of ages (from 5 to 11 years). In Experiment 2 we used the same stimuli to test a larger sample of the population, including individuals who were not yet undergraduate students and older adults. We also varied the wording of the question to see whether describing the question as part of a hide-and-seek game affects the probability of a correct response.

EXPERIMENT 1: PRIMARY SCHOOL CHILDREN

The testing was carried out in a primary school. In England children begin compulsory education in the academic year during which they become 5 (Reception). Primary education finishes 7 years later (Year 6). The task was modified to appear like a game in which one child is trying to find another child who is hiding from her, as illustrated in Figure 1.

Method

Participants. Seventy-five children took part in the study (42 females). Age ranged from 5 to 11 years (from Reception to Year 6). Specifically the

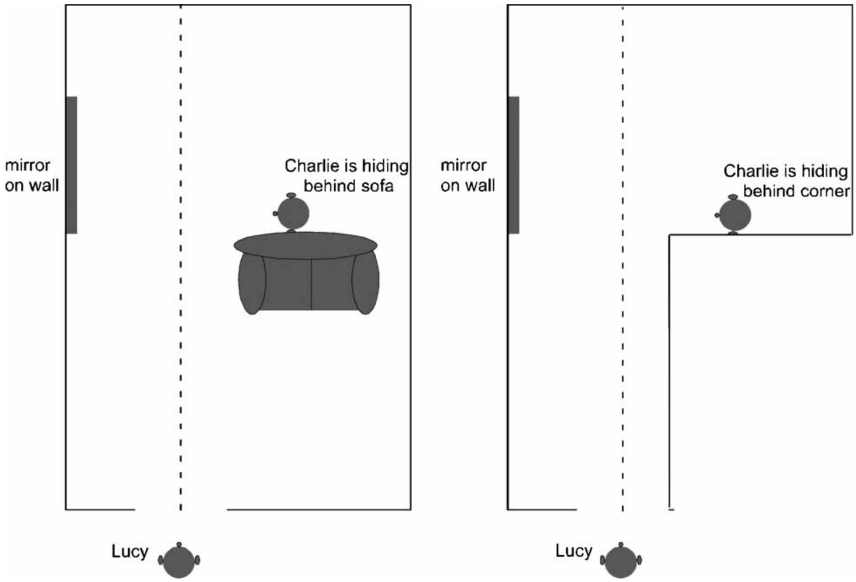

Figure 1. The two diagrams used in Experiment 1 and 2. Each of them was printed on a separate A4 page. The long side of the room was 20.3 cm. Lucy is described as walking in the room along the dashed line. In Experiment 2 instructions were written at the top of the page (see text). Participants indicated at what point they believe that Lucy is able to see Charlie in the mirror.

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children were 5 ($n = 8$), 6 ($n = 10$), 7 ($n = 15$), 8 ($n = 15$), 9 ($n = 6$), 10 ($n = 11$), or 11 years ($n = 10$) of age. The primary school was a mainstream school in which ethnicity and cultural background varied. Caucasian and Asian children made up the majority of the sample.

Design and procedure. The children were presented with a diagram showing the top view of a room. In the room there were two individuals, Lucy and Charlie, a line on the wall described as a mirror, and an occluder (Figure 1). There were two layouts for the room, one in which the occluder was a sofa and one in which the occluder was a corner of the room itself. Children were, therefore, asked to answer twice. Each diagram filled an A4 page; the long side of the room was 20.3 cm and the mirror was 5.5 cm long.

Each participant was tested individually in a quiet area of the school away from other pupils and staff. The child was asked if they would like to play a game. If their consent was given, the child was asked to sit next to the researcher. As each stimulus was presented the researcher explained the drawing in front of the child by means of a story. For example: "This is a picture of a room [pointing at details on picture] as if you were looking down on it from the ceiling. Pretend you are a spider and are looking down on the room. You can see two children, Lucy and Charlie. They are playing hide-and-seek, and Charlie is hiding behind the sofa. Lucy can't see Charlie, all she can see is a sofa [pointing to sofa] and a mirror [pointing to mirror]. Can you guess for me where along this dotty line Lucy will firstly be able to see Charlie's reflection in the mirror?"

After telling the story, children were asked if they understood the story, were allowed to ask questions to make sure they understood the setup of the room, and the researcher ensured children understood what was asked of them.

The child was asked to point at one location along the dashed line, using a finger, where Lucy would have to walk to before she would see Charlie in the mirror. This distance was then measured and recorded. The researcher ensured the child did not see the answers of their peers, and the child was also asked not to mention the nature of the game to other children.

Results

It is important to discuss what is a correct or incorrect answer. Charlie was positioned so as to be level with the mirror; however, the size of Charlie's head means that his right ear would start to become visible slightly before Lucy would arrive at the near edge of the mirror. A correct answer would, therefore, start from 7 mm before the near edge, but a later value may also

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be correct, for instance, if the participant thinks that Lucy has to see most of Charlie's face to recognise him. Indeed this layout has the unfortunate feature that Lucy may find herself in the way when looking to the mirror to see Charlie. Thus, a possible answer would be a bit later, when Lucy has moved towards the centre of the mirror. However, in all cases a response more than 7 mm before the near edge would be incorrect. We used the near edge as the reference and coded distance for earlier responses as negative.

The two versions of the drawing were included to check for consistency and not for any theoretical reason. On average the unsigned difference between the two was small, 5.9 mm ($SD = 6.0$), and the correlation was high (Pearson $\rho = .79$). In subsequent analyses, therefore, we pooled the two measures. Figure 2 shows the mean response as a function of age. An ANOVA with age and sex as factors did not confirm any main effect or interaction. We found little variation in the different age groups. The most surprising result, however, is the absence of an early error. The response, on average, was 7.7 mm after the near edge ($SD = 11.8$). This was significantly different from zero, $t(74) = 5.6$, $p < .01$, but in the positive direction. The mean location of Lucy on the diagram was close to a location exactly lined up with Charlie's, as can be seen in Figure 2.

Assuming a door of 90 cm, the corresponding length of the room was 493 cm and the width of the mirror 133 cm. The mean error (7.7 mm) would therefore correspond to 18.7 cm after the near edge.

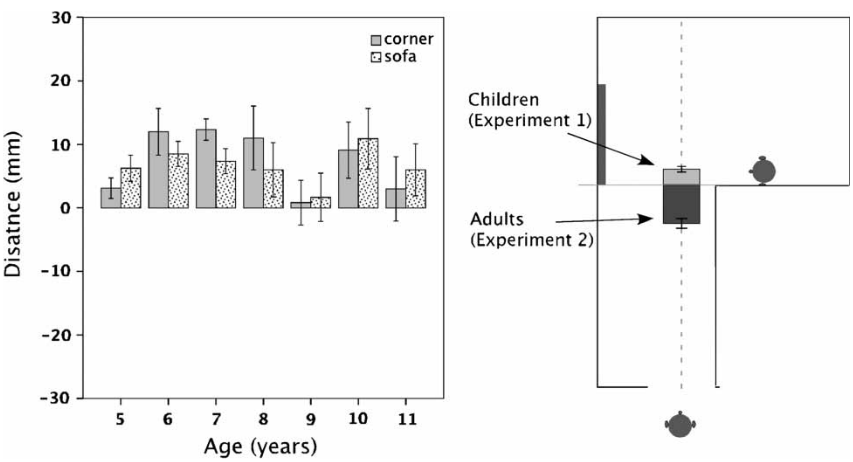

Figure 2. (Left) Data from Experiment 1. On the scale a value of zero is the near edge of the mirror and positive values indicate a position farther along the dashed line, and therefore in front of the mirror. Error bars are ±1 SEM. (Right) The mean response from Experiment 1 is shown on top of the actual stimulus (corner version). For the adults, the mean response comes from Experiment 2 (Open Day data).

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EXPERIMENT 2: CONTROL

Experiment 1 failed to find any evidence of an early error in children. Although data exist in the literature about the early error in adults, the stimuli used in Experiment 1 were novel. In addition to the novel layout, it is also possible that setting the task in terms of a hide-and-seek game might help participants by making the task more concrete. In Experiment 2 we used the same stimuli and presented them either in the hide-and-seek scenario or with a more direct question to two groups of participants to test the effect of wording the task differently. To gain as much information about the time course of the effect we recruited adults and children from outside the University community.

Experiment 2 is a control for Experiment 1 in at least two ways: It tests whether the same material will give rise to an early error in adults, and it tests the role of describing the task in terms of a hide-and-seek game. In addition, Experiment 2 also extends the available data to a broader age range.

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Method

Participants. One hundred and fifty-six individuals took part in a large classroom (125 females). They were prospective University students and their parents, attending an Open Day. Age ranged from 14 to 73 years with a mean of 29.86. Another 62 individuals were tested individually during a Festival of Science (33 females). Age ranged from 7 to 60 years with a mean of 16.84.

Design and procedure. The Open Day participants were handed a sealed envelope as they walked into a lecture theatre. They were instructed verbally before they opened the envelope and completed the test on paper.

One group ($N = 76$) had instructions on the top of the test that matched closely the verbal instructions used in Experiment 1: "Lucy and Charlie are playing hide-and-seek. Charlie is hiding behind a sofa. Lucy is walking in the room along the dashed line. At what point will she be able to see Charlie's reflection in the mirror on the wall? Please mark the point on the line with a cross." A second group ($N = 80$) was given a simpler question: "Lucy is looking for Charlie. She is walking in the room along the dashed line. At what point will she be able to see Charlie's reflection in the mirror on the wall? Please mark the point on the line with a cross." The questions for the diagram in which Charlie was hiding behind a corner of the wall (see Figure 1) were the same except that the corner was mentioned instead of the sofa.

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Results

Open Day. As in Experiment 1, we pooled the sofa and the corner versions because the unsigned difference was small (14mm, $SD = 17$) and the correlation high (Pearson $\rho = .74$). In a first ANOVA we tested for effects of sex and context (hide-and-seek story). The context was the only significant effect, $F(1, 152) = 6.37$, $p = .013$. Figure 3 (top left) shows the mean responses separately for the group that was given the hide-and-seek story

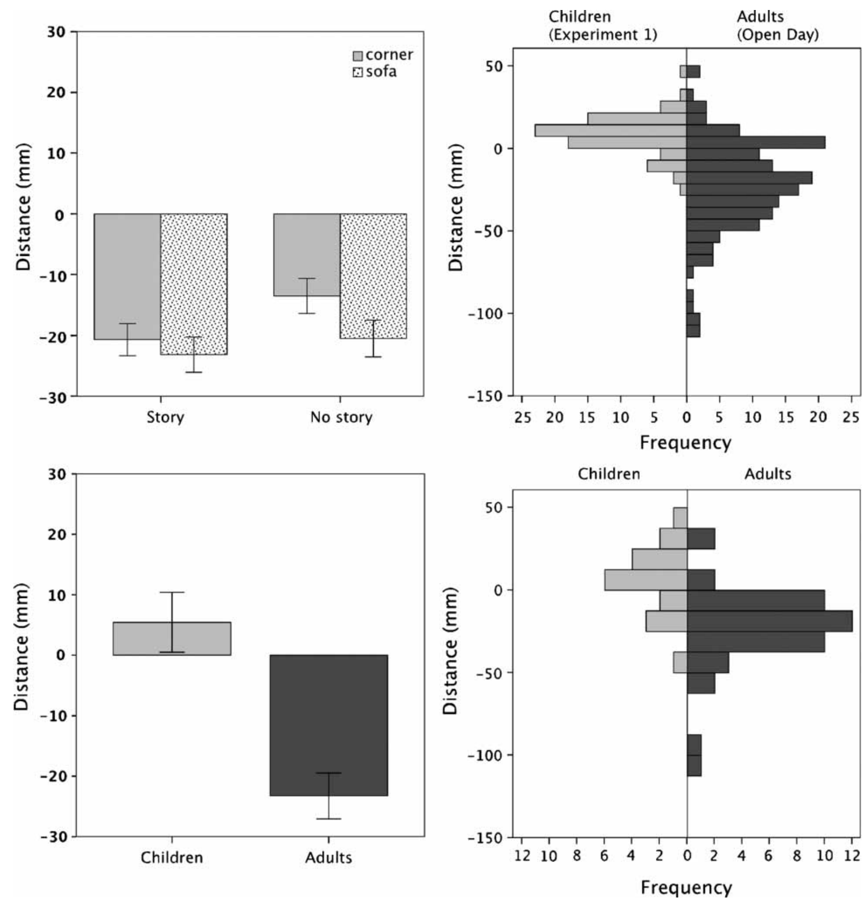

Figure 3. Data from Experiment 2. (Top: Open Day data) On the scale a value of zero is the near edge of the mirror and negative values indicate a position before the near edge. Error bars are ± 1 SEM. On the right the distributions for Experiments 1 and 2 are compared. For adults the multiple peaks replicate previous findings in the literature (e.g., Croucher et al., 2002). (Bottom: Festival of Science data) Error bars are ± 1 SEM. On the right the distributions for children and adults within this subsample are compared.

(−28.32) and the one that was given a direct question (−17.00). It is interesting that the hide-and-seek story led to a larger error (more negative values). Both values were significantly different from zero, $t(74) = -7.7$ and $t(79) = -6.5$; $p < .001$ in both cases. Assuming that the door is 90 cm wide, these errors correspond to −68.9 cm and −41.4 cm.

It is known from the literature that adult responses are not normally distributed (Croucher et al., 2002). A majority of participants tends to make a small early error, but the response of a minority of people is close to the near edge of the mirror, whereas another smaller minority makes a very large early error, as if they believed that as soon as the mirror is visible then the target is visible in the mirror. Consequently the distribution tends to have three peaks, or sometimes even four because a few people tend to give a late response (near the far edge). To compare the distributions Figure 3 (top right) shows the histogram of the responses from Experiment 1 (children) against the histogram of the responses from the adults. For the children the distribution is close to normal and it has a limited range. For the adults instead we see the characteristic peaks described previously.

To help the reader in relating the graphs and the original stimulus, in Figure 2 the mean response (with error bars) overlaps the diagram of the room. The mean for the children of Experiment 1 is shown together with the mean from the adults at the Open Day.

Data from Festival of Science event. This dataset includes both children and adults, therefore as an initial analysis we created a new variable with two groups: children (< 11 years) and adults (11 and above). An ANOVA tested for effects of sex and age (children vs. adults). The only significant effect was that of age, $F(1, 57) = 13.58$, $p < .01$. Figure 3 (bottom left) shows the overall mean for the children (5.4 mm) and for the adults (−23.28 mm). The difference between the two groups under similar testing conditions is striking. For the adults, but not the children, this value is different from zero, $t(42) = -6.15$, $p < .001$. Assuming that the door is 90 cm wide, these errors correspond to 13.1 cm (children) and −56.6 cm (adults).

Because the means can be misleading, Figure 3 (bottom right) displays the distributions. There is less data here compared to the Open Day data, but the pattern is entirely consistent.

Full dataset. Having analysed children and adults separately, we combined the data from Experiments 1 and 2 to look at the trend over the whole age range. The total number of individuals in the full dataset was 293 (200 females).

Figure 4 shows a scatterplot with a linear regression and a 95% confidence interval. We used a logarithmic scale for age to spread out the earlier years of one's life. It seems reasonable to think that going from 5 to 10

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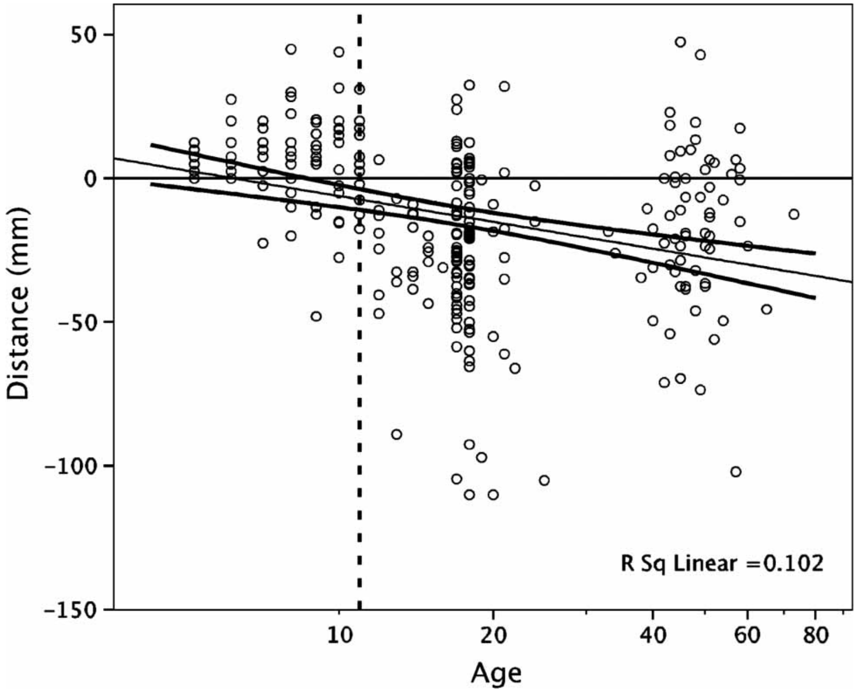

Figure 4. All the available data from Experiments 1 and 2. The linear regression is shown together with a 95% confidence interval. The vertical dashed line is at age 11, the age at which children leave primary school in England.

years of age, for instance, is a greater change than going from 35 to 40 years. However, our conclusions do not depend on this particular transformation. The regression is used to capture a trend and not to provide a quantitative model. The main reason is illustrated by the scatterplot: The mean performance comes from a population with great variability and possibly a set of subgroups of people who used different strategies.

The negative slope was -30.74 mm ($SE = 5.23$), and the intercept was positive: 24.71 mm ($SE = 6.62$). The slope was significantly different from zero, $t(291) = 5.9$, $p < .0001$. Figure 4, therefore, illustrates how the early error does not exist in primary school children but it develops soon after, at least for a large minority of people.

In-depth interviews

To complement the paper-and-pencil data, the first author conducted one-on-one interviews with six children (not included in the dataset) ranging in age between 5 and 9 (two females). All six children predicted that Lucy would see Charlie only after she had reached the mirror or had moved a bit farther on than the beginning of the mirror, consistent with the results of Experiment 1. The children were familiar with mirrors and seemed to be confident in their answers. When questioned about what is visible in a mirror and how a mirror works, their answers were hard to classify and included some vague statements. Five of the six children, however, used words that implied that what is visible in a mirror is "what is in front of it". Note that this prediction is incorrect if it is taken to mean that only a section of the environment with the same width of the mirror would be visible. This principle is, however, incompatible with the early error and therefore may be part of the reason why children do not make such an error. In general, there was no sign that children understood the role of the viewpoint in determining what is visible in a mirror to a given observer. As discussed in the introduction, this is something that adults also find difficult to understand.

In summary, although children behave differently from adults and do not make the early error in the scenario outlined in the diagram of Figure 1, this does not imply that they have a deeper understanding of mirrors than adults. Instead, it appears that their reasoning is different.

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GENERAL DISCUSSION

We learn many things about the physical world from what we see. On the basis of experience we accumulate data but also generate hypotheses. Leaving scientific knowledge aside, theories play an important role in how we understand phenomena in everyday life. This idea is key to explanation-based theories of conceptual knowledge (Murphy & Medin, 1985). However, the development of knowledge is not always incremental.

The early error concerns what is visible from a given viewpoint. In this sense it is reminiscent of the mountain task introduce by Piaget and Inhelder (1967). Children were shown a model with three mountains and asked to select pictures representing the views of dolls placed around the table. Children under 8 years of age generally failed to choose the correct view, and children younger than 6 tended to choose the picture representing their own view. This response is, therefore, "egocentric". More recent work has demonstrated that the perspective-taking abilities of children varies and depends on a number of factors (for a review see Chandler, 2001). In general, the ability to understand that what is visible depends on the viewpoint is acquired over time. For example, Flavell, Flavell, Green, and Wilcox (1981) found that at the age of 5 years children acquire the knowledge that objects "will present the same visual appearance to the self and to another person if the two observers view it from the same position" (p. 356). At the same time they also know that a heterogeneous-sided object will appear different to two observers if they view it from different sides. We can, therefore, assume that this basic knowledge about the role of the viewpoint was present both in the children and in the adults in our study.

Other interesting developmental findings are worth citing here. Children below the age of 5 do not have the concept of straight-line looking path. They are surprised, therefore, that we cannot see through a curved tube (Flavell, Green, Herrera, & Flavell, 1991). In children there is also a strong extramission belief, although this survives to some extent even in adults (Winer, Cottrell, Gregg, Fournier, & Bica, 2002). This is the belief that something comes out of the eye and reaches the object as part of the process of seeing.

It may seem, prima facie, that our findings are at odds with the literature in that children do not make the same prediction error of the adults. However, as noted in the introduction, in the process of generating theories mistakes can happen. Kaiser et al. (1986) have suggested that this is the reason for a U-shaped developmental function in the case of naive physics. Before the stage at which hypotheses are generated the approach is more concrete and less prone to this type of error. We must stress, however, that our data do not imply that children do not make errors about mirrors. We would like to test children with a greater variety of hypothetical situations. For instance, it is possible that a critical aspect of the hide-and-seek scenario was that Lucy could not see Charlie directly as she entered the room. Perhaps if the occluder is removed children may be more willing to say that Lucy can see Charlie in the mirror when she can also see him directly. Another possibility is that, although we know that in adults the early error is just as strong in a real room as on a paper-and-pencil questionnaire (Croucher et al., 2002), this may not be the case for children.

With respect to the role of experience, both children and adults are exposed to mirrors on a daily basis. The early error is, therefore, surprising and counterintuitive. Experience provides people with a memory of a large space visible through a mirror, similarly to seeing a scene through a window. From this vague memory adults build an expectation that much of the layout should be visible. This is true, but because they do not know the relationship between real and virtual worlds they cannot say what can be seen from a given viewpoint (Bertamini & Parks, 2005).

Apart from the developmental data, another interesting result is the difference between the size of the error for the people who were given a hide-and-seek scenario and those who were not given such a scenario (Experiment 2). In general, making the task more concrete does not reduce the early error because Croucher et al. (2002) found a larger error when participants positioned themselves in a real room as compared to the paper-and-pencil

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task. Consistently with that, the concrete example of a hide-and-seek game increased rather than decreased the size of the error in Experiment 2. It is possible that playing the game shifted people's criterion so that they were more willing to say that Lucy had seen Charlie because she had a motivation to look for him. Nevertheless it is interesting that increasing the importance of the task does not help people in avoiding the error. In turn this rules out that children simply did not make an early error because they were motivated by the hide-and-seek task.

CONCLUSION

We have started to investigate the development of beliefs about what is visible in mirrors. The starting point was a systematic mistake found in adults: the early error (Bertamini, Spooner, & Hecht, 2003). Using a paper-and-pencil test, we found that the tendency to respond that a person becomes visible in a mirror before he actually would was absent in primary school children and is likely to develop during the later school years.

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