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OPTIMAL AND NONOPTIMAL CHOICE IN A LABORATORY-BASED SUNK COST TASK WITH HUMANS: A CROSS-SPECIES REPLICATION

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The current four experiments examined the sunk cost effect—nonoptimal persistence following investment—in a laboratory-based decision-making task with adult humans. Subjects made repeated decisions about whether to persist in a course of action—a fixed-ratio schedule whose response requirements varied unpredictably from one trial to the next—or to abandon it and escape in favor of a new trial with a potentially smaller fixed ratio schedule. Satisfying the ratio requirement produced a brief video clip from a preferred television program. In Experiment 1, sunk-cost errors were less likely in subjects who had previously experienced markedly differential reinforcement for escape. In Experiment 2, stimulus changes correlated with changes in mean response requirement, and these changes reduced sunk-cost errors in a small number of subjects. In Experiment 3, sunk-cost errors occurred more frequently as the ratio of the mean response requirements for persistence and escape approached 1.0. The importance of this variable was further supported by the results of Experiment 4, in which features other than this ratio did not markedly alter performance. These four experiments identified some key determinants of whether humans commit the sunk-cost error and confirmed the utility of video clips as reinforcers in experimental research with humans.

Key words: sunk-cost error, choice, ratio schedules, video reinforcers, mouse click, humans

The sunk cost effect refers to situations in which individuals persist with a nonoptimal course of action because of an initial investment. This is considered to be an error (hence, *sunk-cost error*) because normative decision-making rules prescribe considering only future costs and benefits and disregarding past investments. Sunk-cost errors are thus decidedly nonoptimal; examples include businesses that continue to develop a product even after changes in the market make profits very unlikely (Garland, 1990), professional teams that continue to field ineffective players whom they paid large sums of money to acquire (Straw & Hoang, 1995), and doctors who persist with an ineffective treatment due to prior investment in that course of action (Bornstein, Embler, & Chapman, 1999).

Until recently, most of the research on sunk-cost errors has been conducted with human subjects using questionnaire methods (e.g. Arkes & Blumer, 1985; Garland, 1990). Over the past several years, however, attention has focused on cross-species generality of the sunk-cost error, with the results of several studies showing clear evidence of sunk cost effects in rats and pigeons (Avila, Gonzalez-Montiel, Miranda- Hernandez, & Guzman-Gonzalez, 2010; De la Piedad, Field, & Rachlin, 2006; Macaskill & Hackenberg, 2012a,b; Magalhães, White, Stewart, Beeby, & van der Vliet, 2012; Navarro & Fantino, 2005; Pattison, Zentall, & Watanabe, 2011).

Cross-species analyses are important in a causal analysis of sunk cost phenomena. Human sunk-cost errors are often thought to reflect the misapplication of rules (e.g., “waste not, want not”) that encourage persistence even when it is counterproductive (e.g. Arkes & Ayton, 1999). Showing that animals other than humans are capable of such suboptimal choice patterns suggests that sunk cost decisions are not limited to humans and faulty rules. Such cross-species analyses are also helpful in revealing what, if any, aspects of the phenomenon are unique to humans.

Useful in cross-species analyses are procedures that can be adapted for use in more than one species. A two-alternative choice procedure originally developed by Navarro and Fantino (2005) has been the most popular laboratory preparation. In this task, responses on one

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alternative produce reinforcers according to a modified mixed-ratio schedule. On that alternative, during each condition, several (typically, four) fixed ratio (FR) values are possible, and the probability with which each occurs is fixed within a condition. A second (escape) response alternative cancels the current FR and draws a new FR value according to the probabilities assigned to the current condition. Subjects thus make repeated decisions between persistence (completing the FR schedule on that trial) and escape (terminating the current FR and initiating a new trial and potentially smaller FR). Persistence is considered a sunk-cost error under conditions when escaping would produce a more favorable outcome (i.e., a smaller mean response requirement).

The present study used Navarro and Fantino's (2005) procedure to explore decisions about persistence in a series of laboratory-based decision-making tasks with human subjects. The main objective was to further the cross-species analysis of sunk cost decision making by including humans. To date, only three data sets have been published with human subjects on this procedure (Avila, Yankelevitz, Gonzalez & Hackenberg, in press; Navarro & Fantino, 2005, Experiment 4; Navarro & Fantino, 2007); the current study built on these by exploring additional contingency arrangements, and an additional reinforcer type. The subjects in all prior research with humans earned either real or hypothetical money, while the present study used brief video clips from a preferred TV program as reinforcers. Unlike point/money reinforcers, which are accumulated during a session and exchanged after the session, video reinforcers can be presented each trial, immediately contingent on the behavior that produces them. Therefore, subjects repeatedly experience the outcomes of choices within the experimental session. This may make video reinforcers more analogous to the food reinforcers used with nonhuman animals. Several studies have demonstrated the usefulness of video reinforcers in procedures with humans designed to be analogous with those used with other animals (Andrade & Hackenberg, 2012; Hackenberg & Pietras, 2000; Lagorio & Hackenberg, 2010; Locey, Pietras, & Hackenberg, 2009; Navarick, 1996).

To facilitate cross-species analyses, the present experiments were patterned after a pair of recent studies by Macaskill and Hackenberg (2012a, b), but with humans substituted for pigeons and video clips substituting for food. The studies focused on three main variables—(1) recent behavioral history; (2) discriminative effects of added signals; and (3) the expected value of the two courses of action—each of which will be discussed briefly, as they relate to the present study.

First, regarding history effects, Macaskill and Hackenberg (2012a) found that sunk cost patterns could be overcome by giving pigeons a history with conditions with even higher costs of persistence: The pigeons learned to escape, and continued to do so when the original conditions were reinstated. Experiment 1 in the present series investigated whether a similar experimentally created history would reduce sunk-cost errors in humans. The present experiment also explored history effects in the other direction (i.e., creating a history of reinforcement for persistence in subjects who initially escaped).

Second, regarding discriminative effects, Macaskill and Hackenberg (2012b, Experiment 3) found that pigeons were less likely to make sunk-cost errors when the individual FR schedule components were signaled, a result consistent with prior sunk cost studies (Avila et al., 2010; Navarro & Fantino, 2005). Experiment 2 of the present series investigated whether the addition of stimulus changes would similarly reduce sunk-cost errors in humans, and whether experience with these stimulus changes would produce lasting changes in the frequency of such errors. Such stimulus changes have been shown to reduce sunk-cost errors in humans responding for money (Navarro & Fantino, 2007), but the effect has been smaller and less consistent for humans than for pigeons.

Third, regarding sensitivity to overall cost/benefit variables, Macaskill and Hackenberg (2012b) arranged the FRs and their probabilities so that both escape and persistence were optimal during different conditions, and varied the relative costs of optimal and nonoptimal choice patterns. They found that pigeons' choices were sensitive to the ratio of the mean response requirements for persistence and escape, or the overall average cost of making the error. Sunk-cost errors were more likely when the costs were small, and became less likely (more escape) when the costs of persistence were high. Experiments 3 and 4 in the present study explored sensitivity to similar variables with human subjects, seeking to further clarify the major controlling variables in sunk cost decision tasks. Together, these experiments allowed an exploration of the conditions under which humans make the sunk-cost error, and the extent to which they resemble the conditions under which nonhuman animals also make the error.

Experiment 1

Throughout all experiments in this study, subjects made repeated choices between persisting with and escaping from a course of action (completing an FR to produce video clips). The mean number of responses required to produce a video clip if subjects consistently persisted ($R_{persist}$) or escaped (R_{esc}) was varied across conditions and therefore the extent to which one or the other of these patterns was favored by the contingencies also varied. The ratio of R_{esc} to $R_{persist}$ is here used to describe whether persistence or escape is optimal. If $R_{esc}/R_{persist}$ is above 1.0, persistence required fewer responses than escaping. In contrast, if $R_{esc}/R_{persist}$ is below 1.0, then persistence would result in more responses being required and thus persisting is an instance of the sunk-cost error. Note the smaller the ratio the greater the cost of the sunk-cost error.

Experiment 1 investigated whether sunk-cost errors could be reduced by providing humans with a reinforcement history for escaping, an experimental manipulation that Macaskill and Hackenberg (2012a) found reduced the sunk-cost error in pigeons. The effects of this variable were investigated in human subjects across three conditions. To establish a baseline level of persistence, the first condition was a combination of FRs and probabilities that has been shown to produce the sunk-cost error in most subjects (Avila et al., 2010; Macaskill & Hackenberg, 2012a,b; Navarro & Fantino, 2005). An individual subject's level of persistence during Condition 1 then determined the contingencies they experienced during Condition 2. That is, Condition 2 arranged contingencies that favored the less-preferred pattern in Condition 1. Condition 3 was designed to assess any lasting effect of this history created in Condition 2 following an additional change in the contingencies.

Method

Subjects. Subjects were 33 university undergraduates participating in partial fulfillment of a course requirement. No further demographic information was collected.

Apparatus. Subjects completed all experimental tasks alone in a room containing a chair, a desk and a computer with a mouse attached. The keyboard was placed out of reach, and subjects did not use it during the experimental task. The computer was equipped with external speakers with an adjustable volume dial on the front that was accessible to subjects.

Procedure. Subjects began by completing an informed consent form. They were then shown into an experimental room where the following general instructions were presented on the computer screen: *"Thank you for participating! During the time that you are here you will watch three TV program episodes that you choose from a selection that will be presented to you. Each one has been broken up into a series of clips, which will be played in sequence. When you reach the end of an episode, you will be able to choose the next episode that you watch. You can choose the same program more than once- you will be shown the next episode in the season. The way that you respond on the two buttons that will be presented to you changes when you see the next video clip. We are interested in how you make these choices."*

Subjects were then presented with a menu of television programs, consisting of popular television sitcoms. Once the TV program was selected, subjects were presented with the experimental task screen. On this screen were two rectangles: a yellow rectangle on the left (the escape button) and a white rectangle on the right (the video button). Above these were instruction reminders that remained onscreen throughout the task. These read: "*click on the right hand button repeatedly to watch video. Click on the left hand button to quit this trial and try a new one.*" There was also a counter on the top right hand corner of the screen that displayed the number of video button responses made during the current trial, and therefore incremented whenever a click was made on the video button and was reset to zero following either an escape response or the presentation of a video clip. The escape button remained in the same location on the screen throughout the task; the video button moved to a different location on the screen with every click (although never overlapping the video button or the instructions). This movement was included to slightly increase both the response effort and subjects' attentiveness to the experimental task.

Clicks on the video button produced segments of the video according to a modified mixed-ratio schedule. As shown in Table 1, during each trial, one of four FR values was assigned to the video button with a probability unique to each condition. The trial ended when either this FR had been completed (and a video clip played), or an escape response occurred. Table 1 also presents the $R_{persist}$ and R_{esc} values for each condition. $R_{persist}$ (the mean programmed response requirement for persistence) is the mean FR value weighted by the probability of occurrence. R_{esc} (the mean programmed response requirement for consistent escape after 10 responses, the lowest FR value in each condition) was calculated by determining the total number of trials that would be required, on average, to receive 40 reinforcers entirely from FR10 trials, while escaping from any larger FRs. Therefore, in Conditions E2 and E3, in which the probability of the FR 10 was 0.5, it would take, on average, 80 trials to receive 40 reinforcers. These trials would require 800 responses, plus 40 escape responses for an average of 840/40 or 21 total responses for each reinforcer. Note that subjects could, and often did, escape at other than this optimal juncture and this brought their mean obtained response requirement above R_{esc} (the programmed response requirement for consistent escape) even if they escaped consistently. Conditions in Table 1 are labeled E if escape was the more efficient response pattern or P if persistence was more efficient. Numbers indicate the extent to which conditions favor this strategy in the context of the conditions presented across the current four experiments. The $R_{esc}/R_{persist}$ ratio (final column of Table 1) quantifies the extent to which escape was the optimal course of action. When values exceed 1.0, persistence requires fewer responses than escaping and persistence becomes more inefficient as values fall increasingly below 1.0. Thus, the smaller the ratio the greater the cost of the sunk-cost error.

All subjects completed three conditions during the same visit to the lab, and each condition lasted for 40 reinforcers. As shown in Table 2, three groups of subjects completed different sequences of conditions following the baseline condition (E2). Assignment to the second condition depended on an individual's baseline level of persistence. Specifically, subjects who completed a majority of the final 10 trials (excluding FR 10 trials) during the initial baseline condition were placed in the E3 condition (Groups 1 and 2) because it was expected to reduce this high level of persistence. Conversely, subjects who escaped during condition E2 were moved to condition P2 (Group 3) because it was expected to increase persistence. For the first 12 subjects who initially persisted (Group 1), the third condition was a replication of condition E2. Group 2 allowed a determination of how long lasting would be the new pattern of escape when the contingencies changed to favor persistence in condition P2.

A complete sitcom episode was played during each condition, and the subject selected a new episode before moving to the next condition. (The menu of programs included *Friends*, *Will and Grace*, *Family Guy*, *Wallace and Gromit*, *Sports Bloopers*, *Looney Tunes*, *The Simpsons*, and *Seinfeld*.) Subjects were able to take a break of self-determined length between conditions and to leave the experimental room during this time if they chose to do so. Given that each condition lasted for 40 reinforcers and one episode, each video segment presented was 1/40th the length of the sitcom episode (excluding end credits). Therefore, segments were approximately 34 s each but varied slightly with the length of the episode. When videos were played, the images were presented across the entire screen, and the

Table 1

Conditions in Experiment 1, with the FR values (ratio 1–4), the probability of each occurring on a trial, the resulting $R_{persist}$ and R_{esc} values, and the ratio of these values.

Condition	ratio 1	*p* 1	ratio 2	*p* 2	ratio 3	*p* 3	ratio 4	*p* 4	$R_{persist}$	R_{esc}	$R_{esc}/R_{persist}$
E2	10	0.5	40	0.25	80	0.125	160	0.125	45	21	0.5
E3	10	0.5	160	0.25	320	0.125	640	0.125	165	21	0.1
P2	10	0.0625	40	0.0625	80	0.5	160	0.375	103	175	1.7

Note Conditions labeled E favor escape, and those labeled P favor persistence. The number following this letter indicates the extent to which this strategy is favored (in the context of the conditions presented throughout the current experiments) with higher numbers indicating that the optimal strategy is more strongly favored.

Table 2

Conditions experienced by each group in Experiment 1, and the number of subjects assigned to each group.

Group	First Condition	Second Condition	Third Condition	N
1 (initially persisted)	E2	E3	E2	12
2 (initially persisted)	E2	E3	P2	13
3 (initially escaped)	E2	P2	E2	8

Note See Table 1 for complete condition descriptions.

experimental buttons were no longer visible. The final condition was occasionally terminated before 40 reinforcers were obtained because the entire (three-condition) session had exceeded the 170-min maximum. This occurred for two subjects in Group 1, three in Group 2, and two in Group 3; in all of these instances at least 20 reinforcers had been received in the third condition. Given the length of the experimental sessions, some subjects opted to leave before completing 3 hs of participation, and could do so without explanation. This was the case for one subject in each of the first two groups and no subjects in the third group. Data from subjects electing to leave early are not included in subject numbers or analyses.

Results and Discussion

Following previous studies using this procedure, persistence on this task was defined as completing an FR greater than 10 (the smallest). Figure 1 presents the cumulative number of FRs greater than FR10 completed by each subject (individual lines) as a function of the number of reinforcers obtained so far in the session. The slope of this line indicates the rate at which that subject persisted, with flat slopes indicating no persistence and steeper slopes indicating greater persistence. As Figure 1 indicates, within-subject response patterns

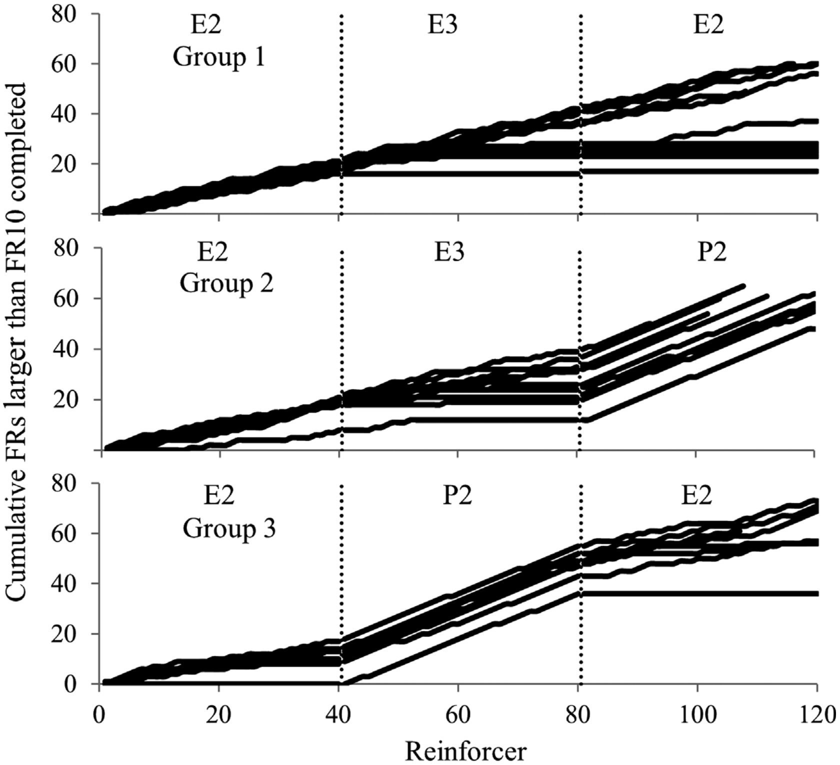

Fig. 1. Cumulative FRs greater than FR10 completed. The slope of the lines indicates the rate at which subjects persisted, with steeper slopes indicating the persistence was more frequent. Vertical dashed lines indicate condition changes. See Table 1 for complete condition descriptions.

were typically stable at the end of each condition, and, when subjects' levels of persistence underwent large changes, this generally occurred soon after changes in the contingencies. Although such changes did not occur for every individual, changes in the contingencies did produce changes in persistence in some subjects. Given that levels of persistence were non-normally distributed, a related-samples Friedman's two-way analysis of variance by rank was used to confirm this effect of condition within each group. There was a significant effect of condition on level of persistence at the end of the condition for all three groups (Group 1: X^2 (2) = 14.0, $p < .05$; Group 2: X^2 (2) = 14.9, $p < .05$; Group 3: X^2 (2) = 8.9, $p < .05$).

Post hoc related-samples Wilcoxon signed-rank tests were used to compare pairs of conditions within each group. Subjects who persisted during the baseline E2 condition showed reduced levels of persistence when moved to condition E3 where it was markedly more advantageous to escape (Group 1: $z = 2.6$, $p < .05$, Group 2: $z = 3.0$, $p < .05$). Condition E3 was the same condition that Macaskill and Hackenberg (2012a) found produced consistent escape in pigeons. More subjects in Group 1 escaped when returned to condition E2 than had during baseline E2. Consistent with this, overall levels of persistence differed significantly between the first and second presentations of condition E2 ($z = 2.7$, $p < .05$) but not between condition E3 and the second presentation of E2 ($z = 0.07$, $p = .46$). This pattern of results indicated that a history of reinforcement for escape produced a lasting reduction in subjects' subsequent likelihood of making sunk-cost errors.

Subjects in Group 2 were more likely to begin persisting when moved to a condition (P2) favoring this response pattern (persistence during P2 differed significantly from E2: $z = 2.0$, $p < .05$ and E3: $z = 3.0$, $p < .05$), indicating that experience with a very high cost for persistence in Condition E3 reduced persistence only when this pattern was favored by the contingencies. The specificity of this effect of reinforcement history was also observed in pigeons. It is also important to consider whether persistence occurs when it is optimal, as persistence is not always an instance of the sunk-cost error (e.g. continuing to study towards a degree even when it is difficult if future salary gains will likely outweigh current costs; Goltz, 1992).

Subjects in Group 3, who had initially escaped when exposed to condition E2, showed an overall increase in persistence when moved to condition P2, which favored this pattern ($z = 2.5$, $p < .05$). Upon return to E2, group levels of persistence were reduced, but not to the level observed during the baseline E2 condition (i.e., persistence during the final E2 condition differed significantly from neither baseline E2: $z = 2.0$, $p = .05$ or P2: $z = 1.2$, $p = .22$), suggesting a combined effect of recent history and the current contingencies. The results from this group indicated that recent reinforcement history can increase the subsequent frequency of nonoptimal response patterns.

Experiment 2

In the current task, when a subject completes the lowest FR requirement arranged in a condition without receiving reinforcement, one of the larger FRs must be in effect on that trial and therefore the mean number of responses to the next reinforcer is higher than it was at the start of the trial. A subject may not discriminate that this increase in mean response requirement has occurred, however. Navarro and Fantino (2005) and Macaskill and Hackenberg (2012b) found that adding stimulus changes correlated with these changes in the mean number of responses to the next reinforcer reduced the frequency of sunk-cost errors in pigeons. These stimulus changes occurred whenever a subject completed any of the FR values in the mixed-ratio array without reinforcement. In both studies the reduction in sunk-cost errors was substantial, and occurred for each pigeon in which nonoptimal persistence had previously occurred. Navarro and Fantino (2007) also found that the addition of such stimulus changes reduced sunk-cost errors in humans making key presses for hypothetical money. The effect of these stimulus changes was weaker and less consistent for humans than it had been for pigeons, however. The first two conditions in Experiment 2 assessed the effects of adding these additional stimuli on the persistence levels of humans responding for video clips, as well as the longer-term effects of any increased sensitivity to the contingencies—a variable not previously assessed with humans.

Method

Subjects. Twenty-two university undergraduates participated in partial fulfillment of a course requirement.

Apparatus. This was the same as in Experiment 1.

Procedure. As shown in Table 3, all subjects began with condition E2, which favored escape ($R_{esc}/R_{persist} = 0.5$). Following this baseline condition, subjects were moved to a condition in which the combination of FRs and probabilities remained identical, but stimulus changes were added (E2S). Note that all subjects included in Experiment 2 initially persisted during baseline; those who initially escaped were routed into Experiment 1 Group 3. The stimulus changes in E2S occurred whenever one of the FR values in the mixed-ratio array was completed without video reinforcement. The video button (initially white) changed to red after 10 responses had been made, then to blue if 40 responses were made, and then to green if 80 responses were made without reinforcement (i.e., the FR160 had been programmed on that trial). To investigate whether any effect of experience with these stimulus changes was enduring, these additional stimuli were removed during a third condition. For the first 11 subjects who participated (Group 1), the contingencies during this third condition favored escape (E2), while for the remaining 11 (Group 2) they favored persistence (P1).

As in Experiment 1, conditions terminated after 40 reinforcers (an entire sitcom episode). One subject did not complete the final condition because the session exceeded the maximum duration.

Results and Discussion

Figure 2 presents the cumulative number of FRs greater than FR 10 completed by condition for each subject (individual lines). The addition of stimulus changes during a condition favoring escape reduced the sunk-cost error in a minority (7 of 23) of subjects. Further confirming the weakness and inconsistency of this effect, repeated-samples Friedman's one-way analysis of variance by ranks indicated that the proportion of the last five FRs greater than FR10 completed differed significantly across condition for Group 1 ($X^2(2) = 6.1$, $p < .05$), but not for Group 2 ($X^2(2) = 1.73$, $p = 0.42$), and that, within Group 1 none of the pair-wise comparisons were significant (1 versus 2: $z = 1.8$, $p = .66$; 1 versus 3: $z = 1.8$, $p = .66$, 2 versus 3: $z = 1.1$, $p = .29$).

Navarro and Fantino (2007) compared the effects of stimulus changes between subjects—one group of which received stimulus changes and one of which did not. Fewer people persisted in the stimulus changes present group (28% completed more than half the FRs greater than the smallest) than in the stimulus changes absent group (56% completed more than half of the FRs greater than the smallest). Thus, while the added stimuli reduced the sunk-cost error in humans, the effects were generally weaker and less consistent than for pigeons exposed to similar conditions, as they were in the current experiment.

One possible explanation for this cross-species difference in the effect of these stimulus changes is exposure time. Pigeons in both previous studies experienced these added stimuli for many sessions, while humans had only experienced them for one or two sessions. Macaskill and Hackenberg (2012b) speculated that the schedule-correlated stimuli had become aversive because they had been repeatedly paired with a high work requirement; the immediate consequence of escape was to terminate these stimuli. One result consistent with this account is that pigeons escaped more frequently during conditions favoring persistence when such stimuli were present and terminated by escape. In experiments with humans to date, these stimuli may not have been paired with high work requirements on a sufficient number of occasions for them to become conditioned aversive stimuli and for their removal to therefore maintain escape responses.

Another potential explanation for the relatively weak effects of stimulus changes in the present study is that humans engage in collateral

Table 3

The sequence of conditions presented to each group in Experiment 2.

Group	First Condition	Second Condition	Third Condition	N
1	E2	E2S	E2	11
2	E2	E2S	P1	11

Note See Table 1 for complete condition descriptions. 'S' following the condition name indicates that stimulus changes were present during that condition.

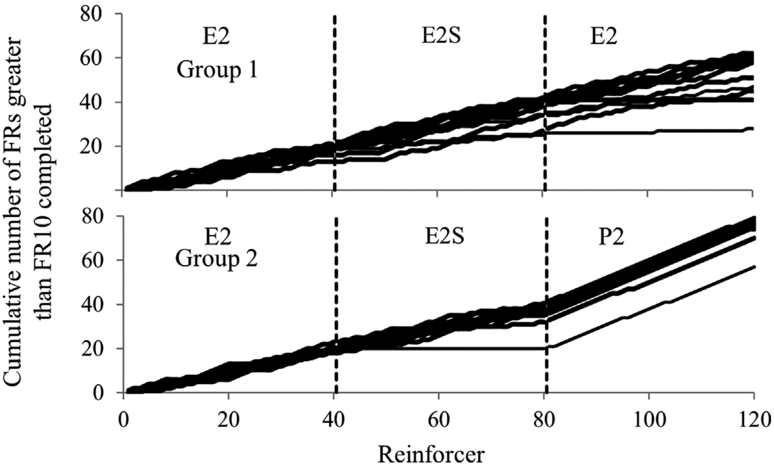

Fig. 2. Cumulative FRs greater than FR10 completed by subjects in Experiment 2. The slope of the lines indicates the rate at which subjects persisted, with higher slopes indicating that persistence was more frequent. Vertical dashed lines indicate condition changes. See Tables 1 and 3 for complete condition descriptions.

behavior, such as counting, that serves discriminative functions, thereby reducing the impact of the programmed stimulus changes. This account could be tested in future research by arranging contingencies that act to disrupt the collateral behavior (e.g., counting backwards or other tasks which engage ongoing verbal behavior).

Experiment 3

Macaskill and Hackenberg (2012b) found that the ratio of the expected response requirement for persistence to that for escape ($R_{esc}/R_{persist}$) was a key determinant of pigeons' levels of persistence. The current Experiment 3 investigated whether altering this feature of the contingencies produced similar changes in levels of persistence in humans responding for video clips. To provide a history similar to that of Macaskill and Hackenberg's (2012b) pigeons, subjects were first exposed to Condition E3 (also presented during Experiment 1), where escape was the far more efficient pattern of response. This was followed by two other conditions: one favoring persistence, and the other favoring escape. The extent to which each of these latter two conditions favored this optimal strategy (i.e., $R_{esc}/R_{persist}$) was varied across groups; conditions were selected to allow for comparison with the earlier pigeon study, and because they produced a range of levels of persistence.

Method

Subjects. Thirty-seven undergraduate university students participated in partial fulfillment of a course requirement.

Apparatus. The same apparatus was used in Experiment 3 as for previous experiments.

Procedure. The general features of the task were as for Experiments 1 and 2. Subjects were divided into three groups, each completing three of the conditions shown in Table 4. For all subjects, the first condition completed was E3, a condition in which $R_{esc}/R_{persist}$ was 0.1 and, therefore, the mean response requirement for persistence was 10 times the mean response requirement for escape. Subjects then completed one condition in which the contingencies favored persistence and another in which they favored escape, but the extent to which the optimal strategy was favored varied by group.

Table 5 shows which of these conditions were presented to each group, and the number of subjects included in each group. As in previous experiments, Conditions 1 and 2 always ended after 40 reinforcers had been presented. Condition 3 typically also ended after 40 reinforcers, but for seven subjects in Group 1, two subjects in Group 2, and two subjects in

Table 4

Conditions presented during Experiment 3: the FRs present and the probability with which they occurred, and the resulting $R_{persist}$ and R_{esc} values and their ratio.

Condition	ratio 1	p 1	ratio 2	p 2	ratio 3	p 3	ratio 4	p 4	$R_{persist}$	R_{esc}	$R_{esc}/R_{persist}$
E3	10	*0.5*	160	*0.25*	320	*0.125*	640	*0.125*	165	21	0.1
P2	10	0.0625	40	0.0625	80	0.5	160	0.375	103.1	175	1.7
E1	10	0.35	34	0.3	70	0.125	100	0.225	45.0	30.4	0.7
P1	10	0.25	33	0.25	40	0.25	80	0.25	40.8	43.0	1.1
E2	10	0.5	40	0.25	80	0.125	160	0.125	45.0	21.0	0.5
P3	10	0.06	50	0.2	70	0.25	100	0.49	77.1	182.3	2.4
E2a	10	0.25	40	0.25	120	0.25	160	0.25	82.5	43.0	0.5

Group 3 it was terminated based on the previously-described time criterion.

Results and Discussion

Figure 3 presents the mean proportion persistence as a function of $R_{esc}/R_{persist}$ for each individual and for each group. On these graphs, conditions plotted to the left of the *y*-axes favor escape, and those to the right of the *y*-axes favor persistence. Instances of the sunk-cost error therefore appear as points to the left of the *y*-axis, but above zero. The likelihood of sunk-cost errors varied systematically with $R_{esc}/R_{persist}$, and errors occurred most frequently when the cost was relatively low. These are also likely the conditions during which the optimal response path is most difficult to discriminate.

Data points below 1.0 to the right of the *y*-axis illustrate that subjects also made the reverse sunk-cost error by failing to persist exclusively when it was optimal to do so. This occurred more frequently than has been observed with pigeons in similar conditions. Related-samples Friedman's two-way analysis of variance by ranks confirmed that varying $R_{esc}/R_{persist}$ produced changes in the average number of the last five FRs greater than FR10 completed for all three groups (Group 1: $X^2(2) = 26.1, p < .05$; Group 2: $X^2\ (2) = 9.8$, $p < .05$; Group 3: $X^2\ (2) = 15.0$, $p < .05$). Post-hoc related-samples Wilcoxon signed ranks tests confirmed that all pairs of conditions within each group differed significantly from each other, with the exception of conditions E2 and E3 in Group 2.

Table 5

Groups in Experiment 3, the sequence in which they experienced conditions and the number of subjects assigned to each group.

Group	First Condition	Second Condition	Third Condition	N
1	E3	P2	E1	17
2	E3	P1	E2	11
3	E3	P3	E2a	9

Note See Table 3 for complete condition descriptions.

Experiment 1 demonstrated that a history of differential reinforcement for persistence is an important contributor to the sunk-cost error. The present experiment showed that behavior is also sensitive to the current contingencies. Most subjects completely avoided the sunk-cost error during the first condition (condition E3) when it was strongly disadvantageous to make the error, but did so to some extent during conditions when the inefficiency of persistence was reduced. Both patterns have also been observed with pigeons (Macaskill & Hackenberg, 2012a, Experiment 2; Macaskill & Hackenberg, 2012b, Experiment 1). This is also consistent with the results of a study reported by Avila et al. (in press). They found that when humans were responding for points later exchangeable for money, sunk-cost errors were most likely in conditions in which the cost of this error was low. In the Avila et al. study, conditions continued until levels of persistence stabilized as is typically done in studies with nonhuman animals.

Experiment 4

Macaskill and Hackenberg (2012b) found that the variable most strongly related to whether pigeons persisted was $R_{esc}/R_{persist}$. Results of E3 are consistent with this as a crucial variable for humans also. This conclusion is rendered tentative, however, by the fact that other variables (e.g., the exact FRs, local

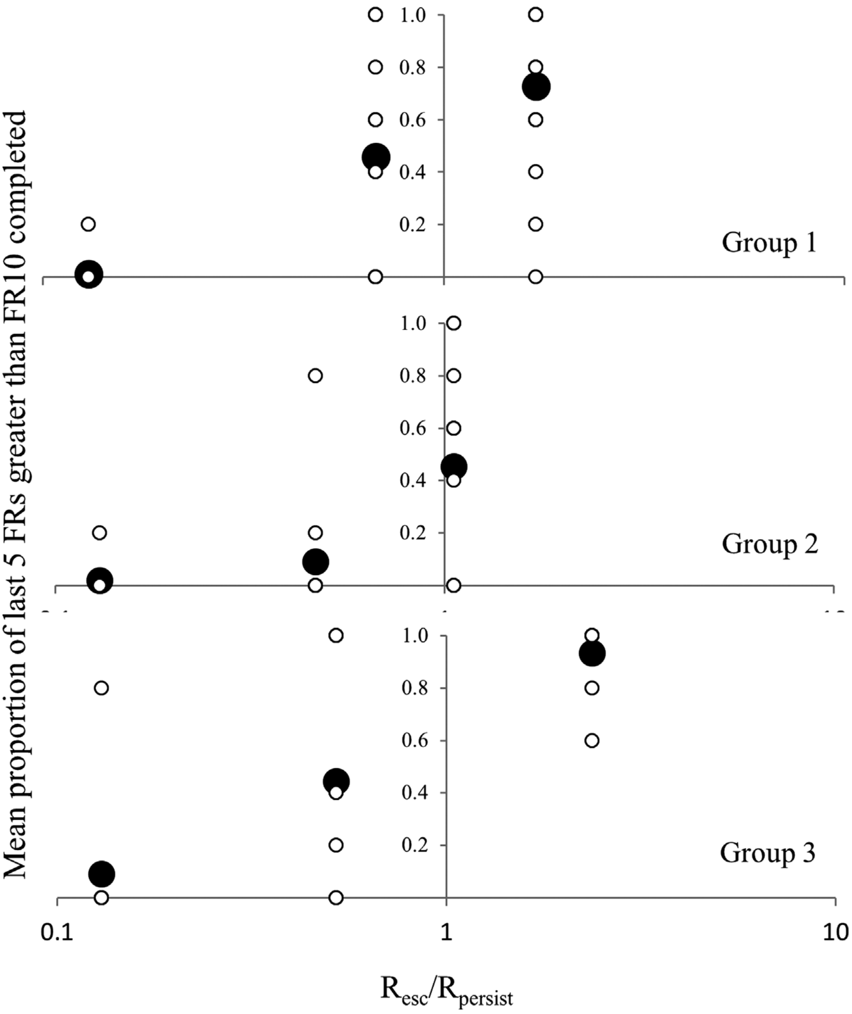

Fig. 3. Proportion of last five FRs greater than FR10 completed, by group as a function of $R_{esc}/R_{persist}$. Larger closed points are group means, smaller, open points are individual means. Conditions to the left of the *y*-axes are those that favor escape and those to the right are those that favor persistence. Note the logged *x*-axes.

response requirements for persistence and escape, likelihood of the smallest FR being programmed on the next trial) also varied across conditions. In order to rule out these variables as alternative explanations for the changes in levels of persistence observed in Experiment 3, these variables were varied in Experiment 4 while $R_{esc}/R_{persist}$ was held constant (a similar approach to that taken by Macaskill & Hackenberg). Two groups of subjects were presented with conditions with identical $R_{esc}/R_{persist}$ values, but different FRs. If persistence varied across these conditions to the extent it had in Experiment 3, while $R_{esc}/R_{persist}$ was held constant, it would implicate another variable such as the local-level response requirements to the next reinforcer for persistence and escape. Conversely, similar levels of persistence across groups would, in combination with the results of Experiment 3, support the $R_{esc}/R_{persist}$ ratio as an important controlling variable for humans as it was for pigeons.

Method

Subjects. Twenty undergraduate university students participated in partial fulfillment of a course requirement.

Apparatus. The apparatus used was as for the preceding studies.

Procedure. The general task presented to subjects was the same as that used in Experiments 1–3. The combinations of FRs and their probabilities varied, however. These ratios and probabilities, along with the corresponding $R_{persist}$ and R_{esc} values are presented in Table 6, , and the sequence with which each group experienced these conditions is presented in Table 7.

Table 7

Groups in Experiment 2, and the sequence in which they experienced conditions.

Group	First Condition	Second Condition	Third Condition	N
1	E3	P2a	E1	10
2	E3	P2	E1a	10

Note See Table 6 for complete condition descriptions.

Each of the two groups completed condition E3 first. All subjects then completed a condition in which $R_{esc}/R_{persist}$ was 1.7 followed by one in which $R_{esc}/R_{persist}$ was 0.7. The FR values and the probability with which they occurred varied across the two groups, however. Conditions with these $R_{esc}/R_{persist}$ values were also presented to a group of subjects in Experiment 3, providing an additional point of comparison. As in the preceding experiments, Conditions 1 and 2 lasted for 40 reinforcers for each subject. Condition 3 typically also lasted for 40 reinforcers, but for seven subjects in Group 2 Condition 3 terminated because the session time limit had been reached.

Results and Discussion

Figure 4 shows, separated by condition, the mean proportion of the final five trials in which the FR completed was greater than FR 10. Data from Group 1 in Experiment 3 are plotted with data from the present experiment to facilitate comparison. As it had during Experiments 1 and 3, presenting a condition in which $R_{esc}/R_{persist}$ was 0.1 (i.e., response requirement for persistence was 10 times that for escape) established consistent escape in almost every subject. This confirmed that a sufficiently high cost of sunk-cost errors substantially reduced the likelihood of such errors. For subjects in the two groups in Experiment 4, and the one group in Experiment 3, who experienced conditions in which $R_{esc}/R_{persist}$ was 0.7 and 1.7, levels of persistence were similar. This similarity in levels of persistence occurred in spite of differences in the FRs presented and the probability with which they occurred. An independent-samples Kruskal-Wallis test found no effect of combination of FRs and probabilities (i.e. group) on the proportion of the last five FRs greater than FR10 that subjects completed for either the conditions where $R_{esc}/R_{persist}$ was 1.7 (X^2 (2) $= 0.94$, $p = .95$) or the conditions where it was 0.7(X^2 (2) $= 2.3$, $p = .32$). While null effects must be treated with caution, we found no support for other features of the contingencies as important determinants of performance in a sunk-cost task.

Instead, we found that changes to the $R_{esc}/R_{persist}$ ratio produced systematic changes in the number of individuals who persisted, as it had in Experiment 3. Related-samples Friedman's two-way analysis of variance by ranks confirmed that there was a significant effect of $R_{esc}/R_{persist}$ persistence (X^2 (2) $= 50.06$, $p < .05$). Post-hoc related-samples Wilcoxon signed ranks test confirmed that there were significant differences in persistence between all three pairs of $R_{esc}/R_{persist}$ values (0.1 vs. 1.7: $z = 4.9$, $p < .05$; 0.1 vs. 0.7: $z = 3.8$, $p < .05$; 0.7 vs. 1.7: $z = 4.2$, $p < .05$). This pattern of findings, which implicates $R_{esc}/$

Table 6

The FRs and the probabilities with which they occurred during each condition in Experiment 4.

Condition	ratio 1	p 1	ratio 2	p 2	ratio 3	p 3	ratio 4	p 4	$R_{persist}$	R_{esc}	$R_{esc}/R_{persist}$
E3	10	*0.5*	160	*0.25*	320	*0.125*	640	*0.125*	165	21	0.1
P2a	10	0.25	21	0.25	30	0.25	41	0.25	25.5	43	1.7
E1	10	0.35	34	0.3	70	0.125	100	0.225	45.0	30.4	0.7
P2	10	0.0625	40	0.0625	80	0.5	160	0.375	103.1	175	1.7
E1a	10	0.1	109	0.35	152	0.35	266	0.3	161.3	109	0.7

Note The final three columns present the mean response requirement for persistence ($R_{persist}$), and escape (R_{esc}), and their ratios.

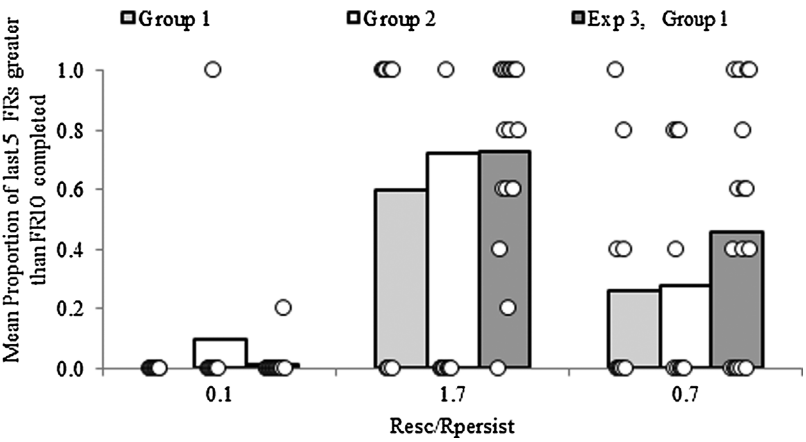

Fig. 4. Mean proportion of last 5 FRs greater than 10 completed by group and $R_{esc}/R_{persist}$. Bars are group means, points are individual subjects (points are offset slightly for visibility).

$R_{persist}$ as an important controlling variable, is broadly consistent with prior results with pigeons (Macaskill & Hackenberg, 2012b).

The high degree of variability, both within and between subjects, however, urges caution in interpretation of the between-subject effects. This variability may reflect in part the relatively brief exposure to the contingencies experienced by our subjects. When performances are studied over time and are allowed to stabilize, the $R_{esc}/R_{persist}$ ratio exerts strong control in sunk-cost tasks with humans (Avila et al., in press), much as it does with pigeons. Such findings lend strong support to the cross-species generality of sunk-cost effects.

General Discussion

The current study was designed to explore with human subjects variables previously shown to reduce sunk-cost errors in pigeons. Experiment 1 examined a history of markedly differential reinforcement for escape on the likelihood of sunk-cost errors. This history enhanced sensitivity to the contingencies, as it had in prior studies with pigeons, even after the conditions were removed (i.e., when conditions that had produced sunk-cost errors were reinstated). Experiment 2 examined the addition of stimulus changes at critical junctures in the FR run on the likelihood of sunk-cost errors. Such stimulus changes produced small changes in the frequency of sunk-cost errors for some subjects. The results mirrored previous findings with humans (Navarro & Fantino, 2007) but were both weaker and less consistent than previously found with pigeons (Macaskill & Hackenberg, 2012b; Navarro & Fantino, 2005). Experiments 3 and 4 examined the impact of additional features of the contingencies, including the ratio of global response requirements associated with the two choice patterns ($R_{esc/Rpersist}$), the feature most directly related to pigeons' choices in prior research. The important role served by this variable suggests that choices in both humans and pigeons are sensitive to global response requirements (as opposed to more local features of the contingencies), and to relative rather than absolute differences in these response requirements.

Despite clear and systematic effects, there was also substantial between-subject variability in decision-making patterns. Similar levels of variability have been observed in previous investigations of sunk-cost decision making with humans. Navarro and Fantino (2005) found that, although persistence was the modal response pattern of humans responding for money, a minority escaped in both of the conditions they presented. This was also the case for the pigeons completing both of Navarro and Fantino's (2007) conditions (stimulus changes present, and stimulus changes absent). Similarly, previous studies using questionnaire methods have reported between-subject variability in sunk-cost effects. For example, in one of the seminal and most frequently cited papers in the sunk-cost literature, Arkes and Blumer

(1985) found that only 54% of subjects committed the sunk-cost error, choosing a hypothetical ski trip characterized as less enjoyable but which had cost more than a more enjoyable but less expensive trip.

Perhaps some of this between-subject variability is related to subjects' preexperimental histories in situations involving persistence. The results from Experiment 1 point strongly to historical variables, specifically, history of differential reinforcement for escape, as a possible contributor to between-subject variability in sunk-cost decisions. Perhaps the subset of subjects who avoided sunk-cost errors had a preexisting history of reinforcement for escaping counterproductive contingencies—a history lacking in the other subjects.

Another potential source of variability arising from preexperimental histories is the relative reinforcing efficacy of TV viewing. The functional control by the contingencies, and the extremely low dropout rates, suggests that the videos functioned as effective reinforcers—consistent with prior results (Andrade & Hackenberg, 2012; Lagorio & Hackenberg, 2010; Locey et al., 2009; Navarick, 1996). Even so, there are likely large individual differences in the relative reinforcing efficacy of videos, and these differences perhaps contributed to variability seen in the present procedures. Little is also known about the functional characteristics of video reinforcers (e.g., range of effective durations, satiation effects, availability of alternative reinforcers). Future research could investigate more systematically the conditions under which video clips function as effective reinforcers for human subjects.

Future research might also explore more systematically the roles of uncertainty, or discriminability, on sunk-cost performance. The results of Macaskill and Hackenberg (2012a) with pigeons are consistent with the idea that sunk-cost errors occur more frequently under conditions in which this optimal escape point is a larger FR, and therefore more difficult to discriminate. Perhaps relatedly, a finding in the more traditional sunk-cost literature with humans is that persistence increases with amount of investment (e.g. Staw, 1981). An important priority for future research should be on the effects of investment per se, apart from other potential controlling variables (including, crucially, the discriminability of the optimal escape point). While challenging from a methodological standpoint, the present procedures, with their ability to disentangle control by overlapping variables, are well suited to a systematic analysis of the contingencies operating in sunk-cost procedures.

Another important topic for future research concerns the impact of rules—either self-created or external—in sunk-cost persistence. Prior research using questionnaire measures has found that instructions about the contingencies can reduce sunk-cost errors in some circumstances. For example, Tan and Yates (1995) found that providing specific instructions about avoiding sunk-cost errors in the situation at hand was more effective than providing general instructions about disregarding past investment when making decisions. As Pattison, Zentall, and Watanabe (2011) note, investigating the effects of additional stimuli, such as rules that disambiguate the choice context, has relevance outside the laboratory, as humans typically lack information about the consequences of persistence and escape when making everyday decisions. Moreover, some important decisions about whether to persist with, for example, a given career path are made so infrequently that direct experience with the relevant contingencies may be less relevant than rule-following repertoires. Arkes and Hutzel (2000) found that people who committed sunk-cost errors also tended to over-estimate the probability that their current course of action would be successful. Therefore, providing complete and accurate descriptions of the contingencies may reduce sunk-cost errors by correcting this over-estimation.

While research along these lines points to some conditions under which sunk-cost decision-making errors can be reduced via the introduction of effective rules, other research has shown the opposite; that is, rules giving rise to suboptimal decision making. For example, Hackenberg and Joker (1994) found that instructions interfered with optimal decision making in a persistence-based task with conflicting short-term and longer-term consequences: Subjects followed initially accurate instructions long after they became counterproductive, showing that faulty rules can override sensitivity to contingencies. Although the task did not involve sunk costs per se, the results of the study demonstrate a potentially useful set of procedures for investigating the interaction of verbally-governed and contingency-governed patterns in sunk-cost decision making.

In conclusion, the current series of experiments demonstrated that humans commit sunk- cost errors in a laboratory decision-making task. The present procedures aimed to approximate as closely as possible the procedures used in recent animal models of sunk-cost decision making. Such studies serve an important function in cross-species comparisons, helping to "close the loop" from (a) an initially human phenomenon, to (b) an animal model of the phenomenon, and back to (c) humans, using the procedures developed in the animal model—what Silberberg and colleagues term an "up-linkage" study (Hachiga, Silberberg, Parker, & Sakagami, 2009; Silberberg et al., 2008; Smith & Silberberg, 2010). Unless the original behavior can be reproduced in humans using procedures modeled after the animal models, the validity of the animal model—the degree to which it functionally captures human sunk-cost decisions—is brought into serious question. The current experiments, and others to date, confirmed that humans often persist on this task even when it produces adverse consequences for them, supporting the idea that it captures essential features of the sunk-cost phenomenon. That the present results were largely consistent with recent findings with other animals endorses the use of this laboratory model as a methodologically sound approach to studying sunk-cost decision making across a range of species. A clearer picture of the similarities across species will also help reveal the parts of the phenomenon that are unique to humans (e.g., verbal and rule-governed behavior), pointing the way to future research with humans.

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