Players of Matching Pennies automatically imitate opponents' gestures against strong incentives

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There is a large body of evidence of apparently spontaneous mimicry in humans. This phenomenon has been described as "automatic imitation" and attributed to a mirror neuron system, but there is little direct evidence that it is involuntary rather than intentional. Cook et al. supplied the first such evidence in a unique strategic game design that gave all subjects a pecuniary incentive to avoid imitation [Cook R, Bird G, Lünser G, Huck S, Heyes C (2012) *Proc Biol Sci* 279(1729):780–786]. Subjects played Rock-Paper-Scissors repeatedly in matches between fixed pairs, sometimes with one and sometimes with both subjects blindfolded. The frequency of draws in the blind-blind condition was at chance, but in the blind-sighted condition it was significantly higher, suggesting automatic imitation had occurred. Automatic imitation would raise novel issues concerning how strategic interactions are modeled in game theory and social science; however, inferring automatic imitation requires significant incentives to avoid it, and subjects' incentives were less than 3 US cents per 60-game match. We replaced Cook et al.'s Rock-Paper-Scissors with a Matching Pennies game, which allows far stronger incentives to avoid imitation for some subjects, with equally strong incentives to imitate for others. Our results are important in providing evidence of automatic imitation against significant incentives. That some of our subjects had incentives to imitate also enables us clearly to distinguish intentional responding from automatic imitation, and we find evidence that both occur. Thus, our results strongly confirm the occurrence of automatic imitation, and illuminate the way that automatic and intentional processes interact in a strategic context.

zero-sum game | face-to-face strategic interaction | neuroeconomics

There is a large body of evidence suggesting that observing an action increases the probability that the observer will immediately perform the same action, even when the observer has not been instructed to imitate and does not obtain any reward from doing so (1–5). This phenomenon has been described as "automatic imitation" and attributed to the operation of mirror neurons (6–8). Each of these neurons, first discovered in the monkey premotor and parietal cortex, responds both to the sight and execution of a given action (9–11). Since the discovery of mirror neurons in the monkey, considerable evidence has been amassed suggesting that humans also have a mirror neuron system (12, 13).

Until recently there was little direct evidence to support the view that automatic imitation is involuntary rather than strategic or intentional. Even evidence of imitation in infants and nonhuman animals has been construed as intentional (14), and experimental techniques that could reliably distinguish automatic from intentional imitation have been hard to find (15). Cook et al. supplied the first direct evidence in a unique strategic game design that gave human subjects a pecuniary incentive to avoid imitation (16). Their subjects played Rock-Paper-Scissors (RPS) games repeatedly in matches between fixed pairs, sometimes with one and sometimes with both subjects blindfolded. There was a money reward for winning each 60-game match but not for losing or drawing, so that imitation (which produced a draw) tended to lower a subject's expected payoff. The frequency of draws in the blind-blind condition was as expected at chance, but in the blind-sighted condition it was significantly higher, suggesting that there was an imitation effect, and that it was automatic rather than intentional.

Automatic imitation would raise important issues concerning how strategic interactions are modeled in game theory and social science. In theoretical analyses of strategic interactions, it is almost universally assumed that the timing of decisions is exogenous; timing influences players' decisions only via its effect on their information about previous decisions; and all decisions are conscious. Timing can make a big difference if some decisions are unconscious when made sequentially under time pressure. Consider a one-stage Prisoner's Dilemma game, but possibly with asynchronous decisions to cooperate or defect. In a standard analysis of the Prisoner's Dilemma, both players respond to their incentives by defecting, and the outcome is worse for both than if both cooperate; furthermore, because defecting is a dominant strategy (better for a player no matter what the other player decides), the conclusion would remain the same even with asynchronous decisions. If, by contrast, decisions are asynchronous, and this creates sufficient time pressure for the second mover that she or he unconsciously imitates the first-mover's decision, then a first-mover who understands the principles of the second-mover's behavior in effect faces a choice between two imitative outcomes: "defect, defect," the standard Nash equilibrium outcome; and "cooperate, cooperate," an outcome that becomes feasible when the second-mover's unconscious decision overrides her or his incentive to defect, even though it is not an equilibrium in the standard analysis. A rational first-mover will of course choose to cooperate, knowing that it will induce the second-mover to cooperate, yielding an outcome that is better for both players. The implications for the optimal design of relationship structures, or for predicting the consequences of existing structures, may be very important.[Asynchronous timing can foster coordination even without observability of earlier decisions (17, 18). However, unlike the automatic imitation of earlier decisions studied here, such timing effects must be intentional. The novelty of our analysis is that it implies: (*i*) choice might in some circumstances be involuntary, (*ii*) involuntary choices can override the incentive constraints that in theory prevent good outcomes in our Prisoner's Dilemma and related examples, and (*iii*) involuntary and conscious choices might interact in novel ways in settings with nontrivial time-sequencing. This implication enhances the value of experimentally separating intentional from automatic imitation.]

However, the evidence reported by Cook et al. (16) is not decisive for two reasons. First, inferring automatic imitation requires

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significant incentives to avoid it and, as explained below, close examination of Cook et al.'s methods reveals that their subjects were given only very weak incentives to avoid imitation: little more than one British penny, less than 3 US cents per 60-game match. Second, a subsequent study using a similar procedure failed to replicate the results of the Cook et al. experiment (19).

Testing more rigorously for automatic imitation in a strategic context, we replaced RPS with a Matching Pennies game, which allows far stronger incentives to avoid imitation for some subjects, with equally strong incentives to imitate for others. We also conducted a more fine-grained analysis of players' behavior, investigating the effects of experience on automatic imitation. Our results are important in providing evidence of automatic imitation against significant incentives, greatly strengthening Cook et al.'s inference. That some of our subjects had incentives to imitate also enables us clearly to distinguish intentional responding from automatic imitation, and we find evidence that both occur. Thus, our results strongly confirm the occurrence of automatic imitation, and illuminate the way that automatic and intentional processes interact in a strategic context.

To explain and motivate our modifications of the procedure used by Cook et al., we need first to examine their design more closely. Cook et al.'s subjects repeatedly played an RPS game, which Cook et al. described as follows (16): "In RPS, two players each present one of three alternative hand gestures. Each player must make either 'rock' (a closed fist), 'paper' (an open hand), or 'scissors' (index and middle finger parted) gestures, typically following a count of three. A paper gesture beats a rock gesture; scissors beats paper; and rock beats scissors. If both players make the same gesture, the round is drawn (Table 1). In this zero-sum game, where one player's victory (+1) results in the other player's defeat (−1), the only Nash equilibrium (where each player behaves optimally given what all others do) is in mixed strategies. Regardless of which action one player chooses, there would always be one specific action for the other player that ensures a win, and vice versa. This 'best-response structure' inherent in RPS ensures that players can only achieve optimal outcomes if they *avoid* imitating each other." (Emphasis in original.)

Cook et al.'s subjects were randomly grouped into triads, with two of the three playing the game at any given time and the third acting as umpire. In the main condition, one player was blindfolded and the other was sighted. Although the umpire "required" players to present their gestures simultaneously, there was a naturally occurring asynchrony between the onsets of the two players' gestures, with one sometimes presenting slightly earlier than the other. If it was the blindfolded player who presented earlier, the sighted player might have been able to observe the blindfolded player's gesture in time to respond to it. However, Cook et al. argued (16) that "response asynchronies long enough to allow intentional response selection would have been detected and disqualified by the umpire." Even so, when evaluating the strength of incentives to avoid imitation in their design, Cook et al. appeared to assume that players who saw their opponents' gestures in time to respond could "achieve optimal outcomes," (e.g., by playing rock against an observed scissors, yielding a payoff of 1) (Table 1). However, if intentional

Table 1. RPS game, where (0,0) denotes a drawn round, (1,−1) denotes a win for player 1, and (−1,1) denotes a win for player 2

		Player 2		
		Rock	Paper	Scissors
Player 1	Rock	0,0	−1,1	1,−1
	Paper	1,−1	0,0	−1,1
	Scissors	−1,1	1,−1	0,0

response selection was not feasible, then a player who saw her or his opponent's gestures in time could at best avoid imitation but not otherwise select among gestures. In that case, a more plausible alternative to imitation is not an "optimal outcome," such as rock against an observed scissors, but rather rock and paper each with probability 1 in 2 against scissors, yielding expected payoff 0, the same as the payoff from imitation.

Although this argument suggests that Cook et al.'s players had no incentive at all to avoid imitation, a subtle "tournament" feature of their reward structure did in fact give players a small incentive. Players did not receive their payoffs for each game or a random subset of games, as is standard in game experiments. Instead, the players were paid an additional £2.50 for each 60-game match won, with no payment for matches lost or drawn. (The players were also paid a £5 show-up fee that did not depend on performance. The experiments were run between September 2007 and November 2008, with £1 ranging from \$1.54 to \$2.02.) Assuming, for simplicity, that players' expected numbers of wins and losses in a game or a match were equal, the fact that they were paid nothing for drawn matches made their expected additional winnings per match £1.25 times the probability that the match was not drawn. Under standard assumptions, the probability of drawing a match decreases with the probability of a draw in any given game in the match. Thus, even though imitation does not reduce the expected payoff in a given game of a subject who can avoid imitation but not otherwise select among gestures, Cook et al.'s payment scheme creates an incentive to avoid imitation. However, with 60 games per match, the probability of a drawn match is very low, and the incentive to avoid imitation is correspondingly very weak. Cook et al. estimated from a subsidiary, filmed treatment that a sighted subject could observe her or his opponent's gesture in time to respond automatically in 17.2% of games. For their payment scheme, for any realistic observation rate (say, less than 40%), the difference between the expected payoffs of responding optimally to all observed gestures and responding randomly is only about £0.0125 per match, less than 3 US cents.

To learn whether Cook et al.'s inference that imitation is automatic holds up under more substantial incentives, we modify their design, replacing their RPS game with a Matching Pennies game and rewarding players' performance game by game (avoiding subtle tournament incentives).

Our subjects, like Cook et al.'s, were randomly grouped into triads, with two of the three playing the game at any given time and the third acting as umpire. In our implementation of Matching Pennies, each player starts with one hand in a neutral position, START in Fig. 1. Players are then asked to show either an OPEN-HAND or a CLOSED-HAND gesture as in Fig. 1, immediately following a count of three by the umpire. The subject designated as Player 1 in Table 2 wins if her or his and the other subject's gestures are the same, and Player 2 wins if the gestures differ (in either way).

Matching Pennies is a zero-sum game, where (as in RPS) one player's win (yielding payoff 1) results in the other's loss (payoff −1), but (unlike in RPS) draws are impossible. The game has no Nash equilibria (combinations of strategies in which each player behaves optimally given what the other does) in pure (unrandomized) strategies: If one player chose a pure strategy (i.e., chose one of the two gestures with probability 1), the second player would have a winning choice and that choice would then make the first player's choice suboptimal. There is a unique Nash equilibrium in mixed strategies, with each player playing each of her or his gestures with probability 1 in 2, so that playing each gesture with probability 1 in 2 is also an optimal response for her or his opponent.

The uniqueness of winning gestures and the fact that there are only two gestures in Matching Pennies allows us to give some players strong incentives to avoid imitation within the game (as

Fig. 1. The START (*A*) position and the OPEN HAND (*B*) and CLOSED HAND (*C*) gestures.

opposed to the match), even if it is possible only for a subject to resist imitating, rather than to select among nonimitative gestures. This factor allows a far stronger test of the hypothesis that imitation is automatic. Matching Pennies also allows us to give other players comparable incentives to imitate, and thereby, in contrast with Cook et al.'s design, the opportunity to find out whether incentives can enhance imitation (i.e., to detect intentional imitation as well as automatic imitation in a strategic context).

Thus, our experimental procedure was designed to mimic Cook et al.'s RPS implementation with three major exceptions. First, instead of asking subjects to make rock, paper, or scissors gestures, we required them to open or close their hand. Cook et al. observed (16) "variability in the salience and distinctiveness of the [RPS] gestures relative to the clenched fist starting position," which may have led to their finding that the imitation effect was strongest for the scissors gesture, weaker for rock, and absent for the paper gesture. In contrast, a number of previous studies, in which there were no incentives to avoid imitation, have reported substantial automatic imitation effects for hand opening and closing (4, 5). Second, the critical comparison in the study by Cook et al. was between games in which one player was sighted (and therefore subject to automatic imitation) and in which both players were blindfolded (and therefore immune to automatic imitation). In contrast, although our subjects were also blindfolded in half of their games, the critical comparison was between the frequency of matching gestures (or of wins) produced by sighted players and chance level. Blindfolded subjects merely presented the gestures that may or may not have been imitated. The frequency of matching responses (and of wins) in blindfolded subjects was necessarily the complement of the frequency of matching responses (and of wins) in their sighted opponents. Third, to find out whether subjects can learn to resist automatic imitation, our analysis compared players' behavior in earlier and later games. Psychological research suggests that, through learning, incentives to match and to mismatch could change the way in which players perceive and react to their opponents' gestures, or even provide a "teaching signal" that transforms the core mechanisms of automatic imitation (15, 20).

As in Cook et al.'s experiment, each of our subjects received £5 for participating, independent of performance. Unlike in Cook et al.'s experiment, each player received an additional 10p per game won, but no further payment for matches won, drawn, or lost. Thus, a subject who won half of the 160 games she or he played would earn an additional £8. If a sighted subject could observe her or his opponent's gesture in time to respond 17.2% of the time, as Cook et al. estimated, the difference between the expected payoffs of responding optimally in all such games and responding randomly is £1.38 per match, more than 100 times larger than in Cook et al.'s design. Over a subject's eight matches in our hour-long experiment, the difference is £11.01, or approximately $17 at the $1.55 exchange rate in December 2011, when we ran our experiments.

Table 2. Matching Pennies game, where (1,−1) denotes a win for player 1 (who wins by matching the other player's gesture) and (−1,1) denotes a win for player 2 (who wins by mismatching)

		Player 2	
		Open hand	Closed hand
Player 1	Open hand	1,−1	−1,1
	Closed hand	−1,1	1,−1

Methods

Our subjects were recruited using Online Recruitment System for Economic Experiments (21) and included 54 healthy students (21 females), almost all of whom started studying at Oxford University in 2010 or 2011. All had normal or corrected-to-normal vision and were naive to the purpose of the experiment, although some had presumably studied game theory. The study was approved by the Nuffield Centre for Experimental Social Sciences Ethics committee and performed in accordance with the ethical standards set out in the 1964 Declaration of Helsinki. Subjects gave informed consent. The experiment took place at the Centre for Experimental Social Sciences at Nuffield College, Oxford, in a well-lit room. Data were collected over five sessions, each lasting ∼60 min.

Detailed instructions were presented to subjects in written handouts at the start of the session. The instructions were then read aloud, giving subjects the opportunity for questions. Using the images in Fig. 1, players were also shown before the start of the experiment what was required in terms of gesture delivery.

Recall that our subjects, like Cook et al.'s, were randomly grouped into triads, with two of the three playing the game at any given time and the third acting as umpire. There were a total of 18 triads. Within each triad, subjects were randomly assigned labels X, Y, or Z. The members of each triad were required to play a total of 12 rounds of games, each consisting of 20 games of Matching Pennies. In the first series of four rounds, series 1 in Table 3, the players were X and Y; in series 2 the players were X and Z; and in series 3 the players were Y and Z. In each round one player was "sighted" and the other blindfolded, with these roles alternating as indicated in Table 3. Each series was preceded by three unpaid practice trials, during which both players were sighted. In each series the triad member who was not a player served as the umpire, recording each game's gestures and outcomes on a paper scoring sheet and announcing them so that the blindfolded player had the same information as the sighted player. Umpires were asked to ensure that blindfolded players were unable to see their opponent and that players were facing each other throughout each round, to prevent deliberately delayed gesture execution, to note any violations of the rules, and to require players to replay any games in which violations were noted. (The umpire ordered a replay in 6.24% of the games.)

Results

Overall, players executed the OPEN-HAND gesture in 50.01% of the rounds and the CLOSED-HAND gesture in 49.99%. Pairwise *t* tests confirm that players executed the gestures with comparable frequencies in each of the four conditions: blindfolded vs. sighted, (P = 0.895) and incentive to match vs. to mismatch (P = 0.339). Note, however, that for the purpose of significance testing, neither the data from individual participants nor player pairings can be treated as independent. A player's matches (or mismatches) in Matching Pennies are perfectly correlated with her or his opponent's matches (or mismatches), and a given subject's idiosyncrasies could influence the outcomes of the two of the three pairings within her or his triad in which she or he played. In the remaining comparisons, we therefore treat the data from each triad as a single independent observation.

Table 4 summarizes the matching and win frequencies for sighted players. Automatic imitation should increase matching

Table 3. Sequence of 12 rounds played by each triad

Series	Triad
Series 1: player X vs. player Y; X wins if gestures do not match; Y wins if gestures match	Player X blindfolded, player Y sighted
	Player X sighted, player Y blindfolded
	Player X blindfolded, player Y sighted
	Player X sighted, player Y blindfolded
Series 2: player X vs. player Z; X wins if gestures match; Z wins if gestures do not match	Player X blindfolded, player Z sighted
	Player X sighted, player Z blindfolded
	Player X blindfolded, player Z sighted
	Player X sighted, player Z blindfolded
Series 3: player Y vs. player Z; Y wins if gestures do not match; Z wins if gestures match	Player Y blindfolded, player Z sighted
	Player Y sighted, player Z blindfolded
	Player Y blindfolded, player Z sighted
	Player Y sighted, player Z blindfolded

frequencies above chance for the sighted player independently of the matching incentives. The appropriate test is therefore a one-tailed t test of the null-hypothesis of frequencies equal chance against the alternative hypothesis of frequencies above chance (>50%). Sighted players match their opponents' gestures more frequently than random whether they have an incentive to match or an incentive to mismatch (one-tailed t test $P = 0.032$). Sighted players therefore win more often over their blindfolded opponents when they have an incentive to match, and are at a slight disadvantage when they have an incentive to mismatch. However, the frequency of matches is only significantly higher than chance for sighted players with an incentive to match (one-tailed t test $P = 0.048$). It is not significant for sighted players with an incentive to mismatch (one-tailed t test $P = 0.29$).

Although Table 4's aggregate matching frequencies may make it seem that there is no significant evidence of automatic imitation, in our design the correct inference is more subtle and depends on the distinction between automatic and intentional responses. Intentional and automatic responses work in the same direction when the sighted player has an incentive to match, but they work in opposite directions, partly offsetting each other, when the sighted player has an incentive to mismatch. The relative frequencies of intentional and automatic imitation can be estimated from the matching frequencies in Table 4 by comparing them under different incentive conditions. Although these estimates ignore the issue of statistical significance, to which we return below, they suggest that there is a substantial frequency of automatic imitation, and probably some intentional imitation as well.

Formally, let p be the frequency that in a given game, the blindfolded subject presents sufficiently earlier to enable the sighted subject to respond (imitate or counter-imitate) intentionally; let q be the frequency that the blindfolded subject presents sufficiently earlier to enable the sighted subject to respond, but only automatically; and let $1 - p - q$ be the frequency with which the sighted subject cannot imitate or counter-imitate either intentionally or automatically. Suppose that intentional responses follow incentives, automatic responses imitate the opponent's gesture without regard to incentives, and subjects otherwise choose gestures randomly. Then sighted subjects with incentives to match should match their opponents' gestures with frequency $p \times 1 + q \times 1 + (1 - p - q) \times 0.5 = 0.5 + p/2 + q/2$ and sighted subjects with incentives to mismatch should match their opponents' gestures with frequency $p \times 0 + q \times 1 + (1 - p - q) \times 0.5 = 0.50 - p/2 + q/2$. The difference between these two frequencies is an estimate of p. (Win frequencies contain the same information and could also be used to estimate p.) Given an estimate of p, either observed matching frequency yields an estimate of q.

Based on Table 4's matching frequencies, $p = 52.13–50.69\% = 1.44\%$ and $q = 2(52.13–50.00\%) - p = 2.82\%$. This result suggests that intentional responses (imitation and counter-imitation) occurred at a nonnegligible rate, but were only half as frequent as automatic ones. The prevalence of automatic over intentional imitation explains why sighted players are at a slight disadvantage when they have an incentive to mismatch.

Note that our calibrated estimate of $p + q = 4.26\%$ is only a quarter of Cook et al.'s estimate of $p + q = q = 17.2\%$, which was based on videotape observation of response asynchronies. (Because Cook et al. did not separate intentional from automatic imitation, their estimate of q is directly comparable to our estimate of $p + q$.) This result suggests that with two response options (open or closed), rather than three (rock, paper, scissors), and therefore less variation in decision time, our subjects responded simultaneously in a higher proportion of trials. Despite this increase in response synchrony, we are able to detect both automatic and intentional imitation.

We can obtain direct estimates of p and q by performing probit regressions on the likelihood that the sighted player would choose a closed gesture (1) or an open gesture (0), conditioning on the gesture of the opponent (closed or open), as well as an interaction between the gesture of the opponent and the players' incentives to match or mismatch. The coefficient corresponding to the opponent's gesture captures the automatic imitation effect (q in our calibration above). The coefficient corresponding to the interaction of the opponent's gesture and the incentives captures the intentional effect (p). We use data at the individual game level, which allows us to control for player fixed-effects and look for effects of timing and experience. All SEs are clustered at the pair level. To look for effects of timing and experience, we ran such regressions not only for the full sample, but also splitting the sample into games played early (games 1–10) in a pairing and late (games 11–20), and then further splitting the sample into games played early in a pairing and late, interacted with whether

Table 4. Matching and winning frequencies

	Matching frequency (P value)	Win frequency (P value)
Sighted with incentive to match	52.13% (0.048)	52.13% (0.05)
Sighted with incentive to mismatch	50.69% (0.29)	49.31% (0.29)

The P values correspond to a one-tailed t test (H_0: frequency = 50%, H_A: frequency > 50%).

the pairing was in an early (rounds 1, 2) or late (rounds 3, 4) round in the experiment. The null hypothesis here is $p = 0$ and $q = 0$, tested against the alternative hypotheses $p > 0$ and $q > 0$, respectively. The appropriate tests are again one-tailed t tests.

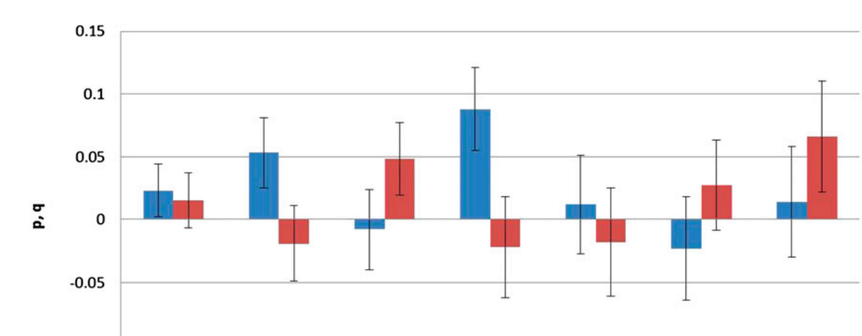
The results of the probit regressions are reported in Table 5 and Fig. 2. As indicated in the central panel of Fig. 2, these results provide compelling evidence of automatic imitation in games 1–10 (i.e., the first 10 games played against each opponent), and of intentional behavior, responsive to incentives, in games 11–20 (i.e., in the last 10 games played against each opponent). More speculatively, the right-hand side of Fig. 2 suggests that the ascendency of intentional responding over automatic imitation between earlier (games 1–10) and later (games 11–20) games occurs initially in rounds 1 and 2, when each player has their first experience of the matching and nonmatching incentives. Automatic imitation appears to be restored to some extent in the earlier games of rounds 3 and 4, and then to be replaced almost entirely by intentional responding in the later games of rounds 3 and 4. Overall, the split-sample regressions show that Fig. 2's full-sample effects are driven mainly by games played early in a pairing.

Discussion

In games such as Matching Pennies and RPS, players are formally required to present their gestures simultaneously, but absolute simultaneity in every game is not possible in practice. Following Cook et al. (16), who made direct recordings of gesture asynchronies, we inferred through the above calibration of p and q that one of the players frequently presented her or his gesture slightly earlier than the other. When it was the blindfolded player who presented earlier, automatic imitation, or even in some cases an intentional response may have been feasible for the sighted player. Our results indicate that sighted players of Matching Pennies exhibit a significant tendency toward automatic imitation of their opponent's gestures, even when such imitation goes against strong incentives; but they also exhibit a smaller but still significant tendency toward intentional responses, either imitation or counter-imitation depending on incentives. Furthermore, our results indicate that whereas automatic imitation dominates in earlier games, this tendency is largely superseded by intentional responding in games played later in the series.

Our findings are in accord with those of Cook et al. (16), and are inconsistent with a recent study challenging the view that automatic imitation occurs in strategic contexts (19). The latter study, by Aczel, Bago and Foldes, used a RPS procedure similar to that of Cook et al., but failed to find a higher frequency of draws when one player was sighted than when both players were blindfolded. Our study suggests that this failure to replicate Cook et al.'s result is likely to be because of two factors. First, in the Cook et al. study subjects produced the three gestures with equal frequency, but in the Aczel et al. (19) study the scissors gesture was produced significantly more often than either paper or scissors. Second, in contrast with Cook et al., Aczel et al. required their subjects to "bob"; before gesture delivery in each game, the subject had to move her or his fist down and then back up toward the chest in time to the umpire's count of three. This bobbing requirement is likely to have reduced very substantially the number of games in which one player presented her or his gesture earlier than the other, and therefore the opportunities for automatic imitation. By showing that automatic imitation occurs against strong financial incentives—the costs of automatic imitation were more than 100-times larger in our study than in the experiment by Cook et al.—the results of the present study provide truly compelling evidence that automatic imitation occurs in strategic contexts.

Our results are also unique in showing that experience with matching and nonmatching incentives can enable players to resist the "irrational" tendency toward automatic imitation. Recall that in earlier games players showed automatic imitation, and in later games their behavior was responsive to incentives. This result suggests that learning occurred in the earlier games. For example, players could have learned to focus on their opponent's gesture when they had an incentive to match, and to avoid looking at their opponent's gesture when they had an incentive to mismatch. This variation in attention to the opponent's gesture would enable automatic imitation to boost performance in the matching condition, and prevent automatic imitation from interfering with performance in the nonmatching condition. Alternatively, experience with the matching and nonmatching incentives could have had a more profound effect on the psychological and neural mechanisms that control automatic imitation. A substantial body of evidence suggests that mirror neurons are motor neurons (cells that were originally involved only in the production of actions) that are linked in an excitatory way to visual neurons that encode the same body movement (cells that were originally involved only in perception of the body movement), and that the visual and motor neurons become linked, and thereby produce a mirror neuron, through experience in which the same action is simultaneously observed and executed (20). If this theory is correct, it raises the possibility that experience with nonmatching incentives "rewires" a part of the mirror neuron system. For example, when players are rewarded by winning the game after responding to an OPEN-HAND gesture with a CLOSED-HAND gesture, this may strengthen a new, excitatory link between a visual neuron coding hand opening and a motor neuron coding hand closing. As a result, the motor neuron would become responsive in some strategic



	All sample	Games 1-10	Games 11-20	Games 1-10 & Rounds 1-2	Games 1-10 & Rounds 3-4	Games 11-20 & Rounds 1-2	Games 11-20 & Rounds 3-4
automatic (p)	0.023	0.053	-0.008	0.088	0.012	-0.023	0.014
intentional (q)	0.015	-0.019	0.048	-0.022	-0.018	0.027	0.066

Fig. 2. Estimated intentional and automatic responses, for early vs. late games. Probit regression coefficients ± 1 SE corresponding to probit regressions with player fixed-effects and SEs clustered at the pair level.

Table 5. Probit regressions determining probability that sighted player chooses CLOSED HAND

	1	2	3	4	5	6	7
	All sample	Early games (1–10)	Late games (11–20)	Early games (1–10); early rounds (1 and 2)	Late games (11–20); early rounds (1 and 2)	Early games (1–11); late rounds (3 and 4)	Late games (11–20); late rounds (3 and 4)
Blind-folded player executes CLOSED HAND	0.023 (0.021)	0.053 (0.028)**	−0.008 (0.032)	0.088 (0.033)***	−0.023 (0.041)	0.012 (0.039)	0.014 (0.044)
Sighted player Incentives to match and blindfolded player executes CLOSED HAND	0.015 (0.022)	−0.019 (0.030)	0.048 (0.029)**	−0.022 (0.040)	0.027 (0.036)	−0.018 (0.043)	0.066* (0.044)
Sighted player fixed-effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
No. observed	4,320	2,160	2,160	1,080	1,080	1,080	1,080

Probit regression coefficients, with SEs in parentheses, clustered at the pair level. *, **, and *** indicates *P* values below 10%, 5% and 1%, respectively (one-tailed *t* test).

contexts to observation of one action and performance of a different action; in these contexts it would have "counter-mirror" rather than "mirror" properties, and contribute to automatic counter-imitation (22). Evidence that this kind of "rewiring" can occur after a brief period of learning, comparable to that of the present study, comes from studies detecting counter-mirror activity in classic "mirror areas" of the brain using functional imaging (23) and transcranial magnetic stimulation (24).

Previous studies have indicated that automatic imitation, like synchronous activity (25), can increase the probability that players will cooperate in subsequent games (26, 27). Our results, like Cook et al.'s, raise the possibility that under some circumstances choice can be involuntary, so that automatic imitation can influence behavior in strategic contexts via an additional route, by changing the structure of the game itself. If this theory is correct, automatic imitation might override the incentive constraints that in theory prevent cooperative outcomes in games such as the Prisoners' Dilemma. In other possibilities, trading on a floor with open outcry and imitable buy and sell gestures might be more conducive to herding than an analogous electronic market, thereby increasing volatility. At the broadest level, it is noteworthy that this study not only used research in psychology and neuroscience to cast light on the kinds of strategic interactions that are of particular interest to economists, but also used analytic techniques from economics to gain empirical traction on a distinction—between automatic and intentional imitation—that plays a key role in psychological theorizing. It therefore underlines the mutual benefit of combining methods and concepts from neighboring social and natural sciences.

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