Implicit model of other people's visual attention as an invisible, force-carrying beam projecting from the eyes

Arvid Guterstam[a,1], **Hope H. Kean**[a,1], **Taylor W. Webb**[a], **Faith S. Kean**[a], and **Michael S. A. Graziano**[a,2]

[a]Department of Psychology, Princeton University, Princeton, NJ 08544

Edited by Michael S. Gazzaniga, University of California, Santa Barbara, CA, and approved November 16, 2018 (received for review September 27, 2018)

As a part of social cognition, people automatically construct rich models of other people's vision. Here we show that when people judge the mechanical forces acting on an object, their judgments are biased by another person gazing at the object. The bias is consistent with an implicit perception that gaze adds a gentle force, pushing on the object. The bias was present even though the participants were not explicitly aware of it and claimed that they did not believe in an extramission view of vision (a common folk view of vision in which the eyes emit an invisible energy). A similar result was not obtained on control trials when participants saw a blindfolded face turned toward the object, or a face with open eyes turned away from the object. The findings suggest that people automatically and implicitly generate a model of other people's vision that uses the simplifying construct of beams coming out of the eyes. This implicit model of active gaze may be a hidden, yet fundamental, part of the rich process of social cognition, contributing to how we perceive visual agency. It may also help explain the extraordinary cultural persistence of the extramission myth of vision.

gaze | social cognition | theory of mind | spatial perception | visual attention

People are sensitive to the gaze direction of others (1–8). We recently suggested that when monitoring the gaze of others, people may do more than compute the direction of gaze (9). They may construct a rich, implicit model of other people's active visual attention. In support of this view, people appear to judge the state of visual awareness of others based on an integration of multiple facial cues, not just eye direction (10). In addition, psychophysical evidence (11) suggests that when attributing visual attention to others, people implicitly encode rich properties such as whether the other person's attention has been directed in a top-down, endogenous manner or in a bottom-up, exogenous manner. These results suggest that some type of implicit model of other people's active visual attention is being constructed.

We proposed (9) that a simplified model of vision may be related to a belief that is extraordinarily persistent across human cultures: the belief that the eyes emit an invisible energy. Since the eyes obviously do not really extrude a beam of energy, this view is typically dismissed by science. However, the belief is worth examining as a possible manifestation of a deeper, simplifying model that the human brain constructs of the social environment.

Versions of the "extramission" theory of vision date back at least to the ancient Greek philosophers (12). Similar beliefs are still common. For example, belief in the "evil eye" is present across many cultures (13). One of the most common extramission beliefs is that people can "feel" someone else's gaze as a pressure or heat on the skin. In the late nineteenth and early twentieth century, Titchener (14) and Coover (15) showed that, although people may believe in eye beams, no such beams exist; people cannot actually detect the gaze of another in the absence of specific sensory information. Despite the lack of a real physical basis for eye beams, the belief is surprisingly persistent. In the 1970s, Piaget (16) found that most children hold a naïve belief that vision is caused by something beaming out of the eyes. In the 1990s, Winer, Cottrell, and coworkers (17–19) reported that more than half of American college students hold the same view. The extraordinary, widespread belief in an extramission account of vision, and especially its universality in children (16), suggests that it may be rooted in a cognitive process that is deeper than just a prescientific error in thinking. It may depend on automatic, implicit models about gaze that are robust against intellectual knowledge (9).

In the present set of experiments, we examined the belief in eye beams in two ways. First, we asked people to judge the mechanical forces acting on an object, and tested whether those judgments were implicitly biased by images of another person gazing at the object. Participants showed a significant bias that, in our interpretation, indicates an implicit belief in an invisible force that emanates from the eyes and mechanically pushes on objects. The implied force was small in magnitude, corresponding to about a hundredth of a newton, comparable to a light puff of air. Participants showed no evidence that they were explicitly aware of this response bias.

Second, we asked participants explicitly how they believed vision worked, and whether they believed that vision was accomplished by something coming into or flowing out of the eyes. We could not replicate the previous finding that most people explicitly believe in an extramission view of vision (17–19). Instead, about 5% of the participants stated that they believed in extramission. The rest correctly and explicitly described vision as caused by light entering the eye, and explicitly rejected the extramission view. However, regardless of their explicit, intellectual beliefs, participants still showed evidence of an implicit construct of a force-carrying influence that emanates from the eyes. These findings add support to the proposal that people construct a schematic model of other people's active vision, a model that contains some simplifying properties that render it physically inaccurate. Even though eye beams do not exist in

Significance

Much of how people process other social agents is hidden under the surface of awareness. Here we report that people automatically and unconsciously treat other people's eyes as if beams of force-carrying energy emanate from them, gently pushing on objects in the world. The findings show how the human brain constructs surprising, rich, and at the same time schematized models of other people's internal processes such as visual attention.

Author contributions: A.G., H.H.K., T.W.W., and M.S.A.G. designed research; A.G., H.H.K., and F.S.K. performed research; A.G., H.H.K., T.W.W., F.S.K., and M.S.A.G. analyzed data; and A.G., H.H.K., and M.S.A.G. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

[1]A.G. and H.H.K. contributed equally to this work.

[2]To whom correspondence should be addressed. Email: graziano@princeton.edu.

reality, and even though most people do not intellectually believe in them, they may exist as a part of the rich, implicit social model that we naturally apply to seeing agents.

Methods for Experiment 1

Subjects. To study a large sample of subjects, we used the Amazon Mechanical Turk subject pool, which allows paid subjects around the United States to participate in experiments on remote terminals. Each subject was paid $1.50. All subjects provided informed consent, and all procedures were approved by the Princeton Institutional Review Board. In the tilt-estimation task, 157 subjects (17 to 65 y, 55 female) were tested. We aimed for 150 subjects on the basis of pilot data, and extra subjects were added to compensate for possible attrition.

After performing the experimental task, the subjects answered a series of questions about how vision works. An additional 567 subjects were also given the vision questionnaire. Thus, a total of 724 subjects answered the questionnaire. Demographic information on the full sample is given in *Results for Experiment 1* and Table 1.

Experimental Design. The behavioral task required each participant to judge the tilt at which a paper tube would likely topple over. After reading the task instructions on a monitor, the subject saw a video performed by an actor. Two real paper tubes of different sizes, resting upright on a table, were tilted to the same angle such that one fell over and the other tipped back upright and remained standing. The video demonstrated the critical angle, the angle at which the tube can no longer right itself but instead will fall over. The subject then began the task trials.

On each trial, the subject saw a display (Fig. 1) including a rectangle representing a paper tube resting upright at the center of a table, and a human face to one side, in profile, facing the tube. The face was a photograph of a young man. Fig. 1 shows a cartoon to avoid privacy issues, but otherwise shows the stimulus accurately. Because of the use of subjects at remote terminals, we could not control the distance of the subject to the screen, and therefore the size of the image in visual degrees could not be specified. On a standard screen, the gray rectangular area that encompassed the stimuli was displayed at ~23 cm across.

The tube could be one of two thicknesses and one of two heights. It could be tall and thin as shown in Fig. 1, short and fat at half the height and twice the width as the one shown in Fig. 1, short and thin, and tall and fat. The four tube types varied randomly among trials to prevent subjects from performing in a rote manner. A vertical line was superimposed on the tube. The line could be tilted toward the left by using the F key on the keyboard, and tilted to the right with the J key. An arrow beneath the tube, pointing either left or right, indicated which direction of tilt was required.

The subject was instructed to adjust the tilt of the line until it matched the estimated critical tilt angle for the tube, the threshold angle at which the tube would be likely to fall over. Having adjusted the line to the desired angle, the subject then clicked a response button to indicate the trial was over. The next trial then began. No time limit was imposed. Subjects took as long as needed on each trial, typically around 5 s.

During the trial, as soon as the subject began to tilt the vertical line, the image of the tube disappeared. All other elements in the display remained. We removed the tube for several reasons that became apparent during pilot testing. If subjects tilted the rectangular image of the tube itself, the task could in principle be reduced to a simple algorithm: Tilt until the top corner of the rectangle is directly above the opposite bottom corner. That stereotyped trick would prevent subjects from using intuition about natural movement and forces. If the tube remained on the screen, untilted, while subjects tilted the vertical line on top of it, then the image of the tube could provide a visual scaffold that again might allow subjects to find a stereotyped algorithm. For these reasons, as soon as the subject began tilting the line, the image of the tube disappeared from the display, preventing the subject from relying on any simple visual trick to solve the task.

The face gazing toward the tube could be in four configurations. It could be on the left facing rightward toward the tube (as in Fig. 1), or it could be on the right facing leftward. It could have open eyes (as in Fig. 1), or its eyes could be covered by a thin black blindfold. Only one face image was used for all trial types. The image was mirror-reflected for placement on the left or right, and the blindfold was added to the image digitally to cover the eyes. The reason for using the same face image was to ensure that the visual stimulus was as consistent as possible across all trial types.

These manipulations resulted in 32 trial types: two tilt directions (to the left versus the right); four tube shapes; two face locations (looking at the tube from the left or from the right); and two gaze conditions (eyes open or covered). Trial types were presented in a randomized, counterbalanced manner. For analysis, trial types were collapsed into four major conditions: The instructed direction of tilt could be toward or away from the face; and the

PSYCHOLOGICAL AND COGNITIVE SCIENCES

Table 1. Demographic results for all subjects in experiment 1, versus subjects who reported some form of extramission belief

Category	All (%)	Extramission belief (%)
Male	386 (53)	9 (26)
Female	331 (46)	24 (71)
Under 18 y	2 (0.3)	0 (0)
18 to 24 y	72 (10)	3 (9)
25 to 34 y	300 (41)	16 (47)
35 to 44 y	197 (27)	7 (21)
45 to 54 y	94 (13)	6 (18)
55 to 64 y	41 (6)	1 (3)
65 and up	11 (2)	0 (0)
Completed some high school	4 (0.5)	0 (0)
High school graduate	92 (13)	6 (18)
Completed some college	162 (22)	8 (24)
Associate degree	92 (13)	4 (12)
Bachelor's degree	271 (37)	12 (35)
Completed some postgraduate	14 (2)	1 (3)
Master's degree	68 (9)	2 (6)
Other advanced degree beyond master's	1 (0.2)	0 (0)
PhD or MD	13 (2)	0 (0)
Midwest US	138 (19)	6 (18)
Northeast US	136 (19)	7 (21)
Southeast US	199 (27)	10 (29)
Southwest US	70 (10)	4 (12)
West US	181 (25)	7 (21)

The column for "all" includes all 724 subjects. The column for "extramission belief" includes the subset of 34 subjects who reported belief in some form of an extramission account of vision. In each cell, both the number of subjects and the percent of total are shown. Because not every subject answered every question, the percentages do not necessarily add to 100.

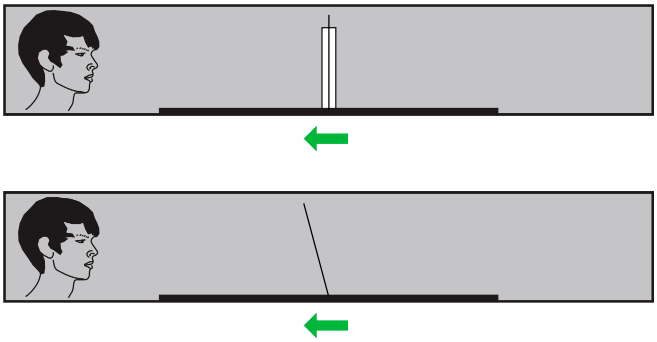

Fig. 1. Example display from the experimental task. (*Top*) The white rectangle represents a paper tube. The face shown is a cartoon but in the actual stimulus material was a photograph. (*Bottom*) On each trial, subjects used specified keys on a keyboard to tilt the vertical line in the direction of the green arrow, to estimate the critical angle at which the tube would fall over. As soon as tilting began, the white tube disappeared to remove any guiding visual scaffold. Subjects clicked a response button to indicate their final choice, before moving to the next trial. A typical final tilt angle is shown here. The following factors were randomly varied across interleaved trials: whether the face was on the left or the right (always facing the tube); whether the face had open eyes or was blindfolded with a thin blindfold that covered just the eyes; whether the instructed direction of tilt was toward or away from the face; and the shape of the tube (four possible shapes).

face could have eyes open or covered. Each subject performed 64 trials, and thus 16 trials per major condition.

The experimental conditions (eyes open) were analyzed first. We hypothesized that subjects would implicitly perceive a physical influence emanating from the eyes and pushing against the paper tube. If so, then the estimated critical tilt angle should be larger when the tube was tilted toward the face, because the force emanating from the eyes should help support the tube, allowing it to be tilted more steeply before falling over. Likewise, the estimated critical angle should be smaller when the tube was tilted away from the face, because the force emanating from the eyes should push the tube in the direction of its tilt, causing it to fall at a shallower angle. To capture this asymmetry, for each subject we computed a difference score, D = [the average angular deviation from vertical when the tilt was toward the face] − [the average angular deviation from vertical when the tilt was away from the face]. We predicted that across subjects, D would be significantly larger than 0.

For the control conditions (eyes covered), we again computed D. We predicted that with a blindfold covering the eyes, the implicit construct of a force emanating from the eyes and pushing on the tube would no longer be present. We therefore predicted that across subjects, in the blindfold trials, D would not be significantly larger than 0.

Of the 157 subjects, 10 were removed from analysis due to poor performance. They either mistook the instructions by tilting the line in the wrong direction, or their mean tilt angles were statistical outliers. Our rationale was that if a subject tilted the line to an implausibly large (almost horizontal) angle, it suggested the subject may have mistaken the instructions. As a result, 147 subjects remained in the final analysis.

Questionnaire. After the subjects performed the tilt-estimation task, they were asked a series of questions. Each question appeared individually on the screen and subjects typed an answer before progressing to the next question. In that way, each successive question could not bias the answers to previous questions.

Two questions probed what subjects thought the purpose of the experiment might be. The first was: "In two or three sentences, what do you think the purpose is of the experiment you just completed? What do you think we were studying?" The second question was more specific: "Do you think the person in the display affected your responses?" The purpose of these questions was to determine whether subjects guessed that we were testing the effect of a belief in, or perception of, anything emitted from the eyes.

Subjects were then asked to briefly describe how they believed vision worked. Two questions were asked. First: "Please explain how eyesight/vision works in one to two sentences." Second, subjects were asked a more specific question: "Do you intuitively think of vision as a process where something is leaving your eye or as a process where something is coming into your eye?" The purpose of these questions was to probe subjects' possible explicit beliefs in extramission.

Results for Experiment 1

Questionnaire. None of the 157 subjects in the tilt-estimation task indicated that they had a correct understanding of the purpose of the experiment. Not a single subject proposed that the experiment might be related to something emitted from the eyes, or to a specific, perceived mechanical or physical effect of gaze on the tube. Fifteen subjects (9%) indicated that they thought the face in the display affected their responses, reporting that the face was distracting, or that it "probably" affected their responses but were unaware of how. In the two questions pertaining to vision, 6 of the 157 subjects in the tilt-estimation task indicated that vision operates by something coming out of the eye rather than going in, and one subject indicated that vision works by a combination of something coming out and going in. Thus, seven subjects (4.5%) reported some belief in extramission.

We asked the vision questions of an additional 567 subjects, resulting in a total of 724 subjects who participated in the vision survey. Table 1 shows the demographic spread based on information collected by the Mechanical Turk interface. The participants covered a wide range of ages, education, and geographic regions of the United States. Of this sample, 68 failed to answer the questions in an interpretable way. Of those remaining, 16/656 (2.4%) reported a belief that vision was accomplished solely by means of extramission, 18/656 (2.7%) reported a belief that vision involved both extramission and intromission, and 622/656 (94.8%) reported the physically correct view that vision involves only intromission. Thus, 34/656 (5.1%) expressed a belief in some form of extramission. A common explanation among this group, in their written answers, was that vision involved light reflecting from the eyes. For example, "Light enters the eye and there is a reflector piece inside the eye. The reflector reflects the light back out and hits the object allowing the eye to see it."

Tilt Judgments. Subjects estimated the critical tilt angle, the angle at which a paper tube should fall over. The mean angle (17.7°) was not crucial to the hypothesis. The important measure was the difference in tilt angle, D = [the angle when the tilt was toward the face depicted in the display] − [the angle when the tilt was away from the face]. The mean across subjects of this difference score is shown in Fig. 2*A*.

In the experimental trials, when the face in the image had open eyes gazing toward the tube, subjects estimated a critical tilt angle that was asymmetric. On average, they estimated that the tube could be tilted by approximately two-thirds of a degree more steeply when the tilt was toward the face than when the tilt was away from the face ($D = 0.64°$, SE 0.23). This difference was statistically significant (two-tailed t test, t = 2.75, df 146, P = 0.006). It is consistent with the subjects treating the eyes as though a force were emanating from them, pushing on the tube. Given that force, the tube can be tilted more steeply toward the face before falling over, because the force should help hold up the tube, whereas the critical angle away from the face should be shallower, because the force should help topple the tube. Given the force required to bias the angle of a tube that has the weight of a standard sheet of paper, the eye beams would have had to exert a force on the order of one hundredth of a newton. In practical terms, subjects appeared to attribute a gentle influence, similar in magnitude to a barely detectable breeze, to the open eyes looking at the tube.

In interleaved control trials, when the face was still present but the eyes were covered with a blindfold, the difference disappeared. The critical tilt angle toward the face was not significantly different from the critical tilt angle away from the face ($D = 0.15°$, SE 0.21, two-tailed t test, $t = 0.71$, df 146, $P = 0.479$).

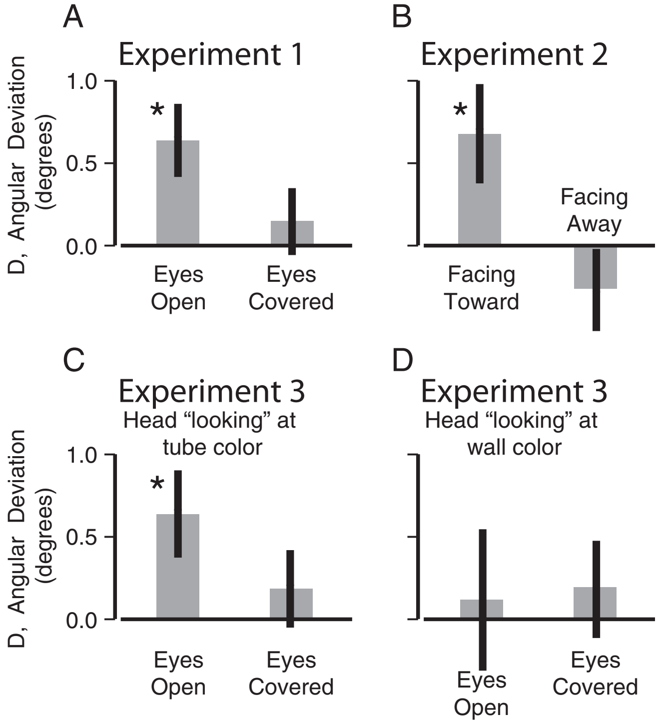

Fig. 2. Angular deviation caused by perceived influence of gaze. (*A*) Experiment 1. Mean results for 147 online subjects. A difference score was computed for each subject: *D* = [mean angular deviation from vertical, when the tilt was toward the face] − [mean angular deviation from vertical, when the tilt was away from the face]. Bars show the mean value of *D* averaged across subjects. Error bars show SE. The first bar shows *D* when the face in the display had open eyes. The second bar shows *D* when the face had blindfolded eyes. The asterisk indicates *D* significantly greater than 0, $P < 0.05$. See text for statistical details. (*B*) Experiment 2. Mean results for 25 in-laboratory subjects. The first bar shows *D* when the head in the display faced the tube. The second bar shows *D* when the head faced away from the tube. (*C*) Experiment 3, group 1. Mean results for 15 in-laboratory subjects who were told the unblindfolded head was looking at the tube. (*D*) Experiment 3, group 2. Mean results for 15 in-laboratory subjects who were told the unblindfolded head was looking past the tube, at the farther wall.

We repeated the analysis after removing the seven subjects who reported an explicit belief in an extramission account of vision. (Of the seven, one had already been eliminated due to mistaking the instructions and tilting in the wrong direction.) The results for the remaining subjects were substantially the same. When the face had open eyes, *D* was significantly greater than zero ($D = 0.64°$, SE 0.24, df 140, $t = 2.70$, $P = 0.008$). When the face was blindfolded, *D* was not significantly greater than zero ($D = 0.17°$, SE 0.22, df 140, $t = 0.79$, $P = 0.430$). Thus, even among people who explicitly reported a belief in the correct intromission view of vision, the gaze of the face biased tilt judgments in a manner consistent with a perceived force emanating from the eyes.

Experiment 2

The online subject pool used in experiment 1 is helpful for large samples and broad demographics but prevents precise control over stimulus presentation. We therefore repeated the experiment in the laboratory on 31 volunteers (18 to 30 y, 24 women). Six were eliminated for poor performance suggesting a misunderstanding of the tilt task. Subjects sat stabilized by a chinrest 54 cm from the monitor and used key presses on a standard keyboard for behavioral responses. Visual stimuli were presented using Matlab (The MathWorks) and the Psychophysics Toolbox (20). Eye position was measured with an infrared eye tracker (SR Research EyeLink 1000 Plus). In the stimulus display (Fig. 1), the head was 15° lateral to the central paper tube.

Our reason for testing the effect of a sighted face and a blindfolded face in experiment 1 was that both faces have the same intrinsic direction pointing at the tube, but one has open eyes and the other covered eyes. However, subjects might spend more time looking at a head with open eyes, the redistribution of the subjects' attention in some manner affecting tilt judgment. To address this possibility, experiment 2 used the same design but replaced the blindfolded head with a head that still had open eyes but was facing away from the tube.

Fig. 2*B* shows the result. The effect was replicated. When the head was looking at the tube, *D* was significantly greater than 0, suggesting that tilt judgments were biased as if a beam from the eyes pushed on the tube ($D = 0.67°$, SE 0.30, df 24, $t = 2.22$, $P = 0.037$). When the head was facing away, *D* was not significantly greater than 0 ($D = -0.26°$, SE 0.24, df 24, $t = -1.08$, $P = 0.290$).

We examined the distribution of eye movements throughout the time window from start to end of each trial, and found no evidence that subjects looked more at the head when it was turned toward the tube than when it was turned away. Subjects tended not to look at the head, presumably because it was task-irrelevant. Moreover, it was positioned far (15°) from the centrally placed tube, the task-relevant item. Subjects looked in the area of the tube (an area 10° wide × 11° high, centered on and encompassing the tube) 99.13% of the time, and in an equal-sized area centered on and encompassing the head 0.57% of the time. The small proportion of time spent looking at the head did not depend significantly on whether the head was facing toward or away from the tube (Table 2).

Experiment 3

We performed another in-laboratory experiment, repeating the paradigm used in experiment 1 in which the head could have eyes open or blindfolded. In experiment 3, subjects were randomly assigned to two groups. Group 1 ($n = 15$, 18 to 31 y, 7 women) was told that when the eyes were open, the head was looking at the tube. Group 2 ($n = 15$, 18 to 27 y, 7 women) was told that when the eyes were open, the head was looking past the tube at the far wall. To ensure that subjects understood which object the head was supposedly looking at, we gave the subjects a related task. In each trial, the tube could be colored either red or blue, and the wall distant from the head was given the opposite color (blue or red). In group 1, subjects were told that Kevin, the person in the image, was interested in the tube's color. At the start of each trial, once the stimulus display appeared, subjects saw the written prompt, "Does Kevin see a red tube?" Subjects answered by typing Y or N. To answer the question correctly, subjects had to note the color of the tube and whether the head had eyes open or blindfolded. After answering this initial question, subjects then saw the prompt, "Now please indicate the critical 'tipping point angle' of the paper tube." In this second

Table 2. Distribution of eye position in experiment 2

Region of eye position	Tube	Head
Head facing tube	99.13 (0.05)	0.57 (0.03)
Head facing away	99.10 (0.06)	0.59 (0.04)
t (df 24)	1.59	−1.28
P	0.125	0.212

Mean percent of looking time among subjects for two display regions, one around the head (an area 10° wide × 11° high, centered on and encompassing the head) and an equal-sized area centered around the tube. Numbers in parentheses are SE. Statistical comparison between "head facing tube" and "head facing away" conditions used repeated-measures, two-tailed *t* tests.

phase of the trial, subjects performed the same tilt judgment as in the previous experiments. In group 2, subjects were told that Kevin was looking past the tube, checking whether the wall to the opposite side was red. At the start of each trial, subjects saw the prompt, "Does Kevin see a red wall?" The task was otherwise the same. Both groups saw the same stimulus displays, with the same head oriented in the same way, and the same colored tube and colored wall; only the instructions differed. All subjects performed the color task at low error rates (mean % accuracy 98.1, SE 0.79).

Fig. 2*C* shows the results for group 1 subjects. Once again, the primary effect was replicated. When the head looked at the tube, *D* was significantly greater than 0, consistent with a beam emanating out of the eyes and pushing on the tube ($D = 0.63°$, SE 0.26, df 14, $t = 2.43$, $P = 0.029$). When the head was blindfolded, *D* was no longer significantly greater than 0 ($D = 0.18°$, SE 0.24, df 14, $t = 0.76$, $P = 0.459$).

Fig. 2*D* shows the result for group 2 subjects. For the first time in these experiments, the effect of the eyes aimed toward the tube disappeared. When subjects thought that Kevin was looking past the tube at the far wall, they no longer responded as if a beam from the eyes pushed on the tube ($D = 0.12°$, SE 0.42, df 14, $t = 0.28$, $P = 0.78$). When the head was blindfolded, again no effect on tilt was obtained ($D = 0.20°$, SE 0.30, df 14, $t = 0.67$, $P = 0.51$).

The color question required participants to attend to the object (the tube or the wall) at which the head was supposedly looking. However, on each trial, subjects finished the color question (taking a mean of 1.9 s) before performing the tilt-estimation phase of the trial (taking a mean of 5.7 s). There was no reason to suppose that during the tilt-estimation phase, fixation would be affected by the earlier question about color. An analysis of eye movement during the tilt-estimation phase confirmed that there was no significant difference in distribution of eye position between conditions (Table 3).

Experiment 4

We collected a final in-laboratory dataset on a new set of participants ($n = 17$, 18 to 22 y, 12 women). The paradigm was the same as in experiment 2 except in the following ways. First, only eyes-open trials were used. Second, participants were told that the tubes were made of concrete and weighed more than 10 lbs. If the angular deviation replicated in the previous three experiments was caused by an implicit perception of a weak force emanating from the eyes, then the deviation should disappear in the case of a heavy object. If, instead, the angular deviation was caused by a low-level visual tilt illusion, it should persist unchanged. The deviation disappeared. *D* was not significantly different from 0 ($D = 0.11°$, SE 0.18, df 16, $t = 0.61$, $P = 0.553$).

Table 3. Distribution of eye position in experiment 3

Region of eye position	Head	Tube	Wall
Head looks at tube	1.04 (0.30)	97.86 (0.73)	0.27 (0.13)
Head looks at wall	1.02 (0.35)	97.51 (0.78)	0.21 (0.14)
t (df 28)	0.05	0.32	0.30
P	0.962	0.749	0.769

Mean percent of looking time among subjects for three display regions, one around the head (an area 10° wide × 11° high, centered on and encompassing the head), one around the tube (an area 10° wide × 11° high, centered on and encompassing the tube), and one around the wall opposite the head (an area 5° wide × 14° high, encompassing the area in front of the wall and the wall itself, located at the edge of the display). Numbers in parentheses are SE. Statistical comparison between "head looks at tube" and "head looks at wall" conditions used two-sample, two-tailed *t* tests. Eye position data were taken from a time window in each trial during which subjects were instructed to perform the tilt-estimation task.

Discussion

People estimated the mechanical forces acting on an object by judging the critical tilt angle that would cause the object to fall. The judgment was influenced by the image of a face to one side, staring at the object. The effect was as if a force-carrying beam came out of the eyes and gently pushed on the object. The influence was not present when the eyes were blindfolded, turned away from the object, or described to participants as gazing past the object at the far wall. It was present when subjects were told the object was light (a paper tube), and not detected when subjects were told the object was heavy (a concrete cylinder). In experiment 1, in a posttest questionnaire, no subjects indicated that they realized the purpose of the experiment or the presence of that influence. About 5% of participants reported an explicit belief in the physically incorrect extramission theory in which vision involves something streaming from the eyes. However, even when those participants were removed from the dataset, the implicit effect of gaze remained. In our interpretation, people construct an implicit model of other people's vision as an active process that emerges from an agent and that can physically affect objects in the world. This fictitious influence of gaze on objects is extremely subtle. If it were not, people would presumably notice the discrepancy between their perceptions and reality. Other explanations of the data, for example involving a low-level visual tilt illusion, might still be possible. We suggest, however, that our interpretation of the implicit perception of eye beams is the simplest way to explain a highly specific pattern of results.

Our finding of an ∼5% incidence of extramission beliefs conflicts with previous work suggesting that more than half of US adults, possibly as high as 60 to 70%, explicitly believe in an extramission account (17–19). We cannot easily explain this difference. It is possible that education about optics has significantly improved since the 1990s. Another possibility is that our sample was skewed, since it included only participants who could sign up for an online service and complete the study on a computer. Although this selection filter probably did play a role, it seems unlikely to explain the entire discrepancy between 5 and 60%. The demographic data show that our sample was not limited to a narrow, elite slice of the population. Note that in Table 1, the proportion of extramission believers was not high at any level of education, for example at 6/92 (6%) for high school graduates, 12/271 (4%) for those with a bachelor's degree, and 2/68 (3%) for those with a master's degree.

We offer a speculative explanation for the discrepancy. Most people know that the Earth orbits the sun, and yet most people recognize that the Earth seems stationary beneath our feet while the sun seems to move across the sky. There is a difference between what people know to be scientifically correct and what they recognize to be perceptually compelling. Depending on how people interpret the question, they might give different answers about extramission. Our questions might have somehow primed people to think more scientifically. We cannot know whether the context and phrasing of the question account for the differing results, but we suggest that a 5% rate of belief among US adults in the folk notion of extramission has more plausibility than the previously suggested 60% rate. Even though most people explicitly reject the extramission theory of vision as a scientific account, in our interpretation, the tilt-estimation data suggest they still construct an implicit model of vision as force-carrying beams that emanate from the eyes.

Humans are especially sensitive to the gaze direction of others (1, 3, 7). Gaze may be one of the most important cues that people use in inferring the mind states of others (2, 6, 8) and in coordinating shared attention (4, 5, 8). A range of evidence shows that the brain has a specialized cortical system for monitoring the gaze of others (21–25). The present results suggest that people do more than merely monitor gaze; they may construct a model of the active visual process occurring inside other people, and the model may contain schematic simplifications to better link the agent to an object on which the agent might potentially act. Eye beams may be a natural part of how we perceive visual agents.

It is not rare for the brain to construct models of the world that are simplified and physically inaccurate. One example is perceptual color as a simplified model of the reflectance spectrum. Before Isaac Newton's discoveries about color in 1671 (26), white light was widely believed to be purified and colored light to be contaminated. Those strongly held but physically incoherent beliefs stemmed from a simplified model constructed in the visual system. That simplified model is still present and still has consequences for our aesthetic and cultural associations with white, even though most people now know intellectually that the underlying construct is physically incorrect.

We speculate that an automatic, implicit model of vision as a beam exiting the eyes might help to explain a wide range of cultural myths and associations. For example, in *Star Wars*, a Jedi master can move an object by staring at it and concentrating the mind. The movie franchise works with audiences because it resonates with natural biases. Superman has beams that can emanate from his eyes and burn holes. We refer to the light of love and the light of recognition in someone's eyes, and we refer to death as the moment when light leaves the eyes. We refer to the feeling of someone else's gaze boring into us. Our culture is suffused with metaphors, stories, and associations about eye beams. The present data suggest that these cultural associations may be more than a simple mistake. Eye beams may remain embedded in the culture, 1,000 y after Ibn al-Haytham established the correct laws of optics (12), because they resonate with a deeper, automatic model constructed by our social machinery. The myth of extramission may tell us something about who we are as social animals.

ACKNOWLEDGMENTS. This work was supported by the Princeton Neuroscience Institute Innovation Fund. A.G. was supported by the Wenner-Gren Foundation, the Swedish Society of Medicine, and The Foundation Blanceflor.

1. Yarbus AL (1967) *Eye Movements and Vision* (Plenum, New York).
2. Baron-Cohen S (1995) *Mindblindness: An Essay on Autism and Theory of Mind* (MIT Press, Cambridge, MA).
3. Kobayashi H, Kohshima S (1997) Unique morphology of the human eye. *Nature* 387:767–768.
4. Friesen CK, Kingstone A (1998) The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychon Bull Rev* 5:490–495.
5. Emery NJ (2000) The eyes have it: The neuroethology, function and evolution of social gaze. *Neurosci Biobehav Rev* 24:581–604.
6. Calder AJ, et al. (2002) Reading the mind from eye gaze. *Neuropsychologia* 40:1129–1138.
7. Symons LA, Lee K, Cedrone CC, Nishimura M (2004) What are you looking at? Acuity for triadic eye gaze. *J Gen Psychol* 131:451–469.
8. Frischen A, Bayliss AP, Tipper SP (2007) Gaze cueing of attention: Visual attention, social cognition, and individual differences. *Psychol Bull* 133:694–724.
9. Graziano MSA, Kastner S (2011) Human consciousness and its relationship to social neuroscience: A novel hypothesis. *Cogn Neurosci* 2:98–113.
10. Kelly YT, Webb TW, Meier JD, Arcaro MJ, Graziano MSA (2014) Attributing awareness to oneself and to others. *Proc Natl Acad Sci USA* 111:5012–5017.
11. Pesquita A, Chapman CS, Enns JT (2016) Humans are sensitive to attention control when predicting others' actions. *Proc Natl Acad Sci USA* 113:8669–8674.
12. Gross CG (1999) The fire that comes from the eye. *Neuroscientist* 5:58–64.
13. Dundes A (1981) *The Evil Eye: A Folklore Casebook* (Garland, New York).
14. Titchener EB (1898) The feeling of being stared at. *Science* 8:895–897.
15. Coover JE (1913) The feeling of being stared at. *Am J Psychol* 24:570–575.
16. Piaget J (1979) *The Child's Conception of the World*, trans Tomlinson J, Tomlinson A (Little, Adams, Totowa, NJ).
17. Cottrell JE, Winer GA (1994) Development in the understanding of perception: The decline of extramission perception beliefs. *Dev Psychol* 30:218–228.
18. Winer GA, Cottrell JE, Karefilaki KD, Gregg VR (1996) Images, words, and questions: Variables that influence beliefs about vision in children and adults. *J Exp Child Psychol* 63:499–525.
19. Winer GA, Cottrell JE, Gregg V, Fournier JS, Bica LA (2002) Fundamentally misunderstanding visual perception. Adults' belief in visual emissions. *Am Psychol* 57:417–424.
20. Brainard DH (1997) The Psychophysics Toolbox. *Spatial Vision* 10:433–436.
21. Perrett DI, et al. (1985) Visual cells in the temporal cortex sensitive to face view and gaze direction. *Proc R Soc Lond B Biol Sci* 223:293–317.
22. Puce A, Allison T, Bentin S, Gore JC, McCarthy G (1998) Temporal cortex activation in humans viewing eye and mouth movements. *J Neurosci* 18:2188–2199.
23. Wicker B, Michel F, Henaff MA, Decety J (1998) Brain regions involved in the perception of gaze: A PET study. *Neuroimage* 8:221–227.
24. Hoffman EA, Haxby JV (2000) Distinct representations of eye gaze and identity in the distributed human neural system for face perception. *Nat Neurosci* 3:80–84.
25. Carlin JD, Calder AJ (2013) The neural basis of eye gaze processing. *Curr Opin Neurobiol* 23:450–455.
26. Newton I (1671) Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; containing his new theory about light and colors: Sent by the author to the publisher from Cambridge, Febr. 6. 1671/72; in order to be communicated to the Royal Society. *Philos Trans R Soc* 6:3075–3087.