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## **Cover Page Footnote**

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Pigeons Choose to Gamble in a Categorical Discrimination Task

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In slot-machine play, near wins are stimuli that visually approximate winning stimuli but deliver no reinforcers. In two experiments, a categorical discrimination task was embedded in a concurrent chain to investigate how near wins affect preference for probabilistic versus certain food. Pecking in variable-interval initial links produced access to a fixed-ratio (FR) 1-FR 1-FR 1 chain. When all links were red, the chain was a “win” that produced access to food. A “clear loss” chain involved three green stimuli, and in a “near win,” key colors during successive FR 1 links were red, red, and green. In Experiment 1, the magnitude and probability of reinforcement were varied across conditions with and without near wins. Response allocation was sensitive to changes in reinforcer magnitude and probability. Generalized matching analyses revealed a consistent bias for probabilistic over certain outcomes, but only when they included near wins. Response rates on near-win trials were also intermediate to that of clear losses and wins. Near-win probability was varied across conditions of Experiment 2 and probability of near wins was positively associated with bias for probabilistic outcomes. The results from both experiments suggest that near wins encourage individuals to choose to gamble by functioning as conditioned reinforcers.

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Gambling is a pervasive behavior that cost gamblers \$37.34 billion in the United States in 2012 (American Gaming Association, 2013a). While the majority of individuals who gamble do so recreationally, 1-3% are classified as problem gamblers (Shaffer, Hall, & Vander Bilt, 1999; Welte, Barnes, Tidwell, & Hoffman, 2008). Gambling is a complex set of behaviors that are controlled by an equally complex set of stimuli. In addition, casino games are often arranged probabilistically and a winner is chosen at random. This combination of factors makes it difficult to study gambling in a laboratory setting and also raises potential ethical consideration when using human participants (Baron, Perone, & Galizio, 1991; Madden, Ewan, & Lagorio, 2007). One approach to address these factors and study gambling in a laboratory setting is to break the complex behavior down into simpler, easier to analyze behaviors that encompass a facet of the overall gambling scenario.

Slot machines are of particular importance and interest in gambling research, as 61% of casino patrons report that their favorite casino games are electronic gaming machines like slot machines and video poker (American Gaming Association, 2013b). An outcome of particular interest in slot-machine play is the near win, also sometimes called a near miss. Near wins are outcomes where no reinforcer is delivered, meaning they are a type of loss, but they visually approximate a win. For example, if getting three cherries in a row is a win, then a near-win outcome would be two cherries and a lemon.

Near wins are thought to be one of the factors that encourage both recreational and problem gambling. Human participants who gambled in a laboratory setting reported that near wins were more similar to wins than to losses (M. R. Dixon & Schreiber, 2004). The perceptual similarity of near wins and wins is presumably responsible for effects such as continued betting in humans when near wins are presented (Côté, Caron, Aubert, Desrochers, & Ladouceur, 2003; Kassinove & Schare, 2001; MacLin, M. R. Dixon, Daugherty, & Small, 2007; Strickland & Grote, 1967). This suggests that the near-win trials may gain conditioned reinforcing value by presenting stimuli previously associated with wins. However, a rat model of slot-machine gambling failed to replicate this finding when using an arrangement of one to five sequential lights (Peters, Hunt, & Harper, 2010). The presentation of four or five illuminated lights signaled a win (food was delivered) and all other trials were losses (no food was delivered). A trial was considered a near win when exactly three lights were illuminated. When wins were subsequently removed after training and no food was delivered during a session, the presence or absence of near-win trials did not differentially affect how long the rats continued to respond. This result is inconsistent with laboratory gambling experiments with human research subjects. Human gamblers often play for longer in no-win conditions when near-win trials are present (Côté et al., 2003).

Although the rat model failed to replicate the prolonging effect of near-win trials on gambling persistence in no-win conditions, there have been demonstrations of nonhuman animal behaviors that resemble gambling. In a series of concurrent-chain experiments, Zentall and colleagues (Laude, Beckman, Daniels, & Zentall, 2014; Laude, Pattison, & Zentall, 2012; Laude, Stagner, & Zentall, 2014; Stagner & Zentall, 2010) demonstrated that pigeons preferred probabilistic schedules of reinforcement, as would be found in a gambling scenario, over schedules where the reinforcer was delivered with certainty. In these experiments, both the left and right keys were illuminated in the initial link. One key led to a terminal link associated with certain food ( $p = 1$ ) and the other key led to a terminal link associated with probabilistic food ( $p < 1$ ). The amount of food delivered in each terminal link varied between experiments, but generally the certain terminal link delivered smaller amounts in a single trial. However, because the certain food was delivered more frequently, this option was the choice that maximized food reinforcement. In spite of the higher rate of reinforcement from the certain terminal link, pigeons preferred the probabilistic terminal link and choose it instead of certain food on over 80% of trials.

While these experiments demonstrated preference for a probabilistic reinforcer, they did not include any near-win trials. To investigate possible effects of including near

wins, Stagner, Case, Sticklen, Duncan, & Zentall (2015) modified the procedure described above such that both side keys delivered probabilistic reinforcement at the same rate but differed in the stimuli associated with reinforcement (and non-reinforcement). In these experiments, the probabilistic terminal link included three possible stimulus arrangements: a stimulus associated with reinforcement, a stimulus associated with non-reinforcement, or a combination of the two stimuli (i.e., a near win). The other terminal link produced a stimulus that signaled reinforcement or a stimulus that signaled non-reinforcement. In contrast to human gamblers, pigeons did not prefer the terminal link that produced near wins. Instead, they chose the other terminal link on 70-80% of trials. Stagner et al. further investigated this by manipulating how long the S+ and S- were presented in the near-win trial and also added a neutral stimulus that preceded or followed the S+ and S-. These arrangements were selected to investigate the possible conditioned reinforcing effects of the S+ on near-win trials.

Across all four experiments, Stagner et al. (2015) found that near-wins decreased preference, a finding opposite to that of human gamblers. The authors concluded that pigeons may not be attracted to near-win outcomes like human gamblers. They suggested that near-win effects observed with humans may be due to an illusion of control fallacy, where human gamblers incorrectly believe they can influence the outcome of probabilistic events. In slot-machine play (a probabilistic event), getting two cherries and a lemon is a loss, though humans report this event to be more similar to a win than other loss types (i.e., three unmatched symbols; M. R. Dixon & Schreiber, 2004). In games of skill, getting close to a target marks an improvement in skills. In probabilistic games, getting closer to a win (i.e., a near win) marks no improvement in the player's skill because the outcome is purely random. According to Stagner and colleagues, this may be the reason humans are attracted to near-win outcomes and pigeons are not.

Another possible explanation for this discrepancy is that choosing to gamble is not equivalent to choosing between probabilistic outcomes with the same payout. For humans, the choice to gamble does not compete with other probabilistic schedules of reinforcement, but with complex outcomes that differ in many dimensions of reinforcement and may include options in which reinforcer probability could be almost certain (e.g., working vs. gambling). To truly appreciate the effect near wins have on the choice to gamble, additional reinforcer probabilities and magnitudes must be arranged. The current experiments modified reinforcer probabilities across three components that we labeled Certain, Probabilistic, and Gambling. In the Certain component, food was delivered each terminal link ( $p = 1$ ). The Probabilistic component delivered food on average every third terminal link ( $p = .33$ ). The Gambling component delivered food on average every third terminal link ( $p = .33$ ) but also had near-win trials arranged as in a previous slot machine analog experiment with pigeon subjects (Kyonka, Rice, & Ward, 2017). Each of these components was also compared to the others by embedding them as terminal links in a concurrent chain. While this arrangement is simpler than a real-world gambling scenario, it has the advantage of analyzing stimulus control and conditioned reinforcement in near-win trials almost exclusively.

The comparison between the Gambling and Probabilistic components are the most similar to those in Stagner et al. (2015), and if our results are consistent with theirs, there will be a preference for the Probabilistic component over the Gambling component. However, if near wins function as conditioned reinforcers, then there should be greater preference for the Gambling over the Certain terminal links than for the Probabilistic over Certain terminal links. Experiment 1 investigated preference for the Gambling component using pairwise comparisons between each component type and determined how preference shifted as a function of component type and reinforcer magnitude. Experiment 2 further investigated the conditioned reinforcing effects of near-win trials by modifying the probability of a near-win trial of the Gambling component when compared to the Certain component. The way these experiments are arranged is important, because choice is often between gambling and non-gambling alternatives (e.g., working, social experiences). In addition, gambling options often have different frequencies of near wins, which could systematically affect preference and therefore the decision to gamble.

## **EXPERIMENT 1**

The experiment by Stagner et al. (2015) presented pigeons with the choice between two probabilistic reinforcers of equal magnitude. Arranging comparisons between terminal links that differ in probability and magnitude of reinforcement may reveal conditions under which near wins affect whether pigeons will choose to gamble. In the present experiment, the initial link was composed of two different stimuli that each led to a different terminal-link schedule. The terminal links were labeled Certain, Probabilistic, and Gambling. The Certain terminal link always delivered food, while the Probabilistic and Gambling terminal links delivered food on average every three trials. The Gambling terminal link also presented near-win trials.

In concurrent chains, response allocation in the initial link is determined by the ratio of reinforcement in the two terminal links (Grace, 1994). The matching law is a formal, quantitative description of this result, which, in its generalized form, states that response allocation in concurrent variable-interval schedules is a power function of relative reinforcer rate (Baum, 1974). The matching law is typically expressed in logarithmic form:

$$\log \frac{B_1}{B_2} = a \log \frac{V_1}{V_2} + \log b, \quad (1)$$

where  $B$  is response rate,  $V$  is terminal-link value, and the subscripts  $1$  and  $2$  indicate the alternative schedules. Equation 1 has two parameters: bias,  $\log b$ , which is a constant preference for responding to either alternative that is independent of the reinforcer ratio, and an exponent,  $a$ , which is the sensitivity of response allocation to the reinforcer ratio. Value is often determined by rate of reinforcement in concurrent schedules and immediacy of reinforcement in concurrent chains (Davison & McCarthy, 1988; Poling, Edwards, Weeden, & Foster, 2011). Here,  $V$  represents the value of the terminal link as determined by multiplying reinforcer magnitude and probability. Although the generalized matching law is used more frequently with concurrent schedules than concurrent chains and other

ways of describing response allocation in concurrent chains exist, our use of the matching law here is for a convenient way to measure bias and not for any other theoretical purpose.

In this experiment, the value of reinforcement delivered,  $V$ , was determined by reinforcer magnitude multiplied by the probability of reinforcement. When Equation 1 is applied to initial-link response allocation, the  $a$  parameter estimates sensitivity to the relative expected food value of terminal links. If initial-link response allocation is sensitive to the probability or magnitude of reinforcement in the terminal links, then the sensitivity parameter should be greater than zero. Likewise, the bias parameter is a measure of any preference that is independent of the ratio of reinforcement value. Given appropriate counterbalancing, a systematic preference for one type of terminal link over another that is independent of expected value will be revealed as a nonzero bias. If near wins function as conditioned reinforcers, their presentation would increase the rate of reinforcement associated with the Gambling terminal links. So, when Equation 1 is fit to the comparisons between the Certain and Gambling or Probabilistic terminal links, bias should be larger when the Certain terminal link is compared to the Gambling terminal link than when it is compared to the Probabilistic terminal link. That is, if near wins function as reinforcers, then initial-link response allocation for that schedule will increase.

By embedding sequential stimuli similar to those presented in slot machines within a concurrent-chain procedure, the reinforcing effect of near wins can be determined by comparing preference for probabilistic schedules with and without near wins to non-gambling alternatives. This was accomplished by making pairwise comparisons between the Certain schedule that always delivered reinforcement, the Probabilistic schedule that delivered reinforcement probabilistically without near wins, and the Gambling schedule that delivered reinforcement probabilistically with near wins. If the near-win trial type has reinforcing value, preference should develop for a schedule with near wins as opposed to a schedule without them.

## METHOD

### Subjects

Three White Carneau pigeons (*Columba livia*) of mixed sex, numbered 303, 305, and 306, were maintained at 85% ad libitum weight  $\pm 15$  g through appropriate post-session feedings and housed individually in cages with a 12-hr:12-hr light:dark cycle with free access to water. These pigeons had experience with a similar categorical-discrimination task (Kyonka et al., 2017) but not with concurrent-chains procedures, so all pigeons began in a concurrent-chains pretraining procedure.

### Apparatus

Three operant-conditioning chambers (25.5 cm deep x 32.0 cm wide x 33.5 cm high) were enclosed in sound-attenuating boxes containing ventilation fans that provided air circulation and white noise. Each chamber contained three keys 24.0 cm above the floor arranged in a row 6.0 cm apart, a houselight located on the back wall at the top of the

chamber, and a grain magazine with a 5.5 cm x 6.0 cm aperture centered 5.5 cm above the floor.

The grain magazine was an L-shaped feeder that was raised and made accessible when reinforcer delivery occurred. Due to the shape of the feeder, extending the duration of presentation of the grain magazine did not lead to larger amounts of food being consumed. Instead, the magazine had to be lowered so that more grain filled the bottom of the magazine. As such, reinforcer deliveries consisted of making the magazine accessible for 2.5 s then resetting it for 0.5 s. Larger reinforcer deliveries were accomplished by making the magazine accessible for multiple 2.5-s intervals.

The houselight provided general illumination at all times, except during reinforcer delivery and intertrial intervals, during all phases of the procedure. A force of approximately 0.15 N was necessary to operate each key. Experimental events were controlled through a computer and MED-PC interface located in an adjacent room.

## **Procedure**

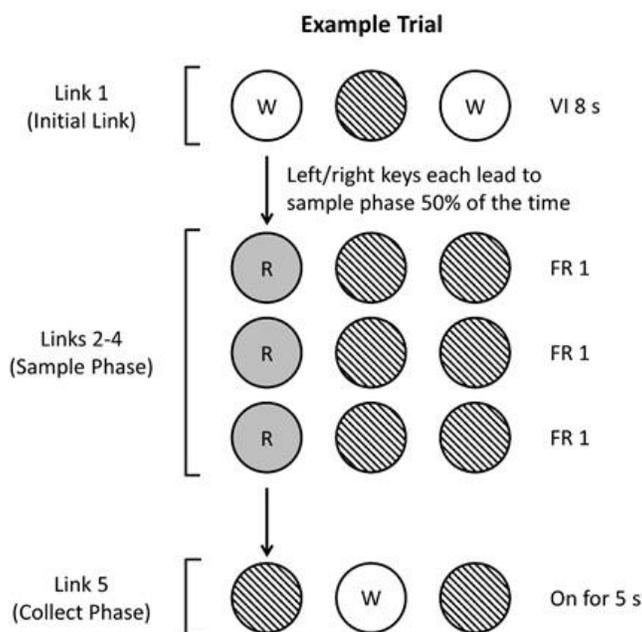
**Pretraining.** All pigeons began pretraining with a concurrent schedule. Sessions lasted for 72 cycles or 70 minutes, whichever came first. At the start of each interval, the left and right keys were illuminated white. Food delivery was interdependently scheduled, such that only one side key was active at any given time (i.e., both keys were illuminated but only one key would lead to further links in the schedule or reinforcement). The active side key was determined pseudorandomly with the constraint that in every block of 12 cycles, six were assigned to each key. A variable interval (VI) 8-s schedule was in effect on the active side key. The schedule for each side key contained 10 intervals sampled without replacement and was constructed from an exponential progression (Fleshler & Hoffman, 1962). Once the initial-link interval timed out and a 1-s changeover delay was satisfied, a response to the active key produced food.

After three to five sessions when responses were recorded on both side keys, the concurrent schedule was changed to a concurrent chain. Each cycle began with initial links that were identical to the concurrent VI 8-s schedule described in the previous paragraph. Satisfying the initial-link schedule produced fixed-interval (FI) terminal links. Terminal-link entry was signaled by darkening the side key that was not active and changing the color of the active key from white to red. Initially, left and right terminal links were identical FI 15-s schedules: the first peck to the active red key after 15 s had elapsed produced 3-s access to food.

To confirm that response allocation was sensitive to changes in relative rate of reinforcement, terminal-link schedules were changed once a pigeon had completed all 72 cycles for at least two consecutive sessions and response allocation in the initial links was stable. Stability was determined by visual inspection of the proportion of responses made to each initial link graphed as a function of session. Terminal-link schedules were changed from FI 15-s schedules to FI 10 s on the left and FI 20 s on the right, or vice versa. A left-right pair of terminal-link schedules was maintained for a minimum of 5 sessions and until

response allocation in the initial link favored the side key that produced the shorter terminal-link schedule based on visual inspection of log-response ratios. At that point, terminal-link schedules were switched and the new intervals were maintained until response allocation in the initial link shifted to favor the new shorter terminal-link schedule. Pretraining ended after two alternations of the terminal-link schedules.

**Training.** Following pretraining, all pigeons were placed into a five-link concurrent-chains schedule. An example cycle is depicted in Figure 1. For reference, the first link will be referred to as the initial link. The second through fourth links will be referred to as the “sample phase” and the fifth link (the terminal link) will be referred to as the “collect phase.”

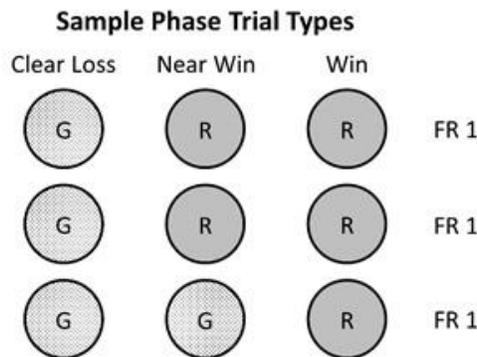


**Figure 1.** Diagram depicting the sequence of experimental events during a winning trial. Each circle represents one of the three keys at the various stages in the concurrent-chains procedure. The order of links progresses from top to bottom. The letters on the keys represent the color, white (W) or red (R). Keys marked with a hatched pattern represent darkened, inactive keys.

The initial link was the same interdependent VI 8-s schedule described in pretraining, except that the active side key was selected without replacement from a block of 30 with both side keys equally probable. The sample phase began as soon as the VI 8-s schedule timed out and the 1-s changeover delay was satisfied by a peck to the active initial-link key. Sample-phase entry was signaled by the darkening of the inactive side key. The active side key changed from white to either green or red, depending on the component and trial type. A three-link sequence of red and green stimuli was displayed on the active side key during each sample phase with the restrictions that the key color could remain the same or change from red to green. Progression from second to third to fourth to fifth links

each occurred with a single side key peck. That is, three pecks were required to progress through the entire three-link sequence presented in the sample phase. Each red or green stimulus was presented as soon as a response registered; there was no delay between the three stimuli shown in the sequence and a stimulus change only occurred during green to red transitions.

During the sample phase, red and green keys were winning and losing stimuli, respectively. Three red stimuli in a row signaled a “win,” three green stimuli a “clear loss,” and two red stimuli followed by a green a “near win.” Figure 2 depicts the possible sequences of red and green stimuli and their associated trial-type labels. Trial type (i.e., win, near win, or clear loss) was determined by selecting without replacement from a list of 30 trials. The number of each type of trial included in the list varied depending on which components (described later) were assigned to left and right keys.



**Figure 2.** Possible trial types and the associated stimuli shown in the sample phase. Each circle represents one of the presentations in the three-link sequence. The letters on the keys represent the color, red (R) or green (G).

The terminal-link “collect” phase began immediately after the third peck in the sample phase. Entry to the collect phase was signaled by darkening the side key and illuminating the center key. This “collect” key was illuminated white for 5 s. On winning trials, the terminal link ended with food delivery if at least one peck occurred at any point during the 5-s presentation of the collect key. Pecks that occurred during the 5-s presentation did not terminate the collect phase, regardless of the current trial type. Pecks were recorded during near-win and clear-loss trials but they had no programmed consequence.

A 10-s intertrial interval separated each trial during which the houselight and all keys were darkened. On winning trials with collect-key pecks, the total duration of food delivery was subtracted from the intertrial interval so that time from the completion of the collect phase to the start of the next sample phase was held constant at 10 s. Sessions lasted 120 minutes, during which time subjects completed approximately 150-200 trials (Pigeon 303:  $M = 201.9$ ,  $SD = 19.0$ ; Pigeon 305:  $M = 164.0$ ,  $SD = 42.0$ ; Pigeon 306:  $M = 193.7$ ,  $SD = 26.2$ ).

**Components.** The relative probability of wins, near wins, and clear losses differed across three different components. In the Certain component, wins were the only trial type that could occur. This made the Certain component a non-gambling option, as it always led to food. In the Probabilistic component, one third of the trials were wins and two thirds of the trials were clear losses. In the Gambling component, each trial type was programmed to occur equally often. For both the Probabilistic and Gambling components, food was only available in one third of the terminal links and therefore the components shared some properties with slot-machine gambling. The difference between the Probabilistic and Gambling components was whether or not near wins were presented.

**Pairwise comparisons.** The three different components were arranged in the three possible pairwise comparisons: Certain versus Probabilistic, Certain versus Gambling, and Probabilistic versus Gambling. The location of a component did not change within each comparison but could vary between comparisons. That is, if the Certain component was on the left key during the Certain vs. Probabilistic comparison, it was located on that key for all of that comparison, but could change position for the Certain vs. Gambling comparison. The location of components and order of conditions were partially counterbalanced across pigeons, as shown in Table 1.

**Table 1.** Arrangement of conditions and their order for all subjects in Experiment 1. Magazine presentations denote the number of times the food magazine was activated for 2.5 s during each reinforcer delivery. The richer component in each condition is italicized. The components listed here could appear on either the right or left keys, but did not change position within each pairwise comparison.

Key 1		Key 2		Log Reinforcer Ratio	Condition Order		
Component	Magazine Pres.	Component	Magazine Pres.		303	305	306
<i>Certain</i>	3	Probabilistic	3	0.48	2	9	6
Certain	2	Probabilistic	6	0	1	7	5
Certain	1	<i>Probabilistic</i>	9	-0.48	3	8	4
<i>Probabilistic</i>	9	Gambling	3	0.48	4	3	8
Probabilistic	6	Gambling	6	0	6	1	7
Probabilistic	3	<i>Gambling</i>	9	-0.48	5	2	9
<i>Gambling</i>	9	Certain	1	0.48	9	6	1
Gambling	6	Certain	2	0	8	5	3
Gambling	3	<i>Certain</i>	3	-0.48	7	4	2

For each pairwise comparison, the relative rate of reinforcement for the two components was varied across three conditions to obtain estimates of bias and sensitivity using the generalized matching relation (Equation 1). The log reinforcer ratio is a logarithmically additive and independent combination of the probability and magnitude of a reinforcer (Kyonka, 2008; Kyonka & Grace, 2008) calculated as:

$$\log\left(\frac{V_1}{V_2}\right) = \log\left(\frac{P_1 \cdot M_1}{P_2 \cdot M_2}\right), \quad (2)$$

Variables  $P$  and  $M$  are probability and magnitude (number of hopper presentations), respectively, and subscripts refer to the two side keys. For each pairwise comparison of components, pigeons were exposed to one condition when the left component was richer, one condition with equivalent rates of reinforcement, and one condition when the right component was richer. Because the probability of food was determined by the components scheduled on each side key, log reinforcer ratios were manipulated by changing the magnitude of reinforcement delivered following wins. The number of 3-s presentations of the food magazine (2.5 s of activation followed by a 0.5-s deactivation) was manipulated across conditions. For each pairwise comparison, the log reinforcer ratios were  $\log(3/1)$ ,  $\log(1/1)$  and  $\log(1/3)$ . That is, the schedule on the left key was richer, programmed rates of reinforcement were equivalent, and the schedule on the right key was richer, respectively. It was possible for a pigeon to earn 60 food-magazine presentations per session in all conditions. Each condition lasted 14 sessions. Responding in initial links, sample phases and collect phases usually stabilized by the ninth session, as determined by visual inspection of response rates for each of the phases. Therefore, the last five sessions of each condition were used for all analyses.

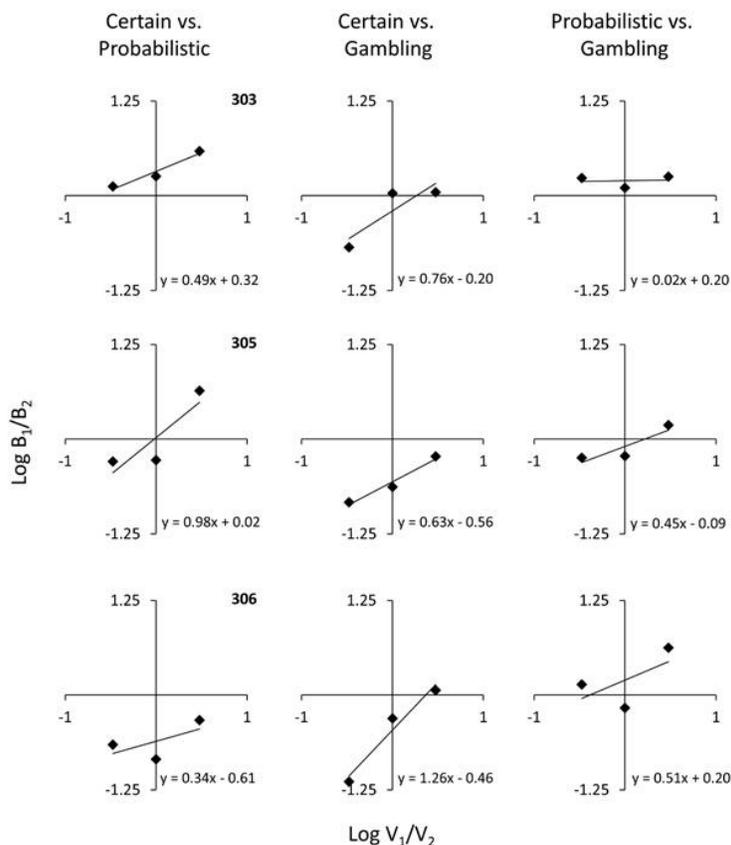
## RESULTS AND DISCUSSION

### Initial-Link Response Allocation

Initial-link responses were counted for the final five sessions of each condition. We calculated a log response ratio for each pigeon and session. Figure 3 shows the average of the five log initial-link response ratios, plotted as a function of programmed log reinforcer ratio, for each pigeon in each condition. Each pairwise comparison consisted of three conditions in which the probability of food did not change, but the magnitude of food delivered on winning trials did. The label for each pairwise comparison lists the two components active at that time. For each column of panels in Figure 3, the first component listed was the numerator for response and reinforcer ratios, and the second component the denominator. For example, in the left column all initial-link response ratios were expressed as  $\log(B_{\text{certain}}/B_{\text{probabilistic}})$  and all programmed log reinforcer ratios as  $\log(1/3)$ ,  $\log(1/1)$ , and  $\log(3/1)$ . Of the 18 cases (six conditions  $\times$  three pigeons) when one key was associated with a richer rate of reinforcement, initial-link response allocation favored the richer schedule in 13 of them.

The best-fitting line (Equation 1) was determined for each pairwise comparison to generate a linear function describing preference in the initial links. Here, preference is indicated by proportionally more responding to one component over another. Figure 3 shows the lines of best fit for all pigeons and each pairwise comparison. The slope of this line is the estimate of sensitivity from Equation 1 and the y-intercept is the estimate of bias. In all comparisons, the slope of the line is positive (Range: 0.02 – 1.26). A positive slope indicates that initial-link response allocation was sensitive to the changes in reinforcer magnitude across the three conditions. The slope in the Probabilistic vs. Gambling comparison for Pigeon 303 was not significantly different from zero, indicating that initial-link response allocation was not sensitive to changes in reinforcer magnitude in this particular comparison. This was the only comparison in which the slope was not

significantly greater than zero. Across pigeons, estimates of sensitivity did not vary systematically between pairwise comparisons or change systematically over time, and there was no systematic ordinal effect across components. Although initial-link response allocation sometimes favored the leaner schedule, estimates of sensitivity show that all pigeons were sensitive to reinforcer magnitude.



**Figure 3.** Matching law functions generated by Equation 1 for all conditions and phases (columns) for all subjects (rows) in Experiment 1. Data points are log response ratios plotted as a function of log reinforcer ratio. Each column represents a separate pairwise comparison and each row represents a subject. Each panel has three data points, which are indicative of the three log reinforcer ratios (1:3, 1:1, 3:1). The leftmost data point represents the 1:3 ratio, the middle data point represents the 1:1 ratio, and the rightmost data point represents the 3:1 ratio. Each data point represents a condition: 1:3 (leftmost), 1:1 (center), and 3:1 (rightmost). The line represents the line of best fit and its equation is shown in the bottom right of each panel.

The y-intercept, or bias parameter, is an estimate of preference for one component over another (i.e., one side over another) that is independent of the programmed relative value of terminal links. It can represent a side-key bias, but the different components were counterbalanced across keys, so this bias parameter instead represents relative preference for the different components. In this experiment, the bias parameter is an estimate of tendency to choose one component over another, all else being equal. For example, in the Certain versus Probabilistic comparison, a positive bias indicates that response allocation

avored the smaller, guaranteed amount of food. A negative bias indicates response allocation was risky: responses were typically allocated towards the probabilistic over certain outcomes. We calculated the 95% confidence interval for all biases to determine which were significantly different from zero. Out of the nine bias parameters, eight were significantly different from zero. Table 2 shows each bias parameter and its associated 95% confidence interval. There was a consistent preference for the Gambling component when the alternative was the Certain component, but no systematic bias in either the Certain vs. Probabilistic or Probabilistic vs. Gambling comparisons. One result that was consistent across all three pigeons was that bias in the Certain vs. Gambling comparison was more negative than the bias in the Certain vs. Probabilistic comparison. This is positive evidence that the presence of near-win trials increases preference for risky over certain, non-gambling alternatives.

**Table 2.** Bias parameters and 95% confidence intervals for all pigeons and all pairwise comparisons in Experiment 1.

Pairwise Comparison	Pigeons		
	303	305	306
C vs. P	0.32 [0.25, 0.36]	0.02 [-0.06, 0.23]	-0.61 [-0.69, -0.47]
P vs. G	0.20 [0.13, 0.22]	-0.09 [-0.22, -0.05]	0.20 [0.02, 0.37]
C vs. G	-0.20 [-0.30, -0.10]	-0.56 [-0.60, -0.52]	-0.46 [-0.57, -0.40]

*Note:* Certain (*C*), Probabilistic (*P*), and Gambling (*G*). A positive bias indicates preference for the component listed first and a negative bias indicates a preference for the component listed second.

The bias for the Gambling component over the Certain component indicates that red stimuli functioned as conditioned reinforcers. Response allocation was only biased towards a probabilistic outcome over a certain outcome when the probabilistic outcome included near-win trials. If preference had been determined by the contingencies regulating food delivery alone, then the same bias should have been observed in the Probabilistic component when it was presented with the Certain component. Instead, bias for the Gambling component was always stronger than bias for the Probabilistic component. Presumably, the inclusion of near wins increased the conditioned reinforcing value of the Gambling initial link (Preston & Fantino, 1991; Williams & Dunn, 1991). One factor that complicates this interpretation is that if near wins added value to the Gambling component compared to the otherwise-identical Probabilistic component, there should have been a bias for Gambling over Probabilistic. Instead, there was no consistent bias for the Gambling component over the Probabilistic component. In fact, bias favored the Probabilistic component for two out of three pigeons, a result consistent with Stagner et al.'s (2015) results from a different concurrent-chain gambling procedure.

Interestingly, for Pigeon 303, the pattern of biases violated the transitive property. Bias parameters indicated preference for the Certain over the Probabilistic component and the Gambling over the Certain component, but the Probabilistic over the Certain component. Some violations of transitivity in concurrent chains (Navarick & Fantino,

1972) have been interpreted as contextual effects (Grace, 1993) and are consistent with the idea that the red lights in near-win trials add conditioned reinforcing value to the Gambling component. However, one caveat to these results is that the duration of the conditions was restricted to 14 sessions for logistical reasons. In the absence of a performance-based stability criterion, intersubject differences in error rates (Birnbauer & Schmit, 2008) cannot be ruled out as an alternative explanation for these discrepancies. If conditions had been longer, it is possible that a bias for the Probabilistic over the Certain component would have emerged for Pigeon 303.

In future research, longer conditions may help to determine when biases for particular components become stable. In the present experiment, the Gambling component was expected to have the highest reinforcing value of all the components, due to the delivery of probabilistic food and the presentation of near wins (conditioned reinforcers). The Certain component was expected to have the lowest reinforcing value of the components, since it delivered smaller, certain food with no near-win trials. As such, the largest discrepancy in reinforcing value was between the Gambling and Certain components, which is where bias was largest and most consistent in the current experiment. Although no pigeon's biases matched expected pattern of Gambling > Probabilistic > Certain, all three pigeons reliably preferred the Gambling component over the Certain component. In concurrent chains, response allocation takes longer to adjust when terminal-link values become more similar than when they become more different (Kyonka, 2014). Longer conditions may be necessary for a stable bias to develop in other comparisons because they involve components with relatively similar conditioned reinforcing values.

### **Sample-Phase Response Times (RTs)**

Responding in the sample phase (i.e., middle links) was to three sequentially presented stimuli that appeared on a single key. For ease of illustration, Figure 4 depicts RTs for each condition and pigeon collapsed across all conditions. White bars indicate when the key was green and black bars indicate when the key was red. Based on RTs from all subjects, components, and comparisons, response times for green keys ( $M = 2.71$  s,  $SD = 3.23$  s) were longer than those for red keys ( $M = 0.33$  s,  $SD = 0.13$  s). In addition, RTs appeared similar across the different components. There was some intersubject variability in RTs: Pigeons 303 and 305 typically had longer RTs than Pigeon 306. To the extent that comparison was possible, component type did not affect RTs, indicating that the presence or absence of trial types within a session did not systematically alter RTs of the available trial types. This suggests that only the currently active trial controlled behavior in the sample phase. These RTs are consistent with previous research using a similar procedure without the initial links (Kyonka et al., 2017).

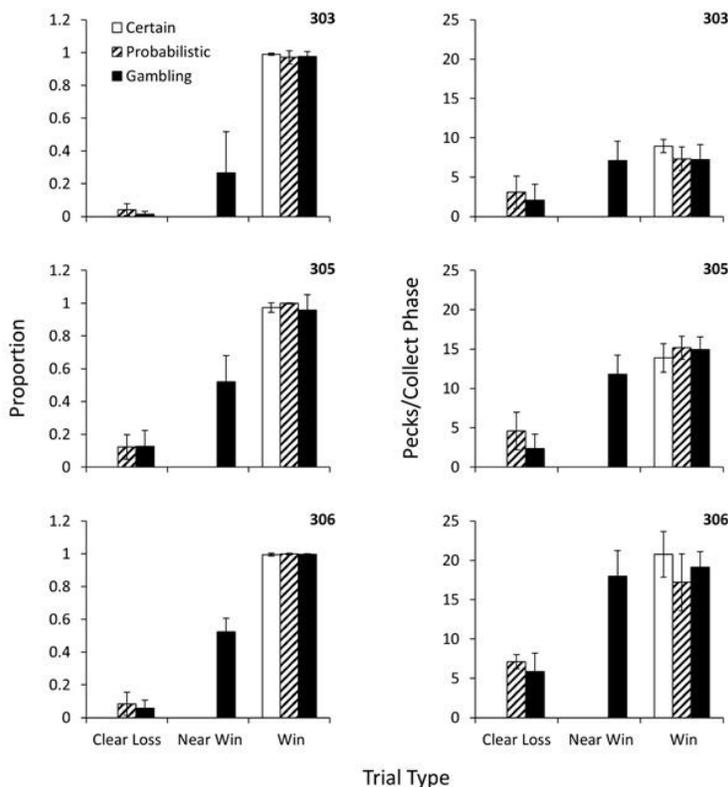
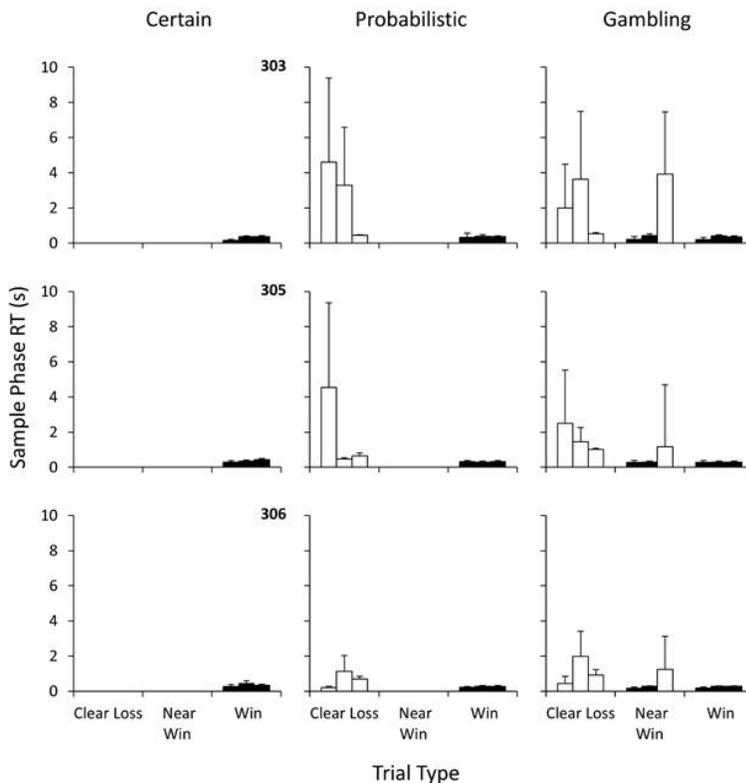
## **Collect-Phase Responding**

The collect key was presented for 5 s after the sample phase and required at least one peck to occur during that time for food to be presented following a win. To characterize responding on the collect key, we calculated the proportion of trials where a peck occurred and the rate of responding on the collect key for each pigeon and condition. Response rates were calculated such that only trials where at least one peck occurred were entered into the analysis. Response proportions and rates, collapsed across the different components, are depicted in Figure 5. There was minimal between-subject variability in response proportions and all proportions were similar across the different components. In addition, proportions were ordinally identical across pigeons. Pecks occurred on almost all win trials (Range: .958 - .999) and occurred rarely on clear-loss trials (Range: .015 - .127). Response proportions on near wins were higher than on clear losses, lower than on wins and were the most variable between subjects (Range: .250 - .523). The more red stimuli shown during the sample phase, the more likely a response occurred during the collect phase. That is, the more similar to a win a trial was, the more likely the pigeon was to peck the collect key to collect food.

Response rates were also similar across components. There were individual differences in response rates, but ordinal effects were once again identical across pigeons. Response rates were the lowest on clear-loss trials (Range: 2.04 – 7.11 pecks/collect phase) and were highest during win trials (Range: 7.22 – 20.78 pecks/collect phase). Response rates for near-win trials were similar to win trials (Range: 7.12 – 18.01 pecks/collect phase) and were higher than clear-loss response rates. So, although near wins and wins differed in the proportion of trials where a peck occurred, when pecking did occur it was at an equivalent rate.

Collect-key response proportions and response rates were consistent with prior results (Kyonka et al., 2017). Although the two variables are related, they appear to be distinct measures that reflect stimulus discrimination and response strength, respectively. Similar to results from slot machine analog tasks with humans (Clark, Crooks, Clarke, Aitken & Dunn, 2012; M. J. Dixon, MacLaren, Jarick, Fugelsang & Harrigan, 2013; M. R. Dixon & Schreiber, 2004), rats (Peters et al., 2010; Winstanley, Cocker, & Rogers, 2011) and pigeons (Kyonka et al., 2017; Scarf et al., 2011), there was a near-win effect observed here for collect-phase responding. Specifically, response rate in collect phases of near-win trials was equal to response rate in collect phases of win trials and higher than the response rate for clear-loss trials, even though clear losses and near wins were similar in that reinforcement was never delivered following these trials. The presence of a near-win effect in the current experiment is important because it suggests that choice in initial links would generalize to situations that involve choosing whether to gamble, even though the structural characteristics of the concurrent chain procedure differ from games of chance in several ways.

**Figure 4.** Response times taken from the sample phase of each component as a function of trial type in Experiment 1. We calculated median response times for each session; bars show the mean from the last five sessions of a condition. White bars illustrate when the key was green and black bars illustrate when the key was red. Errors bars are standard deviation.



**Figure 5.** Graphs on the left depict mean proportion of trials where a peck occurred during the collect phase as a function of component and trial type in Experiment 1. Right graphs depict the mean pecks per collect phase where at least one peck occurred as a function of component and trial type. White bars represent sample-phase responding from the Certain component, striped bars the Probabilistic component, and black bars the Gambling component. Bars show means calculated from pooling the last five sessions of each condition for a component. Error bars represent standard deviation.

## **EXPERIMENT 2**

In an experiment with humans, Maclin and colleagues (2007) gave participants experience with three slot machines with varying probabilities of near-win trials: 15%, 30%, and 45%. The amount of programmed reinforcement (points exchangeable for chances to win small prizes) among the alternatives was equal. The participants were then placed into an extinction condition where wins (and therefore reinforcement with points) were removed. Participants could then choose to play any of the three slot machines. While it appeared that higher near-win probabilities encouraged more gambling in extinction, there was no significant difference in response allocation across all of the subjects. The authors went on to divide participants into a group that played fewer than 100 trials in extinction and a group that played more than 100 trials in extinction. The group that played fewer than 100 trials showed no preference in their choice of slot machine; however, the group that played more than 100 trials showed a minor preference for higher probabilities of near wins, though it was not statistically significant. The authors did not present any individual data or estimates of variability, so it is difficult to determine to what extent individual response patterns varied in this task. Despite these potential limitations, results suggest that near-win probability may affect choice between gambling options for some players.

Experiment 1 demonstrated that preference for probabilistic outcomes was dependent on the way those outcomes were signaled at the molar level, specifically on the presence of the near-win trials. The relative probability of near-win presentations in Experiment 1 was 0% in the Probabilistic component or 33% in the Gambling component. More exposure to stimuli associated with wins should increase the value of the context in which that exposure occurs. A higher probability of near-win trials means more exposure to stimuli that possess conditioned reinforcing value, which should strengthen bias for the Gambling component. In Experiment 2, we tested this prediction by systematically altering the relative probability of near-win trials in the Gambling component across conditions. The other schedule in effect was always the Certain component (i.e., a non-gambling alternative).

## **METHOD**

### **Subjects and Apparatus**

The subjects and apparatus used were as described in Experiment 1.

### **Procedure**

The same concurrent-chains procedure from Experiment 1 was used in the current experiment. However, in all phases and pairwise comparisons of this experiment, the two available components were always the Certain and Gambling components. The relative rate of reinforcement between these two components was manipulated across conditions. The log reinforcer ratios used in the current experiment were  $\log(3/1)$  and  $\log(1/3)$  and the

number of reinforcers per win for each ratio (i.e., magazine presentations) was the same as those described in Experiment 1.

There were four phases in this experiment, which were named according to the probability of a near-win trial in the Gambling component: 0%, 7%, 17%, and 33%. The data for the 0% and 33% phases were obtained from the Probabilistic and Gambling components in Experiment 1, respectively. The data for the 7% and 17% phases were collected in the current experiment. Thus four conditions from Experiment 1 (relative reinforcement ratios of 1:3 and 3:1 in each of two phases) were compared with four new conditions (the same ratios in each of two new phases). As in Experiment 1, each new condition lasted 14 sessions and the order of conditions was partially counterbalanced across pigeons, as shown in Table 3.

**Table 3.** Arrangement of conditions and near-win probabilities for all subjects in Experiment 2. Magazine presentations denote the number of times the hopper was activated for 2.5 s during each reinforcer delivery (which only occurred during a “win” trial).

Pigeon 303						
Left Key			Right Key			Log
Condition	Component	Magazine Pres.	Component	Magazine Pres.	Near-Win Probability	Reinforcer Ratio
1	Certain	3	Gambling	3	7%	0.48
2	Certain	1	Gambling	9	7%	-0.48
3	Certain	3	Gambling	3	17%	0.48
4	Certain	1	Gambling	9	17%	-0.48

Pigeon 305						
Left Key			Right Key			Log
Condition	Component	Magazine Pres.	Component	Magazine Pres.	Near-Win Probability	Reinforcer Ratio
1	Gambling	9	Certain	1	17%	0.48
2	Gambling	3	Certain	3	17%	-0.48
3	Gambling	9	Certain	1	7%	0.48
4	Gambling	3	Certain	3	7%	-0.48

Pigeon 306						
Left Key			Right Key			Log
Condition	Component	Magazine Pres.	Component	Magazine Pres.	Near-Win Probability	Reinforcer Ratio
1	Gambling	3	Certain	3	7%	-0.48
2	Gambling	9	Certain	1	7%	0.48
3	Gambling	3	Certain	3	17%	-0.48
4	Gambling	9	Certain	1	17%	0.48

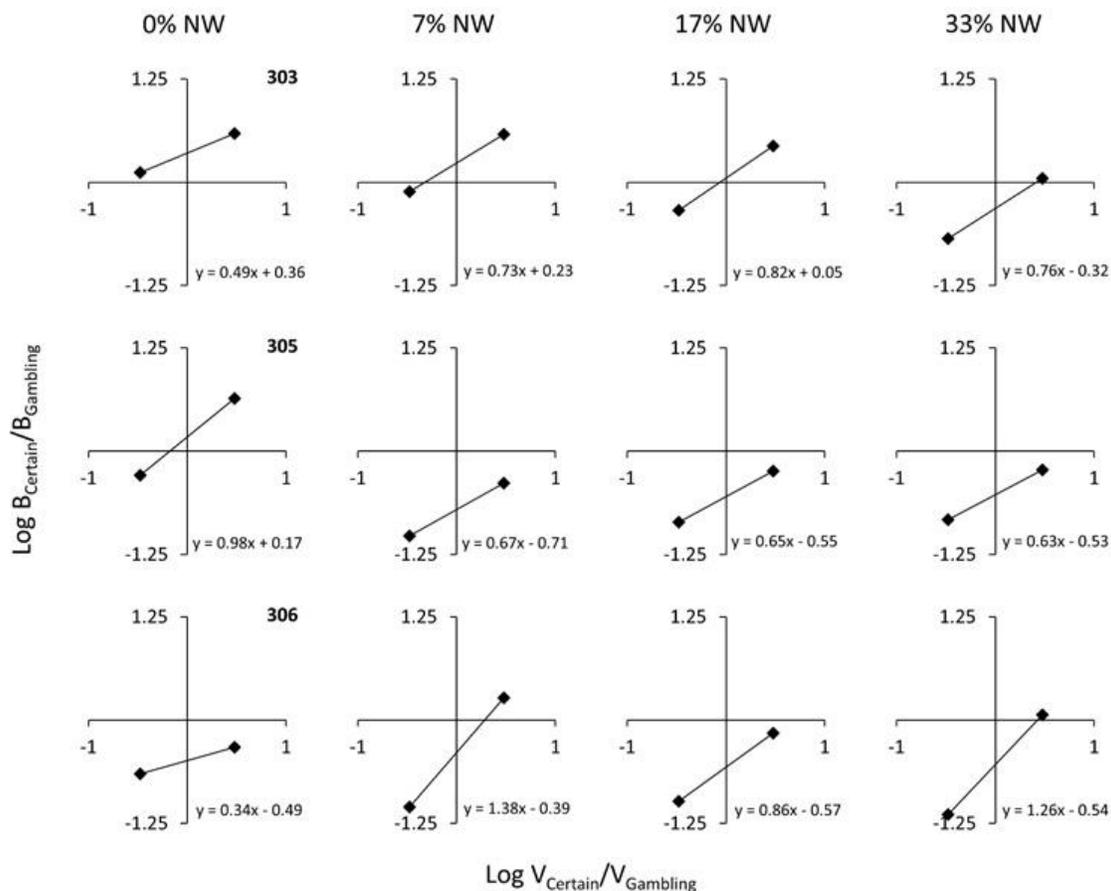
## RESULTS AND DISCUSSION

We analyzed sample-phase RTs and collect-phase responding from the two new conditions of Experiment 2 as described in Experiment 1. Responding in the sample and collect phases was the same as reported in Experiment 1. Due to the similarity and the inability to draw any new conclusions based on these data, those analyses are not included here.

As in Experiment 1, initial-link responses were aggregated across the final five sessions in each condition. Figure 6 displays the log-response ratios and lines of best fit for each pigeon in each condition, plotted as a function of programmed log reinforcer ratio. Unlike Experiment 1, only two components were used: Certain and Gambling. In addition, only two reinforcer ratios were used in each pairwise comparison. As such, each panel consists of two data points; the leftmost data point represents the  $\log(1/3)$  reinforcer ratio (i.e., the Gambling component was richer) and the rightmost data point represents the  $\log(3/1)$  reinforcer ratio (i.e., the Certain component was richer). Of the 24 cases (eight conditions  $\times$  three pigeons) when one key was associated with a richer rate of reinforcement, initial-link response allocation favored that key in 18 cases, but there was evidence of bias in all conditions.

The best-fitting line (Equation 1) was determined for each pairwise comparison to generate a linear function that described preference in the initial links. The slope of this line is the sensitivity parameter from Equation 1 and indicates how initial-link response allocation changed as a function of reinforcer magnitude within a condition. In all twelve comparisons, the slope of the best-fitting line was positive (Range: 0.34 – 1.38). Across pigeons, the sensitivity parameter did not systematically vary between conditions. As in Experiment 1, the bias parameter is an estimate of tendency to choose one component over another, all else being equal. The 95% confidence interval was calculated for all biases to determine which were significantly different from zero – all 12 bias parameters were significantly different from zero. Table 4 shows each bias parameter and confidence interval. Group mean bias parameter estimates for all three pigeons were 0.01, -0.29, -0.37 and -0.46 in the 0%, 7%, 17% and 33% phases, respectively. On average, preference for the Gambling component was stronger when the near-win trial probability was higher. However, it is important to note the different response patterns of the three pigeons. For Pigeon 303, preference shifted gradually from the Certain component to the Gambling component as near-win probability increased. For Pigeon 305, the presence or absence of near-win trials controlled preference for the Gambling component. Lastly, Pigeon 306 was sensitive to the probabilistic reinforcement in the Gambling component in a different way; bias in the 17% and 33% conditions was more extreme than bias in the 0% and 7% conditions. The different patterns shown here may suggest large individual variability in the sensitivity to near-win trials.

Although changes in bias as a function of near-win probability differed between subjects, all pigeons preferred the Gambling component when that component had higher near-win probabilities. Across conditions, mean bias for the Gambling component decreased monotonically from 0.01 in the 0% condition, when near-win trials were



**Figure 6.** Matching law functions generated by Equation 1 for all phases (columns) for all subjects (rows) in Experiment 2. Data points are log response ratios plotted as a function of log reinforcer ratio. Each data point represents a condition: 1:3 (leftmost) and 3:1 (rightmost). The line represents the line of best fit and its accompanying equation is shown in the bottom right of each panel.

**Table 4.** Bias parameters and 95% confidence intervals for all pigeons and all conditions in Experiment 2. All biases were significantly different from zero. Positive bias indicates preference for the Certain component and negative bias indicates preference for the Gambling component.

Near-Win Probability	Pigeon		
	303	305	306
0%	0.36 [0.27, 0.40]	0.17 [0.13, 0.34]	-0.49 [-0.51, -0.41]
7%	0.23 [0.08, 0.44]	-0.71 [-0.76, -0.61]	-0.39 [-0.45, -0.17]
17%	0.05 [0.004, 0.11]	-0.55 [-0.69, -0.51]	-0.60 [-0.72, -0.49]
33%	-0.32 [-0.37, -0.23]	-0.53 [-0.61, -0.50]	-0.54 [-0.79, -0.35]

absent, to -0.46 in the 33% condition, when a third of all trials were near wins. The additional near-win probabilities used in the current experiment revealed intersubject variability in sensitivity of response allocation to different parameters of the experiment.

Consistent with Experiment 1 and previous research (M. R. Dixon & Schreiber, 2004; Kyonka et al, 2017; Reid, 1986), the fact that bias was sensitive to the probability of near wins for all three pigeons in either a linear or an all-or-none fashion reconfirms the view that near-win effects occur because stimuli associated with wins are imbued with conditioned reinforcing value.

These results are particularly interesting when compared to results obtained by Stagner et al. (2015). Those authors found that near wins decreased preference when compared to a probabilistic schedule without near wins. The current experiment found that near wins increased preference when compared to a non-gambling option. It is possible that an important factor in near-win effects is the context in which near-win trials appear. The results may be significantly different when the choice is between two probabilistic outcomes versus one in which a gambling option is paired with a non-gambling alternative, as was the case in the Certain versus Gambling comparisons in Experiments 1 and 2.

In the preextinction phase of a laboratory slot-machine experiment, there was some evidence that human gamblers preferred slot machines that produced near wins on 15% or 45% of trials more than a slot machine that produced near wins on 30% of trials, though the effect was not statistically significant (MacLin et al., 2007). MacLin and colleagues may have found no consistent effect because the range of probabilities was higher or because compared to the pigeons in the current experiment; their human subjects' responding was more sensitive to the specific stimulus-reinforcer relations than to the relative value of the component as a whole. For pigeons, the specific functional relation between near-win probability and preference for gambling over other activities remains unknown, particularly when the rate of presentation of such stimuli is high. The individual variability and limited number of conditions presented here constrain conclusions about how near-win probability affects preference, though the pattern of bias observed in all pigeons suggests that the two are correlated. Further replication with additional near-win probabilities and larger subject numbers is warranted.

## **GENERAL DISCUSSION**

Gambling is a complex behavior that poses unique challenges for laboratory research and is in dire need of additional experiments to be fully understood. The experiments presented here were the first time a task that shares features with slot-machine play and produces a near-win effect has been embedded into a free-operant concurrent-chain procedure. By doing so, we obtained measures of initial-link response allocation that clearly demonstrated an effect of near-win trials on gambling preference. The near-win effect has been observed in human gamblers, where near wins are reported to be more similar to wins than losses (M. R. Dixon & Schreiber, 2004). Analysis of skin conductance in human gamblers also showed that the reaction following a near win was similar to that of a win (Clark et al., 2012; M. J. Dixon et al., 2013). In a rat model of gambling, near-win latencies to initiate a trial were more similar to a win than a loss (Peters et al., 2010). These measures show that near wins were more similar to wins than losses and align with the current results in that response rates were similar between near wins and wins.

In Experiment 1, near-win response proportions were an intermediate value between clear losses and wins, indicating that near wins were functioning as something between a loss and a win. While this finding is similar to the human and rat literature, near-win trials were not identical to wins in the current preparation. The analyses of response proportion and response rates showed that on near-win trials, a response on the collect key is more likely to occur than other loss trials but not as likely as a win. When responding does occur, it occurs at the same rate as a win. This suggests that the process to determine whether a trial leads to reinforcement is separate from the factors that determine the response rate on winning trials. The distinction between these two behavioral processes deserves further research attention.

We examined near-win effects on choice in Experiment 2 by systematically manipulating the programmed probability of a near-win trial. Although there were intersubject differences in effect sizes in individual conditions, patterns of response allocation for all three pigeons revealed that higher near-win probabilities led to a stronger bias for the gambling schedule. In other words, the more near-win trials shown in a session, the more attractive the gambling option became. However, the data collected from this experiment is limited in the degree it can be generalized and warrants additional research to determine if this effect is limited to pigeons or extends to other species, particularly human gamblers.

This need for increased research is apparent when different experimental arrangements produce dissimilar functional outcomes. Stagner et al. (2015) found that near wins decreased preference when compared to a probabilistic alternative that had no near-win trials. However, near-win trials typically increased preference in the current experiments. The context in which these comparisons occurred were different, as the current experiment had a gambling alternative with no near-win trials (Probabilistic component) and a non-gambling alternative (Certain component). Additional research is needed to determine when near-win effects occur, in which animal models and experimental procedures, and whether findings generalize to human gamblers.

Animal models of gambling offer unique opportunities to study basic processes that presumably govern human gambling, such as stimulus control and conditioned reinforcement. In human gambling, these processes likely influence behavior in complex and interconnected ways, but they can be disentangled with the additional experimental control possible in research with laboratory animals. Experiments conducted by Peters et al. (2010), Laude et al. (2014), and Stagner et al. (2015) laid groundwork for more complex experimental arrangements, such as those used here. In the future, research using animal models will be fine-tuned as the complex role near wins play in controlling slot-machine play is understood better. In turn, animal researchers will be able to create better analogs of human gambling that will be more likely to generate results that can directly lead to treatments or interventions.

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