

Automatic imitation in a strategic context: players of rock–paper–scissors imitate opponents' gestures

Richard Cook, Geoffrey Bird, Gabriele Lünser, Steffen Huck and Cecilia Heyes

Proc. R. Soc. B published online 20 July 2011
doi: 10.1098/rspb.2011.1024

References

[This article cites 37 articles, 10 of which can be accessed free](#)

<http://rspb.royalsocietypublishing.org/content/early/2011/07/12/rspb.2011.1024.full.html#ref-list-1>

P<P

Published online 20 July 2011 in advance of the print journal.

Subject collections

Articles on similar topics can be found in the following collections

[behaviour](#) (713 articles)
[cognition](#) (147 articles)
[neuroscience](#) (135 articles)

Email alerting service

Receive free email alerts when new articles cite this article - sign up in the box at the top right-hand corner of the article or click [here](#)

Advance online articles have been peer reviewed and accepted for publication but have not yet appeared in the paper journal (edited, typeset versions may be posted when available prior to final publication). Advance online articles are citable and establish publication priority; they are indexed by PubMed from initial publication. Citations to Advance online articles must include the digital object identifier (DOIs) and date of initial publication.

To subscribe to *Proc. R. Soc. B* go to: <http://rspb.royalsocietypublishing.org/subscriptions>

Automatic imitation in a strategic context: players of rock–paper–scissors imitate opponents' gestures[†]

Richard Cook^{1,*}, Geoffrey Bird², Gabriele Lünser^{3,4}, Steffen Huck^{3,4}
and Cecilia Heyes^{1,4,5}

¹*Cognitive, Perceptual and Brain Sciences Research Department, University College London, London W1H 0AP, UK*

²*School of Psychology, Birkbeck College, University of London, Malet Street, London WC1E 7HX, UK*

³*Department of Economics, and* ⁴*ESRC Centre for Economic Learning and Social Evolution (ELSE), University College London, London WC1E 6BT, UK*

⁵*All Souls College and Department of Experimental Psychology, University of Oxford, Oxford OX1 4AL, UK*

A compelling body of evidence indicates that observing a task-irrelevant action makes the execution of that action more likely. However, it remains unclear whether this 'automatic imitation' effect is indeed automatic or whether the imitative action is voluntary. The present study tested the automaticity of automatic imitation by asking whether it occurs in a strategic context where it reduces payoffs. Participants were required to play rock–paper–scissors, with the aim of achieving as many wins as possible, while either one or both players were blindfolded. While the frequency of draws in the blind–blind condition was precisely that expected at chance, the frequency of draws in the blind–sighted condition was significantly elevated. Specifically, the execution of either a rock or scissors gesture by the blind player was predictive of an imitative response by the sighted player. That automatic imitation emerges in a context where imitation reduces payoffs accords with its 'automatic' description, and implies that these effects are more akin to involuntary than to voluntary actions. These data represent the first evidence of automatic imitation in a strategic context, and challenge the abstraction from physical aspects of social interaction typical in economic and game theory.

Keywords: rock–paper–scissors; zero-sum game; automatic imitation; game theory; mirror neuron system

1. INTRODUCTION

Reports of apparently unconscious, spontaneous mimicry date back several centuries. Recently, these effects have been described as 'automatic imitation' and attributed to a human mirror neuron system (MNS) [1]. While this description implies that such imitation is somehow involuntary or stimulus-driven, there is surprisingly little direct evidence supporting this characterization. For example, no previous studies have explicitly asked participants not to imitate or penalize imitative behaviours. The present study adopts the novel approach of using a strategic context to assess the automaticity of the tendency to imitate. Specifically, we sought to determine whether players of 'rock–paper–scissors' (RPS) imitate the gestures of their opponents in a game where the only way to win is to *avoid* imitating your opponent.

Neurons have been discovered in the macaque pre-motor and parietal cortices that respond both to the

sight and execution of a given action [2–4]. Since the discovery of these 'mirror neurons' in the macaque, considerable evidence has amassed suggesting that humans also have an MNS [5,6]. The human MNS has been implicated in a range of social functions, including action understanding, empathy and theory of mind [7,8]. However, one of the most plausible functions of the human MNS is the mediation of a range of imitative or mirror effects that may be broadly described as automatic imitation.

In the most straightforward cases, automatic imitation is overt—the sight of an action elicits visible execution of the same movement. Experimental demonstrations of such overt imitation date back to Eidelberg [9] and Hull [10]. Early researchers were hampered by methodological problems, but more recent research has confirmed that humans often spontaneously and overtly imitate the topography of each other's behaviour [11–13]. For example, participants are more likely to engage in foot-tapping than face-touching behaviours in the presence of a foot-tapping confederate, while the opposite pattern is observed in the presence of a confederate prone to touch their face [11].

In addition to reports of overt automatic imitation, further imitative effects may be too subtle to be detected by the naked eye. Insight into such covert mimicry has been provided through the use of electromyography

* Author for correspondence (r.cook@ucl.ac.uk).

[†] Cook conducted experimental sessions; contributed to the data analysis and interpretation; wrote the first draft of the paper. Bird contributed to the design of the experiment; conducted experimental sessions. Lünser contributed to the design, data analysis and second draft of the paper. Huck provided the idea for the study; contributed to the design, data analysis, interpretation and second draft of the paper. Heyes contributed to the design, data analysis and interpretation; wrote the final draft of the paper.

(EMG), a technique that allows researchers to measure subtle muscle movements [14–16]. This paradigm has been used to demonstrate imitative effects following extremely brief (30 ms) stimulus exposures [17]. EMG has also been used in conjunction with transcranial magnetic stimulation (TMS) to record motor-evoked potentials (MEPs). When TMS is applied to observers' primary motor cortex during action observation, selectively enhanced MEPs are elicited from muscles recruited by the observed action [18,19].

A covert tendency to imitate has also been detected using reaction time (RT) measures [20–22]. For example, Heyes *et al.* [21] found that participants were faster to make hand opening responses to the onset of hand opening stimuli than to the onset of hand closing, and confirmed that this effect is truly imitative; it depends on the topography of observed action—on how body parts move relative to one another—not merely on the position of the action relative to an external frame of reference (spatial compatibility). That participants make faster imitative responses than non-imitative responses is an extremely robust effect, having been found across several effector systems [23,24], for both transitive [25] and intransitive actions [26,27].

The imitative effects described above represent compelling evidence that the sight of an action facilitates the motor execution of that action. However, it remains unclear just how *automatic* these 'automatic' imitation effects really are [1]. Two criteria that have been applied to assess the automaticity of a psychological process are awareness and intentionality [28]. Previous studies confirm that overt imitation often manifests without the conscious knowledge of the actor. For example, participants imitate face-touching and foot-shaking behaviours, despite failing to notice the mannerisms modelled by the confederate [11]. Similarly, while the magnitude of imitative effects on RT is subject to attentional modulation [29,30], these effects are present even when action stimuli are not the focus of attention [24].

It is more uncertain whether 'automatic imitation' is automatic in the sense of being involuntary. Actions may be thought of as forming a continuum, with voluntary actions at one extreme and automatic reflexes at the other [31]. Reflexes, such as the classic knee-jerk response, are immediate reactions automatically triggered by an external event. Such actions are involuntary; that is, they cannot be inhibited. In contrast, voluntary actions are only very indirectly elicited by an external stimulus and can, by definition, be inhibited. We do not yet know how difficult it is to inhibit automatic imitation. This is because, in previous studies, participants had little or no incentive to inhibit imitative responses. In studies conducted in naturalistic settings, there were no costs associated with imitative behaviour [11], and in more tightly controlled experiments, imitative tendencies interfered with participants' capacity to obey task instructions, but did not incur any further penalties [20]. For example, in experiments where participants were instructed to respond as quickly as possible, they reacted more slowly when their response did not match the action stimulus. However, they received the same honorarium at the end of the experiment, regardless of their response speed.

In the present experiment, we adopted the entirely novel approach of studying automatic imitation in a

Table 1. The rock–paper–scissors 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 1	player 2		
	rock	paper	scissors
rock	0,0	–1,1	1,–1
paper	1,–1	0,0	–1,1
scissors	–1,1	1,–1	0,0

naturalistic, strategic context. To find out how difficult it is to inhibit imitative responding, we observed participants while they played RPS—a game in which imitative responding is suboptimal. While it has been observed that competitors may emulate the strategies of rivals [32–34], automatic imitation, whereby individuals copy the topography of rivals' body movements, has never been demonstrated in a strategic context.

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.

The present study sought to determine whether performance in RPS is influenced by automatic imitation. To address this question, players' performance was compared under two conditions. In the first condition, one of the players was blindfolded and the other sighted. In the second condition, both players were blindfolded. Blindfolded players cannot see and therefore cannot imitate their opponent. Consequently, if there is an effect of imitation, one would expect the proportion of draws to exceed a third in the blind–sighted condition, but not in the blind–blind condition.

2. EXPERIMENTAL DESIGN AND PROCEDURES

Forty-five healthy adults (23 females) with a mean age of 24.9 years served as participants in the experiment. All had normal or corrected-to-normal vision, were familiar with the game, and were naive to the purpose of the experiment. None had studied economics at undergraduate level or higher.

The experiment took place at the ELSE Laboratory, University College London, in a large, well-lit room. Data were collected over three sessions, each lasting approximately 70 min. Written instructions were presented at the start of the session, including a recapitulation of the rules of RPS. The participants, recruited with ORSEE [35], were assigned to triads at random. Six of the triads comprised two males and a

Table 2. The sequence of the nine matches played by each triad.

player A versus player B	player A blindfolded player B blindfolded both players blindfolded
player A versus player C	player C blindfolded player A blindfolded both players blindfolded
player B versus player C	player B blindfolded player C blindfolded both players blindfolded

female, four comprised two females and a male and two comprised three males and three comprised three females. Within each triad, participants were arbitrarily designated A, B and C. Triads were required to play nine matches of RPS, each comprising 20 individual rounds. The first three matches were between players A and B, the second set of three matches were between A and C and the final three between B and C. Matches were played under two conditions; either with one player sighted and one blindfolded, or with both players blindfolded. The sequence of matches is summarized in table 2. The third member of the triad, not involved in the match-pairing, recorded the gestures and outcomes using a computerized scoring sheet, and acted as umpire.

Prior to the delivery of each gesture, players sat facing each other, presenting a clenched fist in front of their body. Following a count of three made by the umpire, players were required to deliver their gestures simultaneously. Consequently, any effect of automatic imitation was due to naturally occurring asynchronies between the onsets of the two players' gestures. Umpires were asked to ensure that blindfolded players were unable to see their opponent; to ensure that players were facing each other throughout each round; to inform blind players of gestures made; and to state aloud the outcome of each round. The presence of an umpire also prevented cheating in the form of deliberately delayed gesture execution. Players were shown what was expected in terms of gesture delivery prior to the experiment.

Each participant received a small honorarium for participating (£5), which was supplemented by an additional payment based on their performance in the experiment. Participants were informed at the start that the player who achieved the greater number of wins within each 60-round match would receive an additional £2.50 win bonus. However, if a match was tied, neither player would receive any bonus. Players could therefore finish the experiment with total bonuses of £0, £2.50 or £5.00. Because a tied match was a suboptimal outcome for both players, this payment structure ensured that the Nash Equilibrium was in mixed strategies. While players may have preferred to draw a round than to lose, the optimal outcome could only be achieved by avoiding draws. In order to establish or extend a lead in the match, or reduce one's arrears, it was necessary to *win* rounds.

3. RESULTS

Data from one of the triads were excluded because participants did not follow the experimental procedure

Table 3. Distribution of the three gestures for the blind-sighted games, the blind-blind games and collapsed across all manipulations.

	rock (%)	paper (%)	scissors (%)
blind-sighted	32.1	33.1	34.8
blind-blind	32.8	33.5	33.7
overall	32.4	33.3	34.4

Table 4. Summary of the outcomes observed across the 14 triads.

	mean	s.d.
blind-sighted		
blind wins (%)	32.4	4.1
sighted wins (%)	31.3	2.9
draws (%)	36.3	4.6
blind-blind		
wins (%)	66.7	5.0
draws (%)	33.3	5.0

correctly—blindfolded players were not informed of their opponents' gestures. The analyses reported were conducted on the data from the remaining 14 triads. A further two data points were lost from the blind-sighted condition owing to participant error. For the purpose of significance testing, neither the data from individual participants nor player pairings can be regarded as independent. As with all zero-sum games, a player's outcomes on RPS are perfectly (negatively) correlated with their opponent's. Moreover, each player was a member of two of the three pairings within each triad. Thus, any tendency of a given individual could influence two pairings. The analyses reported, therefore, reflect the conservative approach of treating the data from each triad as a single observation.

Across the whole experiment, the rock gesture was executed on 32.4 per cent of rounds, the paper gesture on 33.3 per cent of rounds and the scissors gesture on 34.4 per cent of rounds (table 3). One-way ANOVA with gesture as a within-triad factor confirmed that the 14 triads executed the three gestures with comparable frequency in both the blind-sighted ($F_{2,26} = 1.24$; $p > 0.30$) and blind-blind conditions ($F_{2,26} = 0.117$; $p > 0.80$).

The outcomes obtained by the 14 triads across the two conditions are summarized in table 4. One-tailed tests were used to assess the prediction that the proportion of draws in the blind-sighted condition would be greater than chance and greater than the proportion of draws in the blind-blind condition. Given the task requirements, the alternative result—e.g. fewer drawers than expected by chance in the blind-sighted conditioning—would not be intelligible. It would imply a tendency to deliberately counterimitate one's blindfolded opponent, but response asynchronies long enough to allow this kind of intentional response selection would have been detected and disqualified by the umpire [36,37]. Thus, the task permitted response asynchronies long enough for automatic imitation (see below), but too short for deliberate counter imitation. Indeed, blind players actually won slightly more of the blind-sighted rounds (32.4%) than

Table 5. Logistic regressions conducted on the tendency of the sighted player to imitate the blindfolded player.

	β	s.e.	p -value (one-tailed)
sighted player chooses rock			
blindfolded player executes rock			
rock	0.245	0.134	0.034
constant	-0.874	0.069	0
sighted player chooses paper			
blindfolded player executes paper			
paper	0.086	0.162	0.298
constant	-0.677	0.061	0
sighted player chooses scissors			
blindfolded player executes scissors			
scissors	0.266	0.105	0.006
constant	-0.737	0.066	0

the sighted players (31.3%), with only five of the 14 triads producing a greater number of sighted wins than blind wins.

Of principal interest, there was clear evidence of a tendency for the sighted player to imitate the blindfolded player (i.e. to choose the same gesture). As predicted by the imitation hypothesis, there was a greater number of draws in the blind-sighted (36.3%) than in the blind-blind (33.3%) conditions across the 14 triads. One-sample t -tests revealed that the proportion of draws was significantly above that expected at chance in the blind-sighted condition ($t_{13} = 2.49$; $p < 0.025$ (one-tailed)) but not in the blind-blind condition ($t_{13} = 0.07$; $p > 0.90$ (one-tailed)). In the latter case, the frequency of draws was almost exactly that expected by chance. Moreover, a paired-samples t -test revealed that the frequency of draws was significantly higher in the blind-sighted than in the blind-blind condition ($t_{13} = 1.72$; $p = 0.05$ (one-tailed)).

In order to better understand the elevated frequency of draws in the blind-sighted condition, we performed logistic regressions on sighted players' likelihood to imitate. We ran three such regressions, shown in table 5. Each regression estimated the likelihood that the sighted player would imitate depending on whether or not the blindfolded player chose one of the three actions (with robust standard errors and clustering by triad). The regressions revealed that the execution of a scissors gesture by the blindfolded player significantly increased the probability that the sighted player would also choose scissors ($\beta = 0.266$; $p < 0.01$ (one-tailed)). A similar effect was observed when the blindfolded player chose rock ($\beta = 0.245$; $p < 0.05$ (one-tailed)), but not when the blindfolded player chose paper ($\beta = 0.086$; $p > 0.25$ (one-tailed)). The contingencies between the gestures of the blind and sighted players are represented in figure 1.

The proportion of draws did not differ from chance when both players were blindfolded, implying that the elevated proportion of draws in the blind-sighted condition was not owing to players adopting correlated gesture-selection strategies. Nevertheless, as a further check for response strategies, we calculated how often sighted players replicated the gestures presented by the blind player on the n th-1 and n th-2 trials. However, the

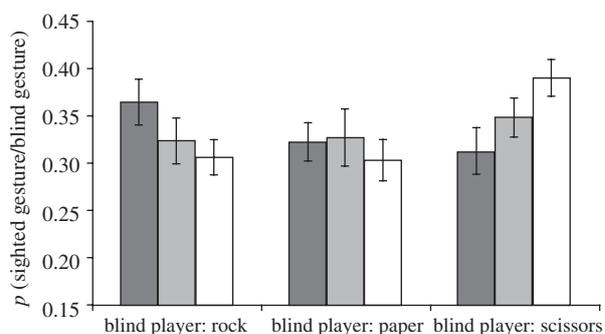


Figure 1. The mean probabilities that each gesture was executed by the sighted player given the gesture executed by the blindfolded opponent across the 14 triads. Error-bars represent standard error of the mean. Dark grey bars, sighted player: rock; light grey bars, sighted player: paper; open bars, sighted player: scissors.

rate at which sighted players replicated the gestures observed in the previous round (27.2%) ($t_{13} = 2.11$, $p > 0.05$ (two-tailed)) or from two rounds earlier (34.3%) ($t_{13} = 0.78$, $p > 0.40$ (two-tailed)) did not depart from chance levels.

Unlike most economic games, RPS is commonly played in everyday life. To ensure that our results were representative of these naturalistic conditions, we did not film the players in the main experiment or record their RTs using an EMG. However, to estimate the magnitude and distribution of their response asynchronies, we conducted an ancillary experiment in which a further four pairs of participants (mean age = 21.8 years) were filmed while playing 80 rounds of RPS in the blind-sighted condition. Two of the pairs comprised female players and two comprised mixed-sex pairings. Each pair played rounds 1–20 and 41–60 with player A blindfolded; and rounds 21–40 and 61–80 with player B blindfolded. As in the main experiment, a win bonus of £2.50 was available for winning the overall match. Participants were filmed from the side at 60 frames-per-second using a Point Grey Grasshopper digital camera. Response onset was taken as the earliest frame when the player's gesture could be identified. The proportion of draws observed in three of the four pairs again exceeded a third, with 35.0 per cent of trials drawn overall. The blindfolded player initiated his or her gesture before the sighted player in 44.7 per cent of rounds, and this positive asynchrony exceeded 200 ms—the minimum required for automatic imitation—in 17.2 per cent of rounds (figure 2). That the positive tail of each pair's distribution exceeded 200 ms provides further support for the view that the draws effect observed in the principal experiment was due to automatic imitation.

4. DISCUSSION

The results of this study indicate that players of RPS tend to imitate their opponents, in spite of the costs associated with imitation in this game. Consistent with this hypothesis, we found a higher frequency of draws when one player could see the other than when both players were blindfolded (a 'draws effect'), and that the execution of the scissors and rock gestures by the blind players predicted the execution of matching gestures by their sighted opponents.

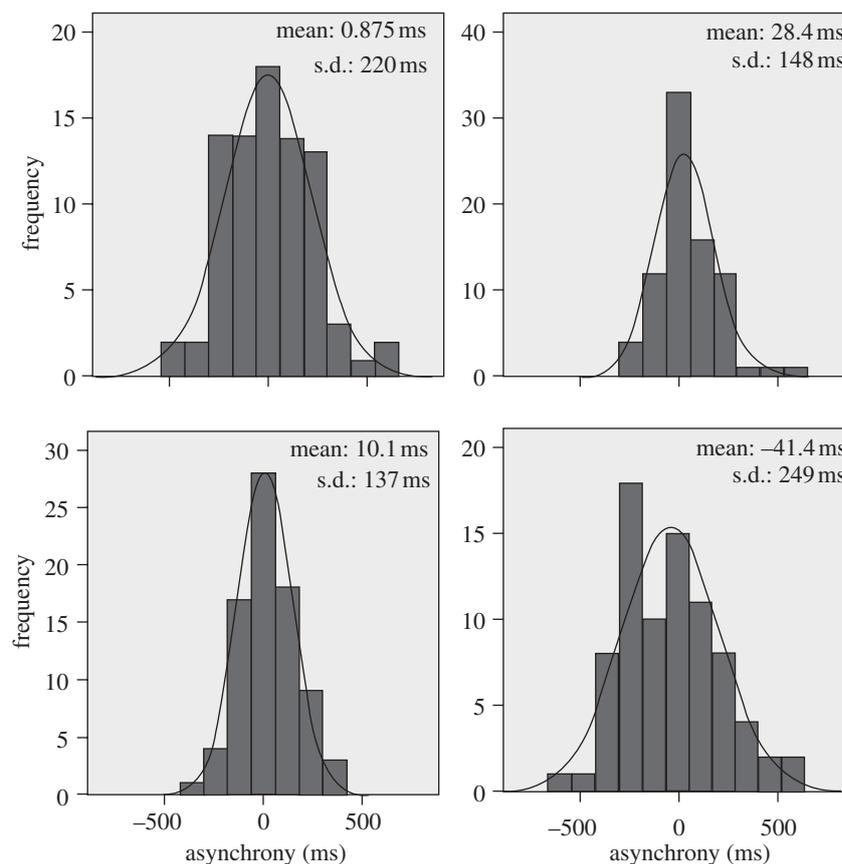


Figure 2. Distributions of asynchronies observed for the four pairs subject to analysis. Positive asynchronies denote rounds where the blind player delivered their gesture ahead of the sighted player; negative asynchronies denote rounds where the sighted player delivered first.

Although players of RPS are formally required to present their gestures simultaneously, we found that one of the players frequently presents slightly earlier than the other. Our results suggest that, on those rounds where the blind player delivered their gesture first, observation of this gesture activated in their opponent a motor representation of the same action. This motor activation made the opponent more likely to select the imitative response relative to the two alternative actions. Thus, it appears that the psychological mechanisms responsible for the higher frequency of draws in our blind-sighted condition are comparable with those that generate automatic imitation [11–13,17,20–22].

An account of the draws effect based on automatic imitation is consistent with evidence from neuroimaging paradigms. Specifically, it appears that playing RPS recruits areas of the human MNS, including the ventral premotor cortex and intraparietal sulcus [38]. Given that the MNS is thought to mediate automatic imitation [1,6,39], these results provide a further indication that players of RPS may be subject to an imitative bias.

To produce the draws effect in games of RPS, automatic imitation must occur very rapidly. That is, perception of the opponent's action and activation of a corresponding motor representation must occur in less than a second. Carefully controlled studies of automatic imitation confirm that this is possible. EMG recording from facial muscles while participants view backward-masked facial expressions have revealed expression-specific muscle activation following a stimulus exposure of only 30 ms

[17]. Similarly, participants execute imitative gestures faster than comparable non-imitative responses even when mean RTs are 200–400 ms [20–22]. Moreover, automatic responses that are 'triggered' by an external event, such as an observed action, are executed faster than voluntary actions [37]. That asynchronies in the order of 200–600 ms were frequently observed in the ancillary experiment therefore ensures that automatic imitation is a plausible account of the draws effect.

Our analyses suggest that the imitation effect was strongest for the scissors gesture, weaker for the rock gesture and absent for the paper gesture. This may have been owing to variability in the salience and distinctiveness of the gestures relative to the clenched fist starting position. The scissors gesture, from which there are two protruding fingers, is very different from a clenched fist, and the execution of the rock gesture typically involves an abrupt thrusting movement of the hand towards the player's opponent.

The tendency to imitate need not be overwhelming. It is hard to generate behaviour randomly under conditions that promote prepotent responses. Even apparently simple tasks, such as the generation of random sequences of numbers or letters, can prove surprisingly demanding when individuals must inhibit prepotent sequences such as '1-2-3' or 'A-B-C' [40]. The execution of truly random responses during RPS may require the inhibition of prepotent imitative responses. Factors such as time pressure, boredom and fatigue may hinder players' ability to inhibit imitative responding. On those trials where

players are undecided as to which gesture to execute, these factors may cause the prepotent imitative response to manifest as overt imitation.

The draws effect observed in this experiment provides evidence that automatic imitation is 'automatic' in the sense of being very difficult to inhibit. Only by avoiding imitation could pairs maximize their chances of achieving the win bonus. Thus, players imitated their opponents' actions despite having a financial incentive to avoid imitation. More broadly, our results challenge the tendency in economic and game theory to ignore, or abstract away, the physical aspects of social interaction. The draws effect shows that physical factors are not only important in complicated strategic interactions, where strong emotional drivers such as fairness, trust and reputation play a role. Rather, the embodied aspects of cognition play a significant role even at the simplest level of game playing, and when they work against players' interests.

The study was approved by the University College London ethics committee and performed in accordance with the ethical standards set out in the 1964 Declaration of Helsinki.

This research was supported by the Economic and Social Research Council (ESRC) research centre for Economic Learning and Social Evolution (ELSE).

REFERENCES

- Heyes, C. 2011 Automatic imitation. *Psychol. Bull.* **137**, 463–483. (doi:10.1037/a0022288)
- di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V. & Rizzolatti, G. 1992 Understanding motor events: a neurophysiological study. *Exp. Brain Res.* **91**, 176–180.
- Gallese, V., Fadiga, L., Fogassi, L. & Rizzolatti, G. 1996 Action recognition in the premotor cortex. *Brain* **119**, 593–609. (doi:10.1093/brain/119.2.593)
- Rizzolatti, G., Fadiga, L., Gallese, V. & Fogassi, L. 1996 Premotor cortex and the recognition of motor actions. *Cogn. Brain Res.* **3**, 131–141. (doi:10.1016/0926-6410(95)00038-0)
- Gazzola, V., Rizzolatti, G., Wicker, B. & Keysers, C. 2007 The anthropomorphic brain: the mirror neuron system responds to human and robotic actions. *Neuroimage* **35**, 1674–1684. (doi:10.1016/j.neuroimage.2007.02.003)
- Iacoboni, M., Woods, R. P., Brass, M., Bekkering, H., Mazziotta, J. C. & Rizzolatti, G. 1999 Cortical mechanisms of human imitation. *Science* **286**, 2526–2528. (doi:10.1126/science.286.5449.2526)
- Gallese, V. & Goldman, A. 1998 Mirror neurons and the simulation theory of mind-reading. *Trends Cogn. Sci.* **2**, 493–501. (doi:10.1016/S1364-6613(98)01262-5)
- Rizzolatti, G. & Craighero, L. 2004 The mirror-neuron system. *Annu. Rev. Neurosci.* **27**, 169–192. (doi:10.1146/annurev.neuro.27.070203.144230)
- Eidelberg, L. 1929 Experimenteller Beitrag zum Mechanismus der Imitationsbewegung. *Jahresbucher Psychiatr. Neurol.* **45**, 170–173.
- Hull, C. 1933 *Hypnosis and suggestibility*. New York, NY: Appleton-Century.
- Chartrand, T. L. & Bargh, J. A. 1999 The chameleon effect: the perception–behavior link and social interaction. *J. Pers. Soc. Psychol.* **76**, 893–910. (doi:10.1037/0022-3514.76.6.893)
- Lakin, J. L. & Chartrand, T. L. 2003 Using nonconscious behavioral mimicry to create affiliation and rapport. *Psychol. Sci.* **14**, 334–339. (doi:10.1111/1467-9280.14481)
- Lakin, J. L., Chartrand, T. L. & Arkin, R. M. 2008 I am too just like you: nonconscious mimicry as an automatic behavioral response to social exclusion. *Psychol. Sci.* **19**, 816–822. (doi:10.1111/j.1467-9280.2008.02162.x)
- Berger, S. M. & Hadley, S. W. 1975 Some effects of a model's performance on an observer's electromyographic activity. *Am. J. Psychol.* **88**, 263–276. (doi:10.2307/1421596)
- Blairy, S., Herrera, P. & Hess, U. 1999 Mimicry and the judgment of emotional facial expressions. *J. Nonverbal Behav.* **23**, 5–41. (doi:10.1023/A:1021370825283)
- Dimberg, U. 1982 Facial reactions to facial expressions. *Psychophysiology* **19**, 643–647. (doi:10.1111/j.1469-8986.1982.tb02516.x)
- Dimberg, U., Thunberg, M. & Elmehed, K. 2000 Unconscious facial reactions to emotional facial expressions. *Psychol. Sci.* **11**, 86–89. (doi:10.1111/1467-9280.00221)
- Fadiga, L., Fogassi, L., Pavesi, G. & Rizzolatti, G. 1995 Motor facilitation during action observation: a magnetic stimulation study. *J. Neurophysiol.* **73**, 2608–2611.
- Strafella, A. P. & Paus, T. 2000 Modulation of cortical excitability during action observation: a transcranial magnetic stimulation study. *Neuroreport* **11**, 2289–2292. (doi:10.1097/00001756-200007140-00044)
- Brass, M., Bekkering, H. & Prinz, W. 2001 Movement observation affects movement execution in a simple response task. *Acta Psychol.* **106**, 3–22. (doi:10.1016/S0001-6918(00)00024-X)
- Heyes, C., Bird, G., Johnson, H. & Haggard, P. 2005 Experience modulates automatic imitation. *Cogn. Brain Res.* **22**, 233–240. (doi:10.1016/j.cogbrainres.2004.09.009)
- Sturmer, B., Aschersleben, G. & Prinz, W. 2000 Correspondence effects with manual gestures and postures: a study of imitation. *J. Exp. Psychol. Hum. Percept. Perform.* **26**, 1746–1759. (doi:10.1037/0096-1523.26.6.1746)
- Gillmeister, H., Catmur, C., Liepelt, R., Brass, M. & Heyes, C. 2008 Experience-based priming of body parts: a study of action imitation. *Brain Res.* **1217**, 157–170. (doi:10.1016/j.brainres.2007.12.076)
- Leighton, J. & Heyes, C. 2010 Hand to mouth: automatic imitation across effector systems. *J. Exp. Psychol. Hum. Percept. Perform.* **36**, 1174–1183. (doi:10.1037/a0019953)
- Craighero, L., Bello, A., Fadiga, L. & Rizzolatti, G. 2002 Hand action preparation influences the responses to hand pictures. *Neuropsychologia* **40**, 492–502. (doi:10.1016/S0028-3932(01)00134-8)
- Bertenthal, B. I., Longo, M. R. & Kosobud, A. 2006 Imitative response tendencies following observation of intransitive actions. *J. Exp. Psychol. Hum. Percept. Perform.* **32**, 210–225. (doi:10.1037/0096-1523.32.2.210)
- Press, C., Bird, G., Walsh, E. & Heyes, C. 2008 Automatic imitation of intransitive actions. *Brain Cogn.* **67**, 44–50. (doi:10.1016/j.bandc.2007.11.001)
- Neumann, O. 1984 Automatic processing: a review of recent findings and a plea for an old theory. In *Cognition and motor processes* (eds W. Prinz & A. F. Sanders), pp. 255–293. Berlin, Germany: Springer.
- Bach, P., Peatfield, N. A. & Tipper, S. P. 2007 Focusing on body sites: the role of spatial attention in action perception. *Exp. Brain Res.* **178**, 509–517. (doi:10.1007/s00221-006-0756-4)
- Chong, T. T., Cunnington, R., Williams, M. A. & Mattingley, J. B. 2009 The role of selective attention in matching observed and executed actions. *Neuropsychologia* **47**, 786–795. (doi:10.1016/j.neuropsychologia.2008.12.008)
- Haggard, P. 2008 Human volition: towards a neuroscience of will. *Nat. Rev. Neurosci.* **9**, 934–946. (doi:10.1038/nrn2497)

- 32 Apesteguia, J., Huck, S. & Oechssler, J. 2007 Imitation-theory and experimental evidence. *J. Econ. Theory* **136**, 217–235. (doi:10.1016/j.jet.2006.07.006)
- 33 Huck, S., Normann, H. T. & Oechssler, J. 1999 Learning in Cournot oligopoly—an experiment. *Econ. J.* **109**, C80–C95. (doi:10.1111/1468-0297.00418)
- 34 Offerman, T., Potters, J. & Sonnemans, J. 2002 Imitation and belief learning in an oligopoly experiment. *Rev. Econ. Stud.* **69**, 973–997. (doi:10.1111/1467-937X.00233)
- 35 Greiner, B. 2004 *The online recruitment system ORSEE 2.0—a guide for the organization of experiments in economics, Working Paper Series in Economics 10*. Cologne, Germany: University of Cologne.
- 36 Kornblum, S., Hasbroucq, T. & Osman, A. 1990 Dimensional overlap: cognitive basis for stimulus–response compatibility—a model and taxonomy. *Psychol. Rev.* **97**, 253–270. (doi:10.1037/0033-295X.97.2.253)
- 37 Welchman, A. E., Stanley, J., Schomers, M. R., Miall, R. C. & Bulthoff, H. H. 2010 The quick and the dead: when reaction beats intention. *Proc. R. Soc. B* **277**, 1667–1674. (doi:10.1098/rspb.2009.2123)
- 38 Dinstein, I., Hasson, U., Rubin, N. & Heeger, D. J. 2007 Brain areas selective for both observed and executed movements. *J. Neurophysiol.* **98**, 1415–1427. (doi:10.1152/jn.00238.2007)
- 39 Catmur, C., Walsh, V. & Heyes, C. 2009 Associative sequence learning: the role of experience in the development of imitation and the mirror system. *Phil. Trans. R. Soc. B* **364**, 2369–2380. (doi:10.1098/rstb.2009.0048)
- 40 Jahanshahi, M., Saleem, T., Ho, A. K., Dirnberger, G. & Fuller, R. 2006 Random number generation as an index of controlled processing. *Neuropsychology* **20**, 391–399. (doi:10.1037/0894-4105.20.4.391)