

THE SUNK COST EFFECT WITH PIGEONS: SOME DETERMINANTS OF DECISIONS ABOUT PERSISTENCE

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The sunk cost effect occurs when an individual persists following an initial investment, even when persisting is costly in the long run. The current study used a laboratory model of the sunk cost effect. Two response alternatives were available: Pigeons could persist by responding on a schedule key with mixed ratio requirements, or escape by responding on a second key. In Experiment 1, mean response requirements for persistence and escape were varied across conditions. Pigeons persisted (committing the sunk cost error) when persisting increased the mean response requirement only slightly but not when persisting was sufficiently nonoptimal. Experiment 2 explored more systematically combinations of ratios and probabilities assigned to the schedule key. Persistence varied with the ratio of the mean global response requirements for persistence and escape. In Experiment 3, transitions between ratios were signaled. This reduced nonoptimal persistence, and produced some instances of a reverse sunk cost error—escaping when persistence was optimal. In Experiment 4, it was optimal to escape after the second-smallest ratio ever presented. Pigeons escaped at approximately the optimal juncture, especially in conditions with added signals. Overall, this series of experiments suggests that the sunk cost error may arise in part because persistence is the default behavioral strategy in situations where the contingencies for escape and persistence are insufficiently disparate and/or it is relatively difficult to discriminate when to escape. The study also demonstrates the utility of animal models of complex decision making situations.

Key words: sunk cost effect, decision making error, decision making, ratio schedules, key peck, pigeon

The sunk cost effect occurs when choices are affected by past investments in one of the choice alternatives, rather than by the likely future costs and benefits of selecting each alternative. One type of sunk cost error involves continued investment in a losing effort. This type of error is exemplified by the results of a study by Garland (1990).

Research supported by NSF Grant IBN 0420747. Some of these data were presented at the 2009 and 2011 meetings of the Association for Behavior Analysis International, and also formed part of the basis of the first author's doctoral dissertation. The authors would like to thank Leonardo Andrade, Carla Lagorio, Jennifer Rusak and Rachelle Yankelevitz for help with conducting sessions, and Marc Branch, Jesse Dallery, David Smith, and Robin LeBoeuf for comments on an earlier draft of this manuscript.

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doi: 10/1901/jeab.2012.97-85

Subjects were told to imagine they worked at a company developing a leading-edge line of military airplanes. The company recently learned that a competitor would likely beat them to the marketplace; their product line would likely be a financial failure. Should they continue to invest (“throwing good money after bad”), or terminate the project, cutting their losses? The majority of subjects continued to invest—exemplifying the sunk cost error—with the probability of investment increasing with amount of past investment.

The sunk cost error has been considered to be an “irrational” decision pattern in that it departs from overall utility maximization, and is one of several types of suboptimal decision-making patterns studied over the past few decades (Fantino, Kulik, Stolarz-Fantino, & Wright, 1997; Goodie, & Fantino, 1995; Stolarz-Fantino, Fantino, & Kulik, 1996). Although there is ample evidence of the sunk cost error with humans, the extent to which nonhuman animals make analogous sunk cost errors is a

matter of some debate. In a review published a decade ago, Arkes and Ayton (1999) concluded that there was insufficient evidence at that time to suggest that nonhuman animals make sunk cost decision making errors. More recent evidence, however, suggests that there are conditions under which prior investments appear to influence decision making in animals.

Kacelnick and Marsh (2002) required starlings to fly between two keys either 4 or 16 times (i.e., fixed-ratio (FR) 4 and FR 16 schedules), with schedules signaled by distinctive key light colors. In a second phase the animals chose between the two key light colors, now providing food on identical schedules. Most starlings preferred the key that had been associated with the FR16 schedule, suggesting preference was increased by previous investment.

De la Piedad, Field and Rachlin (2006) investigated the influence of past investment over future behavior with pigeons in a context in which the animals could persist on a given response alternative, or switch to another, concurrently-available alternative. Responses on one key produced food on a random-interval (RI) schedule of reinforcement (unpredictable from moment to moment) and the other on an FRI-fixed-interval (FRI-FI) schedule of reinforcement (with fixed waiting times from the first response to the availability of food). On the FRI-FI key, persistence was differentially reinforced because time spent on that alternative was correlated with increased reinforcement probability. Persisting on the RI schedule was not differentially reinforced, however. In spite of this, the more time subjects had spent on the RI alternative (without receiving reinforcement), the longer they tended to persist. This control by past investment was reduced if persisting on the RI alternative led to extinction, however.

In a laboratory analogue of decisions made by humans about whether to continue to invest in an already-begun course of action, Navarro and Fantino (2005) presented pigeons with two response keys. One key—termed the schedule key—was programmed with a modified mixed ratio schedule. In each condition there were (typically) four ratios that might be presented on a given trial, and the probability with which each occurred was fixed during a given condition. The particular ratio value was selected randomly each trial. If the pro-

grammed ratio was satisfied, then food was presented and the next trial began, with the FR re-determined according to the probabilities in place during that condition.

Responses on the other key—termed the escape key—terminated the trial and produced a new trial with the ratio re-determined. On most of the conditions that Navarro and Fantino (2005) presented, these probabilities and ratios were arranged such that escape was optimal (i.e., it led to the lowest available mean response requirement per reinforcer delivery). The optimal response pattern was to escape if completing the number of responses equivalent to the lowest ratio did not produce food, because escaping produced a new trial with a potentially more favorable ratio. Unlike the other studies by de la Piedad et al. (2006), and Kacelnick and Marsh (2002), in which persistence was response-requirement-neutral, persistence in the Navarro and Fantino study generally came at a cost. Nevertheless, 3 of 4 pigeons persisted (committing the sunk cost error) in some conditions when doing so increased mean response requirement the least, but not in two conditions in which this penalty for persisting was larger. Avila-Santibanez, Gonzalez-Montiel, Miranda-Hernandez, and Guzman-Gonzalez (2010) used a similar procedure and also found that 3 of their 4 pigeons made the sunk cost error on at least one of three replications of a condition on which escape was optimal. In both studies, under conditions where it was optimal to persist, subjects did so consistently (provided stimulus changes signaling ratio transitions were not present).

The present study (Experiments 1 and 2) extended this finding by including a wider range of conditions that varied the cost of persisting (defined in terms of increased mean response requirement). In Navarro and Fantino's (2005) study, pigeons typically either persisted or escaped with near exclusivity. The present study included conditions with intermediate costs for persisting to investigate whether graded levels of persistence would develop. This is important in determining the form of the relationship between persistence and the costs of such persistence—for example, whether the function is step-like, with a threshold beyond which escape occurs exclusively, or more continuous, with the frequency of persistence varying over a wider range of costs.

Overall, the current series of experiments investigated factors contributing to whether pigeons make the sunk cost error. It also investigated decisions about whether to persist more broadly, including conditions under which the contingencies favored persistence; this allowed an assessment of decisions to persist within a wider contingency space—one that included the possibility of both nonoptimal persistence and nonoptimal escape. This is analogous to the situation faced by humans deciding whether to persist with or desist from a course of action in everyday life.

EXPERIMENT 1

Experiment 1 aimed to replicate the previously observed effects of varying the extent to which persistence was optimal on pigeons' levels of persistence. Additionally, it removed a possible alternative explanation for the levels of persistence observed by Navarro and Fantino (2005). In their study, most pigeons persisted when the ratios were 20, 50, 100, and 200 or 10, 40, 80, 160, but not when they were 5, 50, 100, and 220. This may reflect the increased response requirement for persistence in this last condition, as Navarro and Fantino noted. It is also possible, however, that a larger first ratio increased persistence because it represented a larger investment having been made at that choice point. Another possible explanation is that pigeons escaped more when the smallest ratio was FR5 because the optimal escape point was more discriminable.

The response-requirement advantage of escape is highest when escape responses are produced at the optimal juncture (i.e., immediately upon the nonreinforced completion of the smallest ratio). Even when the overall contingencies favor escape, response requirements are increased by escape-key responses that occur either before or after this optimal point. If escape-key responses are sufficiently mistimed, then escaping may produce higher mean obtained response requirements than persisting. On the assumption that the optimal choice pattern is more discriminable with a smaller than a larger initial ratio, we held constant (at FR 10) this initial ratio while varying the mean cost of making the sunk cost error across conditions. We also included the ordinal position of escape responses as an

additional dependent variable to investigate not just *whether* subjects escaped, but also *when* they did so.

In sum, pigeons were presented with a sequence of conditions that varied along the dimension from strongly favoring escape, to strongly favoring persistence. In order to quantify the extent to which one or other of these strategies were favored by a given condition, we calculated the mean number of responses that would be required for each reinforcer if each response pattern (persistence and escape) was performed exclusively. The ratio of these two values was then taken—ratios greater than 1 therefore indicated conditions favoring persistence, and ratios less than 1 indicated conditions favoring escape.

METHOD

Subjects

Four white Carneau pigeons, numbered 250, 456, 457, and 1770 served as subjects. Pigeon 250 was female; the others were male. The pigeons were maintained at 85% of their preexperimentally-established free-feeding weights through postexperimental feeding with the same grain mix used during sessions. Health grit, and water with added vitamins, were continuously available in home cages, located in a colony room with a 16.5:7.5 light:dark cycle.

Apparatus

A standard three-key operant chamber with internal dimensions of 30.5 cm × 35 cm × 35 cm was used, although only the left and center keys had programmed consequences. The center key was lit white when it was operable and the left key was lit green. A houselight was located directly above the center key, and a food hopper directly below it. The food hopper was used to present mixed grain; when grain was available a hopper light was lit and the chamber was otherwise dark. The chamber was located in a dark room, with masking noise continuously present. Experimental procedures were controlled using MED-PC IV software running on a computer in another room.

Procedure

Pigeons had previously served in other experiments relating to choice, including a study immediately preceding the one de-

Table 1

Features of conditions presented during Experiment 1. For each condition (rows), the four ratios and the probabilities with which they occurred are presented (columns). The rightmost two columns present overall mean response requirements for the two possible global response patterns (persistence and escape).

	condition	ratio 1	<i>p</i> 1	ratio 2	<i>p</i> 2	ratio 3	<i>p</i> 3	ratio 4	<i>p</i> 4	R_{persist}	R_{esc}
Favor Escaping	ES5	10	0.6	40	0.15	120	0.125	160	0.125	47	17.3
	ES4	10	0.5	40	0.25	80	0.125	160	0.125	45	21
	ES3	10	0.4	37	0.25	75	0.2	100	0.15	43.25	26.5
	ES2	10	0.4	31	0.2	70	0.1	81	0.3	41.5	26.5
	ES1	10	0.35	34	0.3	70	0.125	100	0.225	44.95	30.43
Equal	EQ	10	0.25	33	0.25	40	0.25	80	0.25	40.75	43
Favor Persisting	P1	10	0.063	40	0.063	80	0.5	160	0.375	103.1	175
	P2	10	0.06	50	0.2	70	0.25	100	0.49	77.1	182.3

scribed here that used the same apparatus and a similar task. The pigeons therefore began the conditions described here with a history of responding on both keys used in the current study, making unnecessary any preliminary training.

Pigeons were given repeated choices between a center (schedule) key and a left (escape) key. During a given condition, the center key was programmed with four FR schedules each presented with a set probability (technically a mixed ratio). These four FR schedules, and the probabilities with which they occurred during each condition, are presented in Table 1. If the ratio programmed on a given trial was completed, 2-s access to mixed grain was provided. Following a 1-s intertrial interval (ITI), during which the chamber was dark, a new trial began with the ratio re-determined according to the probabilities set for the current condition. A single response on the escape key initiated the ITI and began the next trial with a re-determined ratio.

As shown towards the bottom of Table 1, some conditions favored persisting on the mixed-ratio schedule. In these conditions, the FR 10 was relatively rare and/or the three other ratios were relatively small; thus, the lowest mean response requirement over the entire session was available if no escape responses were made. In other conditions, those presented towards the top of Table 1, the lowest response requirement could be achieved by consistently escaping after the 10th schedule-key response went unreinforced. It was during these conditions, in which the contingencies favored escaping, that the sunk cost error was possible.

The rightmost two columns of Table 1 present the number of responses required per reinforcer if either of these two strategies was adopted on every trial. The mean response requirement for always persisting (R_{persist}) is the sum of the FR values weighted by their probability. The mean response requirement for escaping after 10 schedule-key responses on every non-FR10 trial (R_{esc}) is 10 times the average number of trials required to produce all 40 reinforcers plus the escape responses, divided by the 40 reinforcers in the session. For ES4, FR10 trials were presented on 50% of the trials; therefore, an average of 80 trials was required to produce 40 FR-10 trials. Total mean response output is therefore $(80 \text{ trials} \times \text{FR } 10) + 40 \text{ escape responses} = 840$; creating an R_{esc} of 21 key pecks $(840/40)$ per reinforcer.

Some or all of the conditions described in Table 1 were presented to each pigeon in an individualized order, with the specific sequence determined by two factors. Firstly, conditions were sequenced such that preference reversals would likely be observed, providing compelling evidence of experimental control. Secondly, conditions were individualized in such a way that the full range of response patterns—from escaping consistently to persisting consistently—would be demonstrated. Conditions were replicated when time allowed. The sequence of conditions and the number of sessions at each are listed for all pigeons in Table 2.

A given condition was in effect for at least 10 sessions, and until the subject's levels of persistence (defined as the proportion of response ratios larger than 10 completed) was stable from day to day for five consecutive

Table 2

Sequence of conditions experienced by the 4 pigeons during Experiment 1. See Table 1 for complete condition descriptions. The number of sessions for which each condition was presented in order to establish stable responding is presented in parentheses.

Pigeon	Condition								
	1	2	3	4	5	6	7	8	9
250	ES4 (45)	EQ (14)	ES1 (38)	ES3 (75)	ES2 (76)	ES1 (10)			
456	ES4 (22)	EQ (14)	ES1 (28)	ES3 (42)	P1 (16)				
457	ES4 (46)	EQ (16)	ES4 (26)	P1 (15)	ES5 (19)	P1 (25)	ES5 (17)	ES4 (29)	ES1 (20)
1770	ES4 (20)	EQ (15)	ES1 (62)	P1 (17)	ES1 (27)	P2 (116)	EQ (19)	ES1 (59)	

sessions. Stability was defined as the absence of the highest point, the lowest point and either an upward or a downward a trend. Sessions occurred once daily at approximately the same time of day and lasted (typically) until 40 reinforcers had been presented or (rarely) until 75 min had elapsed. Sessions began with a 5-min blackout period during which all lights in the chamber were dark.

Dependent Variables

The primary dependent variable was the proportion of trials in which persistence was both possible and occurred. That is, proportion persistence was defined as the proportion of ratios larger than FR 10 that were completed. FR-10 trials were not taken into account because completing them did not entail a sunk cost error. This was the same definition of persistence used by Navarro and Fantino (2005). A second dependent variable was the mean number of responses made on the schedule key during a given trial before an escape response was made.

RESULTS

Figure 1 presents, for each pigeon, proportion persistence as a function of $R_{esc}/R_{persist}$ on a log scale. Instances of the sunk cost error appear as points to the left of the y-axis (indicating a condition where the contingencies favored escaping) and above zero (indicating the completion of some ratios larger than FR 10). All pigeons made the sunk cost error in one or more conditions. The sunk cost error was most likely when the costs of making the error were relatively low (near the y-axis). To the right of the y-axis, when contingencies favored persistence, pigeons sometimes made the *reverse sunk cost error* — that is, failing to persist when persistence was appropriate. These were rarer than the sunk cost error, however.

In those conditions favoring escape, it was optimal, in terms of reducing response requirements, to make an escape response after exactly 10 schedule-key responses. Even when pigeons escaped, however, they generally overshot the optimal escape point (bringing the mean number of responses they produced for each reinforcer above R_{esc}). As Figure 2 shows, pigeons typically escaped after between 10 and 20 schedule-key responses. In some conditions, some pigeons escaped prior to 10 schedule key responses, which also increased mean response requirement. There was no clear relationship between the extent to which escaping was optimal and the mean number of schedule key responses made before an escape key response.

DISCUSSION

Pigeons made the sunk cost error by completing relatively large ratios when smaller mean response requirements were available for escaping. This occurred even though the smallest ratio, and therefore the optimal escape point, was held constant at FR10 on the schedule key, suggesting that variations in the size of the smallest FR alone did not drive the similar pattern of results observed by Navarro and Fantino (2005).

Persistence did not occur in every condition in which the sunk cost effect was possible. Persistence increased as R_{esc} and $R_{persist}$ grew closer together (their ratio approached 1). In other words, persistence was sensitive to the overall costs of persisting versus escaping. This general pattern is consistent with the results of Navarro and Fantino (2005), and Avila-Santibanez et al. (2010).

The condition here labelled ES4 is identical to that presented by Navarro and Fantino (2005) during the stimulus-changes-absent condition in their Experiment 1, and replicated in their Experiment 3. In both of their

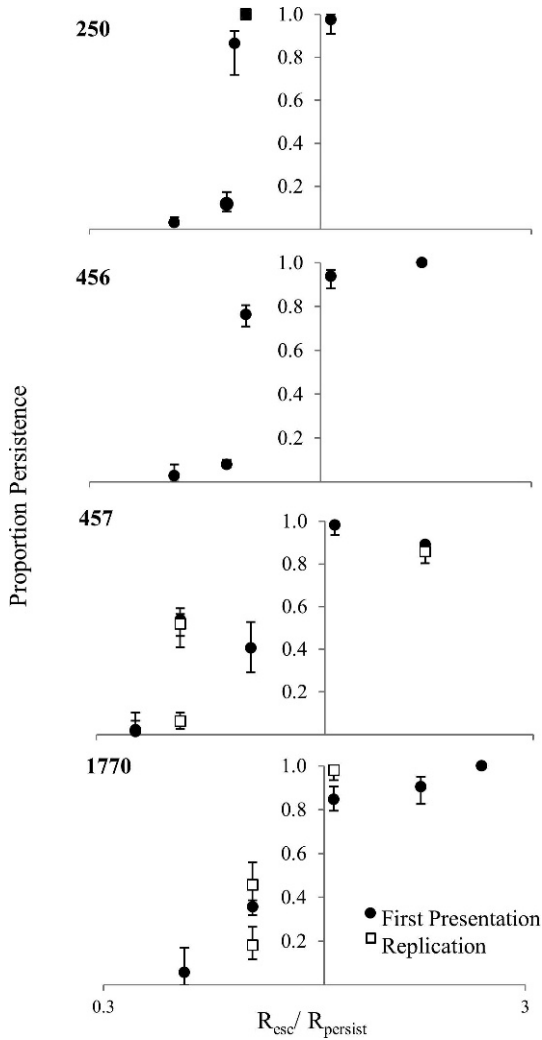


Fig. 1. Mean proportion persistence for the last five sessions of each condition as a function of $R_{esc}/R_{persist}$. Solid circles are the first presentation of each condition; open squares are replications. Error bars are session mean ranges for the last five sessions of the condition. Note the logged x -axes.

experiments, 3 of 4 pigeons persisted on every trial in this condition; only 1 pigeon consistently escaped. Our pigeons' performance was more similar to this final subject. This likely reflects experience on the part of our pigeons that occurred prior to the experiments described here. All 4 of our pigeons—like most of Navarro and Fantino's pigeons—had previously been presented with the ES4 condition, and persisted during it. Following exposure to a training condition during

which the contingencies markedly favored escaping, however, our pigeons then consistently escaped, even when returned to the ES4 condition. This suggests that prior history of contact with the escape contingencies may have reduced the likelihood of the sunk-cost error. This is a topic explored more fully in a separate paper (Macaskill & Hackenberg, in press).

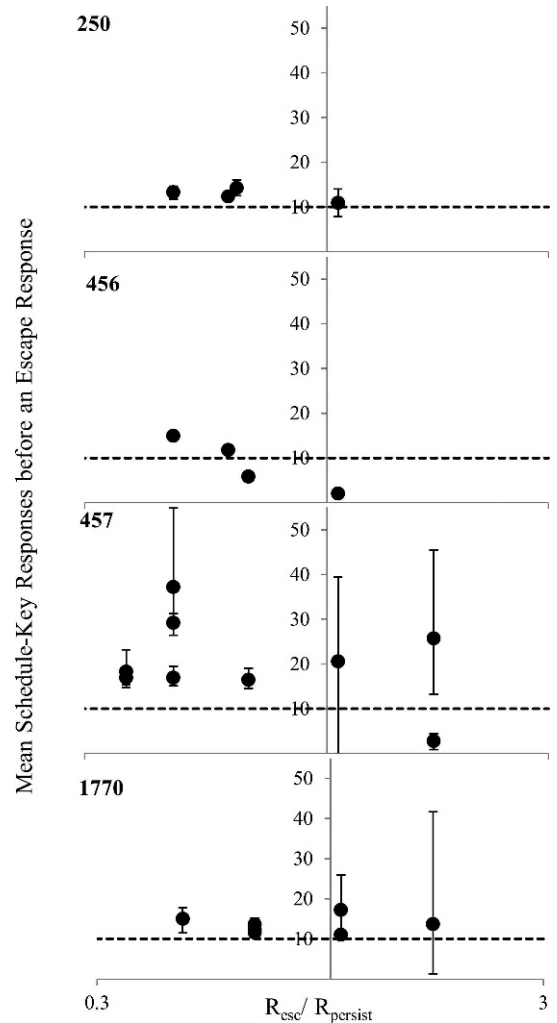


Fig. 2. Mean number of schedule key responses before an escape key response, during the last five sessions of each condition, by pigeon, as a function of $R_{esc}/R_{persist}$. Error bars are session mean ranges. The dashed line indicates the optimal escape point that would have created the lowest possible response requirement during conditions (those to the left of the y -axis) that favored escaping. Note the logged x -axes.

Table 3

Ratios, and the probabilities with which they occurred, for four conditions from Experiment 1, and the matched condition in Experiment 2 (denoted by an 'a' after the condition name). The final three columns provide the mean response requirements for persisting on every trial and for escaping on every trial larger than FR10, and the ratio of the two (the feature on which the conditions were matched).

	condition	ratio 1	p 1	ratio 2	p 2	ratio 3	p 3	ratio 4	p 4	R_{persist}	R_{esc}	$R_{\text{esc}}/R_{\text{persist}}$
Favor Escaping	ES4	10	0.5	40	0.25	80	0.125	160	0.125	45	21	0.47
	ES4a	10	0.2	77	0.2	112	0.25	200	0.35	115.4	54	
	ES1	10	0.35	34	0.3	70	0.125	100	0.225	44.95	30.43	0.68
	ES1a	10	0.1	109	0.25	152	0.35	266	0.3	161.25	109	
Equal	EQ	10	0.25	33	0.25	40	0.25	80	0.25	40.75	43	1.05
	EQa	10	0.1	52	0.2	103	0.3	154	0.4	103.9	108.95	
Favor Persisting	P1	10	0.0625	40	0.0625	80	0.5	160	0.375	103.13	175	1.7
	P1a	10	0.25	21	0.25	30	0.25	41	0.25	25.5	43	

EXPERIMENT 2

In Experiment 1, persistence tended to covary with the ratio of R_{esc} to R_{persist} . Experiment 2 assessed whether this variable was the feature of the current procedure that was most strongly related to levels of persistence. Two other possibilities are that low probabilities of FR 10 trials or low response requirements for persistence played a bigger role in establishing that response pattern. Experiment 2 included conditions that reduced the correlations among these three variables (ratio of R_{esc} to R_{persist} , probability of FR10, and smallest possible mean response ratio), and allowed a more direct assessment of the individual contribution each made to levels of persistence.

It is also possible that variables acting at a more local level make important contributions to levels of persistence. For example, Navarro and Fantino (2005) conceptualized their conditions as defined by the difference between the mean numbers of responses to the next reinforcer given persistence and given escape. This calculation assumed that subjects would complete the FR that followed an escape response and so did not incorporate the possibility of a global strategy: escaping from every ratio larger than the smallest presented during the session (R_{esc} as defined here assumes these additional escape responses are made). The all-or-none persistence demonstrated by Navarro and Fantino's pigeons made it difficult to separate local and global cost effects from other features of the contingency arrangement. The graded levels of persistence observed during our Experiment 1, in combination with the wider range of schedule arrangements in

Experiment 2, should permit a clearer isolation of relevant variables.

In Experiment 2 we created two combinations of FR values and probabilities in conditions in which the ratio of R_{esc} to R_{persist} was identical to a condition in Experiment 1, but other potentially important features of the contingencies differed. If the ratio of R_{esc} to R_{persist} is an important controlling variable, then levels of persistence should be approximately equivalent in the two conditions in each pair. If, on the other hand, one of the other variables—the difference between these two response requirements, the number of FR 10 trials programmed, or the size or probability of the larger ratios—more strongly controlled levels of persistence, then performance in the two conditions in each pair would diverge, and one of these other variables would be more strongly implicated.

METHOD

Subjects and Apparatus

Three of the pigeons (250, 457, and 1770) from Experiment 1 served as subjects; Pigeon 456 died prior to the beginning of Experiment 2. Living conditions and apparatus were as in Experiment 1.

Procedure

The conditions described in Experiment 2 were completed after those described in Experiment 3, but are described first for clarity of description. With the exception of the schedule arrangements shown in Table 3, procedures were unchanged from Experiment 1. In Table 3 conditions conducted in Experiment 2 are denoted by an "a" after the

Table 4

The sequence of conditions experienced by each pigeon in Experiment 2. See Table 3 for complete condition descriptions. The number of sessions for which each condition was presented to establish stable responding is presented in parentheses.

Pigeon	Condition					
	1	2	3	4	5	6
250	ES4a (17)	P1a (16)	ES1a (12)	EQa (11)		
457	ES4a (42)	P1a (11)	ES1a (17)	EQa (27)	P1a (10)	ES1a (22)
1770	ES4a (17)	EQa (36)	ES1a (20)	ES4a (15)	ES1a (14)	P1a (10)

condition title and each is presented below the matching condition from Experiment 1; the latter conditions were not conducted in Experiment 2. Each of the conditions in Experiment 2 had a R_{esc} to R_{persist} ratio that matched a condition from Experiment 1, but had different FR values and encounter probabilities than in Experiment 1; and hence different R_{esc} and R_{persist} values. For example, in Condition P1 R_{persist} was less than R_{esc} because pigeons rarely encountered the smallest ratio (FR10), whereas in condition P1a, FR 10 trials were more frequent but the other ratios were smaller so that the relative advantage gained by persisting was held constant.

As in the previous experiment, the sequence of conditions presented during Experiment 2 was customized for each pigeon so that a clear change in levels of persistence was anticipated after condition changes were made; that is, if a pigeon persisted consistently they were moved to a condition more strongly favoring escape, and vice versa. Replications were completed where time allowed. The sequence of conditions presented to each subject is presented in Table 4 along with the number of sessions needed to obtain stable levels of performance according to the same criteria used for Experiment 1.

RESULTS

Figure 3 presents proportion persistence during each condition in Experiment 2 (open circles), along with performance on the matched conditions from Experiment 1 (filled circles). As can be seen, performance was similar in pairs of conditions where the ratio of R_{esc} to R_{persist} was the same. There were some exceptions, however, in which performance in the two conditions diverged. Such divergence was particularly notable for Pigeon 250.

To identify the properties of the current contingency arrangements that most directly predicted persistence levels across the 3 pigeons, linear correlation coefficients were calculated between mean proportion persistence and various properties of the schedule arrangements. Some variables were selected because they captured potentially important *global* features of the contingencies (presented in the top five rows of Table 5). These relate to the session-level mean response requirements given the two possible global response patterns: always persisting (R_{persist}) and always escaping (R_{esc}). Others were selected because they captured more *local* features of the procedures—immediate consequences for persisting and/or escaping at the choice point. The choice point was assumed to occur after 10 responses on the schedule key on non-FR10 trials. That is, these local variables related to the response requirement for the immediate next reinforcer (e.g., the probability that it would be presented after completing the next-smallest (after FR10) ratio, and the size of the next ratio). When a potential controlling variable involved a comparison of the response requirements for persistence and escape, both the difference and ratio of these response requirements was included to investigate whether subjects were more sensitive to relative or absolute response requirements.

Correlations included the mean proportion persistence during the last five sessions of every condition presented in Experiments 1 and 2. Replications were included as separate points. These linear correlation coefficients are presented in Table 5. For Pigeons 457 and 1770, the ratio of R_{persist} to R_{esc} was most strongly correlated with their levels of persistence. For Pigeon 250, no variable was significantly related to persistence.

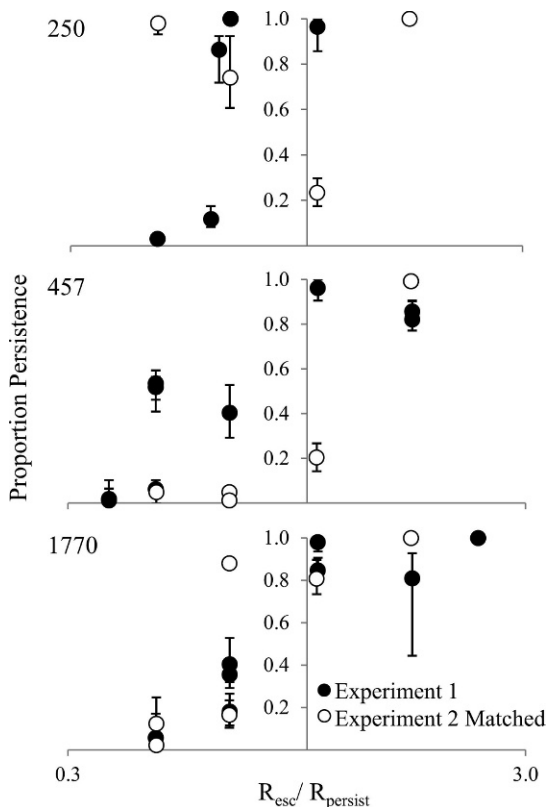


Fig. 3. Mean proportion persistence for the last five sessions of each condition as a function of $R_{\text{esc}}/R_{\text{persist}}$. Solid circles are the conditions presented during Experiment 1; open circles are conditions matched to be in the same location on the x -axis scale using different combinations of ratios and probabilities, presented during Experiment 2. Error bars are session mean ranges. Note the logged x -axes.

DISCUSSION

Experiment 2 presented pigeons with conditions matched to those presented during Experiment 1 based on the ratio of R_{persist} to R_{esc} . Although this variable imperfectly predicted subjects' levels of persistence, it had the strongest linear relationship with levels of persistence of the variables analyzed for 2 out of 3 pigeons. The frequency with which the 3rd pigeon (250) persisted did not appear to be strongly controlled by the current contingencies. One weakness of this analysis is that another variable in Table 3 might have been more strongly related to proportion persistence, except that the relationship between the two was not linear. This is unlikely, however, because visual inspection of graphs of the relationships between each of the variables reported here and proportion persis-

tence did not identify any such strong, but nonlinear relationships.

Navarro and Fantino (2005) used the difference between the anticipated next ratio given persistence and given escape after having completed 10 responses as a way to describe the extent to which a condition favored each response pattern. There are two potential reasons that this variable did not correlate strongly with proportion persistence across the wider range of conditions presented here. Firstly, choices were apparently more sensitive to relative than to absolute differences in response requirements whether global or local—the ratios of response requirements were more strongly correlated than their differences for all subjects in both cases. Secondly, Navarro and Fantino used the mean response requirement for escaping and then completing the next ratio regardless of its size to describe the contingencies for escaping. This measure does not consider the possibility of escaping on the subsequent trial, however, when such iterative use of the escape key reduces response requirement still further. Therefore, Navarro and Fantino's method of describing the extant contingencies may have underestimated the extent to which escaping reduced mean response requirements by assuming a suboptimal pattern of escape.

EXPERIMENT 3

Optimal behavior on the current task requires not only selecting the response path (persistence vs. escape) with the lowest mean response requirement but also—in the case of escape—selecting it at the right time. Escaping prior to or after completing the exact number of responses in the smallest ratio increases mean obtained response requirements. In Experiments 1 and 2 pigeons typically overshoot the optimal point at which to escape. This increased the mean number of responses made on trials with escape, and therefore brought the number of responses made on those trials closer to the number made on trials with persistence during conditions on which escape was optimal (bringing the obtained number of responses produced per reinforcer above R_{esc}). That is, overshooting the optimal escape point reduces the extent to which escaping is advantageous, which may, in turn, increase the likelihood of the sunk cost error.

Table 5

Linear correlation coefficients describing the relationships between the proportion of ratios larger than FR 10 completed by each subject in a given condition (proportion persistence), and the specified feature of the schedule arrangement in that condition. The strongest correlations observed for each subject are presented in bold. Asterisks indicate that correlations are significant at $p < 0.05$ (two-tailed).

Property of the schedule arrangement Subject	Correlation with proportion persistence		
	250	457	1770
Global variables			
Log($R_{\text{esc}}/R_{\text{persist}}$)	0.27	0.79*	0.84*
$R_{\text{esc}} - R_{\text{persist}}$	-0.01	0.76*	0.66*
Mean of the three largest ratios	-0.35	-0.23	-0.40
Lowest achievable mean response requirement	0.16	0.69*	0.56*
Proportion FR10s presented	-0.44	-0.28	-0.47
Local Variables			
Log (anticipated response requirement for next reinforcer if persist/ anticipated response requirement for next reinforcer if escape)	0.48	0.62*	0.78*
Anticipated response requirement for next reinforcer if persist - anticipated response requirement for next reinforcer if escape	-0.20	0.25	-0.11
Size of next ratio (after FR10)	0.06	-0.63*	-0.28
Probability of next ratio being programmed on the current trial	-0.35	-0.23	-0.40

Therefore, manipulations that minimize deviations from the optimal escape point might also be expected to reduce the frequency of the sunk cost error. Navarro and Fantino (2005) found that the addition of stimulus changes signaling the completion of unreinforced ratios reduced persistence, an effect also observed by Avila-Santibanez et al. (2010). Neither study reported the effect of these stimulus changes on the number of schedule key responses after which escape-key responses were made, however, so it is difficult to ascertain whether the changes in overall levels of persistence they observed were mediated by the added stimuli altering the juncture at which escape key responses were made. In Experiment 3, such stimulus changes were added to conditions included in Experiment 1, and the timing and frequency of escape key responses was examined.

METHOD

Subjects and Apparatus

The pigeons used in Experiment 2 completed Experiment 3 in the same chambers. Conditions of feeding and housing were the same as for the above experiments.

Procedure

Pigeons could respond on either the schedule or escape key, as in Experiments 1 and 2. Some conditions from Experiment 1 were

replicated in Experiment 3, each followed by an identical condition that added stimulus changes following the completion of unreinforced FR response requirements. The stimulus changes consisted of flashing the schedule-key light on and off, with the flash rate inversely related to the position in the ratio schedule. Specifically, after the smallest ratio, FR10, was completed the key-light flashed at a high rate (0.5-s On:Off cycle); after the second largest ratio was completed, the key-light flashed at a moderate rate (1-s On:Off cycle); and after the third largest ratio was completed, the key-light flashed at a low rate (1.5-s On:Off cycle).

The sequence of conditions presented in Experiment 3 is presented in Table 6. When it was difficult to determine whether the addition of stimulus changes had affected levels of persistence based on an A-to-B comparison alone, a replication of the same condition without stimulus changes was conducted, creating a reversal A-B-A design. Additionally, conditions were sequenced so that clear changes in responding were anticipated following condition changes in order to demonstrate experimental control, that is, if a pigeon was persisting consistently, the condition was changed to one that more strongly favored escape, and vice versa.

RESULTS

Figure 4 shows proportion persistence as a function of $R_{\text{esc}}/R_{\text{persist}}$ on a log scale; closed

Table 6

The sequence of conditions experienced by the pigeons in Experiment 3. See Table 1 for complete condition descriptions. S indicates that stimulus changes were present. The number of sessions for which each condition was presented to establish stable responding is presented in parentheses.

Pigeon	Condition										
	1	2	3	4	5	6	7	8	9	10	11
250	ES1 (10)	ES1S (39)	ES1 (46)	ES4 (56)	ES4S (23)	ES4 (11)	P1 (13)	P1S (62)	P1 (37)	EQ (12)	EQS (35)
457	ES1 (20)	ES1S (13)	ES4 (58)	ES4S (10)	P1 (27)	P1S (31)	EQ (20)	EQS (37)	P2 (13)	P2S (13)	P2 (11)
1770	ES1 (59)	ES1S (28)	ES1 (59)	P1 (33)	P1S (13)	ES4 (16)	ES4S (38)	ES4 (27)	EQ (23)	EQS (39)	EQ (23)

circles are conditions with no stimulus changes, and open circles those with stimulus changes present. Across pigeons, in 10 of 13 cases, the addition of stimulus changes reduced persistence relative to the identical condition without stimulus changes. For Pigeon 457 the sunk cost error was eliminated entirely whereas; the other 2 pigeons still made the error, albeit less frequently. When reversals were conducted, and the stimulus-changes-absent condition was replicated, persistence typically increased. This indicated that the reduction in persistence caused by the stimulus changes was not associated with a permanent behavior change. Interestingly, this reduction in persistence even occurred in several conditions in which persistence was optimal—a *reverse sunk cost error*.

As during Experiment 1, there was no relationship between the mean number of schedule key responses made before an escape key response and the ratio of R_{esc} to $R_{persist}$. Therefore, an analysis of the effects of stimulus changes on the distribution of the number of schedule key responses after which escape key responses were made was conducted, collapsing across conditions. That is, all of the escape responses occurring during the last five sessions of all conditions with and without stimulus changes were aggregated; their distributions are presented in Figure 5. The presence of stimulus changes shifted the mean number of schedule-key responses after which an escape key response was made towards 10 (i.e., the optimal escape point), and reduced the variability in the distribution of this measure. The presence of the stimulus changes did not mean that every escape key response was made after exactly 10 schedule key responses, however. Also, there were no additional peaks in the distribution of escape

responses corresponding to the completion of ratios larger than 10, even during the stimulus-changes-present conditions where the completion of these larger ratios produced changes in the rate at which the schedule key flashed.

DISCUSSION

The addition of stimulus changes signaling the transition between ratios reduced persistence for most pigeons in most conditions. When this occurred in conditions that favored escaping, the presence of these stimulus changes reduced instances of the sunk-cost error. This effect was also observed by Navarro and Fantino (2005) in their Experiment 1. This reduction in persistence was more complete in their study than in the current one, however, perhaps reflecting differences in the form of the signal used. Navarro and Fantino suggested that the addition of stimulus changes might reduce persistence because it made the global benefits of responding on the escape key more easily discriminated. In our experiment, the addition of stimulus changes increased the efficiency of escape—fewer responses were emitted after the FR 10 was completed without a reinforcer. This reduced the pigeons' mean obtained response requirement (bringing it closer to R_{esc}) when they escaped and, therefore, moved it further from that when they persisted. This increased advantage gained from escape may have increased the frequency of this response pattern.

Although signaling the completion of non-reinforced response ratios led to a reduction in the sunk cost error in conditions under which the contingencies favored escape, in conditions favoring persistence it led to some instances of the reverse sunk cost error—escaping when persistence was appropriate. Avila-Santibanez et al. (2010) also observed

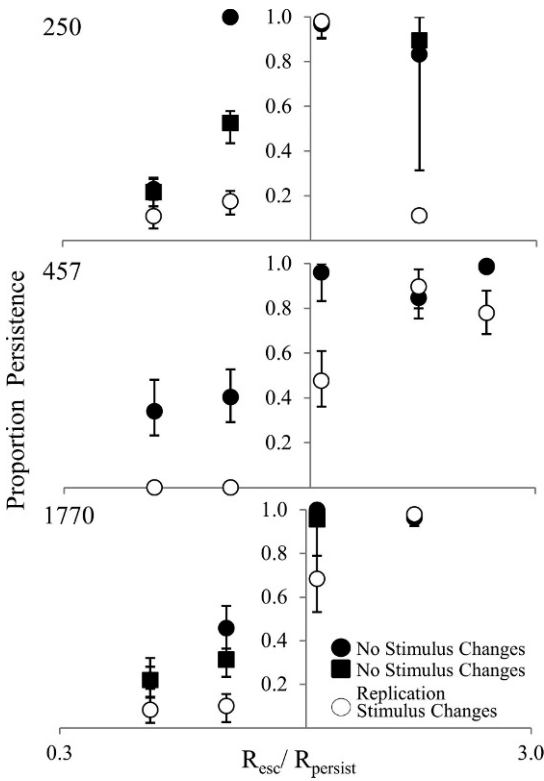


Fig. 4. Mean proportion persistence for the last five sessions of each condition as a function of $R_{esc}/R_{persist}$. Stimulus-changes-absent conditions are indicated by closed circles, replications of these conditions by closed squares, and stimulus-changes-present conditions with open circles. Error bars are session mean ranges. Note the logged x -axes.

this under conditions that favored persistence when stimulus changes were present. Navarro and Fantino (2005) did not observe the reverse sunk cost effect when they presented one such condition, however.

The reverse sunk cost error in our experiment may be due to the order in which the conditions were experienced. Our pigeons first encountered the added stimulus changes during conditions with contingencies favoring escape. However, this is unlikely to provide a complete explanation for these effects for two reasons. Firstly, Navarro and Fantino's (2005) pigeons also first encountered stimulus changes in a condition in which the contingencies favored escape (during Experiment 1), but none made this reverse sunk cost error. Additionally, when conditions were replicated without stimulus changes during the present

study, performance was typically replicated, meaning that there was not elsewhere evidence for lasting effects of prior experience with stimulus changes. The possibility remains, however, that this reversed sunk cost error would have been less likely had the pigeons first encountered stimulus changes during a condition in which the contingencies favored persistence. Other possible explanations for these reverse sunk cost errors will be discussed below.

EXPERIMENT 4

In the preceding experiments, escape occurred either relatively soon after the initial ratio (FR 10) was completed, or not at all. In

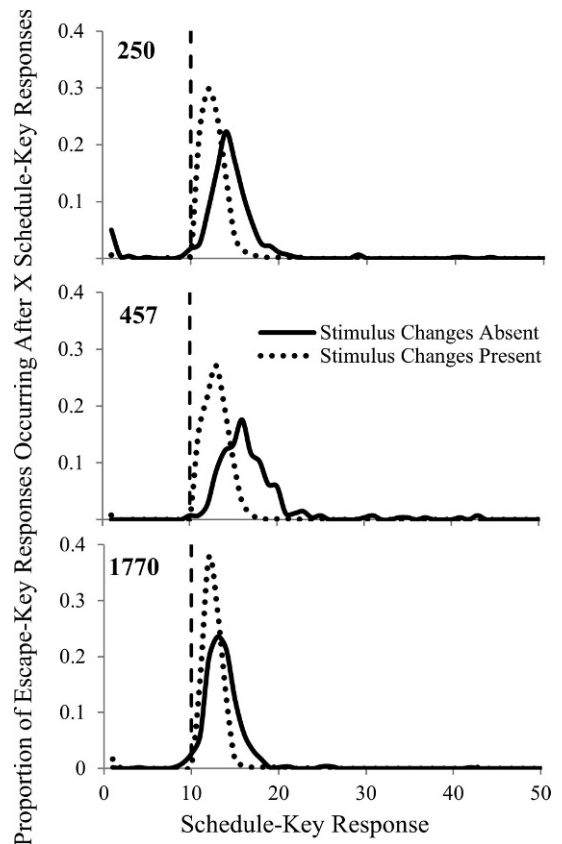


Fig. 5. Distributions of the frequencies with which an escape key response occurred after exactly a given number of schedule key responses, for each pigeon. The dashed distributions are those when stimulus changes were present, and the solid distributions when they were absent. The vertical dashed line indicates the optimal number of schedule key responses after which to make an escape key response (10).

Experiment 2, neither the size nor the probability of the second ratio strongly predicted levels of persistence, suggesting again that the critical choice occurred after the smallest ratio. Experiment 4 investigated whether a consistent pattern of escape following one of the larger ratios would develop if this pattern was sufficiently strongly favored by the contingencies.

More specifically, pigeons were exposed to conditions during which it was optimal to escape after having completed the second smallest ratio (FR 20), and included two stimulus-changes-present conditions. In one, the transitions between every response ratio were signaled. Therefore, pigeons had to disregard the stimulus change after the smallest ratio, and continue responding on the schedule key until the completion of the second ratio (and the associated stimulus change). In the one-stimulus-change condition, only the optimal escape point (here, FR 20) was signaled. It was anticipated that this latter condition would make the optimal escape point more salient, and would therefore increase the frequency of escape and cause subjects to escape at closer to the optimal escape point.

METHOD

Subjects and Apparatus

For logistical reasons, it was only possible to include 2 pigeons, 457 and 1770, in Experiment 4. Conditions of feeding and housing were the same as for the above experiments, as was the apparatus.

Procedure

During all three conditions in Experiment 4, four response ratios were arranged on the schedule key as follows: FR 10 was programmed on 10% of trials, FR 20 on 70%, FR 200 on 10%, and FR 300 during the remaining 10% of trials. Because the FR 10 was rare relative to the FR 20, the optimal response pattern was to complete 20 schedule-key responses before escaping. Such a pattern avoided completing the larger two ratios, thereby minimizing the mean overall obtained response requirement. Specifically, escaping after completing 10 responses would produce a mean response requirement of 109 responses, escaping after completing 20 responses

would produce a mean response requirement of 24 responses (an average session would consist of 5 FR 10 trials, 35 FR 20 trials, and 10 larger ratio trials on which escape responses would occur), and persisting on every trial produced an intermediate R_{persist} of 65.

These response-ratio arrangements were held constant across three conditions. In one condition there were no stimulus changes. In a second condition, there were three stimulus changes—occurring following the nonreinforced completion of each of the smaller ratios. The rate of signal-light flashes served as signals. This arrangement was therefore similar to the stimulus-changes-present conditions presented during Experiment 3. In a third condition, only one stimulus change—after 20 responses (the optimal escape point)—was presented. Pigeon 457 completed the stimulus-changes-absent condition followed by the three-stimulus-changes condition, and the one-stimulus-change condition, while 1770 completed the stimulus-changes-absent condition, followed by the one-stimulus-change condition, and the three-stimulus-changes condition. The stimulus-changes-absent condition was then replicated for both pigeons to investigate any lasting effect of experience with these added stimulus changes.

Dependent Variables

Given that in Experiment 4 the optimal escape point was after the completion of the second ratio (FR 20), proportion persistence was defined as the proportion of ratios greater than this (i.e., FR 300 and FR 400) that were completed. The mean number of schedule key responses made before an escape response was also analyzed.

RESULTS AND DISCUSSION

Neither pigeon consistently made the sunk cost error during any condition. Specifically, Pigeon 457 did not complete any of these larger ratios during any of the four conditions during the stable period. Pigeon 1770 completed 2% of such larger ratios during the one-stimulus-change condition, but did not complete any of them during any of the other conditions.

Neither pigeon made the error of escaping following the completion of the smallest ratio (FR 10). Rather, on average, the pigeons escaped somewhat soon after having complet-

ed the FR 20. This was similar to the point in the trial at which escape-key responses were typically made relative to the (earlier) optimal escape point in the previous three experiments.

Given the floor effect on proportion persistence in the no-stimulus-changes condition, it was not possible for the addition of stimulus changes to reduce persistence as it had in Experiment 2. However, the addition of stimulus changes did affect the accuracy of escape responses, as in Experiment 2. As can be seen from Figure 6, during the first presentation of each condition escape for both pigeons approximated the optimal point most accurately when only that point was signaled, and least accurately when there were no additional stimulus changes; signaling the completion of each response ratio produced intermediate accuracy.

Escape for both pigeons more closely approximated optimality the second time they experienced the stimulus-changes-absent condition, that is, after having experienced the two conditions with stimulus changes added. Experience with the stimulus changes thus appeared to produce long lasting improvements in optimal responding. Such effects were not observed when stimulus-changes-absent conditions were replicated during Experiment 3, however, so it is difficult to draw a firm conclusion regarding such history effects from the present data.

GENERAL DISCUSSION

In the present study, pigeons made two separable but interrelated decisions: (1) *whether* to escape, and (2) *when* to do so. Both of these decisions are important to adaptive behavior in everyday contexts, and the current study suggests that both must be considered in accounting for the sunk cost error. The current data suggest that ease of identifying *when* best to escape may influence choices about *whether* to escape.

The current set of conditions built on past research by adding additional precision about the specific features of the contingencies to which behavior was most sensitive. This was possible because the present Experiments 1 and 2 took the analysis a step further by exploring the sunk cost effect over a wider range of schedule arrangements than had

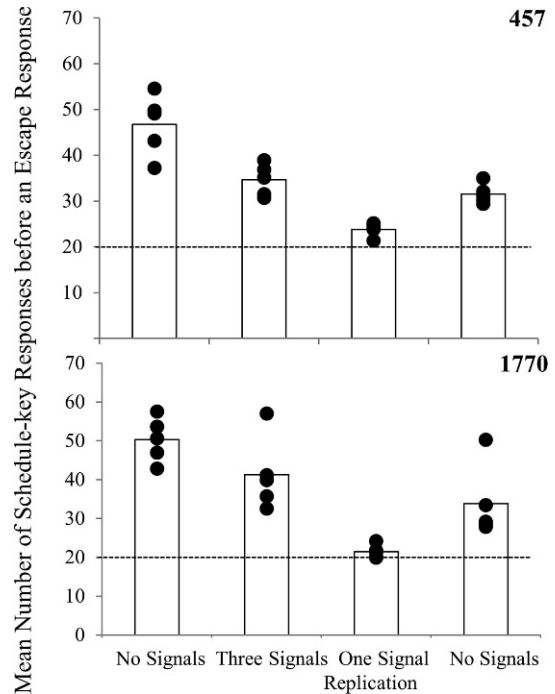


Fig. 6. Mean number of schedule key responses made before an escape key response, by subject and condition. Bars are means of the last five sessions of the condition, and points are individual session means. The horizontal line indicates the number of schedule key responses after which it was optimal, in terms of mean response requirement, to make an escape key response (20).

been done previously. These experiments showed that persistence varied as an orderly function of the ratio of the mean global response requirements for escaping (R_{esc}) to persisting ($R_{persist}$). This is consistent with Navarro and Fantino's (2005) suggestion that, in general, the extent to which the contingencies favored escape was a key determinant of whether the sunk cost error occurred—a general pattern also observed by Avila-Santibañez et al. (2010). The current study, however, added additional precision about the features of the contingencies to which pigeons were the most sensitive.

Experiments 3 and 4 showed that, when the contingencies favored escape, choices became more optimal when a stimulus signaled the optimal escape point. This, too, is consistent with prior results, but the present findings demonstrate even more subtle control by the added stimuli—both in terms of the precise juncture at which the escape responses were

made, and conditional stimulus control demonstrated in Experiment 4. In that experiment, pigeons demonstrated optimal performance by disregarding an initial stimulus change presented after completing the first ratio and escaping only following the second stimulus change.

Taken together, the results of all four experiments demonstrated that pigeons were remarkably sensitive to the contingencies arranged, and to stimulus changes correlated with them. This sensitivity coexisted, however, with an overall tendency to persist and therefore subjects still made the sunk cost error in spite of this sensitivity to the contingencies. All else being equal, the sunk cost error may be seen as a tendency to persist as the default strategy in situations in which either the discriminability of the optimal escape point is low or the ratio of R_{esc} to R_{persist} is close to 1 and therefore the optimal response pattern is difficult to identify.

Experiment 3 also produced some instances of the reverse sunk cost error, or escape under conditions where persistence was optimal. This was most frequent in conditions in which stimulus changes were present. This effect was also observed by Avila-Santibanez et al. (2010), again more frequently when stimulus changes were present. Avila-Santibanez et al. speculated that this error might occur because escape was the response associated with the lowest-ever-available delay to reinforcement, and therefore could be viewed as impulsivity, or choice of a more immediate reinforcer over an alternative with a higher global reinforcement rate.

Navarro and Fantino (2005) had noted that their study left open the possibility that subjects' escape responses (in all conditions) were driven by the probability of producing the smallest-ever-available ratio. This was because the probability of the smallest ratio occurring was highest in conditions where the contingencies favored escape. The current Experiment 2 dissociated these two features of the schedule arrangements and found that the overall cost of persisting predicted levels of persistence better than did the probability of the smallest ratio in the condition being programmed on the next trial. This suggested that escape responses in conditions with no stimulus changes are not best viewed as driven by impulsivity. The current study did not,

however, include the conditions necessary to identify the independent contribution of the probability of FR 10 to levels of escape occurring when stimulus changes were present (although it is not clear why adding such stimulus changes would increase subjects' sensitivity to this variable). In order to determine the extent to which each of these variables controlled persistence when stimulus changes were present, it would be necessary to study additional conditions of the type included in the current Experiment 2 but with stimulus changes added.

Another possible explanation for the instances of the reverse sunk cost error when stimulus changes were present is negative reinforcement; these responses may be maintained by escape from stimulus conditions associated with relatively high ratios. Appel (1963), for example, found that pigeons responded to turn off a key associated with a high ratio of food reinforcement, even when this also removed the opportunity to earn food. In the present study, some nonoptimal escape responses were perhaps maintained by the termination of these stimuli correlated with relatively high work requirements. This possibility could be investigated in future studies by including conditions in which the stimuli associated with these higher ratios could be terminated but without terminating the trial (dissociating escaping the ratio from escaping the associated stimuli).

Decisions about when to escape require sensitivity to the levels of investment already made. In the unsignaled conditions of the present study, pigeons made escape responses at approximately the optimal juncture, suggesting that their behavior was under the control of the number of prior responses on that trial. This is consistent with previous research showing that behavior can be sensitive to the number of recently-emitted responses. For example, Hobson (1975) presented pigeons with one of two sample-response ratios and then two comparison-response alternatives. Responding on one comparison produced reinforcement when the sample ratio had been the shorter of the two possible and on the other comparison when it had been the larger ratio. During the condition most relevant to the discrimination required by the current task, the pigeons chose the correct comparison at above chance when the two possible sample ratios

were FR 9 and FR 10. This result is consistent with current speculation that our pigeons' escape responding was under the control of the number of prior responses on the current trial. The possibility remains, however, that when escape key responses were made was also influenced wholly or in part by the passage of time rather than the number of responses made so far on the current trial. These variables could not be dissociated because pigeons' response rates were relatively constant. Further experimental manipulations could usefully investigate the relative contributions of each, however, by using time-based rather than ratio-based schedules.

Although escape responses occurred at approximately the optimal escape point, the accuracy with which they were timed was improved by the addition of stimulus changes. This suggests that these exteroceptive stimulus changes enhanced the discrimination of response number and/or time investment. This is consistent with previous studies into the relative discriminability of such exteroceptive stimulus changes and subjects' own recent numbers of responses in other procedures (e.g. Ferster & Peele, 1980). It is also notable that our pigeons consistently overshot the smallest ratio. This may be an additional manifestation of their overall tendency to persist. Alternatively, the slight overshooting may also reflect the fact that the costs (defined in terms of increased response requirements) for overshooting were small relative to the costs for undershooting (which includes the risk of missing the small ratio on that trial).

The current study further illustrates the benefits of nonhuman animal models of complex decision-making. Such work allows a more complete examination of the variables contributing to both optimal and suboptimal choices than is practical with human subjects. Demonstrating the sunk cost effect with nonhuman animals is also of relevance to the presumed mechanisms underlying the effect with humans, as some researchers have speculated that the sunk cost error in humans arises largely as a result of the misapplication of verbal rules (Arkes & Ayton, 1999). For example, people are often given rules against wasting resources, and abandoning a course of action may be framed as wasting the resources

already invested. While this may be true, the fact that nonhuman animals do commit the sunk cost error under some conditions demonstrates that such "irrational" decision making is not solely the result of faulty rules. At the same time, the sensitivity shown by our pigeons to the manipulations designed to reduce nonoptimal persistence (e.g., added stimulus changes, extended exposure to the contingencies) suggests potential ways to overcome the sunk-cost error in humans.

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Received: June 28, 2011

Final acceptance: October 11, 2011