Exploring the perceptual inabilities of Eurasian jays (*Garrulus glandarius*) using magic effects

Elias Garcia-Pelegrin[a,1], Alexandra K. Schnell[a], Clive Wilkins[a], and Nicola S. Clayton[a]

[a]Department of Psychology, University of Cambridge, Cambridge CB2 3EB, United Kingdom

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In recent years, scientists have begun to use magic effects to investigate the blind spots in our attention and perception [G. Kuhn, *Experiencing the Impossible: The Science of Magic* (2019); S. Macknik, S. Martinez-Conde, S. Blakeslee, *Sleights of Mind: What the Neuroscience of Magic Reveals about Our Everyday Deceptions* (2010)]. Recently, we suggested that similar techniques could be transferred to nonhuman animal observers and that such an endeavor would provide insight into the inherent commonalities and discrepancies in attention and perception in human and nonhuman animals [E. Garcia-Pelegrin, A. K. Schnell, C. Wilkins, N. S. Clayton, *Science* 369, 1424–1426 (2020)]. Here, we performed three different magic effects (palming, French drop, and fast pass) to a sample of six Eurasian jays (*Garrulus glandarius*). These magic effects were specifically chosen as they utilize different cues and expectations that mislead the spectator into thinking one object has or has not been transferred from one hand to the other. Results from palming and French drop experiments suggest that Eurasian jays have different expectations from humans when observing some of these effects. Specifically, Eurasian jays were not deceived by effects that required them to expect an object to move between hands when observing human hand manipulations. However, similar to humans, Eurasian jays were misled by magic effects that utilize fast movements as a deceptive action. This study investigates how another taxon perceives the magician's techniques of deception that commonly deceive humans.

magic | perception | attention | comparative cognition | corvids

Investigations into how magic effects exploit constraints on cognition in humans have recently sparked the interest of psychologists and neuroscientists alike (1–3). The success of most magic effects is dependent on their ability to take advantage of the perceptual and attentional shortcomings of the spectator. As such, the application of magic effects to investigate the mind can yield thought-provoking results, highlighting the elaborate deceptive qualities of magic and the perceptive and attentional blind spots that they exploit (4–8). Indeed, the recently coined "science of magic" (9) or NeuroMagic (5) offers psychologists and neuroscientists an exemplar tool to explore the constraints of the human mind. Recently, we suggested that magic effects could pose an interesting avenue to investigate whether nonhuman animals (henceforth "animals") possess similar attentional and perceptual blind spots and cognitive roadblocks (10). Notice that magicians and comparative psychologists explore areas of cognition from different points of view: Comparative psychologists are ultimately interested in why and how diverse minds operate, with a focus on similarities and differences between species in capacity and constraints on cognition, whereas magicians aim to create the impossible by focusing on how the mind can be "fooled." Consequently, the use of magic effects in comparative psychology provides an interesting methodological tool to explore how diverse species perceive the world around them, by focusing on their shared psychological constraints instead of their cognitive prowess.

Corvids (large-brained birds in the crow family including jays, ravens, and magpies) have often been observed altering their caching behaviors to secure their caches from potential pilferers (11–13). These birds utilize intricate and highly elaborate cache protection tactics comparable to the deceptive strategies employed by magicians (10, 14). For example, corvids can cache food items discretely in among multiple bluff caching events, making it difficult for the observer to trace the real caching event (12). Moving an object in a series of quick motions to make it harder for the spectator to track is a common technique in magic. Moreover, corvids conceal items in their throat pouch, akin to a magician's use of false pockets, and will manipulate food items within their beak similar to sleight-of-hand techniques performed by magicians (15). Given that corvids naturally employ behaviors that are similar to the tactics used in magic effects, these species may be exploiting similar perceptive and attentional constraints to the ones exploited by magicians.

Here, we performed three different experiments using a sample of six Eurasian jays (*Garrulus glandarius*), in which we utilized three diverse magic methodologies that are typically used to mislead humans into thinking an object has been transferred from one hand to the other. We also tested the effectiveness of the methodologies on a sample of 80 human participants, who observed a subset of the same conditions that were presented to the jays. These methodologies (i.e., palming, French drop, and fast pass; Fig. 1) are an intrinsic part of most magic effects, in which their success heavily relies on not being noticed by the spectator. Magicians often use concealment techniques like palming and the French drop to mislead the audience into thinking the object of attention has been transferred from one hand to the other, when, in reality, the object remains concealed in the initial hand. For these tactics to successfully fool an observer, the spectator requires an expectation of the outcome of making certain hand

Significance

While we know that humans are often deceived by magic effects, little is known concerning how nonhuman animals perceive these intricate techniques of deception. Here, we tested the susceptibility to be misled by three different magic effects on a sample of six Eurasian jays (*Garrulus glandarius*). We demonstrate that, similar to humans, Eurasian jays are susceptible to magic effects that utilize fast movements. However, unlike humans, Eurasian jays do not appear to be misled by magic effects that rely on the observer's intrinsic expectations in human object manipulation. Magic effects can provide an insightful methodology to investigate perception and attentional shortcomings in human and nonhuman animals and offer unique opportunities to highlight cognitive constraints in diverse animal minds.

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[1]To whom correspondence may be addressed. Email: eg573@cam.ac.uk.

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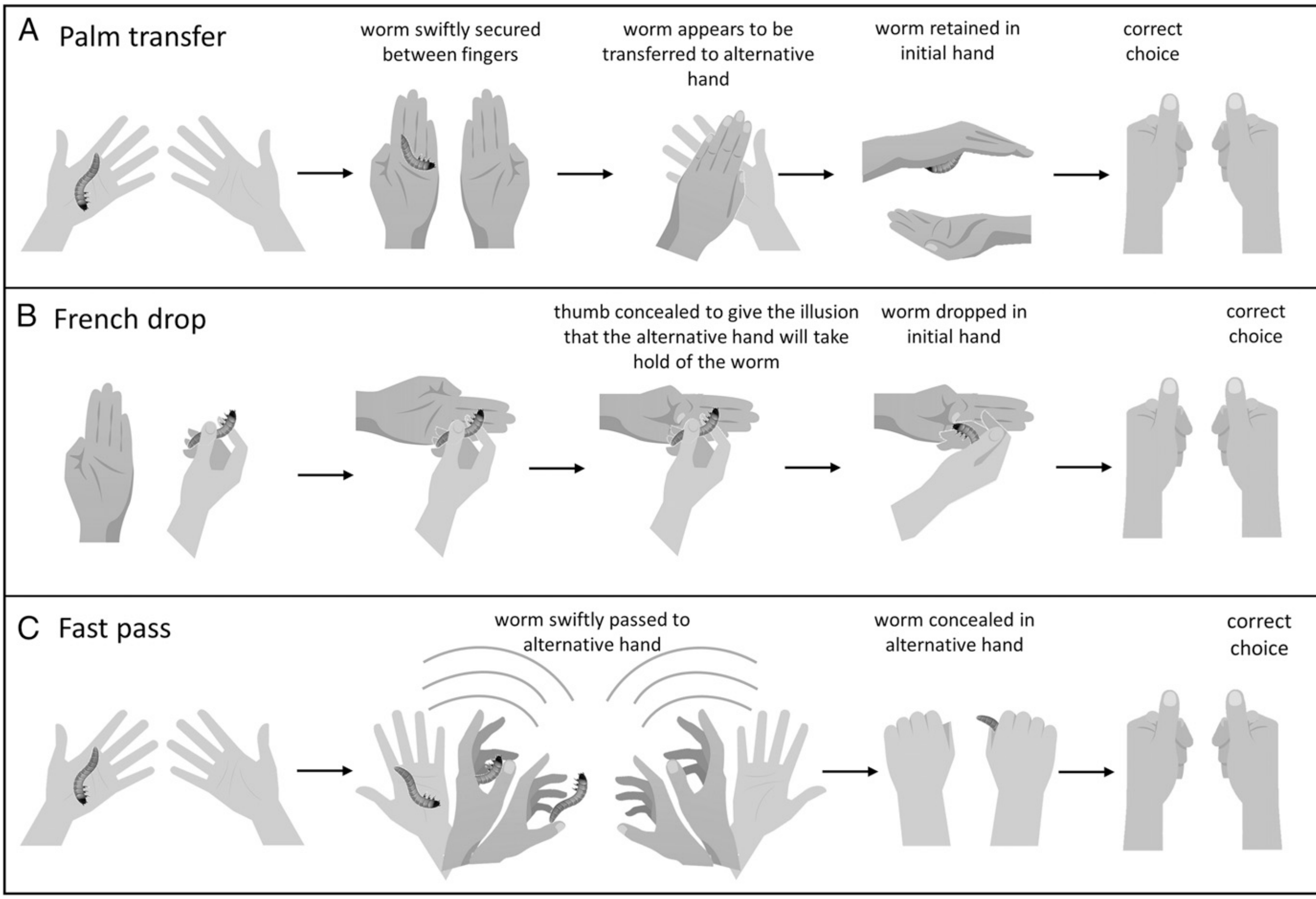

Fig. 1. Sequence of movements required to create (*A*) palm transfer, (*B*) French drop, and (*C*) fast pass. Image sources: ©GraphicsRF (worm); ©peart (hands); ©thruer (hands); ©sstocker (hands).

movements. Such intrinsic knowledge will lead the spectator to unknowingly overlook the unusual components of the effect that might reveal foul play. These expectations seem to underpin the effects, thus prompting the naïve spectator to replace an altered sequence of events with their typical counterpart (16, 17). This, in conjunction with humans' propensity to utilize acquired information from a previous experience to fill in the gaps they do not entirely perceive [i.e., amodal completion (18, 19)], will make these magic effects hard to distinguish from real transfers (20, 21). As such, when the magician operates the hand movement without enabling the object to transfer from one hand to the other, the spectator will assume the transfer has been completed, as this is the most likely outcome (22, 23). Thus, to be fooled by palming and French drop techniques, the spectator inherently needs some knowledge regarding the motions they are about to observe and their typical outcome, because, without this primordial expectation, there would be no preconceptions for the effect to rely on.

Little is known about corvids' preconceptions of human hand motions. Given that birds do not possess similar appendages, the interest lies in either the birds having the notion of such appendages due to either experience or evolutionary pressure, or the absence of such preconceptions even if the birds have extensive experience observing human hand motions. The third experiment (i.e., fast pass) might require neither of those principles as its modus operandi relies on the fast motion of the effect, thus relying on humans' inability to spot the moment in which the object is quickly transferred from one hand to the other. Birds have different visual perception from human and nonhuman apes, possessing a much wider field of view with both binocular and monocular vision (24, 25). Consequently, whether our sample of jays is liable to similar techniques of deception could highlight convergent blind spots in attention and perception, which might make humans and corvids susceptible to similar deception tactics.

Results

Experiment 1: Palm Transfer.

Jays. In experiment 1, the birds were more likely to choose the correct hand when observing a palm transfer (palm transfer correct vs. incorrect: $P = 0.009$) and the same pattern was revealed when they observed the slow transfer (slow transfer correct vs. incorrect: $P < 0.001$). However, there was no significant difference between correct and incorrect choices during the control transfer (control transfer correct vs. incorrect: $P = 0.062$), suggesting that the jays were using a random choice pattern during the control transfer (Fig. 2).

Jays' choices differed significantly across the conditions ($P < 0.001$; effect size 21.4). Post hoc pairwise comparisons with the Holm–Bonferroni adjustment revealed that their choices significantly differed between all three conditions (palm transfer–control transfer: $P = 0.002$; control transfer–slow transfer: $P < 0.001$; slow transfer–palm transfer: $P = 0.01$).

Humans. In experiment 1, the participants were more likely to choose the correct hand when observing both a control transfer and a slow transfer (control transfer correct vs. incorrect: $P < 0.001$; slow transfer correct vs. incorrect: $P < 0.001$) but were more likely to choose incorrectly when observing a palm transfer (palm transfer correct vs. incorrect: $P < 0.001$) (Fig. 3).

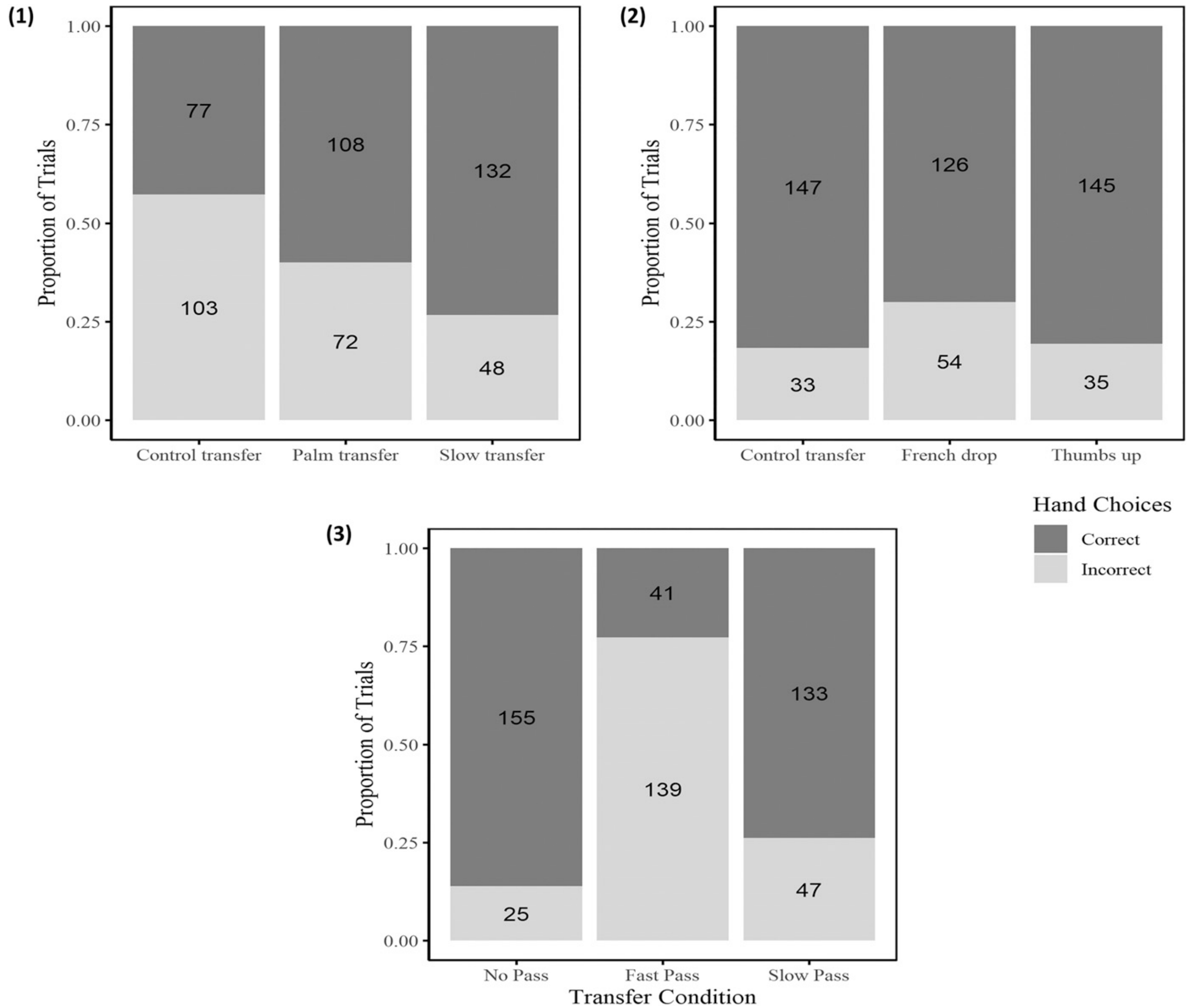

Fig. 2. Hand choice in jays ($n = 6$) in response to three different magic effects. Proportion of trials where jays chose the correct or incorrect hand containing the worm, in 1) experiment 1: palm transfer; 2) experiment 2: French drop; and 3) experiment 3: fast pass.

Participants' choices differed significantly across the conditions ($P < 0.001$; effect size 211). Post hoc pairwise comparisons with the Holm–Bonferroni adjustment revealed that the participants' choices significantly differed between the palm transfer and control transfer ($P < 0.001$) as well as the palm transfer and slow transfer ($P < 0.001$), but no significant differences were found between a slow transfer and control transfer ($P = 1$).

Experiment 2: French Drop.

Jays. In experiment 2, the birds were more likely to choose the correct hand in all conditions (French drop transfer correct vs. incorrect: $P < 0.001$; control transfer correct vs. incorrect: $P < 0.001$; thumbs-up transfer correct vs. incorrect: $P < 0.001$). There was no significant effect of condition ($P = 0.072$; effect size 3.43) in experiment 2, and thus we did not conduct post hoc pairwise comparisons (Fig. 2).

Humans. In experiment 2, participants were more likely to choose the correct hand when observing both a thumbs-up transfer and a control transfer (control transfer correct vs. incorrect: $P < 0.001$; thumbs-up transfer correct vs. incorrect: $P < 0.001$) but were more likely to choose incorrectly when observing a French drop transfer (French drop transfer correct vs. incorrect: $P < 0.001$) (Fig. 3).

Participants' choices differed significantly across the conditions ($P < 0.001$; effect size 91.47). Post hoc pairwise comparisons with the Holm–Bonferroni adjustment revealed that participants' choices significantly differed between all three conditions (French drop–control transfer: $P < 0.001$; control transfer–thumbs-up transfer: $P < 0.001$; thumbs-up transfer–French drop: $P < 0.001$).

Experiment 3: Fast Pass.

Jays. In experiment 3, the birds were more likely to choose the correct hand when observing both a no pass and a slow pass (no pass correct vs. incorrect: $P < 0.001$; slow pass correct vs. incorrect: $P < 0.001$) but were more likely to choose the incorrect hand when observing a fast pass (fast pass correct vs. incorrect: $P < 0.001$) (Fig. 2).

Jays' choices differed significantly across the conditions ($P < 0.001$; effect size 77.93). Post hoc pairwise comparisons with the Holm–Bonferroni adjustment revealed that jays' choices significantly

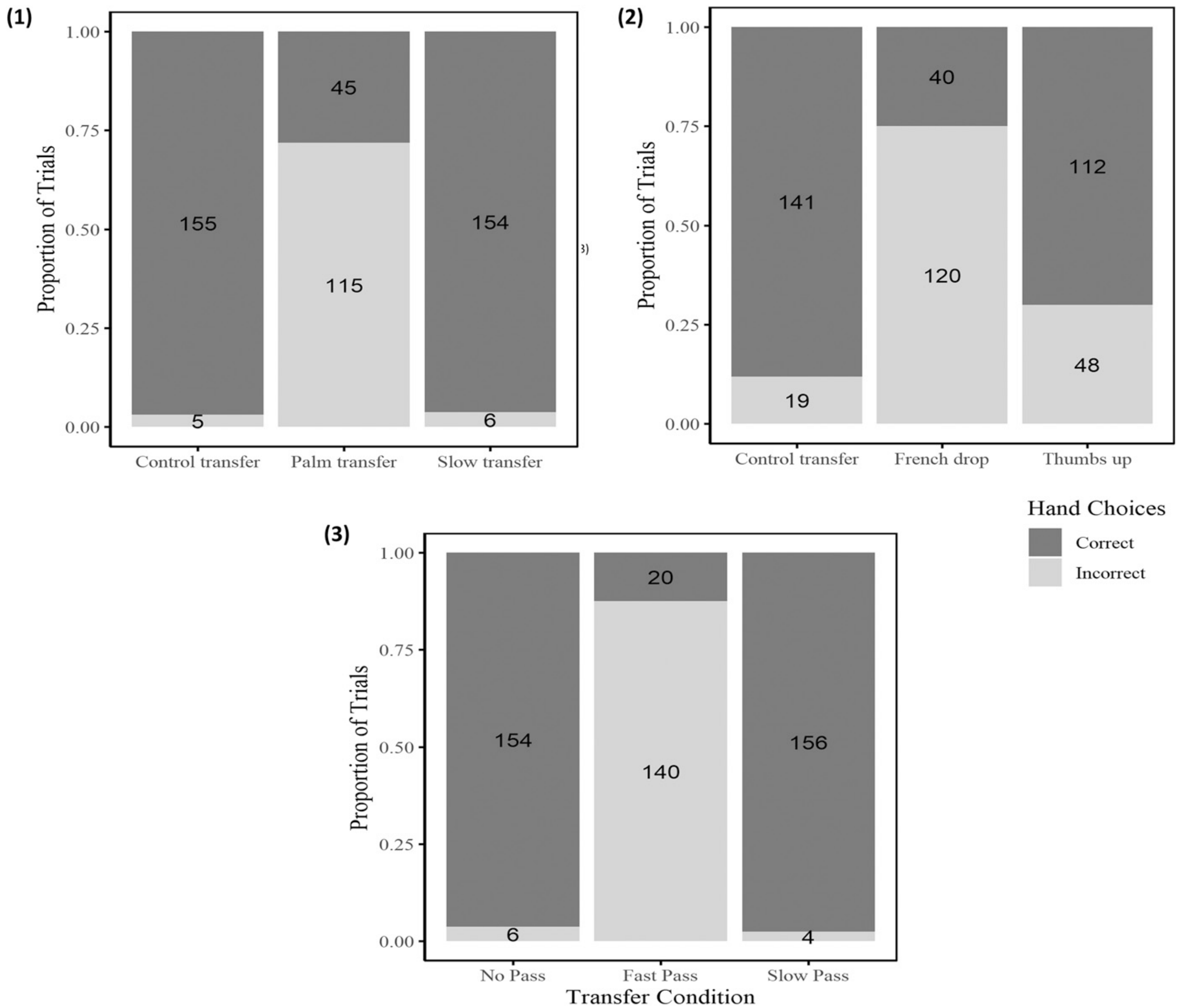

Fig. 3. Hand choice in humans (n = 80) in response to three different magic effects. Proportion of trials where humans chose the correct or incorrect hand containing the worm, in 1) experiment 1: palm transfer; 2) experiment 2: French drop; and 3) experiment 3: fast pass.

differed between all three conditions (fast pass–no pass: $P < 0.001$; no pass–slow pass: $P < 0.005$; slow pass–fast pass: $P < 0.001$).

Humans. In experiment 3, the participants were more likely to choose the correct hand when observing both a no pass and a slow pass (no pass correct vs. incorrect: $P < 0.001$; slow pass correct vs. incorrect: $P < 0.001$) but were more likely to choose the incorrect hand when observing a fast pass (fast pass correct vs. incorrect: $P < 0.001$) (Fig. 3).

Participants' choices differed significantly across the conditions ($P < 0.001$; effect size 597). Post hoc pairwise comparisons with the Holm–Bonferroni adjustment revealed that the participants' choices significantly differed between fast-pass and no-pass conditions ($P < 0.001$) and between fast-pass and slow-pass conditions ($P < 0.001$) but no significant difference was found between no pass and slow pass ($P = 0.75$).

Discussion

In our study, both Eurasian jays and humans were misled by the magic effects that involved fast movement. By contrast, the magic effects that capitalized on the spectator's expectations regarding hand maneuvers did not deceive the jay subjects but did deceive the human participants. Our results suggest that jays might have different expectations from humans when observing these transfer techniques.

The results from experiment 1 suggest that jays are not misled by the same palming methods that deceive humans. The jays' choices in this experiment appear to be moderated by what is observable rather than by what is expected. The slow-palm condition revealed that jays were more successful in choosing the hand that obtained the reward when the transfer was conducted in slow motion. This suggests that the jays had enough time to observe the reward being transferred from one hand to the other during the slow-palm condition. In the palm condition, the jays did not observe the reward moving from one hand to the other, and thus the jays were more likely to choose the hand which had previously been holding the reward item. In the control condition, which emulated the speed and cadence of a fake transfer but not the retention of the reward, the jays were not skillful at choosing the correct hand. One explanation for our result is that the movement was ambiguous, thus not offering the jays enough observable cues to make a clear choice.

In experiment 2, our bird subjects excelled at choosing the hand containing the reward in all conditions; this reinforces the notion that jays appear to utilize what they can observe to make a choice. In the control condition, the reward was observably transferred from one hand to the other, and thus it is not surprising that the jays were successful in choosing the correct hand. Interestingly, jays also succeeded in both the French drop and thumbs-up conditions. The French drop technique typically misleads human spectators because of their inherent expectations associated with hand mechanics. Humans often pre-empt the movement of hand motions and use this when deciding whether an object has been successfully transferred or not. Thus, when the human participants in our study observed the thumbs-up condition, the effect did not typically mislead them, as the thumb which is always in sight cannot perform the grabbing motion. It is important to note, however, that our human sample did present significantly fewer correct choices in the thumbs-up condition than in the control condition. A possibility for this is that identifying the causal cue of the effect (i.e., the thumb not performing the necessary motion) requires the participant to assess the situation more carefully, instead of utilizing intuitive automatic processing (26). By contrast, our bird subjects did not appear to have the same expectations when observing hand transfers of objects; this is perhaps because jays lack the appendages themselves, thus also lacking the attached inherent expectations regarding their mechanics and maneuvers. Interestingly, our jays were raised in captivity, hand-reared, and have participated in a plethora of experiments, some of them involving intricate hand manipulations by the experimenter (27–29). Thus, it is possible that, at least in Eurasian jays, such intricate expectations regarding hand mechanics cannot be gained through observational experience.

In experiment 3, the jays were deceived by the fast-pass technique; this technique relies on the fast-paced motions of the hands. Thus, the spectator misses the transfer, not because of any expectations but because of the inability to perceive the key motion that successfully transfers the object. The jays reacted in a similar manner to a typical human spectator observing the fast-pass effect. Specifically, the jays were misled by a fast pass but were mostly successful when observing the same technique at a slower pace and when no transfer occurred at all. While this technique elicits a similar reaction to the human audience, the response might be moderated by different underlying mechanisms. First, birds have different visual abilities from primates most notably because most avian species have their eyes positioned laterally, on either side of their head (30). As such, the optic axes are not parallel; instead, they are directed outward. This affords birds with a small binocular and a large monocular field of view (24). Accordingly, the jays likely observed the effect with only one eye (i.e., through monocular vision). Further, faster horizontal movements that cross the midline were likely more difficult for them to perceive than slower ones because there was inadequate time to gaze follow and move their head as they might do during slow movements. Moreover, the use of monocular vision by the birds while observing the effect might also make them liable to other perceptual constraints. Birds are not only likely to observe different events with the right eye from the left eye (31, 32) but are specialized to process the information they observe with those eyes differently. Each eye sends the information to the brain hemispheres contralaterally and these hemispheres are highly specialized to perform different functionalities. Specifically, the right hemisphere pays attention to novelty and assumes functional control when the individual is in distress, whereas the left hemisphere pays attention to learned categories in more relaxed environments (33). It is thus possible that these different functionalities affected the way the birds perceived the effects in reference to the eye they were using to observe the effect. Future research might highlight whether animals with laterally placed eyes exhibit different responses to magic effects when they observe the effect with the left or the right eye.

Blind spots in the attentional abilities of the jays might be another potential contributing factor for their failure in perceiving the transfer observed in the fast-pass effect. Previous research on blue jays (*Cyanocitta cristata*), a relative of the Eurasian jay, shows that their attentional abilities can decrease when they are presented with a complex task (34, 35). Specifically, the ability of blue jays to detect peripheral targets substantially decreased when placing their attention on cryptic foraging tasks. This limited attention was attributed to the blue jays requiring more focused spatial attention when presented with a difficult foraging task compared with a simple foraging task. Certainly, when presented with any observational task, the birds ought to choose what zone of the visual field they should place their attention on. The Eurasian jays in the current study might initially place their attention on the hand holding the reward; however, the hand motions send the reward outward toward the peripheral side of the observing bird. Consequently, the reward's transfer in the fast-pass condition may go unnoticed by the observer bird due to similar blind spots in attention to the ones affecting blue jays.

Other factors could also influence the reactions of the jays. A magic effect such as the French drop might only be as good as the magician performing it (22), and thus it is possible that the jays might exhibit different reactions to the effects if they were performed by a more experienced magician. Further, as a single experimenter performed the magic effects, the observable behavioral responses of the birds and humans might be moderated by other factors besides the "magical experience," such as particular movements or mannerisms the experimenter unknowingly has when performing live. It is important to note, however, that the human sample observing the jay conditions elicited similar reactions to the magic effects as the sample of 165 participants who observed the magic techniques performed in a more typical and consistent manner (i.e., purposely prerecorded coin effects, rather than live recordings with worms) (*SI Appendix*). Finally, the field scrutinizing magic effects often utilizes filmed performances rather than live ones; this is, of course, due to the inherent probability that a human cannot ensure that all performances are identical, in all conditions and for all participants. While the human sample was tested using video recordings, logistically this was a hurdle that we could not overcome when testing the birds. It is important to note that the human participants experienced the same trials as the jays, and that the reactions elicited by both, whether alike or dissimilar, are a byproduct of observing the same magic effect, thus making their reactions comparable irrespective of whether these are a product of the techniques performed or the magician's performance. Moreover, current evidence on magic effects and their effectiveness when watched through video suggests that the strength of a magic effect typically stays similar (22, 36, 37) or even decreases (38, 39) when compared with a live performance. Thus, it is fair to assume that the reactions of our human sample stem from the magic effects observed, and not the method of visualization.

In conclusion, Eurasian jays appear to lack the necessary expectations of hand movements to be deceived by magic techniques that routinely fool human spectators but seem to be misled by similar fast-paced actions. These results raise the question of whether magic effects that capture the umwelt of the Eurasian jays would, if performed properly, capitalize on the inherent expectations of the birds. Finally, our results showing that Eurasian jays fail to perceive fast-paced movements raise the intriguing question as to whether the jays themselves take advantage of such constraints when pilfering or protecting caches from thieving conspecifics.

Materials and Methods

Jays.

Subjects. Six Eurasian jays (*G. glandarius*) (three males and three females, all 5 y old) were used in this study. The jays were housed in an aviary with outdoor (20 × 10 × 3 m) and indoor (2 × 1 × 2 m) compartments in N.S.C.'s

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Comparative Cognition Laboratory at the Sub-Department of Animal Behaviour, University of Cambridge in Madingley, United Kingdom. Birds were provided with ad libitum access to a maintenance diet (a mixture of dog kibble, vegetables, eggs, seeds, and fruit) and always had access to water. To ensure that the subjects were motivated to participate in the study, their maintenance diet was removed from the aviary 1 h before testing. The experiments were reviewed and approved by the University of Cambridge and conducted under a nonregulated license (zoo 64/19). The experimenter interacted with the birds through a window in the indoor compartment. The birds participated on a voluntary basis and perched in front of the window just prior to the experimenter beginning the trials.

Training. Subjects were first trained to peck at the thumb of a closed fist to gain access to the edible reward inside the hand. Following this, subjects were trained to determine which hand contained the reward by observing how the experimenter visibly transferred a reward from one hand to the opposite hand. Once the transfer finished, the experimenter held out both fists in front of the subject ∼100 mm apart at equidistance to the subject, who was then allowed to choose. After a minimum score of 8/10 correct trials, the subjects were trained to determine which hand contained the reward even when the reward was hidden inside the hand. To do so, the experimenter presented the reward with one hand, visibly transferred it to the other hand, and then simultaneously closed both hands, thus covering the reward. The subject was then allowed to choose a hand by pecking at the thumb of the chosen hand. The starting hand in every interaction was pseudorandomized so that the subject experienced retrieving rewards from both right and left hands. Once the subject successfully retrieved 8/10 rewards in two consecutive sessions (10 trials per session; average number of sessions 4), the subject moved to the testing phase.

Testing. All three experiments consisted of 9 sessions of 10 trials each. During each session, the food reward was first shown to the subject with one hand and then either transferred to the opposite hand or retained in the same hand (as per condition). Following this, the subject was allowed to choose which hand contained the reward, and the hand was opened upon selection. If chosen correctly, the subject was allowed to consume the reward within. The starting hand and conditions were pseudorandomized across trials, and thus all subjects experienced fake and real transfers from both hands and not in any specific pattern. If, after the transfer was demonstrated, the subject chose the hand that contained the reward, the subject scored "1" on the trial; otherwise, the subject scored "0."

Humans.

Subjects. Eighty participants (36 males, 44 females) between the ages of 16 and 60 y were recruited to complete the online experiment. As the experiment did not require the subjects to disclose any identifying information, the participants were not from any vulnerable group, and the interactions with the experimenter were not intrusive or posed any risk to the participant, the experiment did not require ethical approval by the University of Cambridge.

Procedure. The participants were contacted by either email or social media platforms and provided with access to the survey via a link. The survey was created using Qualtrics and consisted of three blocks of six questions per block (one block per experiment). Each block of questions contained 24 videos (four videos per magic effect, each effect performed twice right to left and twice left to right), and the participants observed a random subset of these videos that contained two videos of each condition (right to left, and vice versa). The order of the blocks and questions within them was randomized for each candidate. The videos of the effects consisted of purposely prerecorded videos of the jays participating in the experiment. The videos were edited for the human sample so that the bird's choice of hand was cut from the recording (*SI Appendix*). The experimenter had an O (left thumb) or X (right thumb) painted on the pad of each corresponding thumb for better identification by the participant. Participants were told that they were participating in a human perception study and were asked to observe each video of the effect and then identify which hand was holding the worm by choosing O or X accordingly.

Magic Effects.

Experiment 1: Palm transfer. This experiment used a magician's technique called palming. Palming involves concealing an object in the palm; when done with skill, the hand palming the object appears to not be holding anything. A palm transfer or fake transfer by palming involves mimicking the transfer of an object from one hand to the other but, instead of transferring it, the object remains concealed in the palm of the original hand. In the control condition, the experimenter transferred a reward from one hand to the other using the same speed and cadence required for a magician's palm transfer but, instead of retaining the reward, the experimenter allowed the reward to transfer from one hand to the other. In the slow-transfer condition, the experimenter transferred the reward from one hand to the other, using a slower speed and more noticeable cadence. In the experimental condition, the experimenter enacted a fake transfer using a palming method.

Experiment 2: French drop. This experiment used a magician's technique known as a French drop. The technique involves mimicking the grab of an object from one hand to the other by holding the object between the thumb and first two fingertips and "fake grabbing" it with the other hand while simultaneously letting the object fall into the palm of the holding hand. In the control condition, the experimenter visibly transferred the reward from one hand to the other while enacting the same movements of a French drop. In the thumbs-up condition, the experimenter performed a French drop, while maintaining the thumb of the hand performing the fake grab in the eyesight of the subject at all times. In the French drop condition, the experimenter performed a French drop with the reward.

Experiment 3: Fast pass. This experiment used a magician's technique known as a fast pass. The technique consists of passing the object from one hand to the other with enough speed so that the transfer is not noticed by the spectator. In the no-pass condition, the experimenter showed the reward in one hand and the other empty hand and then enacted the same movements with the same speed and cadence as when performing a coin flip without transferring the reward from one hand to the other. In the slow-pass condition, the experimenter transferred a reward from one hand to the other using a slower speed and cadence than required for a fast pass. In the experimental condition, the experimenter performed a fast pass.

Analysis. The jay data for all three experiments were recorded while being coded in situ and subsequently cross-referenced with the recordings. Interrater reliability was measured by a naïve coder scoring a pseudorandom selection of 10% of the trials per experiment; the trials included a balanced quantity of all conditions. Reliability was excellent for all experiments (Cohen's Kappa = 1).

Statistical analyses for both humans and jays were accomplished using JASP (version 0.10.3; https://jasp-stats.org/) and RStudio for Mac (version 1.2.1335). To determine the subjects' choices per condition, we used binomial tests (against value: 0.5). To determine whether the subjects' choices were influenced by the conditions, we used nonparametric permutation tests (aovperm function, permuco package). Significant differences between treatments were further explored using post hoc pairwise comparisons and were adjusted using the Holm–Bonferroni method to maintain the overall alpha level at the nominated value or 0.05 for multiple pairwise comparisons.

Data Availability. All data, unique materials, documentation, and code used in the analysis can be found at the Open Science Framework database at https://osf.io/utkd7.

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