Pinocchio's Pupil: Using Eyetracking and Pupil Dilation To Understand Truth-telling and Deception in Sender-Receiver Games

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Abstract

We conduct laboratory experiments on sender-receiver games with an incentive for senders to exaggerate (such as security analysts painting a rosy picture about earnings prospects). Our results show that "overcommunication"—messages are more informative of the true state than they should be, in equilibrium—is consistent with a level-k model. Eyetracking shows that senders look much more on the payoff rows corresponding to the true state, and much less at receiver payoffs than at their own payoffs. Senders' pupils also dilate more when their deception is larger in magnitude. Together, these data are consistent with the hypothesis that figuring out how to deceive another player is cognitively difficult as assumed in the level-k model. A combination of sender messages and lookup patterns predicts the true state about twice as often as predicted by equilibrium. Using these measures would enable receiver subjects to hypothetically earn up to 16-21 percent more than they actually do.

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"Why do almost all people tell the truth in ordinary everyday life? —Certainly not because a god has forbidden them to lie. The reason is, firstly because it is easier; for lying demands invention, dissimulation and a good memory."

– Friedrich Nietzsche, Human, All Too Human, II.54, 1878/1996

I. Introduction

During the tech-stock bubble, Wall Street security analysts were alleged to inflate recommendations about the future earnings prospects of firms, in order to win investment banking relationships with those firms.[1] Specifically, analysts in Merrill Lynch used a five-point rating system (1=Buy to 5=Sell) to predict how the stock would perform. They usually gave two separate 1-5 ratings for short run (0-12 months) and long run (more than 12 months) performance. Henry Blodget, Merrill Lynch's famously optimistic analyst, "did not rate any Internet stock a 4 or 5" during the bubble period (1999 to 2001). In one case, the online direct marketing firm LifeMinders, Inc. (LFMN), Blodget first reported a rating of 2-1 (short run "accumulate"—long run "buy") when Merrill Lynch was pursuing an investment banking relationship with LFMN. Then, the stock price gradually fell from $22.69 to the $3-$5 range. While publicly maintaining his initial 2-1 rating, Blodget privately emailed fellow analysts that "LFMN is at $4. I can't believe what a POS [piece of shit] that thing is." He was later banned from the security industry for life and fined millions of dollars.[2]

[1] For a detailed description of the tech-stock bubble, see Michael J. Brennan (2004). For evidence regarding analyst recommendations affected by conflicts of interest, see Hsiou-wei Lin and Maureen F. McNichols (1998) and Roni Michaely and Kent L. Womack (1999).
[2] See Complaint in Securities and Exchange Commission v. Henry M. Blodget, 03 CV 2947 (WHP) (S.D.N.Y.) (2003), paragraph 11-12 and 70-72, Securities and Exchange Commission Order Against Henry M. Blodget (2003), and United States District Court Final Judgement on Securities and Exchange Commission v. Henry M. Blodget 03 Civ. 2947 (WHP) (S.D.N.Y.) (2003).

This case is an example of a sender-receiver game with divergent preferences (sometimes called a "cheap talk" or strategic information transmission game; see Vincent P. Crawford and Joel Sobel, 1982). Sender-receiver games are simple models of economic situations in which one agent has an incentive to exaggerate the truth to another agent. The central issues in these games are how well uninformed players infer the private information from the actions of players who are better-informed, and what informed players do, anticipating the inference of the uninformed players. Given these behavioral patterns, mechanisms can be designed to encourage telling the truth given likely behavior.

Incentives for strategic information transmission are common. Besides the Blodget case mentioned above, similar dramatic accounting frauds in the last few years, such as Enron, Worldcom, and Tyco, might have been caused by the incentives of managers (and perhaps their accounting firms) to inflate earnings prospects.[3] For instance, Enron executives told shareholders at meetings that earnings prospects were rosy, at the same time as the executives were selling their own shares, leading to indictments and trials in 2006.[4] In universities, grade inflation and well-polished recommendation letters help schools promote their graduates.[5] Other examples of incentives for strategic information transmission include government-expert relationships in policy making, doctor-patient relationships in health care choices, teacher cheating on student tests[6] and the floor-committee relationship in Congress.

[3] See Brennan (2004), pp. 8-9, and Brian J. Hall and Kevin J. Murphy (2003), pp. 60-61.

[4] According to an SEC complaint filed in court, Kenneth Lay, Enron's then chairman and CEO, said "We will hit our numbers" and "My personal belief is that Enron stock is an incredible bargain at current prices" in an employee online forum on September 26, 2001. However, in the prior two months he was actually making net sales of over $20 million in Enron stock (back to Enron). See Second Amended Complaint in Securities and Exchange Commission v. Richard A. Causey, Jeffrey K. Skilling and Kenneth L. Lay, Civil Action No. H-04-0284 (Harmon) (S.D. Tx.) (2004), paragraph 81-82.

[5] See Henry Rosovsky and Matthew Hartley (2002).

[6] For example, Brian A. Jacob and Stven D. Levitt (2003) show how public school teachers cheat on student standardized tests in response to high-power incentive systems based on these test scores.

This paper reports experiments on a sender-receiver game. In the game, a sender learns the true state (a number S) and sends a costless message M to a receiver who then chooses an action A. Payoffs only depend on S and A so the message M is “cheap talk.” The receiver prefers to choose an action that matches the state, but the sender wants the receiver to choose an action closer to S+b, where b is a known bias parameter. The value of b is varied across rounds. When b=0 senders prefer that receivers choose *S*, so they almost always just announce S (i.e., M=S), and receivers believe them and choose A=M. When b>0 senders would prefer to exaggerate and announce M>S if they thought receivers would believe them. Since subjects choose 1-5, the numbers in our game are coincidentally the same as those used by Merrill Lynch. Indeed, when b>0, we find that our subjects hardly ever report the number 1 (in only 8 percent of 208 rounds), much as Blodget never rated a stock 4 or 5 (the equivalent of 1-2 in our game).

Besides measuring choices in these games, our experiment uses “eyetracking” to measure what payoffs or game parameters sender subjects are looking at (see Appendix: Methods). Eyetracking software records where players are looking on a computer screen every 4 milliseconds.[7] These data are a useful supplement to econometric analysis of choices, when decision rules which produce similar choices make distinctive predictions about what information is needed to execute these rules.[8]

[7] Previous studies (see footnote 8) used a “Mouselab” system in which moving a cursor into a box opens the box’s contents. One small handicap of this system is that the experimenter cannot be certain the subject is actually looking at (and processing) the contents of the open box. Our system measures the eye fixation so we can tell if the subject’s eye is wandering, and pupil dilation is measured at the same time (which Mouselab cannot do). Nevertheless, Mouselab systems can be installed cheaply in many computers to measure lookups of many agents at the same time, which could prove useful in running efficient subjects and studying attention simultaneously in complex markets with many agents.

[8] See Camerer et al. (1993); Miguel Costa-Gomes et al. (2001); Eric Johnson et al. (2002); Costa-Gomes and Crawford (2006); Xavier Gabaix et al. (2006); and Crawford (2008).

The eyetracking apparatus also measures how much subjects' pupils "dilate" (expand in width and area). Pupils dilate under stress, cognitive difficulty, arousal and pain.[9] Pupillary responses have also been measured in the lie-detection literature for many years.[10] These studies suggest that pupil dilation might be used to infer deceptive behavior because senders find deception stressful or cognitively difficult.

Lookup patterns and pupil dilation could be useful in the sender-receiver games, because overcommunication of the true state is consistent with two rough accounts: strategizing and guilt, or cognitive difficulty. Senders may feel guilty about deceiving the receivers and potentially costing the receivers money. According to this theory, senders will look at the receiver payoffs (since seeing those payoffs is the basis of guilt) and their pupils will dilate when they misrepresent the state (i.e., choose M different from S) due to emotional arousal from guilt. In this story, the guilt springs from the senders' realization that their actions are costing the receivers money, which depends on seeing the receiver payoffs. For example, Uri Gneezy (2005) and Sjaak Hurkens and Navin Kartik (2006) find that changing the known costs to others from deception lowers deception by subjects. Sánchez-Pagés and Vorsatz (2007) show that overcommunication is caused by the tension between normative social behavior and incentives for lying. Eyetracking helps us explore this insight further using data on whether potential deceivers actually know those costs.

A different story is that senders find it cognitively difficult to figure out how much to misrepresent the state. For example, senders might believe that some other senders always tell the

[9] For pupillary responses to stress, see R. A. Hicks et al. (1967), R. Bull and G. Shead (1979), and Darren C. Aboyoun and James N. Dabbs (1998). For pupillary responses to cognitive difficulty, see Jackson Beatty (1982) and B. C. Goldwater (1972). For pupillary responses to arousal and pain, see C. Richard Chapman et al. (1999) and Shunichi Oka et al. (2000). Min Jeone Kang et al (2007) show that pupils dilate in anticipation of finding out the answers to trivia questions about which they are curious. (Their self-reported curiosity is also shown by fMRI to activate the ventral striatum, a brain region involved in anticipated reward or "prediction error" and learning; and curiosity also enhances later memory for mistaken answers.)

truth, and receivers might therefore believe messages are truthful. Then strategic senders have to think hard about how much to misrepresent the state to take advantage of the receivers' naïveté (as in Crawford, 2003, Kartik, Macro Ottaviani and Francesco Squintani, 2007, Ying Chen, 2007, and Kartik, 2008). In this story, senders do not have to pay much attention to receiver payoffs but their pupils will dilate because of the cognitive difficulty of figuring out precisely how much to exaggerate.

The experimental choices, eyetracking, and pupil dilation measures generate four basic findings:

1. Overcommunication in sender-receiver game is consistent with L0, L1, L2, and equilibrium (Eq) sender behavior produced by a level-k (cognitive hierarchy) model of the sender-receiver game in which L0 sender behavior is anchored at truth-telling.
2. Eyetracking data provide the following justifications for the level-k model of overcommunication:
    a. *Attention to basic structure:* Sender subjects pay attention to important parameters (state and bias) of the sender-receiver game. This indicates subjects are thinking carefully about the basic structure of the game, even if they are not following equilibrium theory.
    b. *Self-centeredness*: Sender subjects look at their own payoffs more than their opponents'. Hence, in addition to concerns regarding others (Gneezy, 2005), self-centeredness also plays an important role in sender-receiver games.

[10] See for example, F. K. Berrien and G. H. Huntington (1942), I. Heilveil (1976), Michel P. Janisse (1973), M. T. Bradley and Janisse (1979, 1981), Janisse and Bradley (1980), R. E. Lubow and Ofer Fein (1996), and Daphne P. Dionisio et al. (2001).

c. *Incorrect beliefs*: Sender subjects focus too much on the true state payoff row. This bias is consistent with a failure to "think in the opponent's shoes" as in Bhatt and Colin F. Camerer (2005).

d. *Strategizing from a truth-telling anchor*: Sender subjects focus on the payoffs corresponding to the action a = s, as well as actions up to a = s+b. These indicate a "truth-bias," which justifies the L0 sender behavior of truth-telling, as well as attempts to strategize from this anchor.

3. Right before and after the message is sent, senders' pupils dilate more when their deception is larger in magnitude. This suggests that subjects feel guilty for deceiving (as in Gneezy, 2005), or that deception is cognitively difficult (as the level-k model assumes).

4. Prediction: Based on the eyetracking results, we can try to predict the true state observed by the sender using lookup data, messages, and pupil dilation. This prediction exercise suggests it could be possible to increase the receiver's payoff (beyond what was earned in the experiments) by 16-21 percent. Finally, this study shows the possible relevance of psychology and neuroscience to economics. Douglas Bernheim (2008) suggests that Neuroeconomics will be successful if it can show how new non-choice data can solve a prediction or normative problem that could not be solved by standard choice data. One such problem is how to extract private information from choices. In the standard model, private information is by definition not directly observable to outsiders (such as receivers in our game) and can only be inferred assuming a particular model of behavior (e.g., inferring private values from auction bids). If eyetracking, pupil dilation, fMRI, or other biological measures enable one to infer more about private information than by using only choices, those "new" data—new to economists, that is—have some added value for something

economists care about. Our data satisfy this criterion because lookups and pupil dilation enhance prediction of the true state beyond the predictions derived simply from observed messages (choice) and equilibrium theory.

This is the first study in experimental economics to use a combination of eyetracking and pupil dilation, and is, of course, exploratory and is therefore hardly conclusive. But the eyetracking and pupil dilation results by themselves suggest that the implicit assumption in theories of "cheap talk" in games with communication— namely, that deception has no cost— is not completely right. The Nietzsche passage quoted above describes the cognitive load of deception. Mark Twain also famously quipped, "If you tell the truth, you don't have to remember anything."[11] The corollary principle is that if subjects want to misrepresent the state to fool receivers, they have to figure out precisely how to do so (and whether receivers will be fooled). This process is not simple and seems to leave a psychological signature in the form of looking patterns and pupil dilation. Future theories could build in an implicit cost to lying (which might also vary across subjects and with experience) and construct richer economic theories about when deception is expected to be widespread or rare.

II. The Sender-Receiver Game

In each round of the experiments, subjects play a game of strategic information transmission, involving cheaptalk (Crawford and Sobel, 1982). One player always acts as the sender, and the other as the receiver. The sender's eye movements and pupil dilation are measured with a head-mounted Eyelink II eyetracker (see Appendix: Methods). At the beginning of the round, the sender is informed about the true state of the world, which is described as a "secret" number S uniformly drawn from the state space $\mathbf{S} = \{1, 2, 3, 4, 5\}$, and is informed about the bias b, which is either 0, 1, or 2 with known probabilities. The receiver knows the bias b, but not the realization of the state S. Both players are informed in instructions about the basic structure of the game.

The sender then sends a message to the receiver, from the set of messages **M** = {1, 2, 3, 4, 5}.[12] After receiving a message from the sender, the receiver chooses an action from the action space **A** = {1, 2, 3, 4, 5}. The true state and the receiver's action determine the two players' payoffs in points according to $u_R = 110 - 20 \cdot |S - A|^{1.4}$, and $u_S = 110 - 20 \cdot |S + b - A|^{1.4}$, where u_R and u_S are the payoffs for the receiver and the sender, respectively. Note that the receiver earns the most money if her action matches the true state (since her payoff falls with the absolute difference between A and S). The sender prefers the receiver to choose an action equal to S+b. This payoff structure is made known to both senders and receivers. Figure S1 shows the screen display for b=1 and S=4.

The most informative equilibrium for b=2 is "babbling", in which the sender sends an uninformative message, while the receiver ignores the message and chooses A=3 based on her prior beliefs. When b=1, the most informative equilibrium requires the senders to send messages {1} when S=1, and send {2,3,4,5} when S is 2-5. When b=1 the receivers should choose action A=1 when seeing M={1}, and A=3 or 4 when seeing M={2,3,4,5}.[13] When b=0, truth-telling by choosing M=S (and receivers choosing A=M) is the most informative equilibrium.

On the other hand, following Hongbin Cai and Joseph T. Wang (2006), the level-k model for the sender-receiver game starts with L0 senders (who has the lowest level of sophistication)

[11] Quotation taken from Mark Twain's Notebook, 1894.

[12] Following Cai and Wang (2006), we use the specific message, "The number I received is X" to eliminate possible misinterpretation of the message (which contributes to the multiple equilibria problem typical in these types of games resulting form the need to assign meaning to messages).

[13] Thanks to David Eil for clarifying the equilibrium analysis. Due to discreteness, there is another knife-edge equilibrium with b=1 that produces higher information transmission: Senders send messages M={1,2} and {3,4,5}, while receivers choose A=2 and 4. However, this equilibrium is not robust since senders who see S=2 is exactly indifferent between sending M={1,2} and M={3,4,5}. Moreover, the main results of the paper do not change even if we consider this equilibrium (then Corr(S,A) = 0.791, and u_R= 94.56).

would simply tell the truth, and L0 receivers best responding to L0 senders by following the message. Moving up the hierarchy, L1 senders best respond to the L0 receivers by inflating the message (stating their preferred states), and L1 receivers best respond to L1 receivers by discounting the message. Such procedure is continued until we reach the most informative equilibrium prediction. In addition, we include a sophisticated type (SOPH) which best responds to the empirical distribution of opponent's behavior. Table 1 provides the list of different level-k types for b=0, 1, and 2.[14]

Under both equilibrium and level-k models, the comparative statics are similar: Information transmission decreases as the bias increases, though the level-k model still allows transmission even when the bias is so big that the equilibrium model predicts babbling (zero transmission). Informativeness is measured by the correlation between actions and the true states, and by receiver payoffs (more informative equilibria have higher expected payoffs). In addition, we assume a literal interpretation of messages, and measure the "informativeness" of senders' messages by the correlation between the true states and the messages M. How "trusting" the receivers are can be measured by the correlation between the messages M they receive and the actions A they take.[15] These comparative statics predictions were tested by John Dickhaut et al. (1995), Andreas Blume et al. (1998, 2001), and Cai and Wang (2006). Overcommunication—messages are more informative of the true state than they should be, in equilibrium—are typically found in these studies, and Cai and Wang (2006) suggest two bounded rationality explanations: the level-k model and quantal response equilibrium.

[14] Cai and Wang (2006) only constructed a level-k model for the case where the most informative equilibrium is the babbling. Here we extend it to other biases. Also, we use the econometric methods developed by Costa-Gomes and Crawford (2006) to estimate individual types.

[15] Such a natural language interpretation is justified by Blume et al. (2001) findings that equilibrium messages tend to be consistent with their natural language meanings, and is used in Cai and Wang (2006). Moreover, many behavioral theories of lying, such as Crawford (2003) and Kartik, Ottaviani and Squintani (2007), also lead to this sort of natural language interpretation since naïve receivers would take the message at face value.

To be sure that subjects learn, and to collect a lot of trials to pool across, the same game is played 45 times among the two players with random choices of bias b (and random states) in each round. Because we could only eyetrack one or two subjects at a time, we ran two sets of similar experiments. Only the senders were hooked up to the mobile Eyelink eyetracker (although studying receivers' eye fixations would be useful in future work). In the first set, we used a partner protocol in which a pair of subjects played repeatedly in a fixed-role protocol where b=0, 1, 2 with known equal probability.

In the second set of experiments, we randomly matched six subjects into pairs using stranger-matching protocol, with different receivers in each round (with no immediate rematching with the same receiver), and eyetracked two of the senders in each group. Values of b=0, 1, 2 were used with known probabilities (0.2, 0.4, 0.4) since we are less interested in the no-bias (b=0) case than in the bias (b>0) cases. We also added some noise (integers -4 to +4 with equal probability, i.i.d. across payoff cells) to each payoff to minimize memory effects. Since the noise is small, the equilibrium remains the same. To further eliminate any memory effect, the bias parameter was not shown to the eyetracked senders on the screen. Instead, they were forced to look at the payoff table to infer it. Thus, the second set of experiments is called the "hidden bias" treatment, while the first set is called the "displayed bias" treatment. The results reported below focus entirely on the eye fixations and pupil dilation of the eyetracked senders, and the message choices of all senders and action choices of receivers.[16]

Subjects' choices are compared to the most informative equilibrium in the one-shot game.[17] Moreover, using predictions from a level-k model (Table 1), we estimate individual sender types

[16] However, in the second set of experiments, two of the twelve eyetracked subjects experienced technical difficulty during the experiment. Hence, we dropped their data (as well as the corresponding receiver subjects' choices).

[17] We do not consider possible dynamic equilibrium that might sustain higher information transmission level. This is not a problem for b = 0 or 2. When b = 2, babbling is the only equilibrium in the one shot game and backward induction

with a quantal response like "spike-logit" error structure, using the econometric analysis developed by Miguel Costa-Gomes and Crawford (2006).

Subjects were 60 Caltech undergraduates recruited from the Social Science Experimental Laboratory subject pool. Twelve pairs were run in the first set and six sessions of six subjects were randomly matched in the second set. They earned between $12 and $27 in addition to a $5-15 show-up fee. To compare across pairs, in the display bias treatment we use the same set of randomly drawn biases and states for 9 of the 12 pairs, and use two other sets of parameters for the remaining 3 pairs to see if there were any effects for using the same parameters. In the hidden bias treatment, we used different randomly pre-drawn parameters for each of the six sessions.

While 60 subjects might appear to be a small sample size,[18] most experimental studies with larger samples have many fewer choices per subject. The eyetracked subjects play 45 games, and make a very large number of eye fixations; so we have a lot of data for each subject and can often draw confident statistical conclusions from these sample sizes.[19]

III. Results

III.A Comparative Statics and Behavior

<u>What do players choose?</u> Figures 1-3 display the three dimensions of the raw choice data—states, messages and actions—for the three bias levels b = 0, 1 and 2. To save space, data are

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yields the babbling equilibrium for all finitely repeated games; when b = 0, the one shot game equilibrium already has full information transmission and there is no room for improvement. Also note that overcommunication is the most striking when b = 2. Random rematching in the hidden bias experiments also make it difficult for repeated-game effects to everyone.

[18] We successfully eyetracked 22 of the 60 subjects, which is considered a *large* sample size for psychophysical studies involving eyetracking.

[19] As we note below, for a primary analysis predicting pupil dilation from observables, a split-sample test comparing two groups of five subjects yields comparable results in the two sub-samples.

shown for the hidden bias condition only; the behavior is similar for the displayed bias condition and analogous Figures are in a supplemental Appendix (Figure S2-S4). [Note to referees: supplemental intended for online access only.]

Each Figure is a 5-by-5 display. The true states 1-5 correspond to the five rows and the sender messages 1-5 correspond to the five columns. Within each stage-message cell, there is a pie chart. The area of the pie-chart in each cell is scaled by the number of occurrences for the corresponding state and message sent by senders; the most common state-message pairs have the largest pies. Hence, the rows indicate senders' behavior with respect to different states and the columns represents the "informativeness" of each message, determined by the distribution of states conditional on each particular message. Several diagonal lines connect predicted messages for various level-k types. Each pie chart shows the distribution of actions chosen by the receiver for that state and message, using a gray-scale ranging from white (action 1) to black (action 5). The average receiver action is the number inside the pie.

For example, when b=0, and there is no conflict of interest, large pie-charts are concentrated on the diagonal (L0/Eq sender behavior), which is a visual way of showing that the senders almost always send a message corresponding to the true state. Moreover, these pie-charts mostly contain the same color ranging from light (lower actions) to dark (higher actions) as the message number increases across columns, showing that the receivers follow senders' recommendation when choosing their actions. The distribution of state frequencies conditional on each message (i.e., down each column) almost degenerates into mass points of the true states, indicating nearly full information transmission. This corresponds to the (most informative) truth-telling equilibrium predicted by equilibrium theory, as well as the L0/Eq type in the level-k model.

When b=1, and there is an incentive to bias the message upward, the results are different. There is a large tendency for deception, which is evident from having some large pie charts off the diagonal. This departure is lopsided—only the upper diagonal of Figure 2 is populated with large pie charts.[20] That is, for a given state, the most common messages are the state itself or higher messages. Furthermore, the largest pie charts of each row are mainly on the line one column or two columns to the right of the diagonal (i.e., states S+1 and S+2), consistent with L1 and L2 sender behavior. Within the upper diagonal, the pie-chart gets darker and darker going down and right, showing how the receivers correctly increase their actions as the state and message increase. Since the conditional distribution of states (columns in Figure 2) shift from a mass point on the true state (as in Figure 1) to a distribution skewed toward state 3 to 5, some information is transmitted. However, this distribution is not consistent with the {1}-{2, 3, 4, 5} partition equilibrium predicted by equilibrium theory, which requires that distributions of messages and actions for the bottom four rows (states 2-5) should all look the same.[21]

Finally, when b=2, equilibrium theory predicts a babbling equilibrium. If they were playing this equilibrium, the pie-charts in each cell would be roughly the same size (up to random sampling error of state frequencies) and the shading distributions on each pie-chart would be the same. In fact, there is still a substantial amount of information transmitted, since the columns in Figure 3 do not all show the same uniform distribution of state frequencies.[22] However, many senders still sent message 5, especially for states 2 to 5. And a substantial amount of receivers did chose action 3, as

[20] Note that this one-sided deception can potentially backfire since if seeing a message 1 indicates the true state is 1, the state is less likely to be 1 when other messages were sent.

[21] If subjects were playing according to the partition equilibrium, column 1 should have probability 1 on state 1, and zero probability elsewhere, indicating the state being in partition {1}, while column 2 to 5 should all have equal probability distributions (say, a mass point at 5 or 1/4 each) on states 2 through 5, and zero elsewhere (indicating the state being in partition {2,3,4,5}).

[22] For instance, in Figure 3, if the message is 1, the true state will never be more than three.

predicted in the babbling equilibrium. This is consistent with the level-k model, since L1, L2, and Eq senders all send message 5 for states 3 to 5.

<u>What are the comparative static results?</u> Looking at subjects' choices (M and A), we find that the key comparative static prediction of Crawford and Sobel (1982) holds in the data. As the bias b increases, the information transmitted decreases, measured either by the correlation between state S and action A, or by receiver payoffs.

Table 2 shows that the actual information transmitted, measured by the correlation between states S, actions A, and messages M. Correlations decrease as b increases, for both the displayed bias and hidden bias treatments. In the hidden-bias treatment, there are data from both senders who are eyetracked and senders with "open boxes" (no eyetracking). They are reported separately as a check on whether eyetracking, per se, changes behavior. Note that even when the bias is so large (b=2) that theory predicts babbling (i.e., no correlation between S, A and M), the correlations are still around 0.5 in the displayed bias treatment and 0.3 in the hidden bias treatment. The difference between the two treatments could be attributed either to noise introduced by the matching procedure, or the reduction of repeated game effects under random matching. There are also very small learning effects: correlations and payoffs rise across trials for b=0 and fall for b>0 (weak convergence toward equilibrium; see supplementary Appendix, Table S2). Payoffs also decline with bias, as predicted by theory. However, the receiver payoffs are close to those predicted by theory. There is also no discernible effect of being eyetracked versus seeing all payoffs ("open boxes") in the hidden bias sessions.

When the bias b is large, information transmission is higher (measured by correlations among S, M and A) and payoffs are higher than predicted by equilibrium theory. These data demonstrate the "overcommunication" (too much truth-telling) reported in Cai and Wang (2006).

Note that the correlations in the display bias treatment are higher than those in Cai and Wang (2006), which is what one would expect given the partner protocol in this treatment (subjects were paired with the same person throughout the experiment). In Cai and Wang (2006), they allow subjects to match with the same person only *once* during the entire experiment.

Can individual players be classified as level-k types? We classify the sender subjects into various types according to Table 1, assuming subjects remain the same type across different biases using the "spike-logit" estimation as in Costa-Gomes and Crawford (2006). The results are shown in Table 4. Together, subjects are classified as types L0-L2 (18%, 25%, 25%), SOPH (14%) and Eq (18%), with good compliance (above 60% except for one who could not be classified). There is more high-type classification in the hidden bias sessions. Individual level classifications do confirm that subjects are choosing according to level-k types, as hinted in the aggregate choice data.[23]

III.B Lookup Patterns

Since the level-k model predictions explain individual behavior, it is natural to ask whether additional lookup data can provide justification for its assumptions. Hence, we organize the lookup results according to the following level-k assumptions:

1. *Attention to structure:* Instead of perceiving any deviation from perfect rationality as impossible to model, the level-k model assumes subjects still think hard when playing the game. Hence, significant attention should be paid to important parameters of the sender-receiver game, such as state and bias.

2. *Self-centeredness:* The level-k model assumes subjects care mainly about their own payoffs and best respond to what they perceive others would do, instead of the consequences to

[23] Comparing the classification results with that of Cai and Wang (2006), we see a similar pattern in the hidden bias (having few L0, mostly L1 beyond) than the display bias treatment (having one third L0). This reflects the effect of the paired design in the display bias treatment.

others, as in Gneezy (2005). This should induce senders to pay more attention to their own payoffs than others.

3. *Incorrect beliefs:* The level-k model assumes subjects best respond to perceived beliefs about their opponents' behavior, which are inconsistent with what opponent's actually do.[24] If senders cannot think like receivers (who does not know the true state), he would put too much attention on the payoff row corresponding to the true state, instead of treating all states equally.

4. *Strategizing from a truth-telling anchor:* The level-k model assumes an anchoring L0 behavior of truth-telling. If truth-telling is what subjects actually perceive as the starting point to strategize, we should see attention put at payoffs corresponding to the action a=s (L0), a=s+b (L1), and so on.

Are senders paying attention at all? Table 5 shows the average lookup time (excluding fixations shorter than 50msec) for various numbers on the screen which are parameters of the game.[25] Senders clearly are thinking carefully about the game because they look up the state and the bias parameter (if available) for about 1 second total (which is 2-6 fixations, about 275msec per fixation). The low time per lookup is a reminder that the eye glances around very rapidly, making frequent quick fixations, as is typical of other tasks including reading. This result supports the level-k model assumption that non-equilibrium behavior *can* be modeled as thoughtful use of payoff information.

Are senders "self-centered"? Senders look at their own payoffs longer. In the display bias treatment, they look at their own payoffs about twice as long as they look at receiver payoffs. The ratio of lookup time for sender and receiver payoffs is the same for a small bias (b=1) and large bias

[24] If all subjects are SOPH who correctly best respond to others, SOPH behavior should coincide with equilibrium (Eq) behavior.

(b=2). Moreover, for b=2, which creates the most scope for guilt to constrain deception, we divide senders into those who looked more often at receiver payoffs, and those who looked less often (relative to the median sender-receiver looking ratio). Importantly, the high receiver-lookup group is actually more deceptive than the low group, which is also inconsistent with the guilt hypothesis that the more one cares about other's payoffs and looks at them, the less one should deceive.[26]

In the hidden bias treatment, subjects look at the state variable less often, compared to the displayed-bias case, but look at payoff numbers about twice as often. There is still a strong bias toward looking at own (sender) payoffs, but the ratio of sender-to-receiver payoff looking time in the b>0 cases is around 1.5, rather than 2. Senders are apparently looking more carefully at receiver payoffs because they must do so to determine the bias. These results support the level-k model assumption that subjects are self-centered so that they mainly care about their own payoffs and best respond to what they perceive others might do.

Note that there *is* a reduction in looking times across trials, which can be seen by comparing total response times in Table 5 from earlier periods (1-15) to those totals in later periods (31-45). Subjects spend about 40 percent less response time in the later trials compared to the earlier one. There are no striking differences in the speedup in looking across bias levels or treatments, however.

Do senders have a "curse of knowledge"? Table 6 shows that subjects look about five times longer at payoffs in the rows corresponding to the true state than they look at payoffs in rows corresponding to each of the four other states. When the bias is 0 this fixation on the actual state is understandable (and subjects typically choose message M=S), but the disproportionate attention to

[25] The number of separate fixations is very highly correlated with the lookup time—in no cell is the average time per fixation less than 250msec or greater than 300msec—so the number of fixations can be approximated well by dividing the Table 5 figures by 275 msec. Both fixations and lookup time are reported in the supplemental Appendix (Table S3).
[26] For the high group, the correlation between states and messages is 0.55, and the average LIE_SIZE is 0.88; for the low group, the correlation is 0.69, and the average LIE_SIZE is 0.71.

actual state payoffs is comparable when there is a bias of 1 or 2.[27] This result indicates that subjects do not "think in others' shoes", and cannot think like a receiver (who does not know the true state). Thus, it supports the level-k model assumption that subjects have incorrect beliefs regarding others.

Do senders strategize starting from "truth-telling"? Tables 5-6 show there is a strong bias for senders to look more at their own payoffs, and to look at payoffs from the state they know to be the true one. More detailed information about looking patterns across state-action pairs is conveyed by the icon graph in Figures 4-5 (developed by Johnson et al., 2002). For brevity we show only data from the hidden bias treatments with positive biases (displayed bias data are in the supplemental appendix, Figures S6-S7).

Each box in Figures 4-5 represents the attention paid to the payoff corresponding to a different state-action combination. Parts (a) and (b) represent attention to the sender payoff boxes and the receiver payoff boxes, respectively. The width of the box is a linear function of the average number of fixations on that box. The height of the box is a linear function of the average total looking time in that box. Boxes which are wide and tall were looked at repeatedly (wide) and for a longer time (tall). The vertical bars in the first columns represent the sum of looking time across each row. Longer bars represent longer time for all state-action boxes in that state. The "ruler" in the upper right shows the scale of looking time and number of fixations that can be used to "measure" each box.

Figure 4 shows the icon graph for bias b=1.[28] The first thing to notice is that subjects spend much more time looking at their own payoffs (Figure 4a) than the payoffs of receivers (Figure 4b),

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[27] Note that Table 6 indicates significant statistical power to detect the actual state (i.e., to detect lies in which the message M deviates from the true state S). That is, a receiver who had online sender looking statistics could predict what the actual state was rather reliably. Of course, it is not clear how the senders would behave had they known that their lookup patterns were monitored by the receivers.

[28] When the bias b=0 the looking data are very clear: Subjects look almost exclusively at their own payoffs corresponding to the actual state S and corresponding receiver action A, and they look at the receiver payoffs from the

as the Table 5 statistics show. Subjects' lookups are also more frequent and longer for actions that are equal to the actual state S or S+1.

Figure 5 shows the lookup icon graphs for bias b=2. Senders again look at their own payoffs more often than their opponents' payoffs. When the state S is 1-3 they tend to look at their payoffs from actions corresponding to S, S+1 and S+2. This is consistent with search behavior required to infer the hidden bias. However, though subjects could have looked at any action A, A+1, A+2, they chose the action corresponding to S, anchoring at truth-telling. However, when the state is 4 or 5 this pattern crumbles as states S+2 and S+1 do not exist and subjects spread attention across more actions. When S = 5 and nothing is better than telling the truth, there is generally less lookup activity.

Comparing the state-*message* choice frequencies illustrated with pie-charts in Figures 2-3 (for b=1 and b=2) with the corresponding attention icon graphs for state-*action* payoffs in Figures 4-5 shows a strong overlap: Senders tend to choose state-message pairs which overlap with the state-action payoffs they look at most. This overlap implies that the messages senders *choose* are most informed by the payoffs from *actions* which correspond to those messages—that is, senders are acting as if they expect receivers to choose actions corresponding to their own (sender) messages. This overlap shows a kind of strategic naïveté in which senders expect receivers to act as if their messages reveal the true state. This overlap sets the stage for a prediction analysis in which the true states might be predicted from the messages senders choose and from the payoffs they look at most often. Before proceeding to those predictive analyses, we introduce pupil dilation responses and see how those correlate with behavior.

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same S-A pair less often than they look at their own payoffs (1/2 in the display bias treatment and 2/3 in the hidden bias treatment). See Appendix Figure S5.

III.C Pupil Dilation

As noted in the introduction, pupils dilate when people are aroused or make cognitively difficult decisions. Our first exploratory step is to treat pupil dilation as a dependent variable and see whether the degree of behavioral deception by the sender is correlated with pupil dilation. It may be that pupil dilation is so poorly measured, or so weakly linked to deception, that there is no reliable correlation. However, we see that deception *is* reliably correlated with pupil dilation.

To correlate pupil dilation with senders' messages, we calculate average pupil sizes for various time periods before and after the sender's message decision, and see if we can predict pupil dilation using the bias b and the amount of deception (measured by the absolute distance between states and messages, |M-S|).

To record their message M, senders are instructed to look at a series of decision boxes on the right side of the screen, which contain the numbers 1 to 5 (corresponding to the possible numerical messages). The software is calibrated to record a decision after the subject has fixated on a single decision box for 0.8 seconds—that is, the subjects choose by using their eyes, not their hands.[29]

Since there is a time lag of at least 0.8 second between the instant subjects "made up their minds" and the recording of this decision,[30] we define the *decision time* as the first time subjects view any of the boxes in the decision boxes area, provided they continue to look at the decision box area for more than 98 percent of the time until the software records a decision.[31]

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[29] Allowing eye fixations to determine actual choices is widely used in research with monkeys. For humans, making choice hands-free is an advantage if psychophysiological measurements are being recorded simultaneously (e.g., galvanic skin conductance on the palms, heart rate) since even small hand movements add noise to those measurements.

[30] This time lag can be longer if the subject is not perfectly calibrated, and hence, needs extra time to perform the required fixation. Another possible situation is when the subject "changed her mind" and looked at different decision boxes.

[31] Running similar regressions show that using a criterion of 99 percent or 95 percent would yield similar results, though slightly weaker in the hidden bias treatment. Moreover, even a noisy 90 percent would still produce the same qualitative results, though some results are less significant.

Average pupil sizes are regressed on the amount of deception for different biases, and the absolute size of the deception (LIE_SIZE = |M-S|), as well as bias and state dummies, controlling for subject random effects and individual learning trends (picked up by round number and squared round number variables interacted with individual dummies). All standard errors we report are robust standard errors. The specification is:

$$\text{(1)} \qquad \text{PUPIL}_{\text{i}} = \alpha + \sum_{b=0}^{2} \beta_{1b} \cdot LIE\_SIZE \cdot BIAS_b + \sum_{b \neq 2} \beta_{2b} \cdot BIAS_b + \sum_{s \neq 3} \beta_{3s} \cdot STATE_s$$

$$+ \sum_{k \neq \kappa} \alpha_k \cdot SUBJ_k + \sum_{k=1}^{K} \left(\gamma_{k,1} ROUND \cdot SUBJ_k + \gamma_{k,2} ROUND^2 \cdot SUBJ_k \right) + \varepsilon$$

where κ is the baseline, and

PUPIL_i = Average pupil (area) size[32] at time frame *i*: 1.2 to 0.8 seconds, 0.8 to 0.4 seconds, 0.4 to 0 seconds before, and 0 to 0.4 seconds, 0.4 to 0.8 seconds after the decision time.[33] Here, we normalize each individual's average pupil size to 100.[34]

LIE_SIZE = The "size" of the lie or the amount of deception, measured by the absolute distance between states and messages, (|M-S|).

BIAS_b, STATE_s, SUBJ_k = Dummy variables for the bias b, true state s, and subject k

ROUND = Round number

The parameter α is the average pupil size, the β_1 coefficients give us the effect of deviating from reporting the true state (deceiving more) under different bias levels, the coefficients β_{2b} and β_{3s} give us the pure effects of different biases b (relative to b=2) and states (relative to S=3) which

[32] Note that we are aggregating 100 observations into 1 data point when averaging for each 400 milliseconds interval.
[33] Rounds with very short response time are discarded if the corresponding PUPIL_i cannot be calculated.
[34] Pupil sizes are measured by area, in relative terms. Absolute pixel counts have little meaning since it varies by camera positions, contrast cutoffs, etc., which depend on individual calibrations. Hence, the eyetracker scales it to a pupil size measurement between 800-2000. Here, we normalize all observations by the average pupil size of each subject throughout the entire experiment, and present all results in percentage terms. (To avoid potential bias created by eyetracker adjustments, all between-round adjustment stages were excluded when performing this normalization.) Therefore, 100 means 100 percent of an individual subject's typical pupil size.

might influence dilation, coefficients α_k capture individual differences, and $\gamma_{k,1}$,$\gamma_{k,2}$ capture (individual) linear and quadratic learning effects.

Look first at the coefficients on the amount of deception in Table 7, interacted with bias (denoted β_{1b} where b is the bias parameter). In the display bias treatment, right before the decision is made (-0.4 seconds to 0 seconds, where 0 seconds is the decision time), the coefficient on the amount of deception is 3.28 percent higher when b=1 and 3.04 percent when b=2. These effects are significant in all 400 millisecond intervals from 1200 milliseconds before the decision, to 800 milliseconds after the decision. Sending more deceptive messages is therefore correlated with pupil dilation when b=1 or b=2. In the hidden bias treatment, the pupil dilation difference is smaller and less significant, and mostly only occurs just after the decision time (0.0-.8 sec). Nevertheless, the coefficients on the amount of deception is still significantly at 1.83-2.64 percent immediately after the decision is made (for b=1 and b=2), and marginally significant at 1.47-2.06 percent just before the decision for b=2.[35] It is likely that the cognitive demands of the hidden bias treatment might raise the baseline pupil dilation even for truth-telling, making additional dilation hard to detect.

Note that the bias condition by itself does not generate pupil dilation (nearly all the coefficients β_{2s} are insignificant and are omitted from Table 7). That is, it is not bias, per se, which creates arousal or cognitive difficulty; it is sending more deceptive messages in the bias conditions. Furthermore, these basic patterns are reproduced when we divided the display bias treatment samples into two halves and compare them, which provide some assurance of statistical reliability even though the sample size is modest.[36]

[35] The reduced predictive power in the hidden-bias treatment could be construed as consistent with the cognitive difficulty story because hiding the bias parameter and adding noise to the payoffs make the hidden bias treatment more difficult in general than the displayed bias treatment. This enhanced difficulty could increase the baseline pupil dilation of truth-telling in all conditions, which makes any additional dilation from deception harder to detect.

[36] Because we measured eyetracking and pupil dilation from ten senders in the hidden bias treatment, it is useful to check how reliable these results are in two subsamples of five subjects each. The 400-msec intervals from +0.4 to +0.8 secs after decision time gives the highest R^2's so we compare those. The β_{1b} coefficients across bias levels (b=0, 1, 2)

IV. Lie-detection and Prediction

As noted, one goal of measuring eyetracking is to see whether these behavioral measures enable us to improve upon predictions of theory. This section reports whether using eyetracking data helps predict deception and uncover the underlying true states. From a practical point of view, it is useful to whether we can detect deception up to the point that we may uncover the underlying truth states. Here, we ask how well receivers could predict the true state using *only* messages and lookup patterns (and how much they could earn using those predictions). That is, we pretend we don't know the true state for predictive purposes, forecast it from observables, then use knowledge of the true state to evaluate predictive accuracy. We focus on b=1 and b=2 since truth-telling is so prominent when b=0 (that lie-detection is not necessary).

In particular, for the dependent variable STATE *j*, ranging from 1 to *5*, we consider an ordered logit regression

$$\log\left[\Pr(STATE \geq j)\right] = \theta_j + \sum_{b=1,2}(\beta_{1b} \cdot MESSAGE + \beta_{2b} \cdot ROW_{self} + \beta_{3b} \cdot ROW_{other}) \cdot BIAS_b + \varepsilon$$

where lookups are consolidated into two integer variables:

$ROW_{self/other}$ = The corresponding state of the own/opponent-payoff row which has the longest total lookup time of all own/opponent-payoff rows

The coefficients β_{1b} represents the information about the state contained in the message, β_{2b} represents the effects of the "most viewed row" of one's own payoffs (i.e., the state number

are the most important. They are 6.35*, 2.40, 2.11 for the first five subjects and 6.11**, 4.14**, and 3.00*** for the second five subjects. For other intervals, as predictive power (R^2) falls the reliability across the two subsamples falls but the coefficient signs are almost always the same in the two subsamples and magnitudes are typically reasonably close.

corresponding to the row that is viewed for the longest time), and β_{3b} represents the effects of the "most viewed row" of the opponent's payoffs. The θ_j are state-specific constants.

In order to evaluate how well these specifications could predict new data, out-of-sample estimation is used. Each observation is used with probability 2/3 to estimate the model, then the model forecast on the remaining 1/3 of the data. For each holdout observation, the estimated logit probabilities are used to calculate the expected state, which is rounded to the nearest integer to make a precise single-state prediction. This partial estimation-prediction procedure is performed 100 times. Average βs and (bootstrap) standard errors across the 100 resamplings are reported in Table 8.

The significance of β_{1b} in Table 8 indicates that the messages are informative about the states (as analyses reported above established). The smaller the message, the smaller is the true state, even though standard game theory predicts that little information should be transmitted in the message (β_{1b} should be zero when b=2).

The lookup data are significantly correlated with states as well. The coefficients β_{2b}, on the most-viewed *own* row variables, are positive and significant for both the display bias and hidden bias treatments. The coefficients β_{3b}, on the most-viewed *other* row variables, are positive and significant in the hidden bias treatment. In the display bias treatment, they are smaller and only significant when b=2 (β_{32}).

The key point is that lookup data improve predictability *even when controlling for the message.* For example, if the message is 4, but the lookup data indicate the subject was looking most often at the payoffs in row corresponding to state 2, then the model could predict that the true state is 2, not 4. Note that this sort of prediction can only come from a setting in which attention is measured.

The error rates in predicting states in the holdout sample are only substantial (greater than 40 percent) in the display bias treatment when bias was b=2 (59.7 percent). (Keep in mind that the error rates in equilibrium would be 60 percent and 80 percent.) Most of the wrong predictions from the logit model (70 percent) only miss the state by one. The model accuracy also is substantially better than the actual performance of the receiver subjects in our experiments: Subjects "missed" ($A \neq S$) 56.2 and 58.5 percent of the time for the displayed bias and hidden bias treatments, when b=1, and missed 70.9 and 77.9 percent for b=2.

An interesting calculation is how much these predictions might add to the receiver payoffs (cf. "economic value" in Camerer et al., 2004). For biases b=1 and b=2, the average actual payoffs earned by receivers who faced eyetracked senders were 93.4 and 86.2 for the displayed bias treatment and 87.5 and 80.9 for the hidden bias one. In the displayed bias treatment, if receivers had based their predictions on the models estimated in Table 8, and chose the same action as the predicted state (for the holdout sample), their expected payoffs would be 100.7 for b=1 and 91.8 for b=2, which is a modest economic value of 6-8 percent.[37] In the hidden bias treatment, the expected payoffs (based on estimates in Table 8) would be 101.7 for b=1 and 98.0 for b=2, which is a large economic value of 15-21 percent. In fact, these payoffs are already close to what subjects actually earn when there is no bias (101.27).[38] In a sense, these economic value statistics suggest that it could be possible to almost erase the cost to receivers of not knowing the true state but looking at attention along with messages.

An important caveat to these analyses is that we do not know what would happen if the senders knew that their pupil dilation and lookups were being used to predict the true state

[37] Of course, this calculation assumes the receivers could measures lookups and pupil dilation without senders altering their lookup patterns because they knew they were being watched and studied. Whether such techniques actually add value is beyond the scope of this paper.

(overriding, perhaps, their messages). Our intuition is that senders would try to signal-jam by looking at the payoffs corresponding to their message more often (a kind of faked sincerity), but it is possible that excessive pupil dilation or more detailed lookup patterns would reveal that they are doing so. Putting senders under time pressure might also make it difficult for them use such a deliberately misleading strategy. In any case, such experiments could be easily done.

V. Conclusion

This paper reports experiments on sender-receiver games with an incentive gap between senders and receivers (such as managers or security analysts painting a rosy picture about a corporation's earnings prospects). Senders observe a state S, an integer 1-5, and choose a message M. Receivers observe M (but not S) and choose an action A. The sender prefers that the receiver choose an action A=S+b, which is b units higher than the true state, where b=0 (truth-telling is optimal), or b=1 or b=2. But receivers know the payoff structure, so they should be suspicious of inflated messages M.

Our experimental results show "overcommunication"—messages are more informative of the state than they should be, in equilibrium this result is consistent with a level-k model of communication anchored at truth-telling. To explore the cognitive foundations of overcommunication, we used eyetracking to record what payoffs the sender subjects are looking at, and how widely their pupils dilate (expand) when they send messages. The sender-receiver paradigm also expands the quality of research on lie-detection in general: Deception in these games is spontaneous and voluntary (most studies use instructed lying); and both players have a clear and

[38] Such gains in the hidden bias treatment are not surprising since subjects are forced to look at the payoff table to discover the bias parameter, and they focus disproportionally on the "true state" row along the way.

measurable financial incentive to deceive, and to detect deception (most studies lack one or both types of incentives).

The lookup data show that senders look disproportionally at the payoffs corresponding to the true state, so they do not appear to be thinking strategically enough to be “in other’s shoes.” Senders’ pupils also dilate when they send deceptive messages ($M \neq S$), and dilate more when the deception $|M-S|$ is larger in magnitude. Together, these data are consistent with the underlying assumptions of the level-k model, and that figuring out how much to deceive another player is cognitively difficult. Guilt does not appear to be the sole driver of overcommunication, because senders who look at receiver payoffs more often are also more deceptive.

When modifying the design to counter memory and repeated game effects (the hidden bias condition), the behavioral results are robust. Furthermore, combining sender messages and lookup patterns, one can predict the true state about twice as often as predicted by equilibrium, and increase receiver payoffs up to 16-21 percent compared to what subjects actually earn in the experiment.

There are many directions for future research. Within this paradigm, eyetracking receivers would be useful for establishing their degree of strategic sophistication in making inferences from messages.

More generally, economic theories often talk vaguely about the costs of decision making or difficulty of tradeoffs. Pupil dilation gives us one way to start measuring these costs. Many economic models also specify a cognitive algorithm that maps acquired information into choices (e.g, dynamic programming applications which require looking ahead). The idea of allocating attention has itself gotten attention in economics (Della Vigna, 2007) and in macroeconomic studies of “rational inattention” (e.g., Christopher Sims, 2006). In both cases, measuring attention directly through eyetracking could improve tests of theories which make predictions about both attention and choice, and how they interact. Given the novelty of using these two methods in studying games, the results should be considered exploratory and simply show that such studies can be done and can yield surprises (e.g., the predictive power of lookups and pupil dilation).

In the realm of deception, two obvious questions for future research are: Why are there substantial individual differences in the capacity or willingness to deceive others for a benefit? And, whether experience can teach people to be better at deception, and at detecting deception. Both are important for extrapolating these results to domains in which there is self-selection and possibly large effects of experience (e.g., used-car sales or politics). In other domains of economic interest, the combination of eyetracking and pupil dilation could be used to study any situation in which the search for information and cognitive difficulty are both useful to measure, such as “directed cognition” (Gabaix et al., 2006), perceptions of advertising and resulting choices, and attention to trading screens with multiple markets (e.g., with possible arbitrage relationships).

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Table 1: Behavior Predictions of the Level-k Model

Sender Message (condition on State)						Receiver Action (condition on Message)					
State	1	2	3	4	5	Message	1	2	3	4	5
b=0											
L0/Eq Sender	1	2	3	4	5	L0/Eq Receiver	1	2	3	4	5
b=1											
L0 Sender	1	2	3	4	5	L0 Receiver	1	2	3	4	5
L1 Sender	2	3	4	5	5	L1 Receiver	1	1	2	3	4
L2 Sender	3	4	5	5	5	L2 Receiver	1	1	1	2	4
Eq Sender	4	5	5	5	5	Eq Receiver	1	1	1	1	4
b=2											
L0 Sender	1	2	3	4	5	L0 Receiver	1	2	3	4	5
L1 Sender	3	4	5	5	5	L1 Receiver	1	1	1	2	4
L2 Sender	4	5	5	5	5	L2 Receiver	1	1	1	1	4
Eq Sender	5	5	5	5	5	Eq Receiver	1	1	1	1	3

Note: L0 senders are truthful and L0 receivers best respond to L0 senders by following the message. L1 senders best respond to L0 receivers, while L1 receivers best respond to L1 senders, and so on. Note that when b=2, due to discreteness both L2 and Eq(=L3) senders best respond to L1 receivers.

Table 2: Information Transmission: Correlations between states S, messages M, and actions A

Bias	Treatment		r(S, M)		r(M, A)		r(S, A)		Predicted r(S, A)
0	Displayed			.99		1.00		.99	1.00
	Hidden	Eyetracked	.92	.93	.90	.92	.86	.86	
		Open Box	.94		.94		.88		
1	Displayed			.73		.74		.72	.65
	Hidden	Eyetracked	.68	.64	.73	.71	.53	.49	
		Open box	.51		.61		.35		
2	Displayed			.63		.57		.50	.00
	Hidden	Eyetracked	.41	.34	.52	.58	.34	.32	
		Open box	.23		.63		.28		

Note: In the hidden bias treatment, some senders' eye movements were recorded ("eyetracked") and others were not ("open box"). This comparison provides a useful test of whether obtrusively tracking a subject's eye fixations affects their behavior.

Table 3: Sender and Receiver's Payoffs

Bias	Treatment	u_S (std)	(combined)	u_R (std)	(combined)	Pred. u_R (std)
0	Displayed Bias		109.14 (4.07) [a]		109.14 (4.07) [a]	110.00 (0.00)
	Eyetracked	101.13 (18.68)	101.30 [b] (17.28)	100.85 (19.28)	101.27 [b] (17.69)	
	Open Box	101.89 (14.89)		102.07 (15.23)		
1	Displayed Bias		93. 35 (20.75)		94.01 (19.86)	91.40 (19.39)
	Eyetracked	71.81 (39.56)	73.28 (37.46)	87.88 (28.63)	86.88 (27.59)	
	Open Box	75.44 (35.11)		84.44 (25.62)		
2	Displayed Bias		41.52 (49.98)		85.52 (25.60)	80.80 (20.76)
	Eyetracked	43.39 (52.17)	43.31 (52.79)	80.78 (27.17)	80.55 (27.57)	
	Open Box	44.21 (53.37)		80.21 (29.11)		

Note: [a] Payoffs are exactly the same for senders and receivers due to the symmetry of the payoffs when b=0.
[b] Payoffs are not exactly the same due to the random noise added and certain groups excluded.

Table 4: Level-k Classification Results

Part (a): Display Bias

Session	ID	log L	*k*	Exact	lambda
1	1	-36.33	L0	0.71	0.06
2	2	-51.47	L0	0.64	0.00
3	3	-33.01	L0	0.78	0.03
4	4	-19.81	L1	0.82	0.49
5	5	-38.93	SOPH	0.76	0.04
6	6	-45.05	Eq	0.69	0.05
7	7	-34.89	L0	0.80	0.00
8	8	-27.36	L2	0.84	0.04
9	9	-31.80	L1	0.80	0.04
10	10	-24.30	L1	0.84	0.48
11	11	-22.35	L2	0.87	0.45
12	12	-31.07	L2	0.73	1.00

Part (b): Hidden Bias

Session	ID	log L	*k*	Exact	lambda	Type
1	1	-46.23	SOPH	0.64	0.06	eyetracked
1	2	-25.99	L1	0.87	0.00	eyetracked
1	3	-15.98	L2	0.91	0.44	open box
2	1	-37.32	L1	0.60	0.52	eyetracked
2	2	-37.34	Eq	0.73	0.52	open box (eyetracked to round 20)
2	3	-25.70	SOPH	0.83	0.07	open box
3	1	-68.84	n/a	0.13	0.01	eyetracked
3	2	-17.71	SOPH	0.89	0.12	eyetracked
3	3	-54.73	Eq	0.60	0.03	open box
4	1	-50.86	L1	0.51	0.04	eyetracked
4	3	-25.22	Eq	0.82	0.48	open box
5	1	-22.26	L1	0.89	0.02	eyetracked
5	2	-35.77	L2	0.78	0.03	eyetracked
5	3	-25.17	Eq	0.87	0.04	open box
6	1	-16.27	L2	0.91	0.43	eyetracked
6	2	-42.02	SOPH	0.62	0.13	eyetracked
6	3	-52.17	L0	0.62	0.01	open box

Table 5: Average Sender Lookup Times (in seconds) across Game Parameters

Treatment	Bias b	Response Time Periods 1-15	Response Time Periods 31-45	State	Bias	Sender Payoffs	Receiver Payoffs	Sender-to-Receiver Ratio
Displayed Bias	0	5.42	2.39	0.65	0.41	0.73	0.27	2.70
	1	7.92	5.44	1.47	0.99	2.29	1.05	2.18
	2	9.73	8.12	1.72	1.52	3.03	1.50	2.02
	all	8.07	5.25	1.34	1.02	2.14	1.00	2.14
Hidden Bias	0	9.78	7.24	0.83	-	2.93	1.71	1.71
	1	11.77	8.76	0.81	-	3.80	2.66	1.43
	2	16.84	8.99	0.91	-	4.67	3.26	1.43
	all	13.47	8.52	0.86	-	3.99	2.72	1.47

Table 6: Average Lookup Time per Row Depending on the State

Treatment	Bias b	True State Rows	Other State Rows	True-to-Other Ratio
Displayed Bias	0	0.54	0.11	4.91
	1	2.06	0.32	6.44
	2	2.24	0.57	4.28
	overall	1.71	0.36	4.75
Hidden Bias	0	2.76	0.47	5.87
	1	3.88	0.64	6.06
	2	4.29	0.91	4.71
	overall	3.83	0.72	5.32

Table 7: Pupil Size Regressions for 400 msec Intervals

Y	$PUPIL_i$	-1.2~ -0.8sec	-0.8~ -0.4sec	-0.4~ 0.0sec	0.0~ 0.4sec	0.4~ 0.8sec
Displayed Bias						
constant	α	99.59	99.78	104.62	111.81	109.95
		(2.45)	(2.41)	(2.19)	(1.84)	(2.07)
LIE_SIZE * $BIAS_b$ interactions	β_{10}	1.20	6.41	3.92	-3.91	0.58
		(3.21)	(6.38)	(3.06)	(2.76)	(7.36)
	β_{11}	2.79*	3.40**	3.28**	4.55***	4.20***
		(1.19)	(1.17)	(0.97)	(0.86)	(0.73)
	β_{12}	3.49***	3.71***	3.04***	2.90**	3.28**
		(0.99)	(0.98)	(0.84)	(0.87)	(0.90)
	N	499	497	499	508	503
	χ^2	224.54	337.22	500.93	785.32	631.21
	R^2	0.271	0.346	0.455	0.539	0.557
Hidden Bias						
constant	α	107.27	108.03	106.19	109.56	108.67
		(2.81)	(2.55)	(2.57)	(2.05)	(2.16)
LIE_SIZE * $BIAS_b$ interactions	β_{10}	2.83	2.36	3.07	5.35**	5.57*
		(1.85)	(2.22)	(2.46)	(1.16)	(2.19)
	β_{11}	-1.02	-0.46	-0.36	2.16^	2.64*
		(1.26)	(1.31)	(1.28)	(1.21)	(1.15)
	β_{12}	2.06*	1.52^	1.47*	1.83*	2.00**
		(0.86)	(0.79)	(0.75)	(0.75)	(0.74)
	N	414	415	414	415	414
	χ^2	323.86	235.43	194.40	258.49	352.49
	R^2	0.291	0.299	0.263	0.365	0.438

Note: Robust standard error in parentheses; t-Test p-values lower than ^10 percent, *5 percent, ** 1 percent, and *** 0.1 percent. (Dummies for biases, states, individual subjects and individual learning trends are included in the regression, but results are omitted.)

Table 8: Predicting True States (Resampling 100 times) (s. e. in parentheses)

X		Display Bias		Hidden Bias	
MESSAGE * BIAS = 1	β_{11}	0.64*	(0.22)	0.46**	(0.12)
MESSAGE * BIAS = 2	β_{12}	0.91**	(0.23)	0.42**	(0.09)
ROW_{self} * BIAS=1	β_{21}	0.98**	(0.21)	1.07**	(0.24)
ROW_{self} * BIAS=2	β_{22}	1.00**	(0.27)	1.72**	(0.20)
ROW_{other} * BIAS=1	β_{31}	0.25	(0.16)	1.27**	(0.22)
ROW_{other} * BIAS=2	β_{32}	0.39*	(0.17)	0.44**	(0.15)
total observations N[a]		208		357	
N used in estimation		139.3		238.3	
N used to predict		68.7		118.7	
		Actual Data	Hold-out Sample	Actual Data	Hold-out Sample
Percent of wrong prediction (b=1)		56.2	29.2	58.5	28.9
Percent of errors of size (1,2,3+) (b=1)		(80, 15, 5)	(74, 19, 7)	(61, 28, 11)	(79, 19, 2)
Average predicted payoff (b=1)[b]		93.4 (22.3)	100.7* (2.4)	87.5 (28.8)	101.7** (2.1)
Percent of wrong prediction (b=2)		70.9	58.7	77.9	37.9
Percent of errors of size (1,2,3+) (b=2)		(67, 26, 7)	(73, 22, 5)	(60, 30, 10)	(72, 24, 4)
Average predicted payoff (b=2)[b]		86.2 (23.8)	91.8* (3.4)	80.9 (26.9)	98.0** (2.2)

Note: * and ** Denotes p<0.05 and p<0.001 (t-test)

[a] Observation with less than 0.5 seconds lookup time and without the needed pupil size measures are excluded.

[b] Two sample t-test conducted against the actual payoffs of receivers in the experiment who are paired with eyetracked senders.

Figure 1: Raw Data Pie Charts (b=0), Hidden Bias

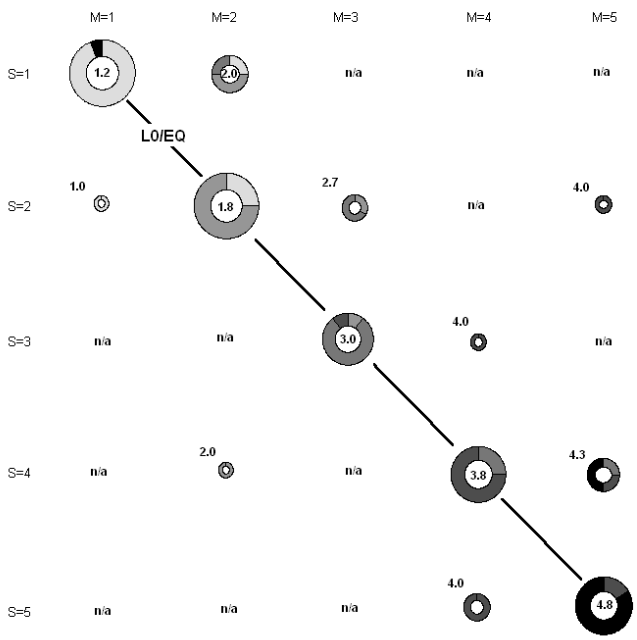


Figure 2: Raw Data Pie Chart (b=1), Hidden Bias

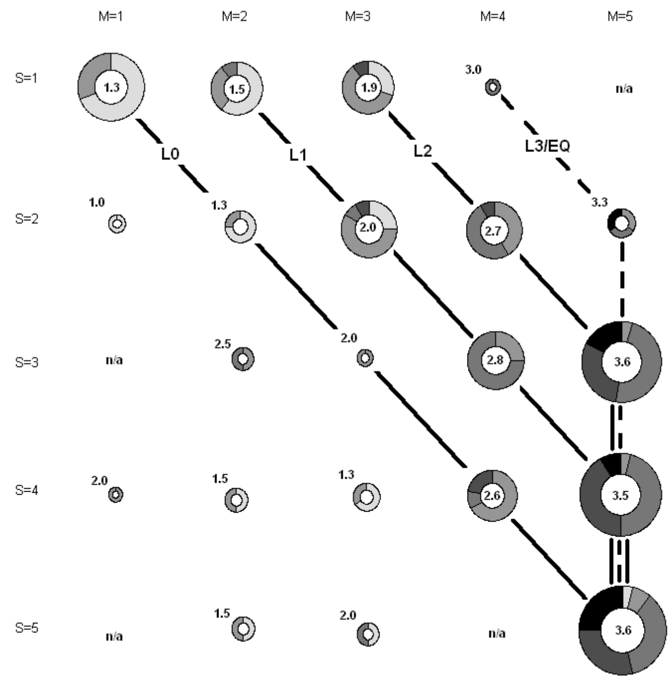
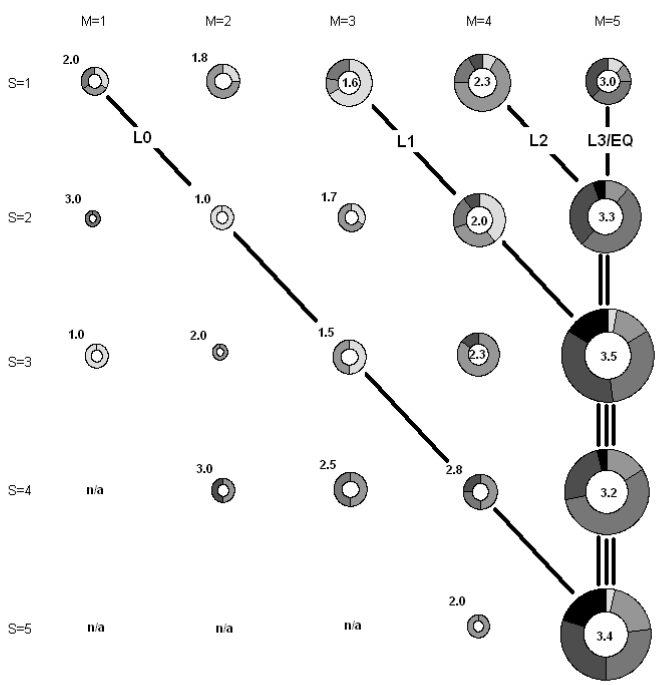


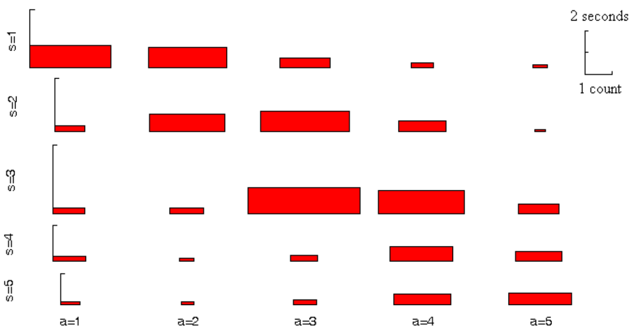
Figure 3: Raw Data Pie Chart (b=2), Hidden Bias



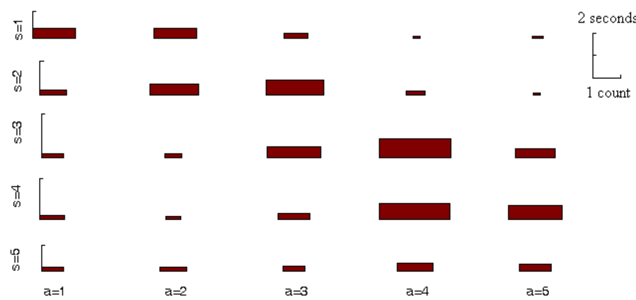
The true states are in rows, and senders' messages are in columns. Each cell contains the average action taken by the receivers and a pie chart break down of the actions. Actions are presented in a gray scale, ranging from white (action 1) to black (action 5). The size of the pie chart is proportional to the number of occurrences for the corresponding state and message.

Figure 4: Lookup Icon Graph for b=1, Hidden Bias

Part (a): Sender Payoffs



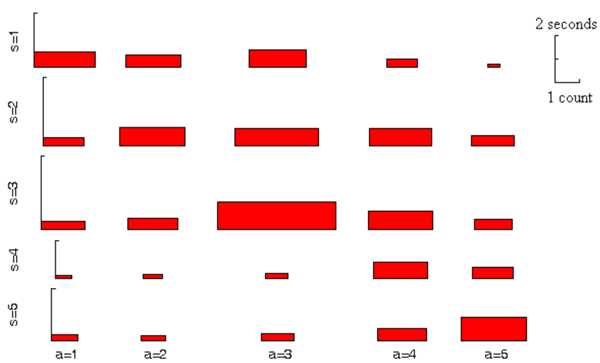
Part (b): Receiver Payoffs



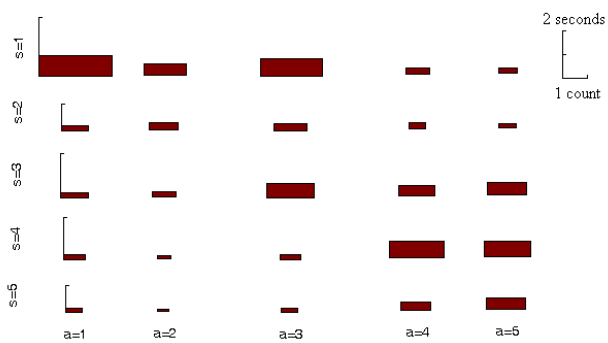
Each row reports the lookup counts and time for the "true state row" corresponding to the given true state. The width of each box is scaled by the number of lookups and the height by the length of lookups (scaled by the little "ruler" in the upper right corner). The vertical bar on the first column icon represents the total lookup time summed across each row.

Figure 5: Lookup Icon Graph for b=2, Hidden Bias

Part (a): Sender Payoffs



Part (b): Receiver Payoffs



Each row reports the lookup counts and time for the "true state row" corresponding to the given true state. The width of each box is scaled by the number of lookups and the height by the length of lookups (scaled by the little "ruler" in the upper right corner). The vertical bar on the first column icon represents the total lookup time summed across each row.

Appendix for Online Access [NOT INTENDED FOR PUBLICATION]

Appendix: Methods

Since this paper incorporates economics experiments in the laboratory, eyetracking devices, and studies the issue of deception, we expect readers who come from various backgrounds, such as economic theory, experimental economics, psychophysiology, and lie-detection. Therefore, we decided to create a methodology appendix to address issues that might already be very familiar to some readers, but not to the rest. In particular, section 1 introduces video-based eyetracking to economists who are interested in learning about methods to study information acquisition, and section 2 demonstrates the relevance of eyetracking in economic experiments. Section 3 provides an argument for adding yet another paradigm (sender-receiver games) to study lie-detection, instead of adopting previous tasks such as CQT, GKT, etc. Section 4 provides the technical details of the equipment and software programs used in this study for those who are interested in replicating our results or applying this technique in future research.

A.I What is Eyetracking?

There are several ways to track a person's eyes. One of the most reliable and non-invasive way is video-based. Video-based eyetracking works by placing cameras in front of subject's eyes to capture eye images and corneal reflection of infrared sensors, and record changes up to 50-250Hz. Using eye movement images when subjects were told to fixate on certain positions on the screen, a procedure called "calibration," the experimenter can trace eye fixations and saccades on the screen and infer subject information acquisition patterns. In addition to information lookups, the eyetracker also records pupil dilation, which is correlated with arousal, pain, and cognitive difficulty. Therefore, eyetracking provides additional data about one's decision making process, uncovering previously unobservable parameters.[39]

A.II What Does Eyetracking Tell Us About the "Real World"?

Since economists are used to judging theories only by whether they predict choices accurately, it is useful to ask what direct measurement of eye fixations and pupil dilation can add. One possible inferential strategy from eyetracking is to separate competing theories that explain the same behavior. Previous studies compared offers and lookups in three-period alternating-offer bargaining (Camerer et al., 1993; Johnson et al., 2002), and in initial responses to normal-form games and two-person guessing games (Costa-Gomes et al., 2001; Costa-Gomes and Crawford, 2006). In those experiments, the same choices could be caused by different decision rules, such as L1 (optimize against perceived random play) and D1 (optimize against perceived random play excluding dominated strategies) in Costa-Gomes et al. (2001), but are separated by different lookup generated by these rules.[40] These studies illustrate the potential for using cognitive data, besides choices, for distinguishing between competing theories or inspiring new theory.[41]

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[39] One potential concern of adopting eyetracking is scrutiny. For example, in our experiments senders could have been more truthful simply because they were watched. Indeed, we do find many L0 and L1 types (seven out of twelve) in the display bias treatment. Nevertheless, such concerns should be dealt with empirically by comparing eyetracked and open box subjects. In our experiment, the hidden bias treatment adopts random matching and contains both eye-tracked and open boxed subjects. Overall type classification results are similar to Cai and Wang (2006). Although the sub-samples of eyetracked and open box subjects do show some interesting differences, the average level of strategic thinking is comparable: None of the eyetracked subjects were L3/Eq, but there were many SOPH; none of the open box subjects were L1, but the only L0 subject was an open box. This results in lower correlation between state and message for the open box subjects, but there is still little difference in payoffs. Hence, we conclude that there is no striking difference between the two, though the sample size is small.

[40] For example, in the three-stage bargaining game of Camerer et al. (1993) and Johnson et al. (2002), opening offers typically fell between an equal split of the first-period surplus and the subgame perfect equilibrium prediction (assuming self-interest). These offers could be caused by limited strategic thinking (i.e., players do not always look ahead to the second and third round payoffs of the game), or by computing an equilibrium by looking ahead, adjusting for fairness concerns of other players. The failure to look at payoffs in future periods showed that the deviation of offers from equilibrium was (at least partly) due to limited strategic thinking, rather than entirely due to equilibrium adjustment for fairness (unless "fairness" means not at all responding to advantages conferred by the strategic structure). Furthermore, comparing across rounds, when players do look ahead at future round payoffs their resulting offer are

Ultimately, the goal is to open up the black box of human brain, and model the decision process of human behavior, which is similar to what has been done to the firm. Instead of dwelling on the neoclassical theory of the firm, which is merely a production function, modern economics has opened up the black box of the firm, and explicitly modeled its internal structure, such as the command hierarchy, principle-agent issues, and team production. Though there is still much to be done before we come close to what has been achieved in industrial organization, eyetracking provides a window to the soul and gives us a hint of the decision process inside the brain. Just as we may infer a factory's technology level by observing its inputs and wastes, we may also infer a person's thought process by observing the information he or she acquires (inputs) and how hard does he think (indexed by pupillary response).

A.III What Does Economics Have to Offer Regarding Lie-detection?

This study introduces an economic framework that is missing in the many previous psychophysical studies on deception and lie detection. An advantage of the strategic information transmission game for studying deception is that game theory makes equilibrium predictions about how much informed agents will exaggerate what they know, when they know that other agents are fully-informed about the game's structure and the incentives to exaggerate. Even when equilibrium predictions fail, there are various behavioral models, such as level-k reasoning and quantal response equilibrium, which provide precise predictions that are testable in the lab. And while in most other

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closer to the self-interested equilibrium prediction (see Johnson and Camerer, 2004). Thus, the lookup data can actually be used to predict choices, to some degree.

[41] Another example comes from the accounting literature: James E. Hunton and McEwen (1997) asked analysts under hypothetical incentive schemes to make earnings forecast based on real firm data, and investigated factors that affect the accuracy of these forecasts. Using an eye-movement computer technology (Integrated Retinal Imaging System, IRIS), they find that analysts who employ a "directive information search strategy" make more accurate forecasts, both in the lab and in the field, even after controlling for years of experience. This indicates that eyetracking may provide an alternative measure of experience or expertise that is not simply captured by seniority. Had they not observed the eye movements, they could not have measured the difference in information search which is linked to accuracy.

deception studies,[42] subjects are instructed to lie or give weak or poorly controlled incentives,[43] subjects in experiments like ours choose voluntarily whether to deceive others or not (see also John Dickhaut et al., 1995, Andreas Blume et al., 1998, 2001 and Cai and Wang, 2006).[44] Senders and receivers also have clear measurable economic incentives to deceive and to detect deception.[45]

A.IV Technological Details

Eyetracking data and button responses were recorded using the mobile Eyelink II head-mounted eyetracking system (SR Research, Osgoode, Ontario). Eyetracking data were recorded at 250 Hz. The mobile Eyelink II is a pair of tiny cameras mounted on a lightweight rack facing toward the subjects' eyes, and supported by comfortable head straps. Subjects can move their heads and a period of calibration adjusts for head movement to infer accurately where the subject is looking. New nine-point calibrations and validations were performed prior to the start of each

[42] For a survey of studies on (skin-conductance) polygraph, see Theodore R. Bashore and Paul E. Rapp (1993). For lie-detection studies in psychology, see the reviews of Robert E. Kraut (1980) and Aldert Vrij (2000). For a comprehensive discussion of different cues used to detect lies, see Bella M. DePaulo et al. (2003). For individual differences in lie-detection (Secret Service, CIA and sheriffs do better), see Paul Ekman and Maureen O'Sullivan (1991) and Ekman et al. (1999). More recently studies in neuroscience using functional magnetic resonance imaging (fMRI) include Sean A. Spence et al. (2001), D. D. Langleben et al. (2002) and F. Andrew Kozel et al. (2004).

[43] One exception is Samantha Mann et al. (2004) which used footage of real world suspect interrogation to test lie-detecting abilities of ordinary police. However, a lot of experimental control is lost in this setting. One interesting findings in this study is that counter to conventional wisdom, the more subjects relied on stereotypical cues such as gaze aversion to detect lies, the *less* accurate they were.

[44] In fact, when the senders were asked after the experiment whether they considered sending a number different from the true state deception, 8 of the subjects said yes, while another 3 said no, but gave excuses such as "it's part of the game" or "the other player knows my preference difference." Only 1 subject said no without any explanation. These debriefing results also suggest that guilt has played little role in the experiment.

[45] Most lie-detection studies have three drawbacks: (1) They do not use naturally-occurring lies (because it is then difficult to know whether people are actually lying or not). Instead, most studies create artificial lies by giving subjects true and false statements (or creating a "crime scenario") and instructing them to either lie or tell the truth, sometimes to fool a lie-detecting algorithm or subject. However, instructed deception can be different than naturally-occurring voluntary deception, and the ability to detect instructed deception might be different than detecting voluntary deception. (2) The incentives to deceive in these studies are typically weak or poorly controlled (e.g., in Spence et al. (2001) all subjects were told that they successfully fooled the investigators who tried to detect them; in Mark G. Frank and Ekman (1997), subjects were threatened with "sitting on a cold, metal chair inside a cramped, darkened room labeled ominously XXX, where they would have to endure anywhere from 10 to 40 randomly sequenced, 110-decibel startling blasts of white noise over the course of 1 hr" but never actually enforcing it.). (3) Subjects are typically not

experiment in a participant's session. Accuracy in the validations typically was better than 0.5º of visual angle. Experiments were run under Windows XP (Microsoft, Inc.) in Matlab (Mathworks, Inc., Natick, MA) using the Psychophysics Toolbox (David H. Brainard, 1997; Denis G. Pelli, 1997) and the Eyelink Toolbox (Frans W. Cornelissen et al., 2002).

Eyetracking data were analyzed for fixations using the Eyelink Data Viewer (SR Research, Hamilton, Ontario). In discriminating fixations, we set saccade velocity, acceleration, and motion thresholds to 30º/sec, 9500º/sec^2, and 0.15º, respectively. Regions of interest (ROIs), or the boxes subject look up, were drawn on each task image using the drawing functions within the Data Viewer. Measures of gaze included Fixation Number (i.e., the total number of fixations within an ROI) and Fractional Dwell Time (i.e., the time during a given round spent fixating a given ROI divided by the total time between image onset and response). Only those fixations beginning between 50ms following the onset of a task image and offset of the task image were considered for analysis.

All task images were presented on a CRT monitor (15.9 in x 11.9 in) operating at 85 or 100 Hz vertical refresh rate with a resolution of 1600 pixels x 1200 pixels, and at an eye-to-screen distance of approximately 24 inches, thus subtending ~36 degrees of visual angle.

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Appendix: Experiment Instructions

The experiment you are participating in consists of 1 session, having 45 rounds. At the end of the last session, you will be asked to fill out a questionnaire and paid the total amount you have accumulated during the course of the sessions in addition to a $5 show-up fee. Everybody will be paid in private after showing the record sheet. You are under no obligation to tell others how much you earned.

During the experiment all the earnings are denominated in FRANCS. Your dollar earnings are determined by the FRANC/$ exchange rate: 200 FRANCS = $1.

In each round, the computer program generates a secret number that is randomly drawn from the set {1,2,3,4,5}. The computer will display this secret number on member A's screen. After receiving the number, member A will send the message "The number I received is XX," to member B by staring at box XX. Hearing the message from member A, member B will then choose an action. In particular, member B can choose action 1, 2, 3, 4, or 5, using the game pad. Earnings of both members depend on the secret number and member B's action.

Member B's earnings is higher when member B's action is closer to the secret number, while member A's earnings is higher when member B's action is closer to the secret number **plus the preference difference**. The preference difference is either 0, 1 or 2, with equal chance, and will also be displayed and announced at the beginning of each round.

For example, if the preference difference is 2 and the secret number is 3, member B's earnings are higher if his or her action is closer to 3. However, member A's earnings is higher when member B's action is closer to 3 + 2 = 5. The earning tables are provided to you for convenience.

To summarize, in each round, the computer will display the preference difference and the secret number on member A's screen. Then, member A stares at a box (on the right) containing the desired message. Member B will hear the preference difference and the message "The number I received is XX," and then choose an action. The secret number is revealed after this choice, and earnings are determined accordingly.

Practice Session: 3 Rounds

Session 1: 45 Rounds

Member B: Please make sure you record the earnings in your record sheet. **Your payments will be rounded up.** Thank you for your participation.

Appendix: Supplemental Figures and Tables

Figure S1: Sender Screen for b=1 and S=4

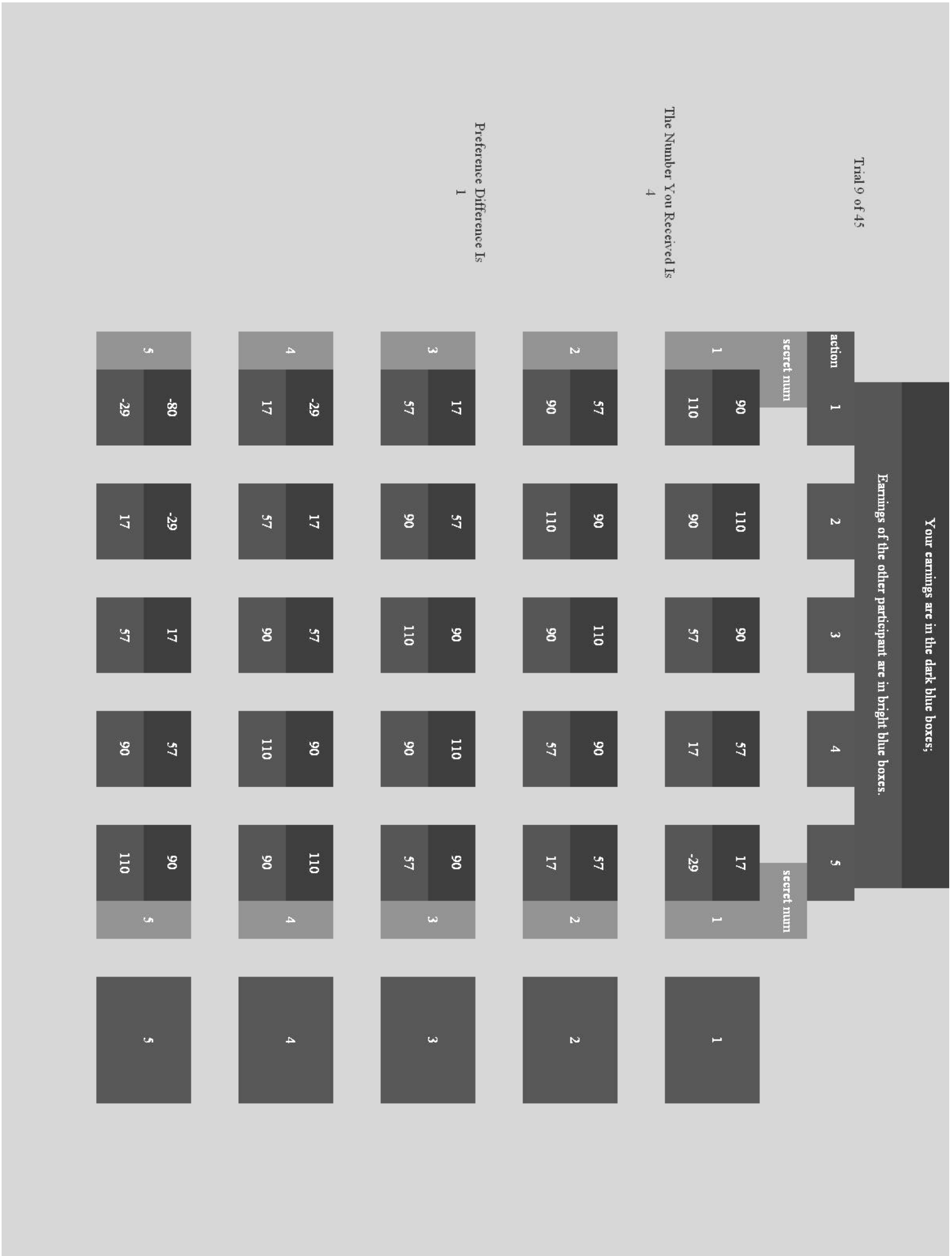


Figure S2: Raw Data Pie Charts (b=0), Display Bias

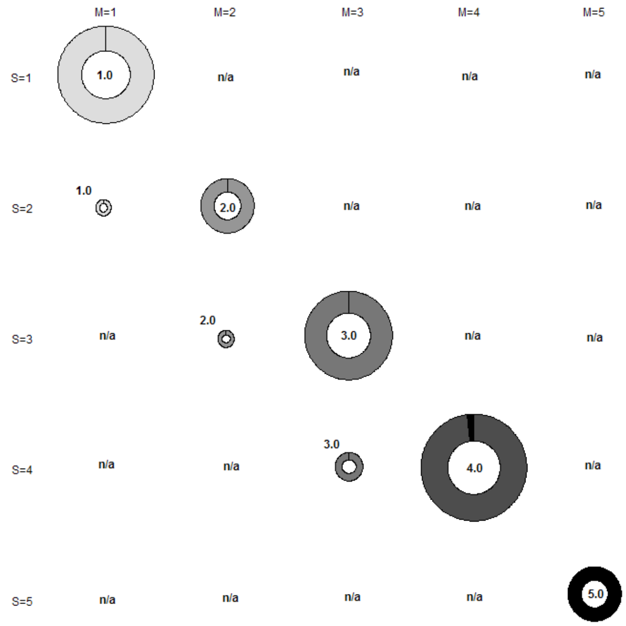


Figure S3: Raw Data Pie Chart (b=1), Display Bias

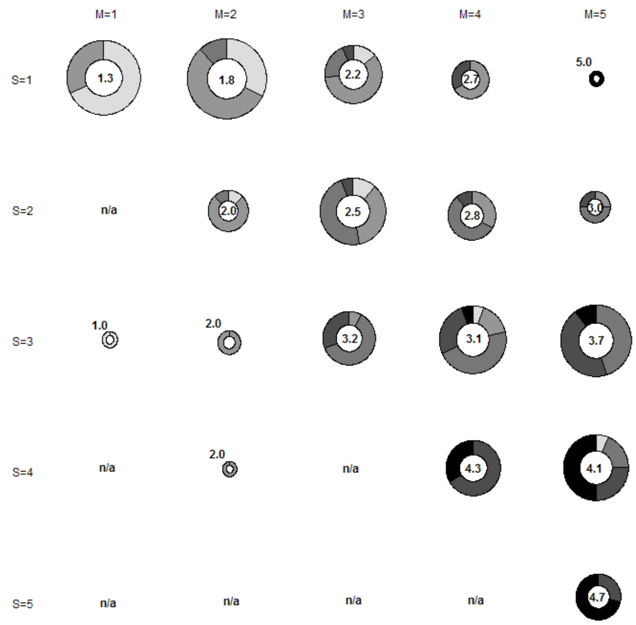
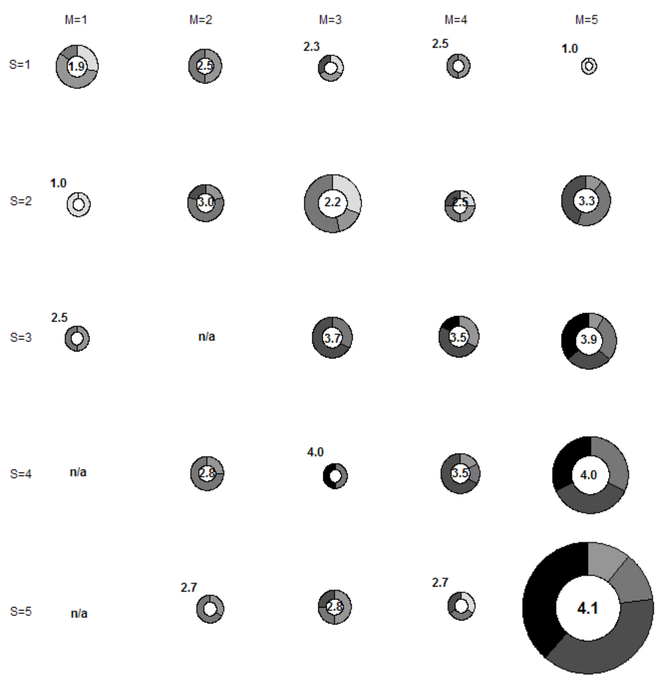


Figure S4: Raw Data Pie Chart (b=2), Display Bias



The true states are in rows, and senders' messages are in columns. Each cell contains the average action taken by the receivers and a pie chart break down of the actions. Actions are presented in a gray scale, ranging from white (action 1) to black (action 5). The size of the pie chart is proportional to the number of occurrences for the corresponding state and message.

Figure S5: Icon graph of lookups (rectangle width) and looking time (shaded area) for b=0

Part (a): Display Bias **Part (b): Hidden Bias**

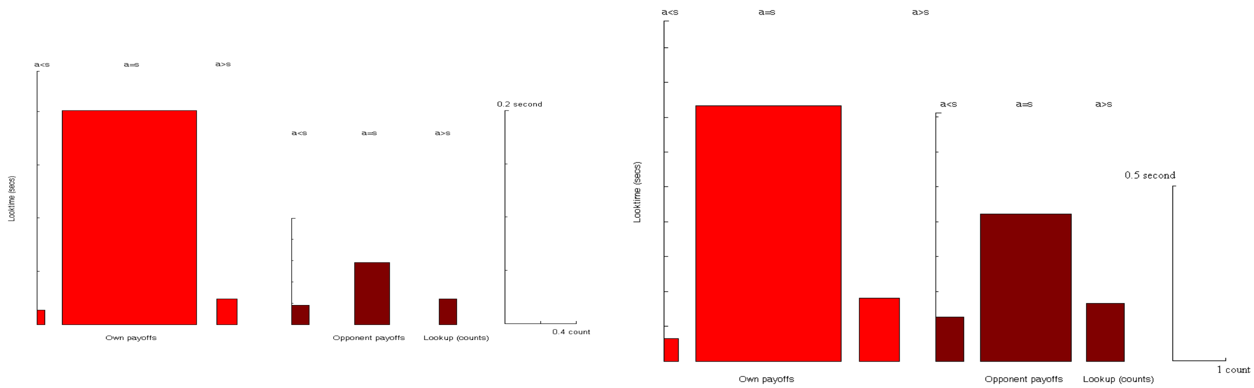


Figure S6: Lookup Icon Graph for b=1, Display Bias

Part (a): Sender Payoffs **Part (b): Receiver Payoffs**

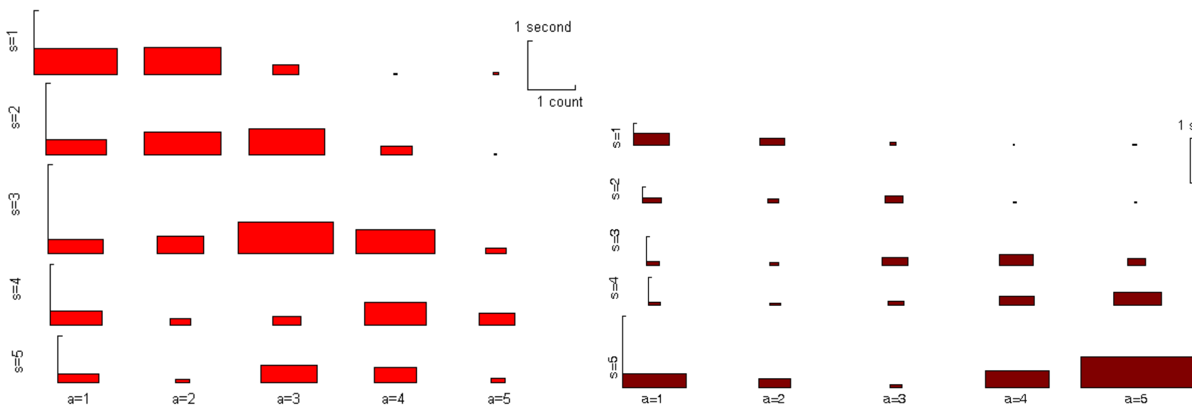
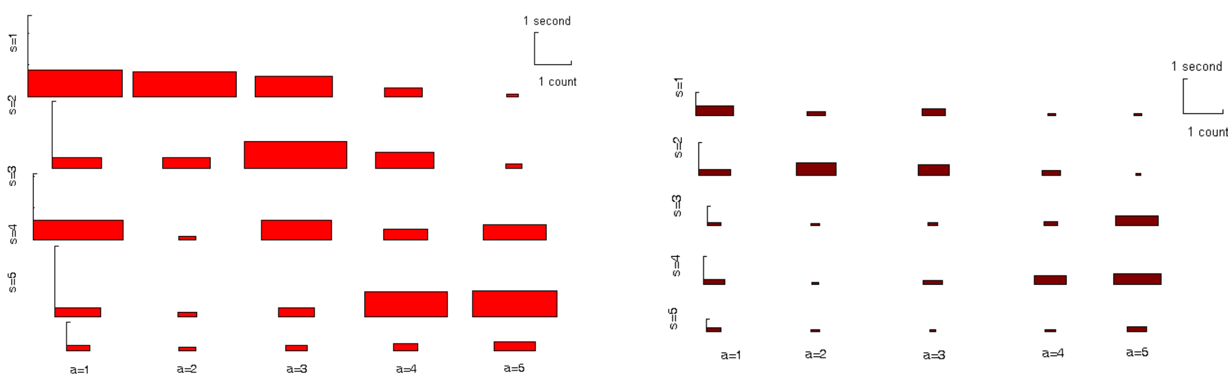


Figure S7: Lookup Icon Graph for b=2, Display Bias

Part (a): Sender Payoffs **Part (b): Receiver Payoffs**



Each row reports the lookup counts and time for the "true state row" corresponding to the given true state. The width of each box is scaled by the number of lookups and the height by the length of lookups (scaled by the little "ruler" in the upper right corner). The vertical bar on the first column icon represents the total lookup time summed across each row.

Table S1A: Average response time change for different biases, Display Bias

Bias	N	Average for first 15 rounds	N	Average for middle 15 rounds	N	Average for last 15 rounds
0	38	5.42	47	2.91	55	2.39
1	73	7.92	60	5.44	59	5.44
2	67	9.73	68	8.96	51	8.12
overall	178	8.07	175	6.13	165	5.25

* The numbers of observations are slightly different because we exclude 10 rounds where subjects had to use the keyboard to make their decision. Also, subject #4 had severe pain and the experimenter was forced to stop the experiment at the end of round 33.

Note: Since the bias was randomly determined each round, and subject #4 stopped at round 33 (due to excess pain wearing the eyetracker), numbers of observations are not equal. Dropping subject #4 does not change the results.

Table S1B: Average response time change for different biases, Hidden Bias

Bias	N	Average for first 15 rounds	N	Average for middle 15 rounds	N	Average for last 15 rounds
0	30	9.78	24	5.54	29	7.24
1	56	11.77	58	10.78	59	8.76
2	61	16.84	65	10.23	49	8.99
overall	147	13.47	147	9.68	137	8.52

* The numbers of observations are slightly different because we exclude 12 rounds where subjects had to use the keyboard to make their decision. Also, subject #3 had calibration issues and the experimenter was forced to stop eyetracking at the end of round 40.

Note: Since the bias was randomly determined each round, and subject #4 stopped at round 40 wearing the eyetracker), numbers of observations are not equal.

Table S2A: Learning – Actual Information Transmission

Display Bias

BIAS	Rounds	Corr(S, M)	Corr(M, A)	Corr(S, A)	Predicted Corr(S, A)
	1-15	0.880	0.833	0.732	
0	16-30	0.976	0.949	0.925	1.000
	31-45	0.937	0.942	0.919	
	1-15	0.620	0.730	0.477	
1	16-30	0.685	0.724	0.577	0.645
	31-45	0.598	0.713	0.415	
	1-15	0.384	0.584	0.372	
2	16-30	0.327	0.526	0.306	0.000
	31-45	0.279	0.643	0.291	

Hidden Bias

BIAS	Rounds	Corr(S, M)	Corr(M, A)	Corr(S, A)	Predicted Corr(S, A)
	1-15	0.887	0.816	0.716	
0	16-30	0.941	0.951	0.885	1.000
	31-45	0.888	0.944	0.866	
	1-15	0.602	0.730	0.436	
1	16-30	0.660	0.727	0.561	0.645
	31-45	0.555	0.714	0.393	
	1-15	0.380	0.592	0.372	
2	16-30	0.347	0.540	0.313	0.000
	31-45	0.232	0.636	0.288	

Table S2B: Learning Sender and Receiver's Payoffs

Display Bias				
BIAS	Rounds	u_S (std)	u_R (std)	Predicted u_R (std)
	1-15	96.36 (23.47)	96.48 (24.37)	
0	16-30	104.63 (11.65)	104.78 (12.01)	110.00 (0.00)
	31-45	103.50 (12.46)	103.19 (12.18)	
	1-15	79.38 (31.83)	87.04 (26.78)	
1	16-30	69.19 (40.15)	87.98 (28.94)	91.40 (19.39)
	31-45	71.83 (39.05)	85.52 (27.09)	
	1-15	46.06 (50.91)	80.63 (25.93)	
2	16-30	46.74 (51.11)	81.20 (27.63)	80.80 (20.76)
	31-45	35.87 (55.73)	79.70 (29.65)	
Hidden Bias				
BIAS	Rounds	u_S (std)	u_R (std)	Predicted u_R (std)
	1-15	95.38 (23.56)	95.72 (24.15)	
0	16-30	102.40 (15.18)	102.52 (15.53)	110.00 (0.00)
	31-45	102.00 (16.89)	101.69 (17.30)	
	1-15	78.76 (35.63)	85.88 (28.92)	
1	16-30	69.18 (39.40)	87.45 (28.61)	91.40 (19.39)
	31-45	71.40 (38.82)	84.73 (26.87)	
	1-15	46.76 (49.84)	81.06 (26.36)	
2	16-30	46.75 (50.19)	81.81 (27.15)	80.80 (20.76)
	31-45	36.22 (55.94)	79.29 (29.10)	

Table S3: Average Sender Fixation Counts and Lookup Time across Game Parameters

Treat-ment	Bias b	Res-ponse time (sec.)	State		Bias		Sender Payoffs		Receiver Payoffs	
			Fixation (count)	Lookup (sec.)	Fixation (count)	Lookup (sec.)	Fixation (count)	Lookup (sec.)	Fixation (count)	Lookup (sec.)
Displayed Bias	0	3.59	2.6	0.65	2.1	0.41	3.0	0.73	1.4	0.27
	1	6.86	5.0	1.47	3.9	0.99	8.1	2.29	3.9	1.05
	2	9.68	6.2	1.72	5.5	1.52	10.6	3.03	5.4	1.50
	overall	7.00	4.8	1.34	4.0	1.02	7.6	2.14	3.7	1.00
Hidden Bias	0	7.65	3.0	0.83	-	-	12.0	2.93	7.5	1.71
	1	10.95	3.1	0.81	-	-	14.2	3.80	10.7	2.66
	2	12.91	3.4	0.91	-	-	17.5	4.67	12.4	3.26
	overall	11.12	3.2	0.86	-	-	15.1	3.99	10.8	2.72

Table S4: Average Fixation Counts and Lookup Time per Row

Treatment	Bias b	True State Rows		Other Rows	
		Fixation Counts (counts per row)	Lookup Time (sec. per row)	Fixation Counts (counts per row)	Lookup Time (sec. per row)
Displayed Bias	0	2.2	0.54	0.5	0.11
	1	6.8	2.06	1.3	0.32
	2	7.8	2.24	2.0	0.57
	overall	5.9	1.71	1.3	0.36
Hidden Bias	0	11.4	2.76	2.0	0.47
	1	14.4	3.88	2.6	0.64
	2	15.7	4.29	3.6	0.91
	overall	14.3	3.83	2.9	0.72