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Permalink

Journal

ISSN

Authors
Lord, Jessica
van der Vliet, William
Anderson, Philip
et al.

Publication Date
2019

DOI

Copyright Information

Peer reviewed

Very superstitious? A preliminary investigation of pigeons' body position during a matching-to-sample task under differential and common outcome conditions

Jessica Lord[1], William van der Vliet[1], Philip Anderson[1], Michael Colombo[1], and Damian Scarf[1]

[1] Department of Psychology, University of Otago, New Zealand

The delayed matching-to-sample (DMS) task is widely employed to assess memory in a range of nonhuman animals. On the standard "common outcomes" (CO) DMS task, correct performance following either sample stimulus results in reinforcement. In contrast, on a "differential outcomes" (DO) DMS task, the outcome following each sample stimulus is different. One of the most consistent findings in the comparative literature is that performance under a DO condition is superior to that under a CO condition. The superior performance is attributed to the fact the DO condition enhances memory for the sample stimulus by tagging each sample with a discrete reward. Here, we investigate an alternative possibility: that pigeons use positional mediation during the delay under DO but not CO conditions. To test this, we tracked the head position of pigeons performing a DO ($n = 4$) or CO ($n = 4$) task. Consistent with the positional mediation account, all subjects in the DO condition displayed evidence of positional mediation. Surprisingly, positional mediation was not unique to subjects in the DO condition, with subjects in the CO condition also displaying evidence of mediation.

Keywords: delayed matching-to-sample, differential outcome effect, behavioral mediation, superstitious behavior

The comparative literature is replete with tasks that purportedly tap memory, such as the delayed-response task (Hunter, 1913), radial-arm maze (Olton & Samuelson, 1976), and the delayed matching-to-sample task (Blough, 1959). Although designed to tap memory, nonhuman animals have come up with a number of ingenious ways to bypass memory on these tasks. For example, in Hunter's (1913) delayed-response task, an animal is placed into a holding box directly opposite three goal boxes. At the start of each trial, one goal box is lit, and, after several seconds, the light is extinguished and a delay imposed. Following the delay, the animal is released from the holding box and is required to enter the goal box that was lit before the delay. Hunter (1913) used this task to assess memory in raccoons, dogs, and rats, with all the animals tested displaying impressive memory abilities. Although, on the surface, the animals appeared to show impressive memory abilities, Hunter (1913) noticed that the animals' body position appeared to change depending on which goal box was lit. One dog, for example, would immediately lay down and face the goal box that was lit and would remain in that position for the duration of the delay, despite showing signs of impatience, such as pawing the ground. The dog did, however, occasionally move

when an external noise caught his attention and, following this movement, typically performed the trial incorrectly. The use of body position indicated to Hunter (1913) that animals appeared to bypass memory to solve the task, and he concluded that the success of animals on the delayed-response task had little to do with their memory abilities.

Ostensibly, the delayed-matching-to-sample (DMS) task is designed in a way that makes it extremely difficult for animals to develop simple positional response strategies like those employed by Hunter's (1913) subjects. Briefly, a single trial on the DMS task typically proceeds as follows. Following an intertrial interval (ITI), a sample stimulus is displayed, and a response to the sample stimulus turns it off and initiates a delay interval. The delay is then followed by the presentation of two comparison stimuli, one of which matches the sample stimulus and one that does not. A response to the comparison stimulus that matches the sample stimulus results in the delivery of reinforcement. Critically, the spatial locations of the comparison stimuli change from trial to trial, making it impossible for animals to employ a simple positional strategy (e.g., standing in front of the correct response key during the delay). The DMS task is used extensively to assess memory in a range of animals including both pigeons (Browning, Overmier, & Colombo, 2011; Colombo, Cottle, & Frost, 2003; Wright, 1997) and primates (D'Amato, Salmon, & Colombo, 1985; Nissen, Blum, & Blum, 1948).

Although it may be impossible to adopt a *simple* positional strategy to bridge the delay period of a DMS task, a more complex strategy in the form of differential behavior to the sample stimuli could still aid an animal in bypassing memory on the DMS task. Indeed, differential behaviors during the delay on operant tasks are common, and forms of behavioral control may appear without any specific reinforcement for them (Urcuioli et al., 2002; Urcuioli & Vasconcelos, 2008). In the context of the DMS task, Blough (1959) investigated whether such was the case for pigeons by video recording them and manually coding their behavior. Two of the four pigeons that Blough (1959) recorded demonstrated differential behaviors following the different sample stimuli. Furthermore, on trials where the pigeons failed to display differential behavior, incorrect responses were almost always made. Interestingly, the pigeons that displayed differential behavior during the delay evidenced almost no forgetting, an outcome that led Blough (1959) to conclude that the birds were bypassing memory by adopting positional strategies to bridge the delay period.

The superior performance of Blough's (1959) pigeons that displayed differential behavior during the delay is similar to the superior performance displayed by animals trained using a differential outcomes (DO) procedure. The DO procedure is a popular variation of the DMS task and simply involves outcomes that depend on the particular sample with which the animal was presented at the start of the trial. For example, if the animal is presented with a red stimulus during the sample phase and, following a delay, selects the red comparison stimulus, then the animal is reinforced with one food type (e.g., corn). In contrast, if the animal is presented with a green stimulus during the sample phase and, following a delay, selects the green comparison stimulus, then the animal is reinforced with a different food type (e.g., wheat). The differential outcomes effect (DOE) refers to that fact that under DO, animals display superior

memory relative to when they are trained with a standard common outcomes (CO) DMS task (Brodigan & Peterson, 1976; DeLong & Wasserman, 1981; Kouwenhoven & Colombo, 2016; Peterson, Wheeler, & Trapold, 1980; Santi & Roberts, 1985; Trapold, 1970; Urcuioli, 2005). Explanations for the DOE range from those suggesting it is due to enhanced discriminability and/or memory of the sample stimuli to explanations suggesting the behavior is driven by the specific expectancy and/or representation of the outcome (Holden & Overmier, 2014, 2015; Urcuioli, 1990).

In the current study, we investigated the possibility that the DOE is the result of pigeons behaving differentially during the delay. We employed a novel tracking method that allowed us to continuously monitor pigeons head and body position. For comparison purposes, we also recorded from animals that were trained on a CO version of the DMS task.

Method

Subjects

The subjects were eight pigeons (*Columba livia*). Each pigeon was maintained at 85% of its free-feeding weight for the duration of the experiment. Grit and water were provided ad lib. The room in which the birds were housed was maintained at 20°C. Overhead fluorescent lights were turned on daily at 7:00 a.m. and turned off 12 hr later.

Apparatus and Stimuli

The birds were trained in an open-top operant chamber. The operant chamber was built in house. The rear and two side interior walls were black. The front wall of each chamber contained a Perspex panel that provided access to a Philips 170s 17-in. LCD computer monitor. Between the Perspex panel and computer monitor was an Elo 17-in. infrared touch frame. The Perspex panel contained six 60-mm × 60-mm holes arranged in two rows of three. Directly below the center squares, in the floor of the experimental chamber, was a food well. Reinforcement (wheat) was delivered via a hopper. The stimuli consisted of a skater image and flower image. White noise (75dB) was played for the duration of each session to prevent distraction due to outside noise.

The tracking system consisted of two See3CAM 130 4K Autofocus USB3.1 Gen1 camera boards (e-con systems) situated above the operant box. The tracking program was built using OpenCV and sampled at a rate of 20Hz (Bradski, 2000). Tracking the pigeon was done by color, with a small blue ball attached to each pigeon's head and a small green ball to their back. Specifically, the image from each camera was converted from RGB to HSV (hue, saturation, & lightness) color space. The images were then thresholded against the ball color to obtain binary images. Morphological openings were used to remove small objects from the foreground of the binary images, and morphological closings were used to fill small holes from the foreground of the binary images. OpenCV's *findContours* function was then used to find objects in the binary images, and the object with the largest area (by bounding ellipse) was taken to be the target. The center of each object was undistorted using OpenCV's undistortPoints function. The 2D centers were projected into 3D using OpenCV's triangulatePoints function. The tracker then outputed the 3D coordinates to a file that was integrated with trial-event data.

Procedure

DO condition. Four birds were trained in the DO DMS task (B1, B3, B5, and B8). There were nine phases of training. The criterion for each phase was two consecutive sessions at or above 75% accuracy.

It is also important to note that, due to limitations of the tracking system, an overhead lamp remained on throughout each session. In Phase 1, the task included no delay and no correction trials. In Phase 2, correction trials were introduced but limited to a maximum of 5 repitions on each trial. In Phase 3, the number of correction trials was increased to 10, and, in Phase 4, it was further increased to 20. Following Phase 4, a delay was added. The delay was increased by 1 s between Phases 5 (1 s) and 9 (5 s). Tracking began once the birds were performing consistently (≥75%) at Phase 9. The aim was to record each bird for 10 sessions.

For tracking, each session consisted of 64 trials. A trial began with a 10-s intertrial interval (ITI), followed by the presentation of the sample stimulus (flower or skater) in the top center square of the Perspex panel. Following three pecks to the sample stimulus, the sample disappeared and the 5-s delay began. Following the delay, the comparison stimuli were presented on the left and right keys. The side on which each stimulus appeared was counterbalanced, such that each stimulus appeared equally often on the left and right sides. On trials where the sample stimulus was the skater, a peck to the skater comparison stimulus resulted in 3 s of reinforcement, followed by the ITI. On trials where the flower was the sample, a correct response to the flower comparison stimulus resulted in no reward and simply initiated the ITI. An incorrect response to either stimulus was followed by a 1-s time out.

CO condition. Pigeons in the CO condition (M1, M6, M9, and M16) had previous DMS training and, therefore, the training phases were truncated. Identical to the DO Condition, an overhead lamp remained on throughout each session. In Phase 1, a 3-s delay was employed, and a maximum of 20 correction trials were used. Phases 2 and 3 consisted of increasing the delay to 4 and 5 s, respectively. The flow of events during a trial was identical to that of subjects in the DO condition, with the exception that a correct response on either the skateboard or flower trials resulted in 1.5 s access to reinforcement. An incorrect response to either stimulus was followed by a 1-s time out. Identical to the DO condition, the aim was to record each bird for 10 sessions. One of the four pigeons (M16) in the CO condition failed to acquire the task.

Results

The accuracy data for each subject is shown in Figure 1. For the majority of subjects (B3, B5, B8, M1, and M6), accuracy is based on 10 sessions of data. However, due to experimental error (B1 and M9) or poor performance (M16), the number of sessions the remaining subjects contributed varied (B1 = 9 sessions, M9 = 20 sessions, M16 = 6 sessions). Due to the exploratory nature of the current study, we included all available sessions in our performance and tracking analyses. Although we could not investigate the standard DOE in terms of speed of acquisition, due to the different training regimes, we did submit the accuracy data to a repeated-measures analysis of variance (ANOVA), with stimulus (2 levels: Skateboard and Flower) as a within-subjects factor and condition (2 levels: DO and CO) as a between-subjects factor. There was a main effect of stimulus, $F(1, 6) = 26.07$, $p < 0.01$, partial $\eta^2 = 0.81$, and a marginal main effect of condition, $F(1, 6) = 5.25$, $p = 0.06$, partial $\eta^2 = 0.47$, qualified by a significant Stimulus × Condition interaction, $F(1, 6) = 14.20$, $p = 0.01$, partial $\eta^2 = 0.70$. As shown in Figure 1, the interaction effect was driven by the fact that subjects in the DO condition performed markedly better than subjects in the CO condition on skateboard trials (Means: 99% vs. 74%) but at a similar level on flower trials (Means: 79% vs. 71%).
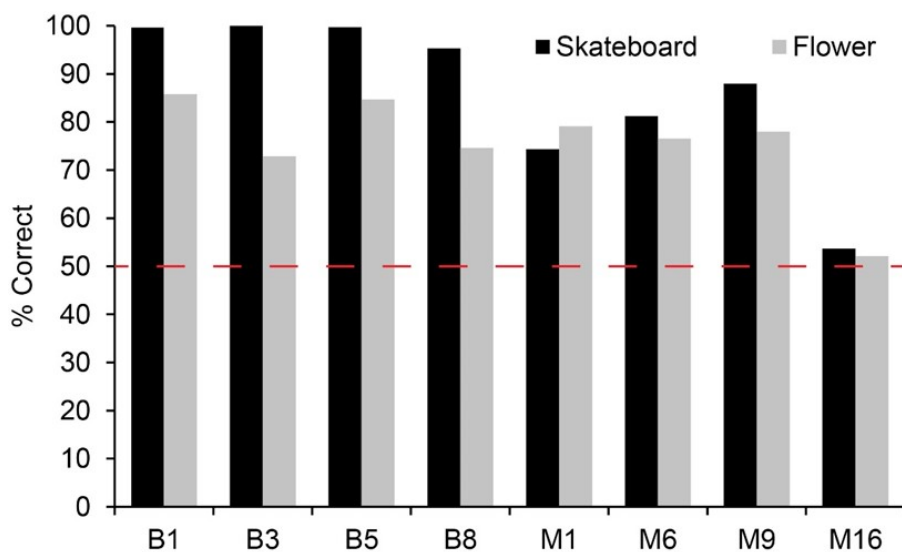
Figure 1. **The performance of subjects in the DO (B series birds) and CO (M series birds) conditions.** The dashed line indicates chance (50%) performance. For the DO condition, correct responses on skateboard trials resulted in reward, while correct responses on flower trials did not. For the CO condition, correct responses on skateboard trials and flower trials resulted in reward.

The ball on the back of the subjects was continually obstructed by the wings and, as a result, we focused solely on the data collected from the ball on the head of the subjects. Data on the reliability of the tracking system are provided in Table 1. Two types of tracking errors were calculated. First, we calculated the proportion of samples in which the system lost tracking of the ball on the head. Second, we calculated the proportion of samples in which the system picked up on objects or light outside of the operant box. Overall, although the system requires some fine tuning, the system has adequate reliability.

Although M16 did not reach the criterion for inclusion, we thought it was important to include the tracking data in order to investigate whether a subject that did not perform above chance displayed any differential behavior. Indeed, if a bird that did not learn the task displayed differential behavior during the delay, it would call into question whether the behavior during the delay is related to performance. The position of the birds at the start of a trial and for each second of the delay is displayed in Figure 2 (DO condition, correct trials), Figure 3 (CO condition, correct trials), and Figure 4 (CO condition, incorrect trials). Ideally, to determine if the position of pigeons during the delay contributed to the DOE, we would first determine whether spatial position differed as a function of trial type (i.e., flower vs. skateboard) and then, for the same trial type, see if spatial position correlated with accuracy. Unfortunately, the near perfect performance of subjects in the DO condition precluded the second step in this analysis approach. As noted above, the mean performance of subjects in the DO condition on skateboard trials was 99%, leaving an extremely small number of incorrect trials.

Table 1

The Proportion of Tracking Errors and Out of Range Errors

Subject	Total Samples	Tracking Errors (%)	Out of Range Errors (%)
B1	68075	2888 (4.24%)	1212 (1.78%)
B3	79478	10302 (12.96%)	470 (0.59%)
B5	73594	2653 (3.60%)	912 (1.25%)
B8	80854	2543 (3.15%)	2617 (3.24%)
M1	84924	4367 (5.14%)	1438 (1.69%)
M6	86064	3796 (4.41%)	978 (1.14%)
M9	162785	22642 (13.91%)	4226 (2.60%)
M16	84738	3082 (3.64%)	1490 (1.76%)

Note. Tracking errors are samples in which the system lost tracking of the head marker. Out of range errors are errors in which the system picked up on objects outside of the operant box.
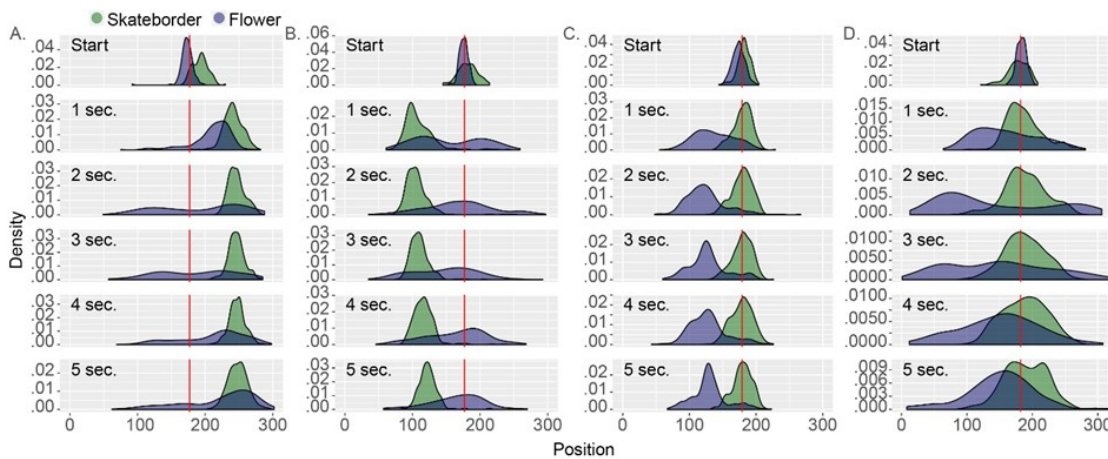

Figure 2. **The position of B1 (A), B3 (B), B5 (C), and B8 (D) during the delay on correct trials.** The blue distribution is the position during flower trials, and the green distribution is the position during skateboard trials. The vertical red line indicates the birds' head position at the start of the trial.

With respect to the first step, we employed *K*-means clustering to determine whether the position of pigeons in the DO condition differed as a function of trial type (Hartigan & Wong, 1979). Specifically, for both trial types, we selected two random points and then grouped the remaining points into two groups that were closest to either of these two points. We then calculated a center (mean) point for each of these two groups and repeated the division of points into two groups based on the closeness to those new center points. We repeated this process until these groups were stable. In essence, this analysis approach allows us to test whether we can predict the trial type

based purely on the position of the pigeon in the operant box. To see if there was any relationship between our predicted trial type and the actual trial type, we calculated the phi coefficient. Consistent with the view that pigeons in the DO condition adopt different body positions on the two trial types, there was a substantial relationship between our groups based on the bird's spatial location and the actual trial type (Figure 5A).
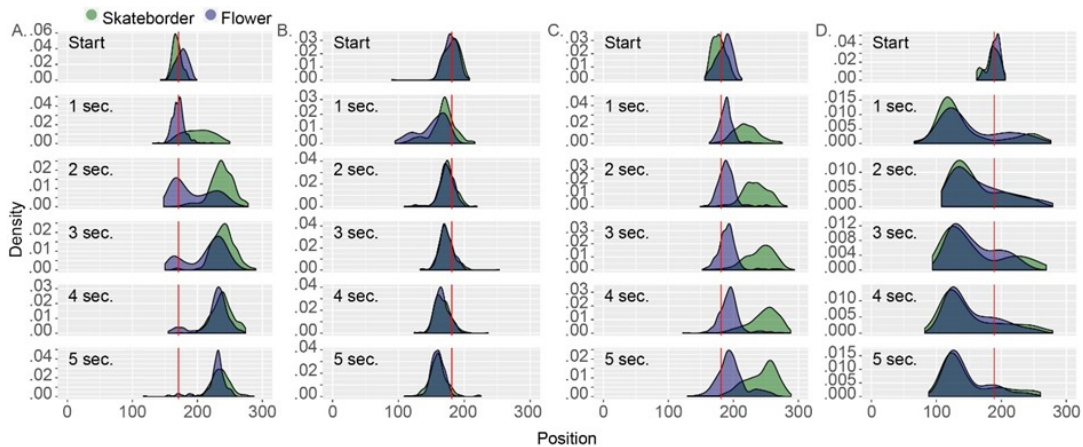

Figure 3. **The position of M1 (A), M6 (B), M9 (C), and M16 (D) during the delay on correct trials.** The blue distribution is the position during flower trials, and the green distribution is the position during skateboard trials. The vertical red line indicates the birds head position at the start of the trial.

Given the more modest performance of birds in the CO condition, we had a relatively large pool of both correct and incorrect trials. First, we analyzed the correct trials using an identical process as that employed for birds in the DO condition. Surprisingly, for M1 and M9, the relationship between the predicted trial type and the actual trial type was comparable to that of the birds in the DO condition (Figure 5B). Visually, this can be discerned in Figure 3A (M1) and Figure 3C (M9). Indirectly supporting the view that spatial position may be related to performance, the two birds that failed to learn the task were the only birds for which there was no relationship between the predicted and actual trial type (Figure 5B). Finally, we analyzed the incorrect trials for birds in the CO condition. Consistent with the view that spatial position is related to performance for M1 and M9, spatial position was not predictive of trial type for incorrect trials (Figure 5). Visually, this is evident from looking at Figure 4A (M1) and Figure 4C (M9).
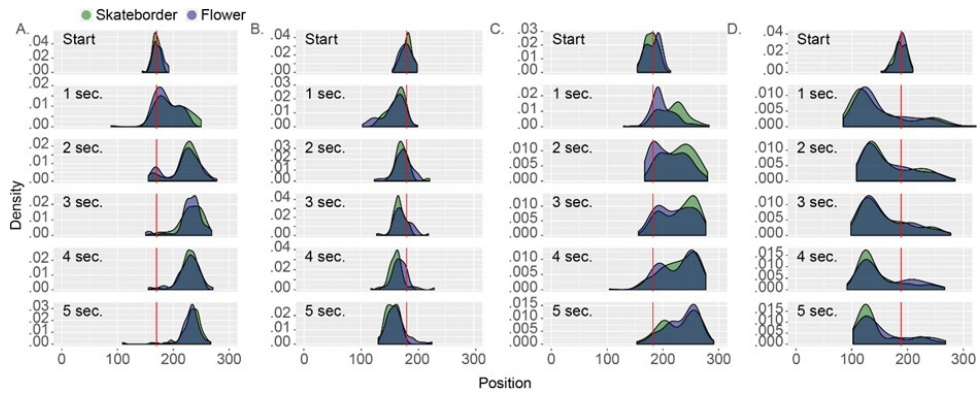
Figure 4. **The position of M1 (A), M6 (B), M9 (C), and M16 (D) during the delay on incorrect trials.** The blue distribution is the position during flower trials, and the green distribution is the position during skateboard trials. The vertical red line indicates the birds head position at the start of the trial.
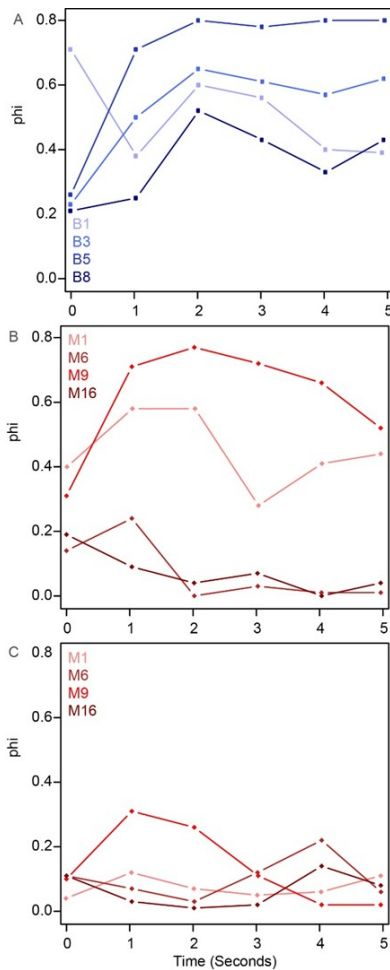

Figure 5. **The phi correlation for the DO condition (A), for correct trials in the CO condition (B), and for incorrect trials in the CO condition (C), calculated separately for each period of the delay.** The "Start" time point reflects pigeons' position when they pecked the sample stimulus.

Discussion

The primary aim of the current study was to investigate whether pigeons display positional mediation during the delay on the DMS task. Consistent with our initial hypothesis, pigeons in the DO condition displayed clear evidence of positional mediation during the delay period, with the position they adopted during the delay dependent on the sample stimulus that was presented. Surprisingly, the birds that acquired the task in the CO condition also displayed evidence of positional mediation. This latter finding suggests that the DOE is not merely due to differential behavior during the delay.

The findings of the current study are consistent with Blough's (1959) observations and a number of other studies that have investigated the behavior of animals during operant tasks (Alling, Nickel, & Poling, 1991; Berryman, Cumming, & Nevin, 1963; Brodigan & Peterson, 1976). Although one interpretation of these earlier findings and those reported in the current study is that the behavior is used to bypass memory, it is also possible that the behaviors are simply superstitious. Superstitious behavior is any behavior that emerges in the absence of an actual contingency (Skinner, 1948). Although Skinner's (1948) initial interpretation was that these behaviors emerge due to the accidental pairing of a random behavior (e.g., standing on the left side of the operant box) and reward delivery, it has also been argued that the behavior may reflect stimulus substitution or a form of species-typical appetitive behavior (Staddon & Simmelhag, 1971; Timberlake & Lucas, 1985). For example, Timberlake and Lucas (1985) manually coded a wide range of behaviors (e.g., pecks, head bobbing, hopper-directed movements, flapping, grooming, etc.) while pigeons were exposed to a fixed-time schedule of hopper presentations. Rather than observing random behaviors, there were consistent behavioral patterns that suggested the behavior was the product of species-typical behavior related to feeding. In the current study, only the spatial locations of the birds were recorded. Future studies could develop more advanced video coding methods to capture the types of behavior that would help distinguish between the competing theories of superstitious behavior.

The current study also has implications for theories of forgetting on the DMS task. Typically, forgetting on the DMS task is attributed to the memory trace decaying over time (Roberts, 1972). White and Brown (2014), however, recently proposed an alternative model based on reinforcement context. The basis of their theory is White and Wixted's (1999) model, in which the subject's choice between two alternatives is based on the ratio of rewards previously gained (R_{1i}/R_{2i}). White and Brown (2014) added reinforcement for other behaviors (R_o) to the model, arguing that they may compete with the rewards provided for completing the actual task. Indeed, as Herrnstein's (1970) matching law notes, the strength of a response is not simply a function of the reinforcement it produces but is relative to the reinforcers provided for alternative behaviors. White and Brown (2014) argued that the superior performance of subjects under a DO condition, relative to a CO condition, was due to rewards under the DO condition having a stronger effect than those under the CO condition. As Figure 1 demonstrates, however, the superior performance of birds under the DO condition is due to averaging their extremely high performance on rewarded (i.e., skateboard)

trials (99%) and their moderate performance on nonrewarded (i.e., flower) trials (76%). Why does the stronger effect of rewards under the DO condition not translate into higher performance on nonrewarded trials? The findings of the current study suggest it may be due to the absence of reward on these trials leading the animal to be distracted by other reinforcing behaviors (R_o). Indeed, as Figure 2 clearly shows, subjects tended to move about a great deal during flower trials, with much flatter movement distributions during the delay.

Beyond studies investigating behavior during the delay period, the novel tracking system employed in the current study could be used to investigate a range of behaviors during operant tasks (e.g., choice models). Importantly, it also has a number of benefits over earlier approaches. For example, Wright and Sands (1981) analyzed video recordings of pigeons during the MTS task to develop a theory of matching behavior. While admirable, manual coding of video recordings is prone to error and extremely time consuming (Badelt & Blaisdell, 2008).

Although the tracking system developed for the current study is novel and allowed us track subjects' behavior with a high level of accuracy, it also had a major drawback. The tracking system employed standard cameras, requiring an overhead light to remain on during each experimental session. This meant that not only could we not use a house light to help the animal distinguish between certain trial phases (e.g., ITI vs. time out) but also likely increased the level of interference pigeons experienced during the delay (Roberts & Grant, 1978; Zentall, 1973). Indeed, the difficulty in training is reflected by the extensive training phases required for the DO birds to adapt to the tracking box and the failure of one of the previously DMS-trained CO birds to ever learn the DMS task in the tracking box. Although it may have increased the difficulty, we find it unlikely that the overhead light is responsible for the behaviors observed in the current study. Indeed, the terminal performance of the birds in the current study is comparable to that of our earlier work in which a typical house light setup was employed (Browning et al., 2011). A promising solution to eliminate this potential confound is to use machine learning techniques that track the animal itself rather than markers placed on the animal's body (Nath et al., 2019; Pereira et al., 2019). Another limitation is that we did not save the video files of the birds performing the task. Although, as noted above, manual coding is prone to error, the video files would have provided an important supplement to the current analysis. In addition, it would have allowed us to investigate the reliability of manual coding against the objective coding provided by our tracking system.

Beyond the tracking system, two additional limitations should be noted. First, the training histories of the birds in the DO and CO conditions were not identical. Second, for animals in the DO condition, we did not counterbalance the sample stimuli across the rewarded and nonrewarded conditions. It is important to remember, however, that behavioral mediation was observed in birds in both the DO and CO conditions suggesting that, while these factors may have contributed to the behavior observed during the delay, they cannot be the sole source of the behavior.

Summary

The findings of the current study demonstrate that pigeons may adopt different body positions not only under a DO condition but also under a CO condition. As noted above, additional studies are needed to determine whether the pigeon's behavior reflects true mediation or whether it is mere superstition.

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