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VARYING THE COSTS OF SUNK COSTS: OPTIMAL AND NON-OPTIMAL CHOICES IN A SUNK-COST TASK WITH HUMANS

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Twelve adult human subjects were exposed to a sunk-cost procedure with two options: a mixed-ratio schedule of points later exchangeable for money, and an escape schedule that cancelled the current trial and initiated a new one. The mixed ratio included four values, arranged probabilistically in such a way that the expected ratios favored either persistence or escape. These probabilities were varied systematically on a within-subject basis across conditions. Absolute ratio size was thus varied across four groups of three subjects each, yielding unique combinations of expected ratios from escaping and persisting. When the differences between escaping and persisting differed the least, subjects tended to persist, committing the sunk-cost error. When the differences between persisting and escaping differed by a larger margin, choice patterns tended toward optimal—escaping or persisting as a function of the contingencies. These findings demonstrate that sunk-cost decision-making errors in humans are sensitive to their relative costs and benefits, and illustrate a promising set of methods for bringing such behavior under experimental control in the laboratory.

Key words: sunk cost, choice, fixed-ratio schedules, monetary reinforcers, adult humans

The sunk-cost effect is defined as persisting in a course of action based on prior commitment of resources, despite the negative long-term outcomes of that action (Arkes & Blumer, 1985). This phenomenon is normally considered irrational because the decision to continue or to interrupt an investment in a task should be controlled only by its future costs and benefits and not by the costs of previous investments.

The sunk-cost effect has traditionally been studied by presenting to college students brief scenarios describing situations of investments that involve gains or losses of money, and asking them to decide whether to continue or to interrupt the investment. Such decisions are affected by the uncertainty regarding the consequences of the investment (Bowen, 1987; McCain, 1986). The sunk-cost error is more likely with ambiguous information regarding the investment; subjects given explicit feedback regarding the costs of the investment show a greater tendency to terminate the investment (Bragger, Bragger, Hantula, & Kirnan, 1998).

Although it is generally assumed that sunk-cost errors are limited to humans (see review by Arkes & Ayton, 1999), there is recent evidence that sunk-cost effects may also be apparent in nonhuman animals (Avila-Santibanez, Gonzalez-Montiel, Miranda-Hernandez, & Guzman-Gonzalez, 2010; Macaskill & Hackenberg, 2012, a, b; Magalhães & White, 2013; Magalhães, White, Stewart, Beeby, & van der Vliet, 2012; Navarro & Fantino, 2005; Pattison, Zentall, & Watanabe, 2012). In the first published laboratory analogue with nonhumans, Navarro and Fantino gave pigeons repeated choices between a series of fixed-ratio (FR) schedules of food reinforcement, arranged probabilistically, and an escape key that terminated the current trial and initiated a new FR. In each trial, one of four FR schedules was in effect: FR 10 (50% of the trials), FR 40 (25%), FR 80 (12.5%), or FR 160 (12.5%). Given the results with humans suggesting that uncertainty, or poor discrimination between alternatives, increased the likelihood of the sunk cost effect, Navarro and Fantino manipulated uncertainty in two different ways: (1) presenting or not an external stimulus that signaled the current FR response requirements; and (2) varying the size of the FR schedules and their corresponding probabilities in such a way

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that the differences in expected ratios of responses per reinforcer after escaping (R_{esc}) versus persisting ($R_{persist}$) on each trial varied systematically across conditions.

The expected ratios, R_{esc} and $R_{persist}$, were computed by multiplying each FR value by its corresponding probability and summing these products. Thus, in the example previously described, the combination of FR response requirements and probabilities results in an R_{esc} of 45 (i.e., 45 responses per reinforcer at the beginning of each trial), computed as follows: $(10*0.50) + (40*0.25) + (80*0.125) + (160 *0.125)$. If 10 responses are completed without reinforcement (i.e., the initial FR has been completed but not reinforced), however, the expected ratio ($R_{persist}$) then increases to 70: computed as the sum of the expected ratios of the remaining FRs in the series: $(30*0.50) + (70 *0.25) + (150*0.25)$. When the initial FR has been completed without reinforcement, the sunk-cost decision is made: persist on the FR schedule, or terminate the current trial by responding on the escape key. Escape responses initiate a new trial, resetting the ratio to its initial value (45).

These sunk-cost contingencies are further characterized in Figure 1, which shows for the above example how the expected ratio of responses per reinforcer changes across unreinforced responses within the FR trial. The vertical dotted lines indicate the FR response requirements and the data points show the expected number of responses per reinforcer at the beginning of a trial and after each FR response requirement without reinforcement. The line parallel to the abscissa shows the expected number of responses at the beginning of a new trial after an escape response.

As Navarro and Fantino (2005) noted, and as shown in the figure, when an FR larger than FR 10 is in effect, escaping that trial and initiating a new trial is optimal because the expected ratio at the beginning of a trial is lower (45) than the expected ratio for persisting (70). This procedure resembles a sunk-cost scenario because an initial investment of effort is made without a reinforcer (the initial FR), there is uncertainty about the reinforcer delivery (the FRs are programmed probabilistically) and the subject must choose between persisting in less favorable conditions or abandoning the task in favor of a better investment.

In Navarro and Fantino's (2005) experiment, four pigeons were exposed in a within-subject design to three response requirement sets: (a) FR 5, FR 50, FR 100, and FR 220; (b) FR 10, FR 40, FR 80, and FR 160; and (c) FR 20, FR 50, FR 100, and FR 200, all with probabilities of presentations equal to those described above. The difference between R_{esc} and $R_{persist}$ changed across conditions: 44 responses per reinforcer for FR set (a), 24 responses per reinforcer for FR set (b), and 19 responses per reinforcer for FR set (c). Persistence was notably higher when the difference between persisting and escaping was relatively small (low discriminability) than when the difference was relatively large (high discriminability).

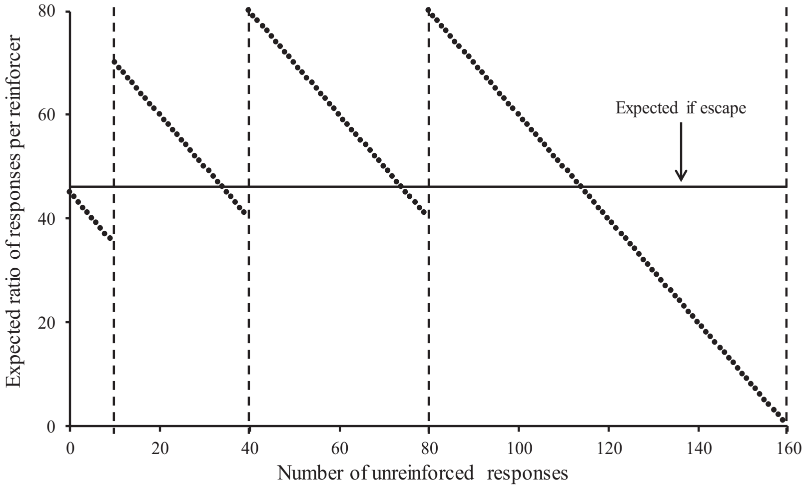

Fig. 1. Expected ratio of responses per reinforcer as a function of the number of unreinforced responses for a FR Set of 10, 40, 80 and 160 responses with probabilities of 0.50, 0.25, 0.125 and 0.125, respectively.

Navarro and Fantino (2005) replicated the effect with human subjects in a computer-based task with point/money reinforcers rather than food reinforcers. Two FR sets were used: (a) FR 5, FR 50, FR 100, and FR 220, and (b) FR 10, FR 40, FR 80, and FR 160, both with probabilities equal to those in the pigeon experiment described above. The subjects were studied for two sessions apiece in a between-group design: one group received FR set (a), the other FR set (b). Despite some between-subject variability, a majority of subjects persisted longer in the FR set (b), the set with the smaller difference between R_{esc} and $R_{persist}$.

The present study was a systematic replication and extension of the Navarro and Fantino (2005) experiment with human subjects. As in their study, we investigated the effects of the difference between R_{esc} and $R_{persist}$ by arranging different sets of FR values. Instead of two sets, we examined four sets in a between-subject design. In addition, we examined on a within-subject basis the effects of three different sets of probabilities associated with the FR schedules.

The combinations of FR values and probabilities yield a contingency space defined in relation to two boundaries. At one end, the difference between R_{esc} and $R_{persist}$ is negative; hence escaping on the task is optimal. At the other end, the difference between R_{esc} and $R_{persist}$ is positive; hence persisting is optimal. This permits an analysis of intermediate values, in addition to the extreme values used by Navarro and Fantino (2005). This kind of analysis could be useful in conceptualizing the sunk-cost effect on a continuum instead of an all-or-nothing phenomenon as traditionally viewed in the literature (e.g., Arkes & Blumer, 1985). In addition, the present experiment examined choice patterns under steady-state conditions, that is, after performance stabilized and under a within-subject design. These features bring the procedures into closer alignment with those commonly used in laboratory research with nonhuman subjects, facilitating cross-species comparisons.

Method

One of the experimental conditions (with three subjects) was conducted at the University of Florida (for brevity, UF) and the other three experimental conditions (with nine subjects) were conducted at the National Autonomous University of Mexico (for brevity, UNAM). Therefore, while there were obvious differences in the characteristics of the subjects, settings and details of the procedure, such as the language of the instructions or the amount of reinforcement, there was an attempt to minimize as much as possible differences in experimental methods and design.

Subjects

Three adult humans, two female and one male, were recruited through an advertisement published in a student newspaper at UF. Nine more female students were recruited through direct invitation at UNAM. All subjects participated in two consecutive 25-min sessions per day, Monday through Friday. Subjects could earn money according to their performance in the experiment plus an extra bonus for attending each scheduled session.

Apparatus

In both settings, subjects worked in a small room (2.6 m high by 2.5 m long by 2.4 m deep, approximately) containing one IBM-PC microcomputer or a Dell laptop computer plugged in to a 36.5 cm monitor. The rooms were artificially illuminated. Stimuli consisted of one yellow square, and one white square and some text (described below). Presentation of the stimuli and data collection was controlled by a Visual Basic 6.0 program. The computer mouse served as the manipulandum.

Procedure

Subjects were seated in front of the computer and mouse and were asked to follow the instructions presented on the screen. The instructions were written in English and Spanish for the UF and UNAM subjects, respectively. Every daily session started with the captions "Click over the left square to reset trial" and "Click over the right square repeatedly to earn money" presented at the upper left of the screen. These captions were only hidden when a reinforcer was earned or when the reset button was clicked. The yellow (escape) and the white (FR) squares were located at the center-left and the center-right of the screen, respectively. After each click, the position of the FR square on the screen changed randomly, requiring subjects to track its position; the position of the escape square was fixed. The caption "Total", followed by an amount of money, was shown at the bottom right of the screen and changed according to the subject's accumulated earnings. At the beginning of each session the "Total" amount was zero, but five cents were added to the count every time a reinforcer was earned. The clicks to the FR square produced monetary reinforcement according to one of four FR requirements. Every time a reinforcer was earned, the following message was shown: "You won 5 cents." A single click to the escape square cancelled the trial and started a new one. Whenever the escape square was clicked or after points were earned by completing the requirement arranged on the FR square, the following message was displayed: "A new trial will begin in a moment." A new trial with a new FR requirement began 2 s later, selected from the 4-value array according to a predetermined probability (see below).

The task can be conceptualized as a concurrent schedule with two options: respond on the FR square, producing an occasional point/money reinforcer, or respond on the escape square, canceling the current trial and initiating a new trial. All subjects completed two consecutive 25-min sessions, separated by a 5-min break, per day.

In addition to the money earned in each session, subjects could earn a $3.00 US or $3.00 Mexican pesos bonus for completing two sessions each day. At the end of the experiment, subjects were paid the total amount of money earned within the sessions plus the bonus money.

Four sets of FR values were tested with three probability sets arranged in each FR set. A mixed factorial design was used, with FR set as a between-subjects factor and probability set as a within-subject factor. The four FR sets were: (1) FR 2, FR 10, FR 20, FR 40; (2) FR 5, FR 20, FR 40, FR 80; (3) FR 10, FR 40, FR 80, FR 160; and (4) FR 20, FR 80, FR 160, FR 320. For convenience, these FR sets will be described 1, 2, 3, and 4, respectively. The three probability sets were: (a) 0.50, 0.25, 0.125, 0.125; (b) 0.125, 0.50, 0.25, 0.125; and (c) 0.0625, 0.0625, 0.50, 0.375. These probability sets will be referred to as A, B and C, respectively. The sequence of probability sets was ABACA.

Table 1

Expected responses per reinforcer ratios for consistent escape (R_{esc}) and consistent persistence ($R_{persist}$) and their difference (R_{esc}-$R_{persist}$) for all FR sets and probability sets.

FR set	Probability set	R_{esc}	$R_{persist}$	R_{esc}-$R_{persist}$
1	A	11.0	18.0	−6.0
	B	15.25	15.14	1.11
	C	25.75	25.33	1.42
2	A	22.5	35.0	−11.5
	B	30.63	29.29	2.3
	C	51.56	49.67	2.90
3	A	45.0	70.0	−24.0
	B	61.25	58.57	3.7
	C	103.13	99.33	4.79
4	A	90.0	140.0	−49.0
	B	122.5	117.14	6.2
	C	206.25	198.68	8.57

Note. See text for calculation details.

Table 1 shows the expected values of R_{esc} (consistent escape) and $R_{persist}$ (consistent persistence), and their differences, for all conditions of the experiment. The R_{esc} value is the expected ratio at the beginning of a trial. For example, considering FR Set 1, Condition A, R_{esc} is the sum of the four FR schedules, weighted by their probability of occurrence: $(2*0.50) + (10*0.25) + (20*0.125) + (40*0.125) = 11$; $R_{persist}$ is the expected ratio of the three remaining FRs, weighted by their probability of occurrence, and subtracting the smallest FR: $(8*0.50) + (18*0.25) + (38*0.25) = 18$. Note that the difference measure in Table 1 includes the single escape response that terminates the trial, bringing the difference between R_{esc} and $R_{persist}$ from seven to six responses per reinforcer. By this measure, negative values indicate conditions in which escape is optimal whereas positive values indicate conditions in which persistence is optimal, with optimal defined in terms of minimizing overall responses per reinforcer.

Conditions were in effect for a minimum of four sessions and until responding was deemed stable, via visual inspection. Table 2 shows the number of sessions of exposure of each subject to the different combinations of FR and probability sets. Due to schedule restrictions Subjects 7 and 9 could not attend the experimental sessions corresponding to the last Condition A of FR Set 3.

Results

Figure 2 shows for each subject the percentage of persist trials across the final five sessions

Table 2

Number of sessions of exposure of each subject to the combinations of FR sets and probability sets.

		Probability set				
		A	B	A	C	A
FR set	Subjects	Sessions	Sessions	Sessions	Sessions	Sessions
1	1	6	8	4	6	8
	2	6	8	4	6	8
	3	12	6	6	8	6
2	4	8	4	4	4	4
	5	6	4	6	4	6
	6	10	8	8	12	8
3	7	10	10	10	8	–
	8	8	8	12	8	6
	9	6	6	6	8	–
4	10	12	6	6	10	6
	11	12	14	15	21	22
	12	16	12	10	12	16

Note. See Table 1 for condition description.

per condition (or four sessions in conditions with fewer than five sessions). In each panel, the data of three subjects are plotted with different symbols, with the vertical lines separating the conditions. Subjects exposed to FR Set 1 (top panel) persisted in nearly all trials across all probability sets. For two of the three subjects exposed to FR Set 2 (second panel from top) there were high levels of persistence across all probability sets, whereas persistence for the remaining subject (S6) varied unsystematically across conditions. For the subjects exposed to FR Sets 3 and 4 (bottom two panels), persistence was generally greater in Conditions B and C (mean percentages of 63.54 and 68.19, respectively) than in Condition A (mean of 9.72).

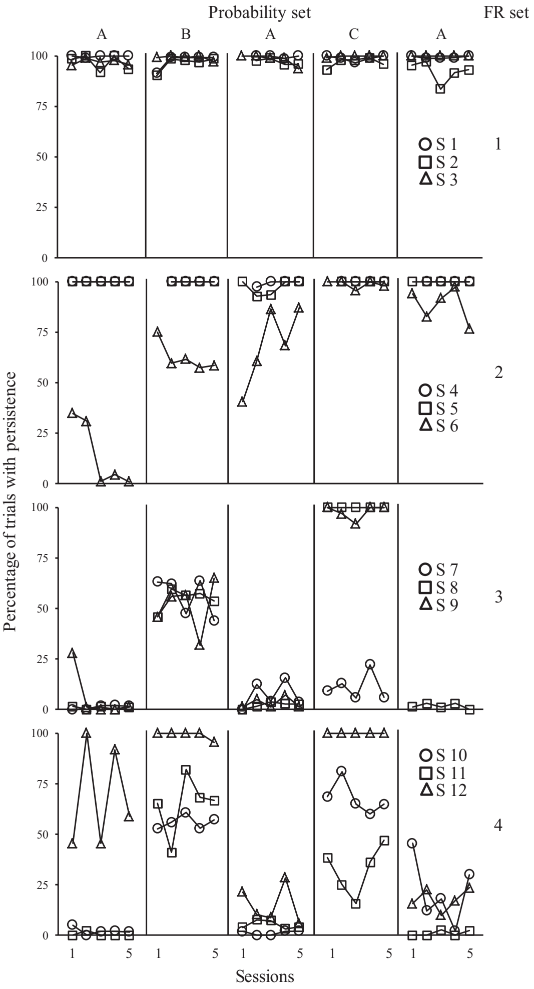

Fig. 2. Mean percentage of trials with persistence for the three subjects exposed to each fixed ratio set (FR set, rows) and each probability set (columns). These data are based on the last five sessions of exposure to each combination of FR sets and probability sets.

For all FR sets, Conditions B and C arranged positive differences between R_{esc} and $R_{persist}$, and hence, persistence was optimal (see Table 1). Conversely, in Condition A, these differences were negative, so escape was optimal. To provide a more direct characterization of this variable, Figure 3 shows the percentage of trials with persistence as a function of differences between R_{esc} and $R_{persist.}$ For the different FR sets each data point is the mean persistence of each subject over the final five sessions per condition; the average of the three exposures to condition A is presented. The differences between R_{esc} and $R_{persist}$ varied between –49.0 and +8.6, with negative values defining conditions of optimal escape and positive values defining conditions of optimal persistence. To facilitate comparison, the variable was standardized by using z-scores. Thus, in all of the panels of Figure 3, z-scores lower than 0 correspond to conditions in which escape was optimal, whereas z-scores greater than 0 correspond to conditions in which persistence was optimal. In all of the panels, the vertical and horizontal dashed lines allow the identification of the four behavioral patterns occupying different parts of the contingency space; namely, optimal escape (lower left quadrant), nonoptimal persistence (upper left quadrant), optimal persistence

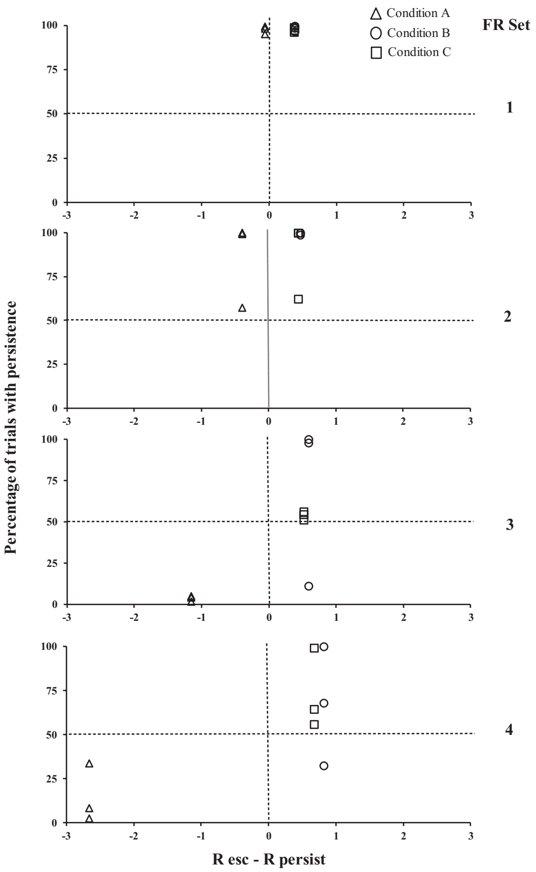

Fig. 3. Mean percentage of trials with persistence as a function of the difference between escaping (R_{esc}) and persisting ($R_{persist}$). The symbols show the individual data for each combination of FR sets and probability sets. The x-axes are normalized with *Z*-scores. The vertical and horizontal dashed lines define the behavioral patterns observed (see text for description).

(upper right quadrant), and nonoptimal escape (lower right quadrant).

For all of the subjects, preference for escape versus persistence was broadly consistent with the differences of R_{esc} and $R_{persist}$ measures. For subjects in FR Sets 1 and 2, persistence was observed when escape was optimal (Condition A, cf. triangles in upper left quadrant of Fig. 3), but persistence occurred when persistence was optimal (upper right quadrant, Conditions B and C). For most of the subjects in FR Sets 3 and 4, persistence was low when escape was optimal (lower left quadrant, Condition A), and was higher when persistence was optimal (upper right quadrant, Conditions B and C). For all subjects, no substantive differences in persistence were found between the B and C conditions, as mixed patterns of preference prevailed under these conditions.

In conditions favoring escape (negative x-values in Fig. 3), optimal responding entailed not only an escape response, but an escape response at a particular position in the FR sequence: after the smallest FR response requirement had been satisfied without reinforcement. The distribution of responses around this optimal escape point can be taken as a measure of optimal performance. Figure 4 shows conditional probabilities of escape responses as a function of ordinal FR position, averaged across subjects within each FR set (columns), in escape-optimal conditions (Condition A in each FR set). Conditional probabilities are preferable to simple probabilities because they are corrected for opportunity and therefore facilitate comparisons across conditions. The three panels in each column correspond to trials in which the FR-value indicated in each panel was arranged. Only the three larger FR schedules in each of the FR sets are shown, because selecting the smallest FR was always optimal under these conditions. It was only after completing this initial FR that the two options, persist and escape, represented conflicting alternatives bearing on optimal behavior. To facilitate comparisons across FR sets, conditional probabilities are reported across 40 ordinal bins within the FR indicated in the panel, each bin being 1/40th of the largest FR in the set. Bin size was thus composed of one, two, four, and eight responses for FR Sets 1 (largest FR 40), 2 (FR 80), 3 (FR 160), and 4 (FR 320), respectively. The conditional probabilities were computed by summing the number of responses within an FR bin divided by the frequencies in that bin plus those in higher bins. Bins with three or fewer escape opportunities were not included.

The vertical reference lines correspond to the nominal FR values–the positions in the overall ratio when transitions between FR components occurred. Thus, for panels in the top row, the reference line corresponds to the lowest FR in that set: FR 2, FR 5, FR 10, and FR 20, for FR Sets 1, 2, 3, and 4, respectively; for the panels in the middle and bottom rows, the reference lines correspond both to the initial FR and to larger nominal FRs within the set. For panels in the top row (the second-lowest FR in each set), the distributions tend to peak just after the

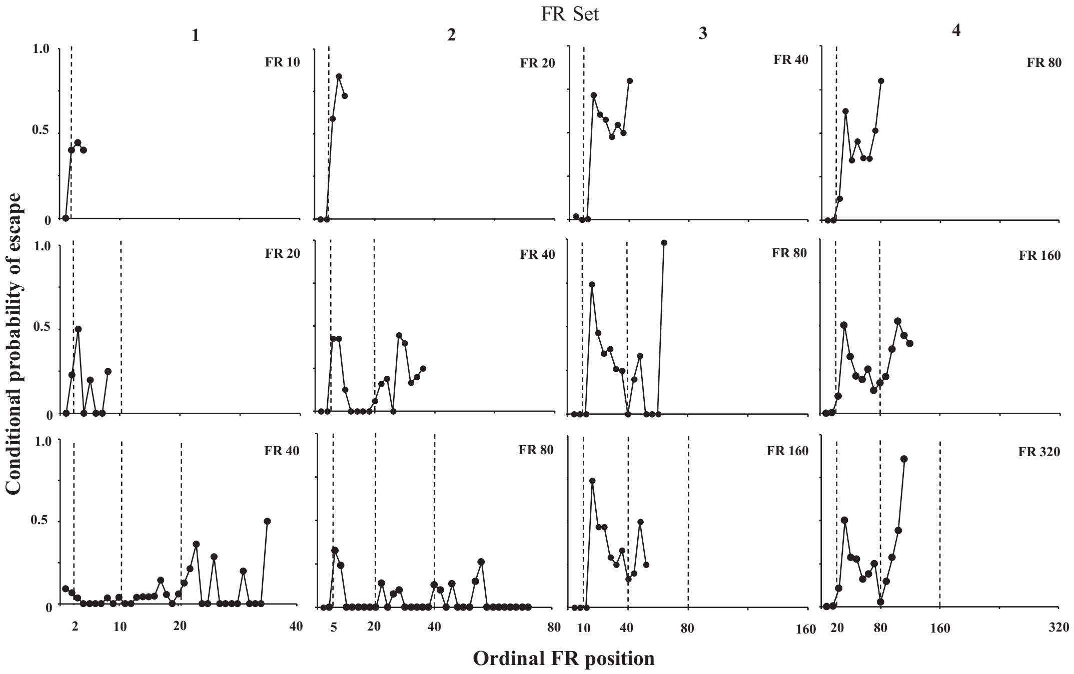

Fig. 4. Conditional probability of escape as a function of the ordinal FR position for each response requirement (panels) that composed each FR set (columns) from the A conditions, in which escape was optimal. The data are averaged across subjects within each FR set, with conditional probabilities reported in ordinal bins, each 1/40th of the largest FR in each set. Bin size is thus one, two, four, and eight responses for FR Sets 1, 2, 3, and 4, respectively. The dashed vertical lines indicate the nominal FR response requirements. See text for additional details.

unreinforced completion of the smallest FR–the optimal escape point under these conditions. For panels in the middle row, the distributions tend also to peak just after the initial FR, but in three of four cases (FR sets 2, 3, and 4), there was a second peak just after the second FR in the set, and in one case (FR Set 3) a third peak close to the nominal value of the FR. This bimodality in the escape distributions was also evident in the same three FR sets in the bottom row (largest FR in each set), with peaks just after the nominal FR schedules, and in one case (FR Set 2) an additional series of peaks beyond the third FR component in the set. These later peaks, while not optimal, reflect sensitivity to the position in the FR schedule at which schedule transitions occurred.

Discussion

The purpose of the present study was to further explore the sunk-cost effect, the seemingly irrational pattern of behavior in which prior expenditure of resources determines present choices (Arkes & Blumer, 1985). More specifically, the study aimed to examine the effect on persistence of the difference between the expected ratio for escaping (R_{esc}) and persisting ($R_{persist}$). When the difference between R_{esc} and $R_{persist}$ differed the least (FR Sets 1 and 2), persistence generally prevailed. Behavior in these conditions provides the best examples of the sunk-cost fallacy, as it exemplifies nonoptimal persistence in a course of action. Conversely, when R_{esc} and $R_{persist}$ differed the most (FR Sets 3 and 4), persistence and escape tended toward optimality, both in terms of the overall preference patterns (Fig. 3) and in the distributions of escape responses across FR position (Fig. 4).

These conclusions are further supported by the analysis shown in Figure 3, which shows how sunk-cost choices vary with their relative costs. Within this basic framework, sunk-cost choices occupy only part of a broader contingency space that extends from situations in which persistence is optimal to those in which escape is optimal. Nonoptimal persistence in escape-optimal conditions (sunk cost, as traditionally defined) was seen (upper left quadrant in Fig. 3). There was also evidence for a type of *reverse sunk-cost error* (see Macaskill & Hackenberg, 2012a): escaping when persistence is optimal (lower right quadrant in Figure 3). Macaskill and Hackenberg (2012a) suggested that this effect might be due to a prior history that favored optimal escape (see also Avila-Santibanez et al., 2010). Consistent with this interpretation, all instances of nonoptimal escape in the present study followed a history of escape responding first established in escape-optimal conditions. Exploring the various histories that give rise to sunk-cost (and reverse sunk-cost) decision-making errors should be a key focus of future research.

The conditional probabilities shown in Figure 4 are important in showing that the broad patterns of escape (like those shown in Figs. 2 and 3) are themselves composed of distributions of responses. While most of the distributions tended to peak just beyond the initial FR (the optimal juncture), many distributions showed a second peak (and one, a third peak), reflecting sensitivity to the programmed ratio requirements in the FR set. Thus, even when escape was not strictly optimal (just after the initial FR), it varied in an orderly way with the programmed FR schedules. The nonoptimal but orderly patterns of escape at these latter junctures may reflect tradeoffs not between global measures of R_{esc} and $R_{persist}$ (as computed in Table 1 and Fig. 3, as the sum of the remaining FR schedules), but between R_{esc} and the local expected ratio associated with the upcoming FR. As shown in Figure 1, each response on the FR reduces the overall expected ratio until it converges with R_{esc} near the end of the current FR. When the FR is completed without reinforcement, the expected ratio increases appreciably. The later peaks in the escape distribution just after the schedule transitions likely reflect sensitivity to these local changes in expected ratios.

Prior research with pigeons (Macaskill & Hackenberg, 2012a) and humans (Macaskill & Hackenberg, 2013) has shown that preference for escape versus persistence varies with the overall ratio of $R_{esc}/R_{persist}$. With the combinations of FR schedules and probabilities in Conditions B and C in the present study, the programmed differences between R_{esc} and $R_{persist}$ varied while the $R_{esc}/R_{persist}$ ratios were constant, permitting a potentially sharper analysis of controlling variables (difference vs. ratio). No systematic differences in persistence were found between the B and C conditions, however, perhaps owing to the small differences between R_{esc} and $R_{persist}$ in those conditions in which the ratios were constant. Future research that samples a wider range of R_{esc} and $R_{persist}$ differences and ratios in this overall contingency space would shed light on sunk cost decision making phenomena on a continuum ranging from optimal to nonoptimal.

On the whole, the results extend those reported in prior studies with human subjects (Macaskill & Hackenberg, 2013; Navarro & Fantino, 2005, Experiment 4), but over a wider parametric range and under steady-state conditions. Investigating human choice under steady-state conditions also makes the procedures more comparable to those used in sunk-cost experiments with pigeons (Avila-Santibanez et al., 2010; Macaskill & Hackenberg, 2012a, b; Navarro & Fantino, 2005, Experiments 1–3). In some conditions of these studies, pigeons were exposed to schedules that generated differences in expected ratios for escaping and persisting under steady-state conditions. As in the present study with humans, pigeons in these experiments persisted when the differences in expected ratios were small and escaped when they were large. This suggests that sensitivity to the contingencies in the sunk-cost procedures is not a uniquely human phenomenon, but rather, reflects more fundamental behavioral mechanisms that cut across species. As such, it joins with a range of other decision-making phenomena that, while apparently human, have been shown to apply as well to other animals (Baker & Rachlin, 2002; Fantino, Kanevsky, & Charlton, 2005; Fantino & Stolarz-Fantino, 2005).

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