Behavioural Processes 89 (2012) 212–218

Contents lists available at SciVerse ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Providing a reinforcement history that reduces the sunk cost effect

Anne C. Macaskill[a,*], Timothy D. Hackenberg[b]

[a] Department of Psychology, University of Florida, P.O. Box 112250, Gainesville, FL 32611, United States
[b] Department of Psychology, Reed College, Portland, OR 97202-8199, United States

ARTICLE INFO

Article history:
Received 20 June 2011
Received in revised form 10 October 2011
Accepted 2 November 2011

Keywords:
Sunk cost effect
Decision-making errors
Persistence
Pigeons

ABSTRACT

The sunk cost error occurs when individuals persist with a non-optimal course of action because they have already invested time or resources in it. The current study examined the effect of specific experiences on the likelihood of the sunk cost error. Six pigeons were given repeated choices between persisting with and escaping from relatively large fixed ratios. In most conditions escaping was the choice pattern producing the smallest mean response requirement. In Experiment 1, four of six pigeons persisted, committing the sunk cost error. Some subjects continued to persist even when persistence increased the mean number of responses to reinforcement by 99. In Experiment 2, the absolute difference between the mean numbers of responses to reinforcement for persistence and escape was increased even further for these subjects, and the relative cost of persistence was increased. Once escape had been established, pigeons were less likely to commit the sunk cost error in some conditions where they had previously made the error frequently. Together, the results of both experiments show changes in the frequency of the sunk cost error caused by specific experiences, and that persistence is likely more sensitive to its relative than absolute costs.

1. Introduction

One type of sunk cost error occurs when individuals choose a course of action in which they have previously invested time, money, or other resources over an alternative with the highest expected future payoff. This is considered an error because normative decision making rules indicate that decisions should reflect future consequences only. This sunk cost error has been repeatedly demonstrated with human participants with a variety of methods, including one-shot questionnaires with hypothetical scenarios (e.g., Arkes and Hutzel, 2000; Garland, 1990; Tversky and Kahneman, 1981), repeated choices with hypothetical outcomes (Goltz, 1992, 1993, 1999), and repeated choices with experienced consequences (Navarro and Fantino, 2005, 2007, 2009). Additionally, Navarro and Fantino (2005), and De la Piedad et al. (2006) used experimental analogues of relevant decision making situations to demonstrate that non-human animals also make the sunk cost error in some contexts.

The current study used a procedure patterned after one developed by Navarro and Fantino (2005) (and also used by Avila-Santibanez et al., 2010, and Macaskill and Hackenberg, 2012), using fixed ratio (FR) schedules of reinforcement to model the costs and benefits of persisting with versus abandoning a course of action. Under an FR*x* schedule, a reinforcer is presented after *x* responses have been produced. In Navarro and Fantino's task, pigeons could choose between responding on a food key and responding on an escape key. Responses made on the food key were reinforced following the completion of one of four possible FRs. Each condition was defined by the size of these FRs, and the probability with which they occurred. Completing an FR produced food, and started the next trial with a newly-determined FR. Responses on the escape key terminated the current FR without food and began a new trial again with a newly-determined FR. Therefore, making such escape key responses allowed subjects to avoid completing relatively large FRs on the food key.

In Experiment 1 of Navarro and Fantino's (2005) study, the food key provided reinforcement according to an FR10 schedule on 50%, an FR40 on 25%, an FR80 on 12.5%, and an FR160 on 12.5% of the trials presented (FR10/40/80/160). Under this arrangement, having completed 10 responses without receiving reinforcement was an indication that one of the higher FR schedules was in effect on that trial. Initially, stimulus changes were present. These were changes in the color of the food key light that occurred upon the completion of the number of responses equivalent to an FR programmed during the condition but not assigned to the current trial. When these stimulus changes were present, no pigeon made the sunk cost error. When they were removed three out of four pigeons persisted, however. Avila-Santibanez et al. (2010) and Macaskill and Hackenberg (2012) also found that the addition of stimulus changes reduced the frequency with which pigeons made the sunk cost error.

In their Experiment 3, Navarro and Fantino (2005) found that increasing the difference in the mean number of responses to reinforcement for escaping and persisting increased the

---

* Corresponding author. Tel.: +1 352 246 2106.
E-mail addresses: annemac@ufl.edu, anne.macaskill@gmail.com (A.C. Macaskill), hack@reed.edu (T.D. Hackenberg).

0376-6357/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.beproc.2011.11.001

frequency of escape. To calculate this difference, it is necessary to first calculate the mean response requirement given persistence, the mean response requirement given escape, and the difference between the two. The mean response requirement following escape is the mean number of responses from the beginning of any trial to reinforcement, i.e., the mean of the FRs programmed during that condition, weighted by the probability of their occurrence. For example, in the FR10/40/80/160 condition, the mean number of responses to the next reinforcer given escape was: $(10 \times 0.5)+(40 \times 0.25)+(80 \times 0.125)+(160 \times 0.125)=45$. The mean response requirement for persisting was the mean number of responses left in the three larger FRs following the completion of the number of responses in the smallest FR in the condition, weighted by the probability that that FR was programmed on the current trial, given that the shortest FR was not. For example, in the FR10/40/80/160 condition the mean response requirement for persisting was: $(30 \times 0.5)+(70 \times 0.25)+(150 \times 0.25)=70$. Therefore, the difference in the mean number of responses to reinforcement (persistence-escape) was 70–45, or 25 responses during this condition, meaning that making the sunk cost error increased the mean cost of a reinforcer by 25 responses.

By manipulating this difference in mean response requirements, Navarro and Fantino (2005) found that there was apparently a point at which the cost of persisting was high enough that the pigeons began escaping, avoiding the sunk cost error. Specifically, the pigeons persisted during the conditions in which the differences in mean numbers of responses to the next reinforcer for persisting versus escaping were 19 and 34 responses, but not when the difference was 44 responses. Navarro and Fantino did not assess whether experience with this condition produced a lasting reduction in subjects' tendency to make the sunk cost error under other conditions, however. Additionally, they did not assess whether all changes in programmed ratios that changed this difference in mean response requirements by the same amount had equivalent effects on pigeons' levels of persistence, or whether absolute or relative differences in response requirements for persistence and escape were most important. The current study extended that of Navarro and Fantino by investigating each of these questions.

To this end, Experiment 1 began by replicating the FR10/40/80/160 condition also conducted by Navarro and Fantino (2005). Across subsequent conditions all of the ratios were multiplied by two while their probability of occurrence was held constant in smallest to largest order. Therefore, the other two conditions presented during Experiment 1 were FR20/80/160/320 and FR40/160/320/640. This approach of multiplying all of the ratios was chosen because it changed the absolute difference between the mean response requirements for persistence and escape while holding their ratio approximately constant.

After initially assessing the effects of multiplying all of the FRs by a common factor in Experiment 1, the present study (Experiment 2) investigated whether experience with a condition on which the contingencies established consistent use of the escape key would alter the frequency with which pigeons would commit the sunk cost error in the future, even after this condition was removed. There is reason to suspect that such history effects might induce more optimal choice patterns, providing subjects with a relevant reinforcement history has been shown to have this effect in the case of two other decision making errors. Specifically, base-rate neglect in both humans (Goodie and Fantino, 1996, 1999; Case et al., 1999) and pigeons (Fantino et al., 2005) and the conjunction fallacy in humans (Fantino and Savastano, 1996). It was therefore anticipated that similar effects might be observed in the case of the sunk cost effect in the current study.

Overall, conditions across the two experiments reported here formed a reversal design, but are presented as two experiments for clarity of exposition. In Experiment 1, the likelihood of committing the sunk cost error was assessed in each of three conditions across which the absolute cost of persisting (mean in number of responses to reinforcement) was increased. The relative difference in response requirements for persistence and escape was held constant during Experiment 1. For pigeons that consistently made the sunk cost error during these conditions, additional training was then provided in Experiment 2 by presenting a condition during which escaping was associated with a markedly more favorable mean number of responses to reinforcement than persisting. This condition also altered the relative cost of persisting, and therefore investigated whether this was necessary to effect a change in levels of persistence. Conditions under which the error was previously made were then replicated, assessing the long-term impact of favorable experiences with escaping. Experiment 2 also assessed the specificity or generality of this training effect by arranging a condition during which persistence was favored by the contingencies.

2. Experiment 1: increasing the absolute cost of persistence

In the current procedure, completing the number of food key responses equivalent to the smallest FR in the condition without receiving reinforcement is an indication that the current FR is relatively high. This is therefore a choice point, at which two courses of action are available to the pigeons, each leading to a different mean response requirement. In Experiment 1 the mean response requirement for escaping was always lower than that for persisting and hence the sunk cost error was defined as persistence beyond this choice point. Navarro and Fantino (2005) found that increasing the difference between these two mean numbers of responses to reinforcement (one for escaping, the other for persisting) reduced the frequency with which pigeons made the sunk cost error. Experiment 1 presented a series of conditions that also increased this difference.

The experiment began with a condition in which the FRs were 10, 40, 80, and 160, at probabilities of 0.5, 0.25, 0.125, and 0.125, respectively. The next condition multiplied all of these FRs by two, and the third condition doubled them again. The probabilities with which these FRs occurred were held constant in smallest to largest order. The first condition was identical to one presented by Navarro and Fantino in their Experiment 1. The other two conditions presented combinations of FRs and probabilities that Navarro and Fantino did not present, but which had the effect of increasing the difference between the mean response requirements for persisting and escaping as their conditions had. The latter two conditions produced a difference between the mean number of responses to the next reinforcer for persisting and escaping above that which Navarro and Fantino found was associated with an absence of the sunk cost error. It was therefore anticipated that subjects would persist during in the first condition but not during the subsequent two. If this did not occur, but rather subjects persisted across all three conditions, then this might suggest that behavior is influenced by relative rather than absolute differences in the mean number of responses to the next reinforcer for persistence and escape.

2.1. Method

2.1.1. Subjects

Subjects were six white Carneau pigeons, numbered 18, 250, 456, 457, 1770, and 1774. When not in experimental sessions, the pigeons were housed in a colony room with a 16.5:7.5 h light:dark cycle, and had continuously available health grit and vitamin-enriched water. The pigeons were maintained at 85% of their free-feeding weights via supplementary post-session feeding.

Table 1
Condition descriptions for study 1. The top four rows describe the schedule arrangement presented during each condition. The bottom four rows present the mean response requirements for the two courses of action available after completing the smallest FR in the condition: persisting and escaping, and their difference and ratio.

	Condition		
	FR10/40/80/160	FR20/80/160/320	FR40/160/320/640
FR 1 (50% of trials)	10	20	40
FR 2 (25% of trials)	40	80	160
FR 3 (12.5% of trials)	80	160	320
FR 4 (12.5% of trials)	160	320	640
A: Mean number of responses to next reinforcer given an escape response	1 escape response + 45 food key responses	1 escape response + 90 food key responses	1 escape response + 181 food key responses
B: Mean number of responses to next reinforcer given persistence after completing number of responses in smallest FR in the condition (if no reinforcement)	70 food key responses	140 food key responses	280 food key responses
$B - A$	24	49	99
A/B	0.65	0.65	0.66

2.1.2. *Apparatus*

A standard three-key operant chamber with internal dimensions of 30.5 cm × 35 cm × 35 cm was used, in conjunction with MED-PC IV® software. The chamber was in a dark room with white noise continuously presented. The only two keys with programmed consequences during this study were the center key, which was lit white when operational, and the left key, which was lit green when operational. Reinforcers consisted of 2-s access to mixed grain from a food hopper directly below the center key. When food was available a white light within the hopper opening was lit, and the chamber was otherwise dark.

2.1.3. *Procedure*

Pigeons were presented with two concurrently available response keys: the center (food) key and the left (escape) key. Pecks on the food key were reinforced according to an FR that varied among a set of possible FRs within a given condition. Specifically, four FR schedules were possible during each condition, and the probabilities with which they occurred were constant throughout each condition. These conditions, defined by this set of FRs and probabilities, are described in Table 1. Completing the current FR produced food, followed by a 1-s inter-trial-interval (ITI) during which the chamber was dark. A single response on the escape key also produced the ITI, terminating the current FR (resetting any responses made on the current FR), and selected a new FR from the set of those possible. Each FR presentation will be referred to as a “trial”. A new trial therefore began whenever either a food presentation or an escape key response occurred.

The bottom half of Table 1 presents the mean number of responses to the next reinforcer, for each of the two courses of action (persisting and escaping) available after completing the number of responses equivalent to the smallest FR in the condition and not receiving reinforcement. It also presents the difference between and ratio of these two response requirements.

All pigeons completed these conditions in order of increasing favorableness, in terms of mean number of responses to the next reinforcer of escaping over persisting (i.e., FR10/40/80/160, FR20/80/160/320, FR40/160/320/640), or until consistent use of the escape key was observed. If consistent use of the escape key occurred, then previously run conditions were replicated before conditions with a larger cost for persistence were conducted. Because Pigeon 1774 used the escape key consistently during the FR10/40/80/160 condition, a floor effect would have prevented the expected reduction in proportion persistence if the FR20/80/160/320 condition was presented next. Therefore, a condition in which the FRs were half those in the FR10/40/80/160 condition was presented to this pigeon alone, because this condition was anticipated to increase persistence levels by bringing the mean number of responses to the next reinforcer for persisting closer to that for escaping.

The primary dependent variable was the mean proportion persistence, defined as the mean proportion of FRs larger than the smallest completed. The smallest FR was not included in this calculation because completing it was not an instance of the sunk cost error. This method of calculating proportion persistence was identical to that used by Navarro and Fantino (2005). Each condition was continued until this measure of persistence was stable for five consecutive sessions. Stability was defined as the absence of upward trends, downward trends, and the highest and lowest points in the condition. See Table 2 for the number of sessions required to reach stability for each subject and condition.

Every session began with a 5-min blackout during which the chamber was dark. Each session continued until 40 reinforcers had been presented, or until 75 min had elapsed, whichever came first. During the stable periods reported here, only sessions during the FR40/160/320/640 condition were ever terminated based on this time criterion, and typically only in instances where subjects persisted consistently during this condition. Therefore, this reduction in the overall number of reinforcers received may have

Table 2
The sequence of conditions presented in Experiment 1, and the number of sessions for which each subject experienced each condition. See Section 3.1.2 and Table 1 for full condition descriptions.

Pigeon	1st	2nd	3rd	4th	5th	6th
18	FR10/40/80/160 (37)	FR20/80/160/320 (53)	FR40/160/320/640 (40)	FR20/80/160/320 (19)	FR10/40/80/160 (37)	
250	FR10/40/80/160 (16)	FR20/80/160/320 (15)	FR40/160/320/640 (21)			
456	FR10/40/80/160 (16)	FR20/80/160/320 (15)	FR40/160/320/640 (14)			
457	FR10/40/80/160 (15)	FR20/80/160/320 (16)	FR40/160/320/640 (14)			
1770	FR10/40/80/160 (16)	FR20/80/160/320 (11)	FR40/160/320/640 (11)			
1774	FR10/40/80/160 (37)	FR10/40/80/160[a] (13)	FR5/10/20/40 (21)	FR10/40/80/160 (27)	FR20/80/160/320 (28)	FR40/160/320/640 (56)

[a] A condition in which the schedule arrangement was changed from ratio- to interval-based was conducted between these replications of the FR10/40/80/160 condition for this subject, however the results are not presented here.

represented an additional disadvantage of persisting during this FR 40/160/320/640 condition.

2.2. Results and discussion

Table 3 presents the proportion of FRs larger than the smallest that each subject completed. Pigeons tended to either persist consistently or escape consistently in each condition; only Pigeon 457 in the FR40/160/320/640 condition produced a somewhat intermediate level of persistence.

Given that persisting during these conditions entailed making the sunk cost error, five of the six pigeons consistently committed the error during the FR10/40/80/160 condition. Three of Navarro and Fantino's (2005) four pigeons also made the sunk cost error on this condition, as did three of Avila-Santibanez et al.'s (2010) pigeons during at least one of three replications of that condition. Therefore, it has consistently been the case that most but not all subjects persist under these contingency arrangements. Pigeon 18 persisted in the FR10/40/80/160 condition the first time it was presented, but not in the FR20/80/160/320 condition, or when the FR10/40/80/160 condition was subsequently replicated. The remaining four subjects continued to persist during the three other conditions of the experiment, despite the widening difference in mean absolute number of responses to reinforcement for persistence and escape.

Pigeon 1774 demonstrated an across-condition pattern of persistence that was not predicted by the increasing mean number of responses to reinforcement for persisting; that is, this subject escaped during the FR10/40/80/160 and FR20/80/160/320 condition, but persisted when presented with the FR40/160/320/640 condition. Pigeon 1774, also completed a condition where the FRs were half those in the FR10/40/80/160 condition. During this condition, the proportion of trials with persistence increased to 0.54 (standard deviation: 0.04) during the last five sessions of the condition. Thus, this pigeon's level of persistence was not linearly related to increases in differences between the mean number of responses to reinforcement for persistence and escape.

Navarro and Fantino (2005) found escape occurred consistently in a condition when the difference between the mean number of responses to the next reinforcer for persisting and escaping was 44. Two of the conditions in the present study included even larger differences (49 and 99), yet four pigeons still consistently persisted. Difference in mean number of responses to the next reinforcer alone cannot therefore be the only variable responsible for the sunk cost error.

One possibility is that behavior is more sensitive to the relative than the absolute difference between these two mean response requirements. That is, the ratio between the mean number of responses to reinforcement for persistence and for escape might be a more important controlling variable than the difference between these two measures. This variable was explored more systematically in Experiment 2.

3. Experiment 2: establishing consistent escaping

During the first condition in Experiment 2, the four subjects (250, 456, 457, and 1770) that had made the sunk cost error consistently during Experiment 1 were presented with a condition in which the smallest FR was decreased to FR10, while the other three remained as they had for the FR40/160/320/640 condition in Experiment 1 (FR10/160/320/640). There are three reasons that this schedule arrangement might be expected to reduce the frequency with which these subjects made the sunk cost error. Firstly, it further increased the difference between the mean response requirement to the next reinforcer for persisting and escaping. In this condition, the mean number of responses to the next reinforcer following escape was 165, while that for persisting was 310, creating a difference of 144 (larger than any of the differences in Experiment 1). Secondly, it altered the relative difference between these two values; in all of the conditions in the first experiment, the mean response requirement to the next reinforcer following escape was approximately 2/3 the mean response requirement for persisting. In Experiment 2, the mean response requirement to the next reinforcer following escape was approximately 1/2 that for persisting. Thirdly, reducing the smallest FR in the condition to 10 may make the optimal escape point more salient, on the assumption that having completed 10 responses is easier to discriminate than having completed 40 responses. For all of these reasons, we expected pigeons to escape more frequently in the FR10/160/320/640 condition of the present experiment than in any condition presented during Experiment 1.

The three conditions presented in Experiment 1 were then replicated to assess the effects of this FR10/160/320/640 condition. In Experiment 1, Pigeon 18 did not initially escape when presented with the FR10/40/80/160 condition. However, that subject did begin to escape during the FR20/80/160/320 condition, and this pattern of escape continued when Pigeon 18 returned to the FR10/40/80/160 condition suggesting that a history with a condition that established consistent escaping caused that subject to escape even during conditions on which it had not previously. Therefore, it was anticipated that if consistent escape was established during the FR10/160/320/640 condition for the four subjects in Experiment 2, then escape also occur when those subjects were returned to conditions during which they had previously persisted.

Finally, the pigeons that had completed this FR10/160/320/640 condition were presented with a condition during which it was optimal to persist. This allowed an assessment of the specificity of the effect; in other words, whether the FR10/160/320/640 condition created a general reduction in persistence, or whether this increased tendency to escape only occurred in contexts where doing so was differentially reinforced by a reduction in response requirement.

3.1. Method

3.1.1. Subjects and apparatus

Four pigeons, numbered 250, 456, 457, and 1770, from Experiment 1 served. Living conditions and apparatus were as for Experiment 1.

3.1.2. Procedure

As in the first experiment, the schedule and escape keys were presented concurrently. Pigeons were first presented with a condition with the following four FRs: FR10 on 50% the trials, FR160 on 25% of the trials, FR320 on 12.5% of the trials, and FR640 on the remaining 12.5% of trials (FR10/160/320/640). Pigeons then repeated the three conditions from Experiment 1 (FR10/40/80/160, 20/80/160/320, and FR40/160/320/640). Pigeons also received 20–30 sessions in which the component schedules were interval based between conditions 1 and 2. Specifically, the FR schedules described here were altered to fixed-interval schedules where the interval length was equivalent to the mean inter-reinforcement time under the FR schedules reported here. These conditions are not described here because neither subjects' response rates nor levels of persistence changed when the contingencies were changed from ratio- to interval-based. Therefore, subjects apparently did not make contact with this change in contingencies, and the data were uninformative.

Pigeons were then exposed to a condition during which it was optimal, in terms of response requirement, to persist on the food key, and to never respond on the escape key. Specifically, the

Table 3
Mean proportion of FRs greater than FR10 completed by each pigeon during the final five sessions of each condition or Experiment 1. Standard deviations are presented in parentheses.

Pigeon	Condition		
	FR10/40/80/160	FR20/80/160/320	FR40/160/320/640
18	0.99 (0.02)/0.13[a] (0.06)	0.06 (0.05)/0.04[a] (0.03)	Responding ceased
250	0.98 (0.03)	0.99 (0.02)	0.97 (0.06)
456	1.00 (0.0)	1.00 (0.0)	0.98 (0.03)
457	0.99 (0.02)	1.00 (0.0)	0.82 (0.09)
1770	0.95 (0.06)	1.00 (0.0)	0.96 (0.04)
1774	0.06 (0.04)/0.03[a] (0.03)/0.06[a] (0.04)	0.07 (0.05)	0.97 (0.05)

[a] Replication.

set of possible FRs consisted of the following: an FR10 schedule on 3/12 trials, an FR 30 on 7/12 trials, and an FR50 on 2/12 trials (FR10/30/50). This condition was identical to one under which Navarro and Fantino's (2005) pigeons persisted, producing the lowest available response requirement. Because their pigeons did not have a history with a condition similar to the current FR10/160/320/640 condition, the condition was included here to assess the specificity of any reductions in persistence observed as a result of our pigeons' experience with the FR10/160/320/640 condition; that is, whether a history of escaping reduced persistence in general (including in cases where persisting was optimal), or only in conditions where such persistence was suboptimal (a case of the sunk cost error).

As before, the major dependent variable was proportion persistence. For conditions in which escape was established, it was also possible to consider a more graded measure of performance: the number of food key responses made prior to an escape key response. All conditions were continued until the proportion persistence was deemed stable, using the same stability criteria applied in Experiment 1. See Table 4 for the number of sessions required to produce stable responding for each subject and condition.

3.2. Results and discussion

Table 5 presents the proportion of trials in which pigeons persisted in each condition during Experiment 2. The FR10/160/320/640 condition reduced persistence (and thereby the sunk cost error) to near-zero levels for all four subjects. Therefore, this condition where the contingencies favored use of the escape key extremely heavily led to an absence of the sunk cost error.

Pigeons were presented with the FR10/40/80/160, FR20/80/160/320 and FR40/160/320/640 conditions after reliable use of the escape key had been established. The effects of this experience were most consistently observed during the FR10/40/80/160 condition. None of the four made the sunk cost error on the FR10/40/80/160 condition during Experiment 2, despite having consistently made it during the same condition in Experiment 1.

During the FR20/80/160/320 condition, Pigeon 250 consistently made the sunk cost error, as it had done before training, while the other three pigeons used the escape key consistently. During the FR40/160/320/640 condition, all but one pigeon (Pigeon 456) made the sunk cost error, although all three had used the escape key consistently in at least one previous condition. That is, in spite of having a larger difference between the mean number of responses to the next reinforcer for persisting and escaping, the FR40/160/320/640 condition led to more instances of the sunk cost error than did the FR10/40/80/160 and FR20/80/160/320 conditions. This pattern was also observed for Pigeon 1774 in Experiment 1. Possible explanations for this pattern will be considered below.

All four pigeons persisted consistently when presented with a condition during which it was optimal in terms of response requirement to persist (the right-hand-most column in Table 5). Therefore, the experience with the prior conditions in which escape was optimal did not produce a generalized tendency to escape.

Given the consistent escaping in Experiment 2, it was possible to assess the number of food key responses that occurred before escape key responses were made, and how closely escape responses approximated the optimal point (i.e., immediately after the non-reinforced completion of the number of responses in the smallest FR). Table 6 presents the number of food key responses after which escape key responses were made. Pigeons tended to somewhat overshoot the optimal escape point, making more food key responses than were optimal. Deviations from optimality were asymmetrical, however: rarely did the pigeons escape too early (after having made too few food key responses). The exception to this was Pigeon 456 during the FR40/160/320/640 condition, who escaped, on average, prior to having completed the number of responses in the smallest FR in the condition, thereby markedly increasing the obtained response requirement.

4. General discussion

The current study demonstrated that it is possible to create a history that reduces the subsequent frequency with which pigeons commit the sunk cost error. This is consistent with previous research indicating that errors on other decision-making tasks (e.g., base-rate neglect, the conjunction fallacy) could also be altered in frequency by providing a particular reinforcement history (Fantino and Savastano, 1996; Goodie and Fantino, 1996, 1999; Case et al., 1999; Fantino et al., 2005). These findings are also consistent with the results of Navarro and Fantino's (2005) final experiment in which a group of pigeons with a particular history committed the sunk cost error less frequently than had previous subjects. That history consisted of a series of sessions in which the food key was available while the escape key was not, and schedule transitions were signaled by key-light color changes.

In the present condition most closely replicating a condition presented by Navarro and Fantino (2005), the pattern of results was similar. Three out of their 4 pigeons, and 5 of our 6 pigeons, consistently committed the sunk cost error when first presented with what is here called the FR10/40/80/160 condition (FR 10 at a probability of 0.5, FR 40 at a probability of 0.25, FR 80 at a probability of 0.125, FR 160 at a probability of 0.125) in the absence of stimulus changes (during their Experiment 1). This was also the case in the study conducted by Avila-Santibanez et al. (2010), although some of their pigeons showed varying levels of persistence across three replications of the FR10/40/80/160 condition. Additionally, subjects in both the present Experiment 2 and Navarro and Fantino's Experiment 2 persisted as appropriate when presented with the FR10/30/50 condition during which persistence minimized mean response requirement.

Table 4
The sequence of conditions presented in Experiment 2, and the number of sessions for which each subject experienced each condition (columns from left to right are in the sequence conditions were run). See Section 3.1.2 and Table 1 for full condition descriptions.

Pigeon	Condition				
	FR10/160/320/640	FR40/160/320/640	FR20/80/160/320	FR10/40/80/160	FR10/30/50
250	11	39	19	25	38
456	25	23	14	16	51
457	13	83	16	16	11
1770	20	65	29	13	14

Table 5
Mean proportion of FRs greater than FR10 completed by each pigeon during the final five sessions of each condition or Experiment 1. Standard deviations are presented in parentheses.

Pigeon	Condition				
	FR10/160/320/640	FR40/160/320/640	FR20/80/160/320	FR10/40/80/160	FR10/30/50
250	0.00 (0.00)	0.98 (0.06)	0.98 (0.02)	0.02 (0.02)	1.00 (0.00)
456	0.00 (0.00)	0.01 (0.03)	0.00 (0.00)	0.01 (0.01)	0.98 (0.03)
457	0.00 (0.00)	0.52 (0.09)	0.06 (0.00)	0.02 (0.02)	0.95 (0.07)
1770	0.01 (0.01)	0.98 (0.04)	0.07 (0.00)	0.03 (0.01)	1.00 (0.00)

This study provided some additional information about the features of the current arrangement controlling levels of persistence. Specifically, some of the present results were not consistent with Navarro and Fantino's (2005) suggestion that the difference in mean number of responses to the next reinforcer for persisting and escaping was a key contributor to levels of persistence observed. Increasing this difference in Experiment 1 did not reliably reduce levels of persistence. Additionally, in some conditions of Experiment 2, multiplying all of the FRs by a common factor increased the sunk cost error, despite increasing the absolute difference between the mean number of responses to the next reinforcer given escape and given persistence. This is in contrast with Navarro and Fantino's conditions in which increasing this difference had the opposite effect, i.e., reducing the sunk cost error.

In the current study, the sequence in which the conditions occurred led pigeons to experience several other conditions between the FR10/160/320/640 condition and the FR10/40/80/160 condition during with reductions in persistence were most consistently observed. Therefore, it is possible in principle that one of these intervening conditions caused or contributed to these reductions in persistence. This is unlikely for several reasons. Firstly the immediacy with which escape – which had never been previously observed – was established by the introduction of the FR10/160/320/640 condition. Consistent escape began within only a few sessions for several pigeons. Additionally, it is unclear why presenting conditions during which consistent escape did not occur would have produced such consistent escape when the FR10/40/80/160 condition was subsequently presented. An additional study in which the sequence of conditions was altered is necessary to confirm this speculation conclusively, however.

If the FR10/160/320/640 condition did cause the subsequent reductions in persistence, there are several potential explanations for these reductions occurring in the FR10/40/80/160 condition but not the FR40/160/320/640 condition. Firstly, it could be that the FR10/160/320/640 condition, which established consistent escape in the FR10/40/80/160 condition, had very specific effects. That is, during this condition it was optimal to escape after 10 food key responses and perhaps it increased escape only in subsequent conditions during which this was also the optimal escape point. Overall, pigeons tended to persist during conditions in which the optimal response pattern was least similar to that during the FR10/160/320/640 condition. This speculation could be tested by presenting naïve subjects with a condition in which escaping after 40 food key responses was as strongly favored by the contingencies as escaping after 10 responses was during the training condition experienced by the current subjects. This would be expected to reduce the sunk cost error during conditions in which escaping after 40 food key responses was the optimal response pattern, but not when the optimal pattern was escaping after 10 schedule-key responses.

Secondly, it may be that this pattern represented a sunk cost magnitude effect. Perhaps completing 40 responses during the FR40/160/320/640 condition represented a greater investment than completing 10 responses during the FR10/40/80/160 condition, and this might be why subjects were more likely to persist in the former case than in the latter case. Such magnitude effects have been observed with human participants (Garland, 1990), but have not been to date studied with non-human animals. In the Garland study, the more participants were told had been invested in a hypothetical airplane project, the more likely they were to report that they would continue to invest further money in that project.

A third possible explanation for the higher levels of persistence observed in the FR40/160/320/640 condition relates to discriminative control. More specifically, making escape key responses at the optimal point in the trial depends on sensitivity to the number of responses made since the beginning of the trial. Conditions in which it was optimal to choose the escape key after 40 food key responses presumably are more difficult than conditions in which

Table 6
Mean number of food key responses made before an escape key response, by pigeon and condition. Standard deviations are in parentheses. Data is only presented from conditions during which there were sufficient escape responses.

Pigeon	Condition			
	FR10/160/320/640	FR40/160/320/640	FR20/80/160/320	FR10/40/80/160
250	17.21 (2.23)	Persistence	Persistence	17.11 (1.84)
456	16.25 (1.51)	23.38 (3.27)	24.84 (2.75)	13.30 (1.39)
457	16.61 (2.07)	139.75 (58.44)	36.82 (5.41)	15.66 (1.58)
1770	22.18 (11.37)	Persistence	39.39 (2.22)	13.21 (0.61)

the optimal choice occurred after just 10 responses. As can be seen from Table 6, pigeons produced their escape responses at the least optimal juncture in these conditions with the larger smallest FR. That is, as the smallest FR in the condition (and therefore the optimal escape point) increased, the mean escape point became more divergent from the optimal escape point, and the across-session variability in mean escape point increased. This increased mean escape point had the effect of increasing the number of responses made on trials with escape, and therefore, as a consequence, reducing the extent to which escape was optimal. This may have, in turn, led to increased persistence.

This speculative explanation about the importance of the discriminability of the optimal escape point is consistent with two of Navarro and Fantino's (2005) findings. Firstly, in their Experiment 3, pigeons escaped most consistently during the conditions in which the smallest FR in the condition had the smallest parameter value (i.e., they persisted when the smallest FR was 10 or 20, but not when it was 5). It may be that this variable, rather than the absolute difference between the mean response requirements for persisting and escaping (with which it was confounded) explained the pattern of persistence that they observed. Secondly, this discriminative control explanation is consistent with Navarro and Fantino's (2005) finding that the addition of stimulus changes signaling the schedule completions reduced persistence. The first of these stimulus changes signaled the optimal escape point, and this exteroceptive stimulus change likely enhanced whatever discriminative control was exerted by number of responses alone. Adding such signals to a condition in which the optimal escape point occurred after 40 food key responses would allow a test of this explanation against one in terms of a sunk cost magnitude effect, because it would presumably alter the ease of discriminating the optimal escape point, but would not change the number of food key responses that had been invested to that point. Some unpublished data from our laboratory taking this approach are consistent with this explanation in terms of discriminative processes.

This explanation in terms of stimulus control is also consistent with the behavior of Pigeon 456, the one subject who escaped consistently during the FR40/160/320/640 condition. When the optimal escape point was after 10 or 20 food key responses, this pigeon consistently escaped after approximately that many food key responses—slightly overshooting, as was typical of all pigeons. When the optimal escape point was FR40, however, escaping became erratic. The distribution of the number of schedule-key responses produced before each escape key response was bimodal, with one peak occurring before 20 responses (when escape responses could only increase mean response requirement), and another peak well after the optimal escape point (at approximately 60 food key responses), suggesting a breakdown in the discriminative control previously seen when the smallest FR was smaller.

If the ease with which the optimal escape point is discriminated is shown to be an important contributor to performance on this task, future research could also usefully investigate whether it is the number of responses that pigeons have produced, or the amount of time that they have spent responding on the key that most strongly controls the juncture at which subjects make escape responses. Such research would also have the potential to answer more general questions about whether investments of time have equivalent effects on decisions about persistence to investments of effort of the type required to make key-peck responses.

5. Conclusions

In conclusion, the present study showed that specific experience with situations in which the sunk cost error produces exceedingly high costs can reduce the frequency with which such errors occur. It also showed, however, that the absolute difference in response requirement between persisting with and abandoning a course of action does not alone predict whether the sunk cost error will occur. Rather, other factors, such as the ratio of these two values, and the discriminability of the optimal escape point, may also be important determinants of the sunk cost effect.

Acknowledgements

Research supported by NSF Grant IBN 0420747. Some of the these data were presented at the 2010 Meeting of the Association for Behavior Analysis International. The authors would like to thank Leonardo Andrade, Carla Lagorio, Jennifer Rusak and Rachelle Yankelevitz, for help with conducting sessions.

References

Arkes, H.R., Hutzel, L., 2000. The role of probability of success estimates in the sunk cost effect. J. Behav. Decis. Making 13, 295–306.

Avila-Santibanez, R., Gonzalez-Montiel, J.C., Miranda-Hernandez, P., Guzman-Gonzalez, M.D., 2010. Stimuli effects on optimal behavior in a sunk-cost situation with pigeons. Mex. J. Behav. Anal. 36, 17–29.

Case, D.A., Fantino, E., Goodie, A.S., 1999. Base-rate training without case cues reduces base-rate neglect. Psychon. Bull. Rev. 6, 319–327.

De la Piedad, X., Field, D., Rachlin, H., 2006. The influence of prior choices on current choice. J. Exp. Anal. Behav. 85, 3–21.

Fantino, E., Kanevsky, I.G., Charlton, S.R., 2005. Teaching pigeons to commit base-rate neglect. Psychol. Sci. 16, 820–825.

Fantino, E., Savastano, H., 1996. Humans' responses to novel stimulus compounds and the effects of training. Psychon. Bull. Rev. 3, 204–207.

Garland, H., 1990. Throwing good money after bad: the effect of sunk costs on the decision to escalate commitment to an ongoing project. J. Appl. Psychol. 75, 728–731.

Goltz, S.M., 1992. A sequential learning analysis of decisions in organizations to escalate resources investments despite continuing costs or losses. J. Appl. Behav. Anal. 25, 561–574.

Goltz, S.M., 1993. Examining the joint roles of responsibility and reinforcement history in recommitment. Decision Sci. 24, 977–994.

Goltz, S.M., 1999. Can't stop on a dime: the roles of matching and momentum in persistence of commitment. J. Organ. Behav. Manage. 19, 37–63.

Goodie, A.S., Fantino, E., 1996. Learning to commit or avoid the base-rate error. Nature 380, 247–249.

Goodie, A.S., Fantino, E., 1999. What does and does not alleviate base-rate neglect under direct experience. J. Behav. Decis. Making 12, 307–335.

Macaskill, A.C., Hackenberg, T.D., 2012. The sunk-cost effect with pigeons: some determinants of decisions about persistence. J. Exp. Anal. Behav., in press.

Navarro, A.D., Fantino, E., 2007. The role of discriminative stimuli in the sunk cost effect. Mex. J. Behav. Anal. 33, 19–29.

Navarro, A.D., Fantino, E., 2005. The sunk cost effect in humans and pigeons. J. Exp. Anal. Behav. 85, 1–13.

Navarro, A.D., Fantino, E., 2009. The sunk-time effect: an exploration. J. Behav. Decis. Making 22, 252–270.

Tversky, A., Kahneman, D., 1981. The framing of decisions and the psychology of choice. Science 211, 453–458.