Suboptimal choice in nonhuman animals: Rats commit the sunk cost error

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Abstract The present experiments investigated the sunk cost error, an apparently irrational tendency to persist with an initial investment, in rats. This issue is of interest because some have argued that nonhuman animals do not commit this error. Two or three fixed-ratio (FR) response requirements were arranged on one lever, and an escape option was arranged on a second lever. The FRs were of different sizes, and escaping was the behavior of interest. Several variables that might influence the decision to persist versus escape were manipulated: the number of trials with different FR schedules in an experimental session (Exps. 1 and 2), effort to escape (Exp. 2), and the size of the larger FR (Exp. 3). The sunk cost error would result in never escaping, and the optimal strategy would be to escape from the larger FR. The main variable that determined persisting versus escaping was the size of the large FR. Rats that escaped from the large FR—apparently optimal behavior—did so at a suboptimal point, and hence committed the sunk cost error.

Keywords Sunk cost · Concorde fallacy · Decision making · Suboptimal choice · Persistence · Rats

Frequently, humans choose between continuing one course of action or abandoning it to pursue a new one. In general, theories of choice and decision making assume that choice is determined by future costs and benefits. Ignoring irrecoverable or sunk costs already incurred is therefore

the optimal course of action. If prior investments determine a current choice, the behavior is seen as irrational, and the sunk cost error is committed (Arkes & Blumer, 1985).

The sunk cost error has been frequently demonstrated in studies of human decision making. Most of these have been paper-and-pencil studies and used hypothetical scenarios to evaluate choice (Arkes, 1996; Arkes & Blumer, 1985; Arkes & Hutzler, 2000). Usually, each participant read one scenario describing a dilemma between persisting in the original option (high monetary investment, but less preferred) versus switching to a new alternative (low monetary investment, but more preferred), as in the scenario presented below:

Assume that you have spent \$100 on a ticket for a weekend ski trip to Michigan. Several weeks later, you buy a \$50 ticket for a weekend ski trip to Wisconsin. You think you will enjoy the Wisconsin ski trip more than the Michigan ski trip. As you are putting your just-purchased Wisconsin ski trip ticket in your wallet, you notice that the Michigan ski trip and the Wisconsin ski trip are for the same weekend! It's too late to sell either ticket, and you cannot return either one. You must use one ticket and not the other. Which ski trip will you go on? (Arkes & Blumer, 1985, p. 126)

Because rationality tells us that only future costs and benefits should guide choice, *all* participants are expected to choose the alternative that is more preferred—the Wisconsin ski trip—instead of the one for which a higher investment has already been made—the Michigan ski trip—(Arkes & Blumer, 1985). In many of these studies, as many as half of the participants choose to stay with their initial option, in which more money has been spent, rather than choosing the preferred option. In more recent investigations, actual

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behavioral investments have been used to study the sunk cost error (Cunha & Caldieraro, 2009; Navarro & Fantino, 2008, 2009). In these studies, participants had to complete a task such as rating “electronic gadgets” and to select one on the basis of those ratings; however, before their final choice, a new product with a better rating was introduced. At this point, the participants had to choose between their initial option (for which they had incurred effort) and the new option (which had a better rating). When the difference between the initial choice and the new product was small, participants were more likely to stay with their initial option, and hence to commit the sunk cost error.

Not only humans, however, have to make choices between persisting in one course of action or abandoning it and switching to a new one. Nonhuman animals face similar everyday choices, such as to continue to forage for prey in one patch or to search for a new one. Hence, a question of interest is whether nonhumans also commit the error of continuing to invest in an option because of prior investments in that option. This question was first addressed in the context of parental investment (Trivers, 1972). The dilemma of parental investment is that at any given point during the breeding season, parents have to make a decision between continuing to raise the current offspring versus deserting it. According to Trivers, in the case of desertion, parents who have invested most in the offspring will be the least likely to desert. Dawkins and Carlisle (1976) have argued that such behavior is fallacious, naming it the Concorde fallacy. Prior investments in the offspring should only be regarded as an indicator of how much will be necessary to invest in the future in order to raise it (see also Boucher, 1977). Maximizing future returns (in terms of reproductive success) and not prior investment should determine parental decisions.

Many studies have attempted to address this question (e.g., Coleman, Gross, & Sargent, 1985; Maestripieri & Alleva, 1991; Weatherhead, 1979), but as Arkes and Ayton (1999) stressed, in most of them there is no clear-cut evidence for the phenomenon. In fact, in most studies, both a past-investment interpretation and a future-benefits interpretation could equally well account for the results. In addition, they argued that humans are more prone to commit this logical error than nonhumans. Arkes and Ayton suggested that humans’ ability to generate rules about their environment and their tendency to generalize those rules may sometimes be disadvantageous and may make humans less sensitive to changes in the environment—namely, in the conditions for reward. According to Arkes and Ayton (see also Arkes, 1996), the rule “Don’t waste” and its overgeneralization may be responsible for people committing the sunk cost error. In contrast, unlike humans, nonhumans are less likely to generate and generalize such rules, making them more sensitive to the contingencies of reinforcement, and hence

less likely to commit the sunk cost error. For example, pigeons are more sensitive to the contingencies of reinforcement and less likely to commit this sort of logical error, and they behave optimally in situations in which they have to attend to the base rates (Hartl & Fantino, 1996) or estimate relative probabilities in a pigeon analogue of the Monty Hall dilemma (Herbranson & Schroeder, 2010).

A laboratory study of the sunk cost error in nonhumans using reinforcement schedules was first reported by Navarro and Fantino (2005). Fixed-ratio (FR) schedules of reinforcement were arranged on one key (food key), and a response on a second key could abort the trial and start a new trial (escape key). On each trial, one of four different schedules could be randomly selected, with a higher probability of trials with the smallest schedule. The FR arranged on a trial was not differentially signaled; the color of the response key was the same for all trials (technically, a mixed-ratio schedule). The optimal strategy would be for the pigeons to escape from the trial once the number of responses exceeded the smallest FR value. All birds but one failed to behave optimally and persisted in every trial. That is, the persistent birds never pecked the escape key. In a second experiment, using a similar procedure, two conditions were arranged. In one, escaping was the optimal behavior, whereas in the other, persisting was the optimal behavior. This was achieved by changing the probabilities of trials with each FR. All birds behaved optimally by escaping from the large FR when that was the optimal behavior, and by persisting in all trials in the condition in which not escaping was the optimal choice.

Ávila-Santibañez, González-Montiel, Miranda-Hernández, and Guzman-González (2010) further explored the idea of *optimal persistence* versus *optimal escaping*. In their experiment, the probabilities of trials with each FR were varied systematically. Decreasing the probability of the small FR on the next trial decreased the likelihood of escape and increased persistence.

The general purpose of the present experiments was to investigate whether rats would persist in a suboptimal alternative and commit the sunk cost error. In the context of the present study, *optimality* refers to maximizing gains and minimizing losses. That is, animals should obtain as many rewards as they can with minimal effort. The procedure employed here was similar to the basic procedure developed by Navarro and Fantino (2005). On each trial, responses on a food lever resulted in reward, according to different FR schedules, and a response on the escape lever could terminate the current trial and start a new one. The different FR schedules were randomly selected across trials and were not differentially signaled. In the present Experiment 1, three FR schedules were arranged on the food lever, and a single leverpress on the escape lever was necessary to terminate the current trial and start a new one.

Experiment 1

In Experiment 1, three FR schedules were arranged on the food lever—FR 5, FR 20, and FR 50—and each session contained more trials with the smaller FRs—45, 10, and 5 trials, respectively. Because of this characteristic of the procedure, completing an FR other than the FR 5 was suboptimal, because this would increase considerably the number of responses per reinforcer obtained. We could calculate the mean number of responses per reinforcer for any given trial by multiplying each FR by its corresponding probability of occurrence and summing the values obtained. If the rats always persisted, the average number of responses per reinforcer would be 11.25. However, after the fifth nonreinforced response, the mean number of responses to the next reinforcer would increase to 25, because the FR value on that trial would be 20 or 50 with respective probabilities of .17 and .08. If the rats always escaped immediately after performing the number of responses corresponding to the smallest FR, the effort per reinforcer obtained would be lower—7 responses per reinforcer. This measure was calculated by dividing the total number of responses performed in a session—including the escape response—by the number of trials with the small FR. Therefore, persisting in the larger-FR schedules was a suboptimal strategy.

Method

Subjects A group of 14 Long-Evans rats, about 18 months of age at the beginning of the experiment, were housed in an enriched environment in group cages containing 4 or 5 rats, in a colony room maintained at a constant temperature and humidity on a 12:12 light/dark cycle. The rats were maintained at approximately 85% of their free-feeding body weight and had free access to water in their home cages. All rats had previous experience with pressing left and right levers to obtain condensed-milk reinforcement, followed by one week of preliminary training in the Experiment 1 procedure.

Apparatus Each of 12 identical, custom-built experimental chambers was enclosed in an isolating chamber equipped with a ventilation fan that provided masking noise. The internal dimensions of the chambers were 25 cm wide, 20 cm high, and 23 cm deep. The floor was a metal grid. The intelligence panel on the left wall contained two retractable levers 3.5 cm wide and 1.5 cm high that could extend 1.5 cm into the chamber. These were located 6.75 cm to the right and left of the central reinforcer opening, which was 5.25 cm wide, 6 cm high, and 4 cm deep. The opening was covered by a moveable Plexiglas

flap and provided access to a 0.1-cc dipper dispenser that delivered one part sweetened condensed milk mixed with one part water. A 1.5-cm diameter light was mounted 4 cm directly above each lever and 10 cm above the reinforcer opening. A houselight was centered in the ceiling of the chamber. Events in each experimental chamber were controlled by a personal computer.

Procedure The houselight remained illuminated throughout each session. At the start of each trial, both right and left levers were extended, and the lights above the levers were illuminated with white light. Responses on the right lever were reinforced according to different FR schedules in which completion of a fixed number of responses resulted in 3-s access to diluted sweetened condensed milk (food lever). One FR schedule was in effect on each trial. A single response on the left lever aborted the current trial and started a new one (escape lever). Following a reinforced response on the right lever or an escape response on the left lever, both levers were retracted and the lights above them were turned off. A 1-s intertrial interval (ITI) preceded the start of the next trial. Three FR schedules on the right lever—FR 5, FR 20, and FR 50—were randomly ordered across trials within each session. The FR schedules were not signaled (a mixed schedule of reinforcement). There were 60 trials per session, with 45, 10, and 5 trials, respectively for the FR 5, FR 20, and FR 50 schedules, in a total of five sessions. In all three experiments in the present article, the significance level was set at $p = .05$.

Results

Two response measures were calculated, based on totals from the last two sessions. First, the probability of escape was calculated by dividing the number of trials with each FR when an escape response was made by the number of opportunities to escape in each type of trial. For example, if a rat made 15 escape responses on FR 5, which was arranged on 45 trials, the probability of escape was $15/45 = .33$. Figure 1 (upper panel) shows that the mean probability of escape increased with increasing FR value. A repeated measures analysis of variance (ANOVA) indicated a significant main effect of FR on the probability of escape, $F(2, 26) = 17.54$, $p < .001$. Newman-Keuls post-hoc comparisons revealed significant differences in the probability of escape between FR 50 and FR 20 ($p < .001$) and FR 50 and FR 5 ($p < .001$). The probabilities of escape on FR 5 and FR 20 trials did not differ, $p = .351$.

The second measure was the mean number of responses on the right lever before the rat made a left-lever escape response. This measure was calculated only for trials on which rats

Fig. 1 Probabilities of escape as a function of the fixed-ratio (FR) requirement (upper panel) and mean numbers of responses on the food lever before making an escape response as a function of the FR requirement (lower panel) in Experiment 1. Error bars indicate standard errors of the means

emitted escape responses, and excluded 1 rat that made no escape responses in any condition. Figure 1 (lower panel) shows that the mean number of responses made before escaping increased with increasing FR value. A repeated measures ANOVA on the data for 13 rats confirmed the significant increase in mean responses made before the escape response with increasing FR value, $F(2, 22) = 11.29, p < .001$.

Discussion

The results of Experiment 1 indicate that when rats are trained with several unsignaled FR schedules on the food lever and have the possibility of aborting the current trial to start a new one by pressing the escape lever, they rapidly adjust their behavior to the contingencies. That is, the probability of rats escaping from the current trial increased with the size of the FR in effect on a particular trial (Fig. 1, upper panel). Escaping from the large FR was an efficient strategy, since the likelihood of a short FR on the next trial was high, and hence the amount of effort per reinforcer earned was lower if rats did escape. Despite the adoption of

this efficient strategy, however, the rats had a tendency to persist. This was because on over half of the FR 50 trials, and on 80 percent of the FR 20 trials on average, the rats completed the trial without escaping. Additionally, in trials with a large FR requirement, more responses were made on the food lever before escaping (Fig. 1, lower panel). Instead of escaping soon after the fifth nonreinforced response on the food lever, they continued to respond further before escaping to start a new trial.

It might seem puzzling that the number of responses before escape increased with the FR, as they were not differentially signaled. However, it should be noted that the larger the FR, the more opportunities to press the food lever. Consider the following: In an FR 20 trial, the number of responses performed on the food lever before an escape response cannot be higher than 19, as the 20th leverpress will be reinforced. In an FR 50 trial, the number of responses on the food lever before an escape response can surpass 20 responses. Because the escape response was made later than 20 responses into some FR 50 trials, it was possible for the mean number of responses on the food lever before an escape response to increase with the size of the FR, despite the fact that the FR values were not differentially signaled.

A potential shortcoming of Experiment 1 was that with relatively few sessions, performance might not have been stable. We found, however, that the rats adapted rapidly to the contingencies and showed consistent patterns of responding over the last three or four sessions. Data analyses were based on responses summed over the last two sessions. An additional analysis in which the means of each of the last two sessions were entered into a repeated measures analysis of variance confirmed the strong effect of FR value. Over the last two sessions, there was a significant overall reduction in the probability of escape (from .35 to .16), $F(1, 13) = 7.37, p < .05$, but the effect of FR remained significant, $F(2, 26) = 17.54, p < .001$, and importantly, there was no interaction between the effect of sessions and FR, $F < 1$. That is, there was a clear effect of FR over the last two sessions. This main result was confirmed in the next two experiments, with an improved design.

Experiment 2

In Experiment 2, we examined two ideas, both related to the assumption that escaping is influenced by its benefits. The first was that a higher likelihood of escape would occur when escaping resulted in a higher probability of a small FR. The possibility that an escape response in Experiment 1 reflected a tendency not to persist with the current FR suggests that future benefits might determine whether the rat escapes. That is, the benefit of an escape response is an

increase in reinforcer probability owing to a high likelihood of an FR 5 schedule on the next trial. This possibility was tested in Experiment 2 by varying the probability of trials with small versus large FR values, using the same FR schedules as in Experiment 1: FR 5, FR 20, and FR 50. In one condition, there were 35 trials with FR 50, 15 with FR 20, and 10 with FR 5. In another, there were 35 trials with FR 5, 15 with FR 20, and 10 trials with FR 50, and in a third there were 20 trials each with the three FR schedules. If future benefit influences the likelihood of escape, a higher probability of returning to an FR 5 trial should result in less persistence on FR 50 trials (see Ávila-Santibañez et al., 2010).

The second idea examined was that increasing the cost of escaping would reduce the overall probability of escape by reducing the immediate benefit. It is known that increasing the ratio required to switch schedules, under concurrent scheduling in one key, will increase the time a pigeon spends in one schedule before it makes a switch response (Findley, 1958). More specifically, White (1979) has shown that switching between concurrent variable-interval schedules in rats becomes less likely when the FR requirement for the switching response is increased. That is, increasing the cost of switching increases persistence in one schedule before a switch response is performed. Thus, we hypothesized that increasing the ratio requirement for an escape response would reduce the overall likelihood of escaping, and hence increase persistence.

Method

A group of 12 Long-Evans rats that had participated in Experiment 1 were housed and maintained as in Experi-

ment 1. Sessions were conducted 7 days per week. The same apparatus and procedure were used as in Experiment 1, with right-lever responses reinforced accordingly to three randomly ordered FR schedules: FR 5, FR 20, and FR 50. Each session lasted for 60 trials. Three conditions were conducted, each with a different number of trials with the different FR values. In the first condition, FR 5, FR 20, and FR 50 schedules were arranged for 10, 15, and 35 trials, respectively. In a second condition, these FR schedules were arranged for 35, 15, and 10 trials, respectively, and for a third condition, the FR schedules were arranged for 20 trials each. These three conditions were conducted with a single response required to escape, and in a further three conditions, with two not necessarily consecutive responses on the left lever required to escape. The escape requirement on the left lever followed a standard FR 2 arrangement. For example, the rats could respond once, switch to the food lever and then return. Each rat experienced each of these six conditions, and different orders of the conditions were counterbalanced over rats. A total of five sessions were conducted in each of the six conditions.

Results

Probability of escape was calculated as in Experiment 1 on the basis of totals from the last two sessions of each condition. Figure 2 (upper row) shows the mean probabilities of escape from each FR with the two escape requirements in the three “HEL” conditions: high likelihood of FR 50 trials (10–15–35), equally occurring FR trials (20–20–20), and low likelihood of FR 50 trials (35–15–10). A $2 \times 3 \times 3$ repeated measures ANOVA with Escape Response Requirement (one

Fig. 2 Probabilities of escape as a function of the fixed-ratio (FR) requirement (upper row) and mean numbers of responses on the food lever before making an escape response as a function of the FR requirement (lower row) across the three conditions in Experiment 2. Filled symbols represent conditions in which the requirement to escape was one response on the escape lever, and open symbols represent conditions in which the requirement to escape was two responses on the escape lever. Error bars indicate standard errors of the means

or two leverpresses), HEL condition (high, equal, or low probability of occurrence of the FR 50), and FR (FR 5, FR 20, and FR 50) as factors revealed significant main effects of escape response requirement, $F(1, 11) = 4.74$, $p = .05$, and FR, $F(2, 22) = 5.60$, $p < .05$. There was no main effect of HEL, $F(2, 22) = 2.15$, $p > .05$. There was, however, a significant interaction between HEL condition and FR, $F(4, 44) = 2.69$, $p < .05$. As in Experiment 1, there was an overall higher probability of escaping with larger FR schedules, but this tendency was attenuated when there were many FR 50 trials (in the 10–15–35 condition). Increasing the requirement to escape from a single response to two responses had the effect of decreasing the probability of escape in all types of trials and across conditions. There were no interactions with escape response requirement.

A separate analysis, in which the probability of escape on each of the last two sessions was entered as a factor in the repeated measures ANOVA, showed no main effect of session and no statistically significant interactions between session and the other variables. That is, performance over the last two sessions in each condition of Experiment 2 could be regarded as being stable.

Figure 2 (lower row) shows that the mean number of responses before escaping increased with increasing FR. In particular, whether FR 5 versus FR 50 schedules were more or less probable, and whether one or two responses were required to escape, had no effect on the mean number of responses made in the FR before an escape response was made. Only trials on which escape responses were made were included in this analysis. These conclusions were confirmed by an ANOVA on the data for conditions with the FR 1 escape response requirement. Data for conditions with the FR 2 escape requirement were not analyzed, owing to the large number of instances (52% of 108 possible cases) in which rats did not escape, and thus created missing values for the analysis. Even for conditions with the FR 1 escape requirement, 4 rats did not escape at all in at least four of their conditions, and their data were not included in the analysis. For the remaining 8 rats, means were substituted for instances of no escapes (missing values), which were 19% of the remaining 72 instances. The resulting, somewhat compromised, ANOVA confirmed the significant effect of FR value, $F(2, 8) = 11.54$, $p < .01$, and the absence of significant effects of the main factor HEL Condition and the interaction between FR and HEL condition, $p > .05$.

Discussion

The results of Experiment 2 confirmed the conclusion from Experiment 1 that rats adjust their behavior to the contingencies in effect on the food lever by increasing

their level of escape with increases in the FR requirement (Fig. 2, upper row). Furthermore, the finding that rats will increase the mean number of responses on the food lever before they escape with increases in the FR requirement was also repeated (Fig. 2, lower row). These findings were corroborated and extended to different experimental conditions from the one used in Experiment 1. Thus, the rats adopted a useful strategy by escaping from the large FR, although they tended to persist on almost 90% of the FR 20 trials and over 75% of the FR 50 trials. As suggested by the significant interaction between HEL and FR value, the tendency to persist was greater when there were more FR 50 trials.

Experiment 2 also showed that increasing the response requirement to escape from the current trial reduced the overall probability of escape but had no effect on the number of responses made on the food lever before escape. This result suggests that the extra effort needed to escape directly increases persistence, by reducing the overall probability of escape.

Similar to Experiment 1, in Experiment 2 there was an overall higher probability of escaping with the large FR schedule. Moreover, there was an interaction between FR and HEL condition; that is, the relative frequency of trials with different FR schedules had an effect on the probability of escape. With more FR 50 trials, there was a higher probability of persisting—leftmost graph on the upper row of Fig. 2—than with fewer FR 50 trials—rightmost graph on the upper row of Fig. 2. The latter result addresses a possible concern that could arise from terminating sessions in the present experiments after a fixed number of trials rather than a fixed number of reinforcers. Specifically, with a fixed number of trials, escaping reduces total reinforcers per session, whereas persistence maximizes reinforcers per session.

Navarro and Fantino (2005) terminated experimental sessions after a fixed number of reinforcers or after a certain amount of time had elapsed, whichever came first. In the present experiments, sessions were terminated after a fixed number of trials so that the random order of FR values across the session could be determined without replacement, thus maintaining an equality between obtained and arranged probabilities of the different FR schedules. It could be argued that this procedure might induce persistence, due to a reduction in the overall number of reinforcers obtained in a session that results from repeated escape responses. However, when more trials of the small FR are available, rats escape more from the large FR, whereas in the condition in which fewer trials of the small FR are available, rats escape less. This strongly suggests that the number of reinforcers that can be earned is not the only influence on behavior, but also the cost at which each reinforcer can be obtained.

Experiment 3

The results of Experiments 1 and 2 suggest that the key variable determining whether a rat persists in responding on a current trial or escapes is the size of the FR. In Experiment 3, the size of the FR was systematically varied over several values in a two-component mixed-ratio schedule, using a procedure similar to those in Experiments 1 and 2, in which three component FR schedules were included. One component was always FR 10, and the other was varied over conditions from FR 10 to FR 100.

Method

A group of 8 Long-Evans rats were housed and maintained as in Experiment 1. Sessions were conducted 7 days per week at approximately the same time each day. The same apparatus and procedure were used as in Experiment 1, but with right-lever responses reinforced according to two randomly ordered FR schedules: FR 10, and another that varied across conditions. All rats had previous experience with a similar procedure but had not participated in Experiments 1 and 2. As in the previous experiments, on each trial, responses on the right lever were reinforced according to an FR schedule, and an escape response on the left lever terminated the trial. Each session lasted for 60 trials. In all conditions, the FR 10 schedule was arranged randomly on 40 trials, and an FR schedule that varied across conditions was arranged on the remaining 20 trials. Values of the varying FR across conditions were 10, 15, 20, 25, 30, 40, 50, 75, and 100. Each of the 13 conditions was conducted for two sessions, with replications of the FR 10, FR 25, FR 50, and FR 75. For 4 rats, the varying FR began with a small value and was first increased and then decreased over the series of 13 conditions, and for the other 4 rats, the varying FR was decreased and then increased over conditions.

Results

Figure 3 (upper panel) shows the probabilities of escape averaged over all rats for both FR 10 and the varying FR as a function of the value of the varying FR in the different conditions. The probability of escape was higher overall for the varied-FR components than for the FR 10 components, $F(1, 7) = 18.18$, $p = .005$, and it increased with increasing size of the varied FR, $F(8, 56) = 7.41$, $p < .001$. There was no main effect of the different orders of conditions, $F < 1$. Importantly, there was a significant interaction between the size of the varying FR and whether the component was the varying FR or FR 10, $F(8, 56) = 20.77$, $p < .001$. Whereas

Fig. 3 Probabilities of escape as a function of the varying fixed-ratio (FR) requirement (upper panel) and mean numbers of responses on the food lever before making an escape response as a function of the varying FR requirement (lower panel) in Experiment 3. Filled symbols are data for the FR 10 trials, and open symbols are data for the varying-FR trials. Error bars indicate standard errors of the means

the probability of escape from the FR 10 remained low, the ratio increased with increasing size of the varying FR in the varying-FR component.

Figure 3 (lower panel) shows that the mean responses made in an FR component before making an escape response were influenced overall by whether the component was FR 10 or the varying FR, and by the size of the varying FR across conditions. Mean responses before escaping increased with the increasing size of the varying FR in the varying-FR component, but not in the FR 10 component. Only trials on which escape responses were made contributed to this analysis. In at least 4 of the 13 possible conditions, 3 rats made no escape responses and were not included in a repeated measures ANOVA. For 3 rats, means were substituted for a total of six cases (6.66%) in which there were no escape responses (missing values). The ANOVA confirmed the significant main effects on the responses made before escaping the varying versus the fixed FR, $F(1, 3) = 105.95$, $p < .001$, the size of the varying

FR, $F(8, 24) = 16.06$, $p < .001$, and the interaction between these two variables, $F(8, 24) = 20.25$, $p < .001$.

Discussion

Experiment 3 further explored the idea that the work requirement is the key variable that influences escaping or persisting by rats under mixed FR schedules. In Experiment 3, the procedure was simplified so that in each session there were only two FR components on the food lever. The FR 10 component served as a comparison, and its value was kept constant throughout the experiment. The varying FR varied in size across different conditions, ranging from FR 10 to FR 100. Experiment 3 confirmed the results from the previous experiments—the animals' probability of escaping from the current trial and the mean number of responses made on the food lever before making the escape response increased with increasing size of the larger FR. The results of Experiment 3 confirmed the conclusions from Experiments 1 and 2 that rats adjust their behavior to the contingencies of reinforcement by increasing their level of escape with increases in the FR requirement. Hence, it would seem that the rats adopted an optimal strategy. However, they tended to persist on almost 90% of the varying-FR trials up to the value of FR 40, and on about 50% of trials with a varying FR of 50 or higher.

General discussion

The general aim of the present experiments was to investigate a nonhuman analogue of the sunk cost error in human decision making, using rats as subjects. Several variables that might influence the decision to persist versus escape were manipulated. Specifically, we manipulated the probabilities of trials with a given FR schedule in an experimental session (Exps. 1 and 2). We hypothesized that as the number of trials with the small FR decreased, escaping would also decrease, because the likelihood of encountering a better option would diminish. The effort to escape was also manipulated (Exp. 2), and we anticipated that increasing the requirement to escape would both decrease such behavior and increase persistence. Another variable studied was the size of the larger FR and its influence on escaping (Exp. 3). Our hypothesis was that as the larger FR increased, escaping should increase, owing to an increased effort per reinforcer. In general, the sunk cost error would result in never escaping, and the optimal strategy would be to always escape from the large FR.

The results of all three experiments might lead us to ask whether the rats adopted the optimal strategy of escaping

from the larger FR on every trial, rather than persisting on every trial (upper panels of Figs. 1, 2, and 3). Prior studies, however, showed that in similar situations animals did not adopt the optimal strategy and committed the sunk cost error (Ávila-Santibañez et al., 2010; Navarro & Fantino, 2005). In these experiments, the behavior seems to involve an almost exclusive choice, with pigeons persisting in every instance and never escaping. The only instances in which escaping was reliably observed were in conditions in which cues signaled the size of the FR, and hence that the contingencies of reward had changed (see, e.g., Navarro & Fantino, 2005, Condition 1 of Exp. 1). In the present study, we did not include conditions in which changes in the contingencies were signaled.

In the present experiments, we observed that the escape probability increased with increases in the size of the FR, which might seem to be an optimal strategy. We did not observe such an acute preference for either always persisting or always escaping as had been reported in prior studies (see, e.g., Navarro & Fantino, 2005, Exp. 1). We do acknowledge, however, the possibility that an exclusive preference for escaping or persisting on trials with the large FR might have developed if rats were given more substantial exposure to the contingencies. This possibility is suggested by the likelihood of exclusive preference in concurrent FR schedules (Davison & McCarthy, 1988, p. 101).

In the present experiments, the tendency to persist was also evident—that is, the sunk cost error. This finding was evident in two ways. First, the overall level of escape responses in the three experiments was low. Second, the results for the mean number of responses before escape indicated that with larger FR requirements, the rats showed a higher tendency to persist before they made an escape response (lower panels of Figs. 1, 2, and 3). Previous studies (Ávila-Santibañez et al., 2010; Navarro & Fantino, 2005) did not report responses made before escaping—that is, how much was invested on the food key prior to the choice of the escape key. Their studies described only the percentages of trials on which the FR requirement was completed as a measure of persistence.

This observation highlights an apparent inconsistency. Measures of the probability of escape in the three experiments suggest that the higher the FR requirement, the higher the likelihood of escape, whereas measures of responses performed on the food lever before an escape response was made suggest that the higher the FR, the more persistence before escape. This apparent inconsistency is resolved by noticing that animals may escape more in the large FR simply because they have more opportunities to escape than in the small FR. *Opportunity to escape* can be conceptualized in the following way: Every single response made on the food lever represents an opportunity to switch

to the escape lever and terminate the trial. So, for instance, in the FR 10 trials an animal has nine opportunities to escape, as the tenth response will be reinforced, whereas in the FR 50 trials, there are 49 opportunities to switch to the escape lever. If the rat pressed the escape lever after 35 responses on the food lever, there would be 35 opportunities to escape on that trial. Log opportunities to escape was calculated as the logarithm (base 10) of responses performed by each rat for the FR 10 and the varying FR in the last two sessions of each condition of Experiment 3. Figure 4 (upper panel) shows that opportunities to escape increased with increases in the requirement of the varying FR. Next, we plotted escape responses per log opportunity to escape across the different conditions. Confirming the results for probability of escape, the higher the FR, the greater the escape responses per log opportunity. Specifically, Fig. 4 (lower panel) shows that there was an overall tendency to persist in trials with the varying FR, up to FR 40. When

Fig. 4 Log of the opportunity to escape as a function of the varying fixed-ratio (FR) requirement (upper panel) and escape responses per log (base 10) opportunity as a function of the varying FR requirement (lower panel). Filled symbols are data for the FR 10 trials, and open symbols are data for the varying-FR trials. Error bars indicate standard errors of the means

the varying FR was 50 or higher, the animals escaped consistently. This conclusion was confirmed by a significant interaction between the varying FR and trial type, $F(8, 56) = 15.37$, $p < .001$, followed by Newman–Keuls post-hoc comparisons that showed that escapes per log opportunity on trials with FR 50, FR 75, and FR 100 were higher than on trials with any of the other FR values (all $ps < .001$), which in turn did not differ. In a further ANOVA on escapes per log opportunity for only trials with FR 50, FR 75, or FR 100, there was no significant interaction between the varying FR and trial type, $F(2, 14) = 2.39$, $p > .05$. Note that although the pattern in Fig. 4 (lower panel) is similar to that in Fig. 3 (upper panel), the figures are not identical. The y-axis values in the two figures are not related, because the denominator for the probability-of-escape measure is the number of trials, whereas for the escapes-per-log-opportunity measure it is log opportunities. The numerator of these two measures—number of escapes—was the same, however, and the similarity between the two figures results from the pattern of change of the escape responses. The similarity between the two figures further confirms the relative lack of dependence of the probability of escape on opportunities to escape.

This analysis verified that our rats escaped more frequently with increases in the FR requirement, and not simply as a result of more opportunities to escape. That is, our rats seem to have behaved optimally, as they were less likely to continue to press the food lever when a higher effort was required.

As mentioned above, this finding of what seems to be optimal behavior is inconsistent with previous reports of exclusive persistence in every trial under similar conditions. Therefore, we next asked if the point at which rats started to escape consistently (FR 50) was the optimal point to do so. To answer this question, we calculated the mean number of responses per reinforcer if the rats persisted on every trial. This measure was calculated by multiplying each FR by its corresponding probability of occurrence and summing the values obtained. We also calculated the mean number of responses per reinforcer if the rats always escaped after completion of the requirement corresponding to the small FR. This measure was obtained by dividing the total number of responses performed in one session—including the escape response—by the number of trials with the small FR, as only these would be reinforced. Table 1 shows the values for these two measures. The first column lists the values of the varying FR across the different conditions. The second column shows the mean number of responses per reinforcer if the rats always persisted, and the third column shows the mean number of responses per reinforcer if the rats escaped after having made 10 responses on the food lever. Two observations are of interest. First, the mean number of responses per reinforcer increased with increases

Table 1 Mean numbers of responses per reinforcer if rats always persisted in the different varying fixed-ratio (FR) trials or escaped after the tenth response without reinforcement

Varying FR	Mean Responses per Reinforcer If Always Persisted	Mean Responses per Reinforcer If Escaped After 10 Responses
15	11.67	15.5
20	13.33	15.5
25	15.0	15.5
30	16.67	15.5
40	20.0	15.5
50	23.3	15.5
75	31.7	15.5
100	40.0	15.5

Mean responses for always persisting were calculated by multiplying each FR by its corresponding probability of occurrence and summing the values obtained, and mean escaping responses were calculated by dividing the total number of responses performed in one session—including the escape response—by the number of trials with the small FR.

in the varying FR if rats always persisted. Second, the mean number of responses per reinforcer was the same, independent of the size of the varying FR, if the rats always escaped after 10 responses were made without reinforcement, and was 15.5, not 10. The reason for this was that rats would not be rewarded in the trials on which they escaped, and the unreinforced responses increased the mean number of responses per reinforcer if an escape response occurred after 10 responses. This calculation assumed that rats should escape after having made 10 responses (the number of responses that corresponded to the small FR), but the numbers obtained would be different if a different criterion had been adopted.

Table 1 shows that when the varying FR was 30, the effort expended with persistence became higher than if the animal always escaped after completing the number of responses corresponding to the small FR. This hypothetical value of the number of responses to food suggests that the optimal point at which rats should start to escape was at the FR 30. Clearly, our rats seem to have committed the sunk cost error by failing to escape on trials with FR 30 and FR 40, so the point at which rats started to escape consistently (FR 50) was not the optimal point to do so.

Navarro and Fantino (2005, Exp. 3) manipulated the difference between different FR schedules, because they suspected that with smaller differences, greater persistence would be observed. In the present Experiment 3, exactly this result was observed—as the difference between the FR schedules increased, there were more escape responses from the larger FR. Navarro and Fantino argued that this result was due to a decrease in the level of uncertainty about the conditions for reinforcement—the smaller the

difference of the expected ratio given escape, the more uncertain the situation. By *uncertainty*, the authors meant the level of unpredictability of the outcome of a given economic decision. It is known that despite negative outcomes, decision makers may continue to invest in a losing course of action until the losses are too big to be ignored, or until the situation changes and it becomes more obvious that discontinuing the investment is the best course of action. Both of these possibilities are associated with a decrease in the level of uncertainty in the situation (e.g., Bragger, Hantula, Bragger, Kirnan, & Kutcher, 2003).

It remains unclear, however, both in the present study and in Experiment 3 of Navarro and Fantino (2005), whether subjects escaped because the discriminability between schedules was higher with bigger differences between the FR schedules or because of the higher effort expended to obtain each reinforcer in the large FRs. From the experimenter's point of view, the optimal rule of the thumb that could be adopted was that animals should escape after making the number of responses corresponding to the small FR without receiving a reinforcer.

The only measure of sunk cost Navarro and Fantino (2005) presented was the proportion of all trials with persistence, excepting the small-FR trials. This measure was also used in the present study (Figs. 1, 2, and 3, upper panels), but it fails to distinguish clearly whether the rats persisted *beyond* the optimal point to escape or escaped at the optimal point. For example, did the animals choose to escape after 10 pecks or 19 pecks?

Figures 1, 2, and 3 (lower panels) show the mean responses made on the food lever before an escape response

Fig. 5 Mean response frequency as a function of the varying fixed ratio (FR). Plotted are both the optimal mean number of responses per trial if rats always escaped after 10 food lever responses (horizontal line) and the mean numbers of responses on the food lever before escape with varying FRs (filled symbols)

was made. Note that rats that never escaped, but always persisted, were not included in this analysis, because those animals without doubt committed the sunk cost error. The question of interest was whether the rats that escaped did so at the optimal point to escape. To answer this question, in Fig. 5 we replotted the data on the mean numbers of responses before an escape response, together with the optimal behavior, which was to escape after 10 responses without reinforcement (note that this is not the same as the mean number of responses per reinforcer if the rat always escaped after 10 responses—i.e., 15.5). The first measure is a *local* measure, while the second is a hypothetical measure. Figure 5 shows that rats behaved suboptimally when the FR was higher than FR 40. That is, they spent more than the optimal level of effort per reinforcer. Note, for instance, that when the varying FR was 100, the rats made as many as 30 responses on the food lever before they escaped, three times as many as they should have invested.

In recent years, sunk cost and Concorde-like behavior have been conceptualized as instances of optimal rather than fallacious behavior. Because there is a positive correlation between past investment and future effort or benefits—for instance, in terms of raising offspring—using information about past investment to make decisions can be regarded as an adaptive behavior (Curio, 1987). This idea that sunk cost or Concorde-like behavior can be regarded as adaptive is shared by those who study self-control, as sinking costs may in the long run be translated to higher gains that will surpass any eventual losses that were suffered in the process (Rachlin, 1989, 2000). It is our view, however, that in that case the question is being framed on very large time scales. In the hypothetical scenarios used to study the sunk cost error with human participants, the temporal scale has typically been short, with a clear beginning and end, and the consequences of choosing one option or the other are clearly differentiated and do not impact on individual everyday behavior. Accordingly, short-term rather than long-term consequences should be used in studies with nonhuman animals about the effect of prior choices or investments on current decisions (Jokela & Vuorisalo, 1992). That is, nonhumans should be regarded as behaving fallaciously when they continue to perform an activity despite the costs exceeding the benefits for performing that particular activity.

Arkes and Ayton (1999) questioned the existence of compelling evidence for a parallel to a sunk cost error in nonhumans. The present report adds evidence to the contrary. We demonstrated that rats will persist in a course of action despite the increasing costs of persisting. We developed a sensitive analysis to assess whether the rats committed the sunk cost error, and we showed that rats will escape from a situation, but after persisting beyond the

optimal point for escape. The present results therefore suggest that nonhumans may commit the sunk cost error and may persist in a suboptimal course of action.

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