

THE SUNK COST EFFECT WITH PIGEONS: SOME DETERMINANTS OF
DECISIONS ABOUT WHETHER TO PERSIST

By

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The sunk cost effect is said to occur when an individual persists in a course of action due to a prior investment of resources. The current study used a laboratory model of the sunk cost effect, with pigeons making repeated decisions about whether to persist with or abandon a course of action. Two response alternatives were available: pigeons could choose to persist by responding on a schedule key with mixed ratio requirements, or escape, by responding on a second key to terminate the current ratio and assign a new, randomly-selected ratio to the schedule key. In Experiment 1, the set of ratios assigned to the schedule key, and the probability with which they occurred was varied in order to alter the effect of persisting on the mean response requirement across conditions. Pigeons made the sunk cost error when persisting increased the mean response requirement only slightly, but escaped when persisting was sufficiently non-optimal. Experiment 2 compared combinations of ratios and probabilities where persistence was associated the same approximate cost; this demonstrated that persistence varied most closely with the ratio of the response requirements for persistence and escape. Experiment 3 introduced stimulus changes that delineated more clearly the optimal choice patterns. This reduced the frequency with which the

error was made, and also produced some instances of a reverse sunk cost error — escaping when persistence was optimal. Experiment 4 examined the effects on persistence of altering the optimal point in the ratio at which to escape. Overall, this series of studies suggested that the sunk cost error may arise because persistence is the default behavioral strategy in situations where the consequences of making the error do not differ sufficiently from those of escaping, and/or it is difficult to discriminate when to cease persisting.

CHAPTER 1 THE SUNK COST EFFECT AND DECISIONS ABOUT WHETHER TO PERSIST

The sunk cost effect occurs when previous investment influences choices, and behavior therefore deviates from normative decision-making prescriptions. The sunk cost effect has been repeatedly documented with human subjects, and experimental research with non-human animals has much to add to this body of knowledge. Experiments with non-human animals allow for more control of the relevant contingencies than is available in either experimental studies with humans or observational studies with non-human animals. Such control has been necessary to demonstrate that non-human animals do make the sunk cost error under some conditions. This, in turn, has implications regarding the contribution of rules to the sunk cost effect in humans. The current study used an experimental analog of the sunk cost effect with pigeons in order to further investigate the environmental variables controlling whether or not the sunk cost effect occurs.

The Sunk Cost Effect

The sunk cost effect involves choosing an alternative because an investment has already been made in that alternative rather than because its future benefits outweigh its future costs. This behavior breaks normative decision making rules because they state that only future consequences should influence choice. Choosing an alternative associated with past investments might have similar consequences to choosing another alternative (e.g., the tasks used by De la Piedad et al. 2006, and Kacelnick & Marsh, 2002), or may have negative future consequences, as in the task used by Navarro and Fantino (2005). Given this potential for negative future outcomes, the sunk cost effect is of applied relevance for humans, and of interest within Behavior Analysis

as an example of a failure of control by global reinforcement rate (Rachlin, 1989). The sunk cost effect is also an instance in which individuals' behavior is apparently controlled by their own past behavior, a relatively under-explored controlling variable (De la Piedad et al., 2006).

There are two types of sunk cost scenarios: resource allocation decisions, and continuing-to-invest decisions (Fantino, 2004). Resource allocation decisions involve direct choices between two or more alternatives, one of which represents a larger past investment. For example, Arkes and Blumer (1985) randomly allocated different season ticket prices to groups of theater attendees. They then assessed whether the amount that people had previously spent on tickets subsequently affected their likelihood of allocating time resources to that alternative by attending plays. Arkes and Blumer found that people who had paid more for theater tickets were more likely to attend performances. Each decision between attending a show and an alternative evening activity is an instance of a resource-allocation decision because it involves a one-shot choice between two alternatives, one associated with higher previous investment.

In contrast, continuing-to-invest situations involve repeated choices between persisting with and abandoning a course of action (Fantino, 2004). Such a course of action is (typically) begun because the information available indicates that it is likely to produce future gains. An investment of time, money or resources is then made in that course of action; after this initial investment, however, some additional information is received, indicating that it is no longer likely to pay off in the future. Following this negative feedback, continued persistence becomes a sunk cost error.

For example, Straw and Hoang (1995) observed such a continuing-to-invest sunk cost effect when they analyzed the factors best predicting the amount of time NBA players were assigned to play. They used a player's draft order as an indication of the amount of money teams had previously invested in them, and their on-court success as an indication of that player's likely future contribution to the team. Straw and Hoang found that past investment predicted the amount of playing time a player was given even when likely future benefits were controlled for, suggesting the influence of past investment. This is a continuing-to-invest sunk cost situation because teams decide repeatedly whether to continue to invest in the course of action of playing a high-previous-investment. This is the type of sunk cost scenario that was investigated in the current study.

The Sunk Cost Effect with Human Subjects

The sunk cost effect has been repeatedly demonstrated with humans. In another example of a continuing to invest situation, Garland (1990) presented subjects with a hypothetical scenario in which they were in charge of research and development for a company that was working on a project aiming to develop an airplane that could not be detected by radar. In the scenario, after some proportion of a research budget (varied across conditions) had been invested, the company learned that a competitor was also developing a radar-blank plane that for several reasons was likely to be more successful in the marketplace than the plane the subject's company was developing. Subjects were then asked whether they would continue with their now-failing project. There was a positive correlation between the amount the scenario stated had been invested and subjects' likelihood of reporting that they would continue with the project.

In general, studies with human participants have used this type of hypothetical scenario, and have proposed explanations for subjects' behavior in terms of cognitive biases, for example, self-justification and framing (Goltz, 1992). Of most relevance to the current study, however, are the handful of studies that have investigated the sunk cost effect by presenting human subjects with repeatedly-experienced choices and consequences, and which have drawn upon behavior analytic concepts in interpreting their results.

Goltz(1992,1993,1999) conducted a series of such studies. In each experiment, subjects were required to make repeated decisions about whether to continue allocating money to a hypothetical investment. Each time a subject invested he or she received feedback about whether the investment had made or lost money. The first study in this series (Goltz, 1992) consisted of two phases. First, subjects made such investments, and the schedule on which they paid off varied across groups. Some groups' investments earned money on a fixed-ratio schedule (and therefore when the next investment would pay off was predictable), and other groups earned money on a variable-ratio schedule with the same mean reinforcement rate. In a second phase, however, every investment resulted in a loss of money. Therefore this study assessed the influence of past reinforcement schedule on future (non-optimal) persistence during extinction. Goltz found that subjects whose behavior had been reinforced according to a variable schedule during the first phase persisted for longer, making investments on a larger number of extinction trials.

It is known that behaviors that have been reinforced intermittently are subsequently more resistant to extinction than are behaviors that have been reinforced

continuously, a phenomenon termed the partial reinforcement extinction effect. Goltz (1992) suggested that some instances of the sunk cost error may also be instances of this effect, offering this as an alternative to explanations in terms of cognitive biases. Therefore, variables that increase resistance to extinction may be seen in some contexts as creating instances of the sunk cost error. Similarly, Goltz (1999) proposed that behavioral momentum might be a mechanism through which some instances of the sunk cost effect arise. Behavioral momentum is a proposed property of behavior that affects how resistant it is to disruptors including, but not limited to, the onset of extinction. In that study, subjects who had rich but variable reinforcement histories subsequently showed higher levels of persistence during extinction, an effect predicted by behavioral momentum theory.

Goltz (1993) found that subjects who were told that someone else had made the investments and thus produced the resulting consequences during the first phase were less prone to non-optimal persistence during extinction than were subjects with a direct personal history with these investments. This demonstrated the importance of a history of personal reinforcement for investing, rather than the past consequences of that course of action per se. Past studies have found that increased personal responsibility for past investment is associated with an increased tendency to make the sunk cost error. Goltz suggested that this variable could be construed in terms of reinforcement processes.

In a second experiment, Goltz (1992) placed some subjects' hypothetical investments on extinction from the first trial of the session. Goltz reasoned that their behavior would then be under the control of their pre-experimental history for making

similar decisions. Subjects in this group persisted, investing approximately the same dollar amounts as subjects in another group who had experienced a partial reinforcement schedule before the extinction phase. This effect can be explained in several ways, and one such possible explanation is that this behavior was created by demand characteristics. It is also consistent, as Goltz suggested, with the typical subject having a pre-experimental history of partial reinforcement for investment decisions. This explanation remains speculative because of a problem inherent to research with humans: their uncontrolled pre-experimental history. One way to address this problem is to study non-human animals, because their pre-experimental history can be controlled and therefore known.

Navarro and Fantino (2005, experiment 4) also studied such continuing to invest sunk cost situations with humans, working for (non-hypothetical) money. Subjects could either persist to complete a relatively large ratio they had already begun, or make another response to abandon that ratio and produce a new, perhaps smaller ratio. Persisting always increased mean response requirement, but the size of this cost for persisting varied across two conditions. Persistence, and therefore the sunk cost effect, was more frequent in the condition where this cost of persisting was smaller. Navarro and Fantino (2007) added stimulus changes to the condition from their 2005 study in which most persistence had occurred. These stimulus changes made the negative feedback indicating that persisting had become non-optimal more salient, and decreased the frequency with which subjects persisted. This procedure was used with pigeons in other experiments in Navarro and Fantino's (2005) study, and in the current study, and is discussed in more detail below.

In both of Navarro and Fantino's (2005, 2007) studies, although the number of subjects adopting each response pattern varied with the experimental manipulations there were subjects who never persisted and subjects who always persisted in every condition. This between-subject variability may reflect their uncontrolled pre-experimental history and/or insufficient exposure to the contingencies because their time participating was constrained by practical concerns. Both of these problems can be reduced in studies using non-human animal subjects.

The Advantages of Studying the Sunk Cost Effect in Non-Human Animals

The extended timeframes possible in animal research also make it possible to observe subjects making repeated choices between persisting and escaping. Hantula (1992) and Goltz (1992) argued that this makes these experimental tasks more analogous to applied situations than one-shot questionnaire measures of the type often used with human participants. That is, in everyday life, the alternative of abandoning a course of action (for example, by quitting a job or dropping out of college) is often available continuously, and people repeatedly chose whether to persist or quit. Additionally, people experience the consequences of their decisions in everyday life, and providing such experienced consequences is easier to arrange in the animal laboratory.

An additional reason that the control of subjects' extra-experimental histories and of relevant controlling variables afforded by experimental research with non-human animals is particularly useful in the case of the sunk cost effect is that it has been difficult to determine whether non-human animals show the sunk cost effect through non-experimental, observational studies alone. As an example of such an observational study, Weatherhead (1979) studied predictors of how vigorously Savannah sparrows

defended their nests, and concluded that the most important contributor was the amount of time and effort they had invested in building them, rather than the future advantages they stood to gain from their completed nests.

Others have suggested, however, that such observational studies have not sufficiently demonstrated that the sunk cost effect occurs in non-human animals. Dawkins and Carlisle (1976) argued that the link between past investment and future pay-offs could not be disentangled in naturalistic settings because higher past investments often produce higher future payoffs. For example, a parent may defend an older offspring more vigorously because they had more invested in them, or because they were closer to the future payoff of reaching adulthood.

Making a similar case, Arkes and Ayton (1999) reviewed the previous literature regarding whether non-human animals show the sunk cost effect. For each study where the authors proposed that an animals' behavior reflected the sunk cost effect, Arkes and Ayton concluded that the kinds of alternative explanations Dawkins and Carlisle had proposed almost twenty years before remained viable. For example, they argued that Weatherhead (1979) had incorrectly assessed the costs and benefits available to late-nesting sparrows, and that these might provide an alternative explanation to past investment for the sparrows' behavior. Studying the sunk cost effect in non-human animals experimentally can rule out such alternative explanations by controlling future costs and benefits directly.

Although they noted that this absence of evidence for the sunk cost effect in non-human animals did not prove it never occurs, Arkes and Ayton (1999) suggested that the sunk cost effect may be caused by human-specific processes, such as the use of

rules (see also Rosenfarb et al., 1992 for the same argument). For example, people are often advised both to show persistence even when an immediate result is not produced by their efforts, and not to waste resources -- investments made in a subsequently abandoned course of action may be perceived as wasted. Arkes and Ayton argued that this explanation is consistent with the fact that children, who have had less time to acquire such rules, have also been found to be less likely to make the sunk cost error.

If the sunk cost effect does reflect the influence of rules, then the fact that it may occur even when the contingencies support an alternative course of action is consistent with what is known about rule governed behavior. Specifically, rule governed behavior is less sensitive to changes in the contingencies than behavior under the direct control of these contingencies (Fantino, 2004; Hackenberg & Joker, 1994). Therefore, if persistence is an instance of rule-governed behavior it might be insensitive to instances in which it is not supported by the extant contingencies, creating a sunk cost error.

Additionally, if the sunk cost effect is primarily driven by rules, this might suggest that providing people with other, normative decision making rules that emphasize disregarding past investment as a factor would reduce the frequency with which they made the error. Contrary to this hypothesis, however, Tan and Yates (1995) tested students who had recently received direct instruction in avoiding the sunk cost error as part of an economics course, and compared the frequency with which they made the error to students enrolled in courses that did not include this material. The two groups made demonstrated the sunk cost effect about equally frequently on hypothetical scenarios.

Experimental research with non-human animals can help to resolve the question of how central rules are to the sunk cost effect (Fantino & Storlarz-Fantino, 2005). If non-human animals show the sunk cost effect, then such verbal processes are not *necessary* for the error to occur. Rules may contribute to the sunk cost effect in humans in some instances, however.

Experimental Evidence for the Sunk Cost Effect in Non-Human Animals

Experimental studies with non-human animals have demonstrated that they do make the sunk cost error under some circumstances. There are two major implications of these experimental results. First, that an experimental analysis was necessary to demonstrate the sunk cost effect with non-human animals when it was apparently not possible to demonstrate it unambiguously without experimental control. Secondly, the presence of rules is not necessary to produce the sunk cost effect (De la Piedad, Field, & Rachlin, 2006).

Kacelnick and Marsh (2002) produced one such experimental demonstration of the sunk cost effect in starlings. The target response was flying between two keys located at either end of a cage. When the keys were lit one color, food was presented on a fixed-ratio four (FR4) schedule, meaning that four flights across the cage were required to receive food. Another key-light color indicated that an FR16 schedule of reinforcement for flying across the cage was in effect. In a second phase subjects were able to choose between the two key light colors, which now provided food on the same schedule. Under these conditions most starlings allocated more than half of their responses to the key color that had been associated with the higher past investment. This study therefore demonstrated that non-human animals show the resource-allocation type sunk cost effect.

This finding is consistent with a study by Feltus, Kaiser and Zentall (2000), although they termed the effect they observed the work ethic effect rather than the sunk cost effect the two are very similar. During the training phase two trial types were interspersed. During one type, one response to the white center key produced one red side key and one yellow side key, responding on the red key (the S^+) was reinforced, but responding on the yellow key was not (the S^-). During the other trial type, 20 responses were required on the white center key to produce a green S^+ on one side key and a blue S^- on the other. When pigeons had learned to consistently choose the S^+ on both trial types, test trials began. During test trials, subjects were required to choose between the two S^+ or between the two S^- , and any choice was reinforced on a VR2 schedule. Subjects responded most frequently on the stimuli that had previously required the most responses to produce. This procedure differed from Kacelnik and Marsh's procedure in that the stimuli were produced by completing the ratio, rather than being present while it was completed, but the results were consistent in indicating an effect of past investment on future choice. Subsequently, however, Vasconelos, Urcuioli and Lionello-DeNolf (2007) were unable to replicate this work ethic effect over a series of six experiments. Therefore, the conditions under which non-human animals make this resource-allocation form of the sunk cost error remain to be comprehensively identified

De la Piedad et al. (2006) demonstrated the sunk cost effect with pigeons using an analog of the continuing-to-invest scenario. Throughout the session, pigeons could persist on a given response alternative, or switch to another alternative. Responses on one key produced food on a random-interval (RI) schedule of reinforcement (unpredictable from moment to moment) and responses on the other produced food on

a response-initiated fixed-interval (RI-FI) schedule of reinforcement (with fixed waiting times prior to food). On the RI-FI key, persistence was differentially reinforced because time spent on that alternative was correlated with increased reinforcement probability. Persisting on the RI schedule was not differentially reinforced, however. In spite of this, the more time subjects had spent on the RI alternative (without receiving reinforcement), the longer they tended to persist on that alternative.

In a second experiment, De la Piedad (2006) demonstrated that such control by past investments did not entirely override reinforcement effects. They did this by adding a condition where persistence past a set point in the trial was never reinforced. That is, the random-interval key eventually switched to an extinction schedule. Under this arrangement, subjects were less likely to persist past this point, in spite of already having invested time on that alternative. Therefore, subjects' behavior was apparently controlled by a combination of past investment and the contingencies for persistence.

In a third experiment, De la Piedad et al. (2006) investigated the influence of the availability of the fixed-interval option, and therefore whether control by past investments only occurs when subjects have chosen to invest in one response over another. Their results suggested that this choice context was important, because pigeons for which the fixed interval key was unavailable at the beginning of the trial tended to switch to that key when it became available more frequently than they had in conditions during which both options were always available. That is, the sunk cost effect may occur more frequently in situations where one alternative is invested in in preference to other available alternatives.

Navarro and Fantino's Task and Results, and Introduction to the Current Study

The current study used a task designed by Navarro and Fantino (2005) in order to investigate further the conditions under which non-human animals show the sunk cost effect. The task is an experimental analog of the continuing-to-invest sunk cost situation. Across four studies with pigeon subjects, and one with humans (see above), Navarro and Fantino presented subjects with two concurrently-available response alternatives. For the experiments with pigeons, one key – termed the schedule key – was programmed with a modified mixed ratio schedule. In each condition there were (typically) four ratios that might be presented on a given trial, and the probability with which each occurred was fixed during a given condition. The particular ratio value assigned to the schedule key on a given trial was selected at random. If the programmed ratio was satisfied, then food was presented and the next trial began, with a new ratio re-determined according to the probabilities in place on that condition.

The other key – termed the escape key – terminated the trial and produced a new trial with the ratio re-determined. Responding on the escape key therefore provided an opportunity to avoid completing relatively high ratios on the schedule key. Making an escape response also cancelled all schedule-key responses made on the previous trial meaning that it was necessary to complete the entire newly-determined schedule key ratio following an escape key response.

On most of the conditions that Navarro and Fantino (2005) presented, these probabilities and ratios were arranged such that frequent escape produced the lowest available mean response requirement for each reinforcer delivery. The optimal response pattern entailed completing the smallest ratio and, if no food was presented, responding once on the escape key, thereby producing a new trial with a potentially

more favorable ratio. These conditions were therefore different to those presented by De la Piedad et al. (2006), and Kacelnick and Marsh (2002), because persisting actually increased response requirement rather than being response-requirement-neutral. On this task, having completed the smallest ratio without receiving reinforcement entails negative feedback about the utility of persisting on the schedule key. This negative feedback is analogous to subjects in Garland's (1990) radar-blank plane scenario being told that a competing company had developed a better product than the one they were developing. Persisting on the schedule key only increased mean response requirement after this negative feedback (completing the smallest ratio and not being reinforced) has been received; completing the smallest ratio was not an error.

Navarro and Fantino (2005) found that pigeons did persist to complete some of these larger schedules under this arrangement, making the sunk cost error. They did not do so under all conditions, rather, Navarro and Fantino identified two procedural variables that influenced the frequency with which pigeons persisted. These were the cost (in terms of increased response requirement) of persisting, and the presence or absence of added stimuli correlated with the different schedules. These two variables were also shown to affect the frequency with which human participants made the sunk cost error on this task (see above).

Navarro and Fantino (2005, experiment 3) manipulated the cost of persisting by varying the ratio set programmed on the schedule key; the probabilities with which they occurred were held constant (in smallest-to-largest sequence of ratio size, these probabilities were: 0.5, 0.25, 0.25, and 0.125). Subjects escaped consistently when the ratios were 5, 50, 100, and 220, and persistence markedly increased response

requirement. Three out of four subjects, however, generally made the sunk cost error and persisted in the other two conditions where the ratios were 10, 40, 80 and 160, and 20, 50, 100, and 200, and persistence increased response requirement to a smaller extent. The fourth subject escaped, that is never persisted, in all three conditions.

Navarro and Fantino (2005) concluded that this pattern of escape was consistent with control by the overall extent to which escaping reduced response requirement. They suggested that the sunk cost error tended to occur in conditions where escaping was only slightly optimal. This explanation is consistent with De la Piedad et al's (2006) finding that when persistence was never reinforced, subjects did not tend to persist. That is, non-optimal persistence can occur when it increases response requirement slightly, but not when it is sufficiently penalized by the contingencies.

The other explanation for Navarro and Fantino's (2005) pattern of results, however, was that pigeons escaped most frequently in the condition where the smallest ratio was FR5 because it was easier to discriminate the optimal escape point when it occurred upon the completion of a smaller ratio than a larger ratio. This is also consistent with the effect of adding stimulus changes given that the one of these changes coincided with the optimal escape point, presumably enhancing its salience. That is, although Navarro and Fantino suggested that adding stimulus changes reduced persistence by making the fact that the contingencies favored escaping more salient, an important additional feature of this condition may be making the optimal point at which to escape more identifiable.

This variable is of potential importance because accurately discriminating when to escape is important to using the escape key in a way that reduces overall response

requirement. The response-requirement-reduction advantage of escaping is highest when escape key responses are made at the optimal time – that is, after having completed the smallest programmed ratio on the schedule key but not having received reinforcement. Even when the overall contingencies favor accurately-timed escaping, response requirement may be increased by escape responses that occur either too early or too late. Therefore, any manipulation that affects how easy it is to discriminate when to escape may reduce the sunk cost error on the current task. The current study therefore held the smallest ratio constant (at FR10) in order to assess the effect of changing the relative response requirements for persisting and escaping while holding this variable constant.

The second variable that Navarro and Fantino (2005, Experiment 1) found influenced the frequency of persistence was further investigated in the current Experiments 3 and 4. This was whether stimulus changes signaling transitions between ratios were present or absent. In the stimulus-changes-present conditions, whenever a pigeon completed one of the three smaller programmed ratios but did not receive reinforcement, the color of the schedule key light changed. In Experiment 1, Navarro and Fantino found that three out of four subjects consistently persisted when these stimuli were absent, but escaped when they were present.

In their Experiment 2, Navarro and Fantino (2005) replicated the condition from Experiment 1 in which stimulus changes were present, and the contingencies favored frequent use of the escape key, with the same result. This condition was compared to a condition where the stimulus changes were also present, but the contingencies favored persisting. That is, completing every ratio presented produced a lower mean response

requirement than escape. This condition assessed whether stimulus changes reduced subjects' tendency to persist in a manner that was insensitive to the contingencies. On the contrary, however, this condition indicated that when stimulus changes were present, subjects behaved to reduce their overall mean response requirement, escaping reliably when the contingencies supported this behavior, and persisting reliably in the condition where that pattern was supported. Navarro and Fantino argued that the fact that subjects persisted when doing so was optimal also demonstrated that their tendency to escape when escape was optimal was not controlled purely by the possibility that escape key responses would meet with reasonably immediate (after ten schedule key responses) reinforcement, but rather reflected a broader sensitivity to the contingencies.

Avila-Santibanez et al. (2010) also found that presenting stimulus changes influenced the frequency with which subjects persisted compared to identical contingency arrangements absent these stimuli. In a replication of Navarro and Fantino's (2005) Experiment 1, they found that when the contingencies favored escape, subjects escaped more consistently and therefore achieved a lower mean response requirement when the added stimuli were present. Avila-Santibanez et al. also included a condition with a combination of ratios and probabilities not included by Navarro and Fantino where the contingencies favored persistence. When no stimulus changes were present, subjects persisted and therefore achieved the minimum available response requirement. When stimulus changes were present, however, all subjects escaped on some trials, and two out of four escaped consistently. Therefore, Avila-Santibanez et al.

found that adding stimulus changes created instances of a *reverse sunk cost error*, or escape when persistence is optimal.

Experiments 3 and 4 in the current study built upon these previous results of Navarro and Fantino (2005) and Avila-Santibanez et al (2010) by further investigating the effects of these stimulus changes in several ways. Firstly, by extending the range of contingencies over which the effect of adding stimulus changes was investigated in order to identify the effect of these signals on the frequency of optimal response patterns, the sunk cost effect and the reverse sunk cost errors. The second way in which the current study extended this previous research was by investigating the influence of stimulus changes on the timing of escape key responses as well as on levels of overall persistence.

To summarize the current experimental conditions: Experiment 1 varied the cost of persisting while holding the smallest ratio constant to investigate whether sensitivity to the contingencies was still present under these conditions. Experiment 1 also identified the function relating the ratio of the mean response requirement for persisting to that for escaping to levels of persistence. Experiment 2 further investigated the effect of varying the ratio of the response requirement for persisting to that for escaping, which also allowed an assessment of the predictive power of a set of other features of the current contingency arrangements, both global and local. Experiment 3 investigated the effect of adding stimulus changes across a wide range of contingency arrangements on the frequency of optimal and non-optimal response patterns. Experiment 4 varied the point at which it was optimal to make an escape key response. Specifically, the smallest two ratios were FR10, and FR20, and it was only optimal to make an escape key response

after having completed 20 responses. Together, this set of four experiments works to further identify the environmental variables that contribute to instances of the sunk cost error in pigeons.

CHAPTER 2

EXPERIMENT 1: THE EFFECTS OF THE RELATIVE COSTS OF PERSISTING AND ESCAPING ON PERSISTENCE LEVELS

In Experiment 1 pigeons were presented with a sequence of conditions that varied along the dimension from strongly favoring escaping to strongly favoring persistence at a global level. This dimension was characterized by the ratio of the mean number of responses required for each reinforcer given persistence to the mean response requirement given escape after making 10 schedule key responses. Levels of persistence and the timing of escape responses were assessed for each condition. The smallest ratio was held at FR10 so that the discriminability of the optimal escape point was constant across conditions.

Method

Subjects

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

Apparatus

A standard three-key operant chamber with internal dimensions of 30.5 x 35 x 35 cm was used, although only the left and center keys had programmed consequences. The center key was lit white when it was operable and the left key was lit green. A house-light was located directly above the center key, and a food hopper directly below it. The food hopper was used to present mixed grain; when grain was available a

hopper light was lit and the chamber was otherwise dark. The chamber was located in a dark room, with masking noise continuously present. Experimental procedures were controlled using MED-PC IV software running on a computer in another room.

Procedure

Pigeons had previously participated in other experiments relating to choice, including a study immediately preceding those described here that used the same apparatus and a similar task. The pigeons therefore began the conditions described here with a history of responding on both keys used in the current study, removing the need for preliminary training.

One aspect of the subjects' past experience is particularly relevant to the current experiment because it included one of the conditions presented here: condition R4. R4 is a condition that favors escape. The current subjects had previously experienced this condition twice. The first time they experienced it all four persisted consistently, making the sunk cost error. Subsequently, however, they were exposed to a condition during which escaping markedly reduced overall response requirements because the three larger ratios (FR 160, FR 320, and FR 640) were much larger than the smallest ratio (FR 10). This condition established consistent escaping in all four subjects, and this experience affected the frequency with which subjects escaped when they were subsequently returned to the R4 condition. Specifically, after this history with a condition that so strongly favored escape, subjects escaped more frequently during condition R4 than they had previously. It is possible, therefore, that this history will also be reflected in an increased tendency to escape during some of the conditions presented during the current study.

Pigeons were given repeated choices between a center (schedule) key and a left (escape) key. During a given condition, the center key was programmed with 4 FR schedules each presented with a set probability (technically a mixed ratio). These 4 FR schedules and the probabilities with which they occurred during each condition are presented in Figure 2-1. If the ratio programmed on a given trial was completed, 2-s access to mixed grain was provided. Following a 1-s inter-trial interval (ITI), during which the chamber was dark, a new trial began with the ratio re-determined according to the probabilities set for the current condition. A single response on the escape key initiated the ITI and began the next trial with a re-determined ratio.

In some conditions, those presented towards the bottom of Figure 2-1, the lowest mean response requirement over the entire session was available if no escape responses were made. This is because the smallest ratio (FR 10) was relatively rare and/or the three other ratios were relatively small. In other conditions, those presented towards the top of Figure 2-1, the lowest response requirement was available for consistent use of the escape key. In these conditions, the optimal response pattern was to respond 10 times on the schedule key, and if food was not presented, respond immediately on the escape key. It was during these conditions, in which the contingencies favored escaping, that the sunk cost error was possible.

The rightmost two columns of Figure 2-1 present the number of responses required for each reinforcer if each of these two possible strategies was adopted on every trial. The mean response requirement for persisting is the mean ratio size weighted by the probability with which each ratio occurred; for example, for the R4 condition, $(10 \times 0.5) + (40 \times 0.25) + (80 \times 0.125) + (160 \times 0.125) = 45$. The response

requirement associated with escaping on every trial was calculated by first determining the average number of trials required to produce 40 instances of the lowest, FR10 ratio, given that sessions ended after 40 reinforcers had been presented. Taking the R4 condition as an example again: given that FR10 trials were presented on 50% of trials, it would take on average 80 trials to produce 40 FR10 trials, these 40 FR10 trials would require 400 (40 x 10) responses to complete. The remaining 40 trials, on which the escape key was used, would require 440 responses to complete (40 x 11 where the 11th response is on the escape key). Therefore a session in which escaping occurred exclusively (and optimally timed) would require, on average, 840 key pecks to complete, creating a mean response requirement of 21 key pecks (840/40) per reinforcer.

Conditions terminated after either 40 reinforcers had been received, or after one hour and fifteen minutes of session time. Some or all of the conditions described in Figure 2-1 were presented to each pigeon in an individualized order, with the specific sequence determined by two factors. Firstly, conditions were sequenced such that preference reversals would likely be observed, providing compelling evidence of experimental control. Secondly, conditions were individualized in such a way that the full range of response patterns—from escaping consistently to persisting consistently—would be demonstrated. Conditions were replicated when time allowed. Each condition continued for at least ten sessions and until stable responding was observed over five consecutive sessions. Stability was defined as the absence of the highest and lowest points and upward or downward trends. The sequence of conditions presented to each subject, and the number of sessions conducted in order to establish stable responding, is presented in Table 2-1.

Dependent Variables

The primary dependent variable was the proportion of trials where persistence was both possible and occurred. That is, proportion persistence was defined as the proportion of ratios larger than FR10 that were completed. FR10 trials were not taken into account because completing them did not entail a sunk-cost error. This was the same definition of persistence used by Navarro and Fantino (2005) and Avila-Santibanez et al. (2010). A second dependent variable was the mean number of responses made on the schedule key during a given trial before an escape response was made.

Results

Figure 2-2 presents proportion persistence as a function of the ratio of the mean response requirement for escaping (after 10 schedule key responses) to the mean response requirement for persisting for each pigeon. On this figure, instances of the sunk cost error appear as points the left of the y -axis (indicating a condition where the contingencies favored escaping), but above the x -axis, (indicating the completion of some ratios larger than the smallest). All pigeons made the sunk cost error in one or more conditions. This sunk cost error did not occur to the same extent in every condition in which the contingencies favored escaping, rather it was made in conditions in which the contingencies favored escaping over persisting least strongly (i.e., conditions in which the costs of making the error were relatively low). Additionally, pigeons did not consistently complete every ratio larger than FR10, even during conditions in which the contingencies favored such persistence; rather they sometimes made the reverse sunk cost error—that is, failing to persist when persistence was appropriate. This was rarer than the sunk cost error, however.

In those conditions favoring escape, it was optimal, in terms of reducing response requirements, to make an escape response after exactly 10 schedule key responses. Even when pigeons escaped, however, they generally overshot the optimal escape point. As can be seen in Figure 2-3, pigeons typically escaped after between 10 and 20 schedule key responses. In some conditions, some pigeons escaped prior to 10 schedule key responses, which always increased mean response requirement. There was no clear relationship between the extent to which escaping was optimal and the mean number of schedule key responses made before an escape key response.

Discussion

During Experiment 1, pigeons made the sunk cost error by completing relatively large ratios when smaller mean response requirements were available for escaping. This occurred even though the smallest ratio on the schedule key, and therefore the optimal escape point, was held constant at FR10, suggesting that this factor alone did not drive the similar pattern of results observed by Navarro and Fantino (2005).

Persistence did not occur in every condition. For each subject, there were conditions during which escape also reliably occurred—those when the differences between the mean response ratios for escaping and persisting were large. In other words, levels of persistence were partially sensitive to the contingencies for escaping and persisting rather than being entirely optimal or consistently in error. This general pattern is consistent with the results of Navarro and Fantino (2005) .

The condition here labelled R4 is identical to that presented by Navarro and Fantino (2005) during the stimulus-changes-absent condition in their Experiment 1, and replicated in their Experiment 3. Both times this condition was experienced, 3 of 4 pigeons persisted on every trial; only 1 pigeon consistently escaped. Avila-Santibanez

et al. (2010) also included this condition, presenting it to each of four subjects three times. One subject persisted consistently, one escaped consistently, and two others escaped consistently on two of the three replications conducted.

Our pigeons therefore escaped more consistently on this condition than did those in either of these previous two studies that have included this exact set of contingencies. This likely reflects prior experience on the part of our pigeons. All four of our pigeons had previously persisted on the R4 condition, behaving more similarly to subjects in those previous two studies. Following exposure to a training condition during which the contingencies markedly favored use of the escape key, however, our pigeons then consistently escaped, even when returned to the R4 condition. This suggests that prior history of contact with the escape contingencies made a difference. The condition here labelled P1 was also included by Avila-Santibanez et al. (2010). Each of their four subjects persisted consistently, as did those in the current study.

Table 2-1. Sequence of conditions experienced by the four experimental subjects during Experiment 1. See Figure 2-1 for complete condition descriptions. The number of sessions for which each condition was presented in order to establish stable responding is presented in parentheses.

Subject	1	2	3	4	5	6	7	8	9
250	R4 (45)	E (14)	R1 (38)	R3 (75)	R2 (76)	R1 (10)			
456	R4 (22)	E (14)	R1 (28)	R3 (42)	P1 (16)				
457	R4 (46)	E (16)	R4 (26)	P1 (15)	R5 (19)	P1 (25)	R5 (17)	R4 (29)	R1 (20)
1770	R4 (20)	E (15)	R1 (62)	P1 (17)	R1 (27)	P2 (116)	E (19)	R1 (59)	

	condition	ratio 1	p 1	ratio 2	p 2	ratio 3	p 3	ratio 4	p 4	Mean response requirement if persist on every trial	Mean response requirement if escape after every 10 th response
FAVOR ESCAPING	R5	10	0.6	40	0.15	120	0.125	160	0.125	47	17.3
	R4	10	0.5	40	0.25	80	0.125	160	0.125	45	21
	R3	10	0.4	37	0.25	75	0.2	100	0.15	43.25	26.5
	R2	10	0.4	31	0.2	70	0.1	81	0.3	41.5	26.5
	R1	10	0.35	34	0.3	70	0.125	100	0.225	44.95	30.43
EQUAL	E	10	0.25	33	0.25	40	0.25	80	0.25	40.75	43
FAVOR PERSISTING	P1	10	0.063	40	0.063	80	0.5	160	0.375	103.1	175
	P2	10	0.06	50	0.2	70	0.25	100	0.49	77.1	182.3

Figure 2-1. Features of conditions presented during Experiment 1. For each condition (rows), the four ratios and the probabilities with which they occurred are presented (columns). Rightmost two present overall mean response requirements for the two possible response patterns (persistence and escape).

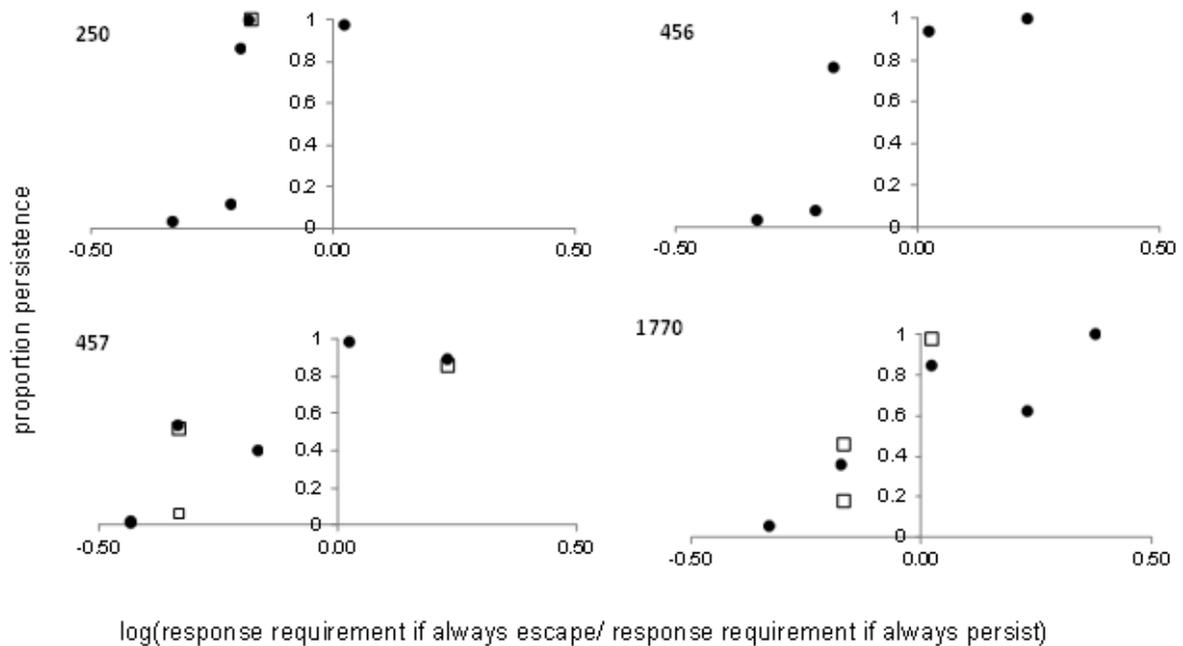


Figure 2-2. Mean proportion persistence for the last five sessions of each condition as a function of the ratios of the expected mean response requirements for persisting and escaping on every trial. Conditions plotted to the right of the y-axis favor persisting, those to the left favor escaping; the ratio is logged so that distance from the y-axis indicates the extent to which the optimal strategy is favored on a consistent scale. Solid circles are the first presentation of each condition; open squares are replications.

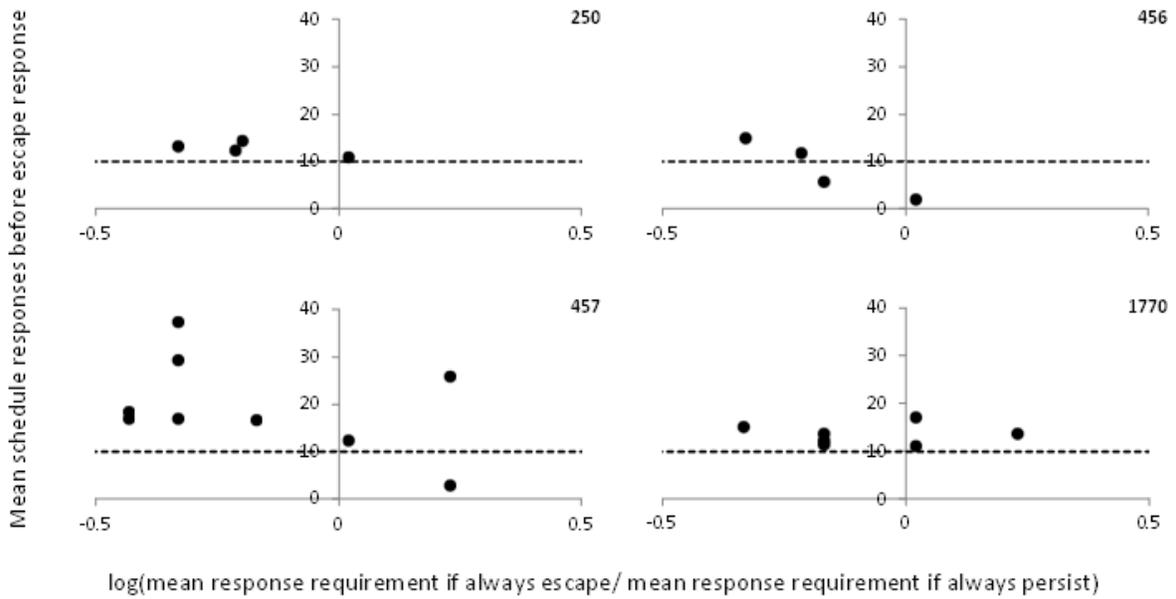


Figure 2-3. Mean number of schedule key responses before an escape key response, during the last five sessions of each condition, by pigeon, as a function of the relative response requirements for persisting to that for consistently using the escape key. The dashed line indicates the optimal escape point that would have created the lowest possible response requirement during conditions (those to the left of the y-axis) that favored escaping.

CHAPTER 3

EXPERIMENT 2: WHICH FEATURES OF THE SCHEDULE ARRANGEMENT CONTROL LEVELS OF PERSISTENCE?

In Experiment 1, levels of persistence changed when alterations were made to the contingencies for persisting and escaping. These changes in levels of persistence generally co-varied with a global feature of the contingency arrangement — the ratio of the mean response requirement given persistence to that given optimally timed escape. Experiment 2 assessed whether this variable was the feature of the current procedure that was most strongly related to levels of persistence.

Avila-Santibanez et al. (2010) identified two variables other than the strategy that the contingencies favor that may provide alternative explanations for previous patterns of persistence on this task. These were both systematically related to the response patterns favored by the contingencies in the current Experiment 1, and so remain alternative explanations for the patterns of persistence observed in that experiment. The first variable Avila-Santibanez et al. identified was the probability with which FR10 trials occurred; in Experiment 1 conditions on which FR10 trials were more likely were also generally those on which the contingencies favored escape. The second such variable was the mean response requirement that would be achieved if response patterns were optimal; in Experiment 1 in conditions that favored escape this lowest achievable mean response requirement was generally lower in those conditions that favored persistence than in those that favored escape. Experiment 2 included conditions that reduced the correlations between the number of FR10 trials, the size of the smallest available response requirement, and the cost of persistence. This allowed the contribution that each of these variables made to be assessed more directly.

It is also possible that variables acting on a more local level make important contributions to levels of persistence. For example, Navarro and Fantino (2005) conceptualized their conditions as defined by the difference between the immediate/local consequences of escape and those of persisting. These were both defined assuming the choice point was the non-reinforced completion of the smallest ratio in the condition. The consequence for escape was defined as the mean response requirement if one escape key response was made, and then the next ratio was completed whatever its size. The consequence for persistence was defined as the main number of responses remaining in the larger three ratios. It was difficult in their study, however, to separate the effects of this variable from the effects of other possible features of the contingency arrangement because of the all-or-none levels of persistence they observed. The more graded levels of persistence observed during the conditions presented in Experiment 1, and anticipated in Experiment 2, in combination with the wider range of stimulus arrangements, should permit a clearer isolation of relevant variables.

To achieve this goal, Experiment 2 took advantage of the flexibility of the current procedure. Specifically, it is possible to create two (or more) combinations of FR sizes that occur with probabilities such that the ratio of the mean response requirement for persisting to that for escaping is identical, but where other potentially important controlling variables differ. Experiment 2 consisted of four such conditions, each matched to a condition presented during Experiment 1. If the relative mean response requirements for persisting and escaping is an important controlling variable, then levels of persistence should be approximately equivalent in the two conditions in each pair. If,

on the other hand, one of the other potential variables described above more strongly controlled levels of persistence, then performance in the two conditions in each pair would diverge, and one of these other variables would be more strongly implicated.

Method

Subjects and Apparatus

Three of the four subjects used during Experiment 1 served; 456 died prior to the beginning of Experiment 2. Pigeons' living conditions were as for Experiment 1. The apparatus used was also as for Experiment 1.

Procedure

The conditions described in Experiment 2 were conducted after those described in Experiment 3, but are described first to facilitate clarity of description. The overall procedure, in which subjects had the opportunity to respond on either the schedule or escape key, was as for the previous experiment. The schedule arrangements during the three conditions during Experiment 2 are presented in Figure 3-1. Each shaded column presents a matched pair of conditions. Those on the left hand side of each shaded column are conditions presented during Experiment 1, provided here for reference. Those on the right (denoted by 'a' after the condition title) were presented during Experiment 2. As can be seen from the figure, the ratios and the probabilities with which each occurred differed within each pair. This created a difference in the absolute mean response requirements for persisting and escaping between the two matched conditions. The ratio of these two response requirements was identical, however. For example, in Condition P1 persistence led to a lower overall mean response requirement than did escaping because the smallest (FR10) ratio was presented only rarely,

whereas in condition P1a, FR 10 trials were more frequent but the other ratios were smaller so that the relative advantage gained by persisting was held constant.

As in the previous experiment, the sequence of conditions presented during Experiment 2 was customized for each subject so that a clear change in levels of persistence was anticipated after condition changes were made. Replications were completed where time allowed. The sequence of conditions presented to each subject is presented in Table 3-1 along with the number of sessions needed to obtain stable levels of performance according to the same criteria used for Experiment 1.

Results

Figure 3-2 presents the proportion of trials in which persistence occurred (defined as ratios larger than 10 that were completed) in each condition in Experiment 2 (open circles), along with performance on the matched conditions from Experiment 1 (filled circles). As can be seen, performance roughly approximated that under the matched conditions during Experiment 1 on many of the conditions in Experiment 2. There are some exceptions, however, in which performance in the two conditions diverged. Such divergence was particularly notable for Pigeon 250.

To identify the properties of the current contingency arrangements that most directly predicted persistence levels across the three pigeons, linear correlation coefficients were calculated between mean proportion persistence and various properties of the schedule arrangements. Some variables were selected because they captured potentially important global features of the contingencies (presented in the top five rows of Table 3-2). Others were selected because they captured more local features of the procedures--immediate consequences for persisting and/or escaping at the choice point (presented in the bottom five rows of Table 3-2). The choice point was

assumed to occur after 10 responses on the schedule key on non FR10 trials.

Correlations included the mean proportion persistence during the last five sessions of every condition presented in Experiments 1 and 2. Replications were included as separate data points.

For Pigeons 457 and 1770, the ratio of the mean response requirements for each of the two possible response patterns (persisting and escaping) was moderately strongly correlated with their levels of persistence. For Pigeon 250, no variable analyzed was strongly related to levels of persistence; however, the ratio of the anticipated response requirement for the next reinforcer given persisting and escaping was the most strongly correlated.

Discussion

Experiment 2 presented pigeons with conditions matched to those presented during Experiment 1 based on the ratio of the mean response requirement for persisting to that for escaping. Although this variable imperfectly predicted subjects' levels of persistence, it had the strongest linear relationship with levels of persistence of the variables analyzed for two out of three subjects. The frequency with which the third subject persisted did not appear to be strongly controlled by the current contingencies. One weakness of this analysis is that another variable might have been more strongly related to proportion persistence, but that the relationship between the two was not linear. This is unlikely, however, because visual inspection of graphs of the relationships between each of the variables reported here and proportion persistence did not identify any such strong, but non-linear relationships.

Navarro and Fantino (2005) used the difference between the anticipated next ratio given persisting (and completing the next ratio presented) and given escaping after

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

Table 3-1. The sequence of conditions experienced by each subject in Experiment 2. See Figure 3-1 for complete condition descriptions. The number of sessions for which each condition was presented in order to establish stable responding is presented in parentheses.

Condition	1	2	3	4	5	6
250	R4 a (17)	P1 a (16)	R1 a (12)	E a (11)		
457	R4 a (42)	P1 a (11)	R1 a (17)	E a (27)	P1 a (10)	R1 a (22)
1770	R4 a (17)	E a (36)	R1 a (20)	R4 a (15)	R1 a (14)	P1 a (10)

Table 3-2. Linear correlation coefficients describing the relationships between the proportion of ratios larger than FR 10 completed by each subject in a given condition (proportion persistence), and the specified feature of the schedule arrangement in that condition. The strongest correlations observed for each subject are indicated with asterisks.

Property of the schedule arrangement	Correlation with proportion persistence			
	Subject	250	457	1770
Global variables				
Log(mean response requirement if always persist / mean response requirement if always escape after 10 schedule key responses)		0.27	0.79*	0.84*
Response requirement if always persist – response requirement if always escape		-0.01	0.76	0.66
Proportion FR10s presented		-0.44	-0.28	-0.47
Mean of the three largest ratios		-0.35	-0.23	-0.40
Lowest achievable mean response requirement		0.16	0.69	0.56
Local Variables				
Log (mean response requirement for next reinforcer if persist/ mean response requirement for next reinforcer if escape)		0.48*	0.62	0.78
Mean response requirement for next reinforcer if persist - mean response requirement for next reinforcer if escape		-0.20	0.25	-0.11
Size of next ratio (after FR10)		0.06	-0.63	-0.28
Probability of next ratio being programmed on the current trial		-0.35	-0.23	-0.40

	condition	ratio 1	p 1	ratio 2	p 2	ratio 3	p 3	ratio 4	p 4	Mean response requirement if persist on every trial	Mean response requirement if escape after every non-reinforced 10 th response	Mean response requirement if always escape/ unit price if always persist
FAVOR ESCAPING	R4	10	0.5	40	0.25	80	0.125	160	0.125	45	21	0.47
	R4 a	10	0.2	77	0.2	112	0.25	200	0.35	115.4	54	
FAVOR ESCAPING	R1	10	0.35	34	0.3	70	0.125	100	0.225	44.95	30.43	0.68
	R1a	10	0.1	109	0.25	152	0.35	266	0.3	161.25	109	
EQUAL	E	10	0.25	33	0.25	40	0.25	80	0.25	40.75	43	1.05
	Ea	10	0.1	52	0.2	103	0.3	154	0.4	103.9	108.95	
FAVOR PERSISTING	P1	10	0.0625	40	0.0625	80	0.5	160	0.375	103.13	175	1.7
	P1a	10	0.25	21	0.25	30	0.25	41	0.25	25.5	43	

Figure 3-1. Ratios and the probabilities with which they occurred for each condition presented in Experiment 2 (top of each shaded row), with the conditions to which each was matched from Experiment 1 (bottom of each shaded row). The final three columns provide the mean response requirements for persisting on every trial and for escaping on every trial larger than FR10, and the ratio of the two (the feature on which the conditions were matched).

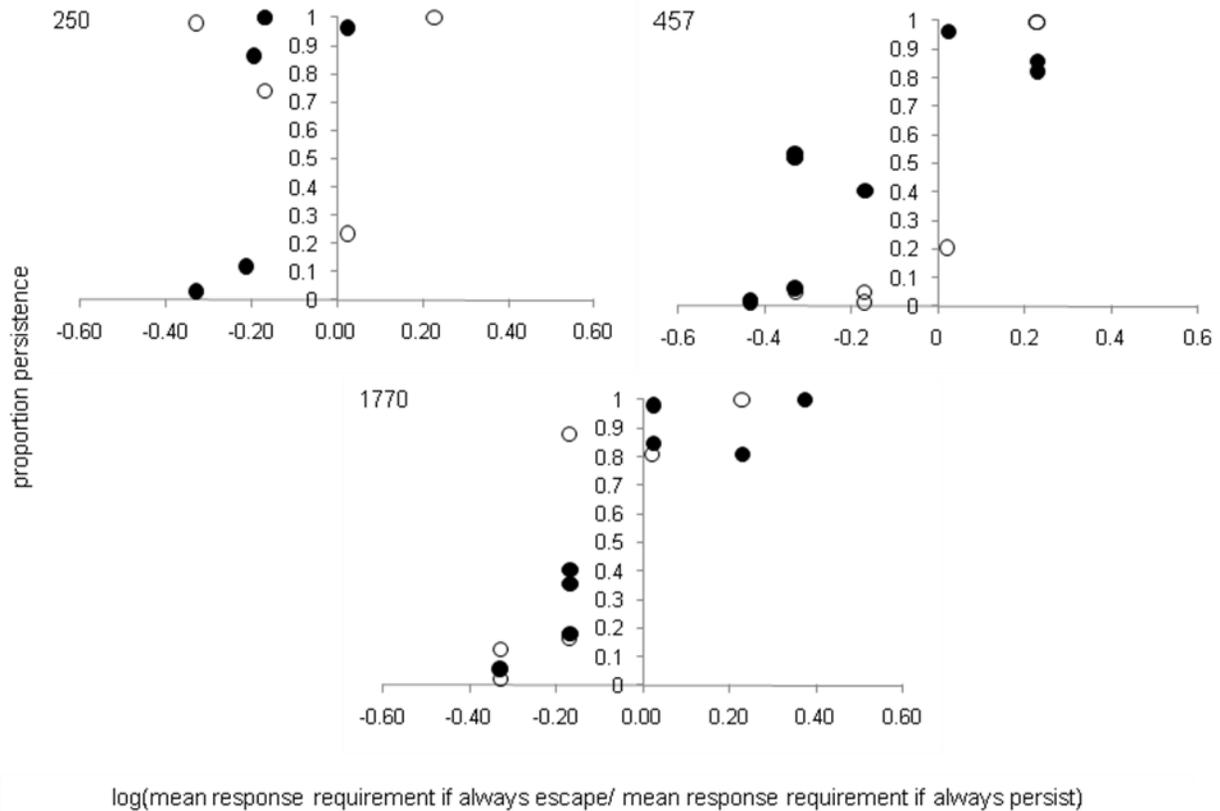


Figure 3-2. Mean proportion persistence for the last five sessions of each condition as a function of the ratios of the expected response requirements for persisting on every trial and escaping on every trial. Solid circles are the conditions presented during Experiment 1; open circles are conditions matched to be in the same location on the y-axis scale using different combinations of ratios and probabilities presented during Experiment 2. Conditions plotted to the right of the y-axis favor persisting, those to the left favor escaping. The contingency ratio is logged so that distance from the y-axis indicates the extent to which the relevant strategy was favored on a consistent scale.

CHAPTER 4

EXPERIMENT 3: THE EFFECTS OF ADDED STIMULI ON THE FREQUENCY AND TIMING OF ESCAPE

Experiment 3 investigated the effects of adding stimulus changes across a wider range of conditions than those included in previous studies. Additionally, the effect of these stimuli on the timing of escape responses was investigated. This was done because optimal behavior on the current task requires not only selecting the response path (persistence vs. escape) with the lower overall mean ratio, but also—in the case of escape—selecting it at the right time. The optimal point at which to escape was after the completion of the smallest ratio; escaping prior to or after the smallest ratio increases mean response requirements. During Experiments 1 and 2 in no condition was the timing of escaping precisely controlled by the optimal escape point (i.e. after 10 schedule key responses). As well as being a deviation from optimality in itself, this mistiming of escape responses may have increased the frequency of persistence by reducing the experienced differences in response requirements between persisting and escaping.

Navarro and Fantino (2005) found that the addition of stimulus changes signaling the completion of unreinforced ratios reduced persistence but did not report the effect of these stimulus changes on the timing of escape key responses. Therefore, it is difficult to ascertain whether the changes in overall levels of persistence they observed were mediated by the added stimuli altering the timing of escape-key responses. In Experiment 3, such stimulus changes were added to conditions included in Experiment 1, and the timing and frequency of escape key responses was examined. The condition

during which Avila-Santibanez et al. (2010) observed instances of the reverse sunk cost error was included in order to investigate the reliability of that effect.

Method

Subjects and Apparatus

The same three subjects (250, 457, and 1770) that had served in Experiment 2 also served in Experiment 3. Subjects' living conditions were as for Experiments 1 and 2. The apparatus was that used in Experiments 1 and 2.

Procedure

Subjects could respond on either the schedule key or escape key, as in Experiments 1 and 2. Some conditions from Experiment 1 were replicated in Experiment 3, each followed by a condition that was identical but with the addition of stimulus changes. These stimulus changes consisted of flashing the schedule key light on and off, with the flash rate inversely related to the position in the ratio schedule. Specifically, after the smallest, FR10, ratio was completed the key-light flashed at a high rate (0.5- s on: off cycle); after the second ratio was completed, the key-light switched flashed at a moderate rate (1-s on: off cycle); and after the third ratio was completed, the key-light flashed at a low rate (1.5-s on: off cycle).

When it was difficult to determine whether the addition of stimulus changes had affected levels of persistence based on an A-to-B comparison alone, a replication of the same condition without stimulus changes was conducted, creating a reversal A-B-A design. Additionally, conditions were sequenced so that clear changes in responding were anticipated following condition changes in order to demonstrate experimental control. Each condition was presented until proportion persistence was stable from day to day using the same criteria used in the previous two studies. Table 4-1 presents the

sequence of conditions that each subject experienced, and the number of session required for stable levels of persistence to emerge.

Results

Figure 4-1 presents proportion persistence as a function of the log of the ratio of the response requirement for escape to that for persisting; closed circles are conditions with no stimulus changes, and open circles those with stimulus changes present. The addition of stimulus changes had the effect of reducing persistence relative to the identical condition without stimulus changes present in 10 out of 13 cases, across subjects. For Pigeons 457 this reduction was such that the sunk cost error was eliminated entirely; the other two pigeons still made the error, but less frequently. When reversals were conducted, and the stimulus-changes-absent condition was replicated, persistence always (six out of six reversals) increased following the removal of the stimulus changes. This indicated that the reduction in persistence caused by the stimulus changes was not associated with a permanent behavior change. This reduction in persistence even occurred in several conditions in which persistence was optimal and it therefore represented instances of the reverse sunk cost error.

As during Experiment 1, there was no relationship between the mean number of schedule key responses made before an escape key response and the relative response requirements for persisting and escaping. Therefore, an analysis of the effect of the addition of stimulus changes on the distribution of timing of the escape key responses was conducted, collapsing across conditions. That is, all of the escape responses occurring during the last five sessions of all conditions with stimulus changes were aggregated and those without stimulus changes were aggregated; their distributions are presented in Figure 4-2. The presence of stimulus changes both shifted

the mean number of schedule key responses after which an escape key response was made towards 10 (i.e. the optimal escape point), and reduced the variability in the distribution of this measure. The presence of the stimulus changes did not mean that every escape key response was made after exactly 10 schedule key responses, however. There were no additional peaks in the distribution of escape responses corresponding to the completion of ratios larger than 10, even though completing these ratios was associated with an additional increase in mean response requirement during some conditions and with a change in the rate at which the schedule key light flashed during stimulus-changes-present conditions.

The data presented in Figure 4-2 are consistent with subjects' behavior being under the control of the number of schedule key responses they had made since the beginning of the current trial. There remains, however, the possibility that the timing of these escape key responses was controlled instead or in addition by the passage of time. In order to investigate whether the passage of time might provide an alternative explanation for the timing of subjects' escape responses, the data from Figure 4-2 were re-plotted as a function of time since the beginning of the trial. These data are presented in Figure 4-3.

The functions relating the proportions of escape key responses made to the seconds of the trial that had elapsed are similar to those for the number of schedule key responses made. One exception to this was Pigeon 250 in the stimulus-changes-absent condition. The wide distribution of delays after which escape responses were made in contrast to the narrower distribution of number of schedule key responses after which escape key responses were made suggest that this subject was more sensitive to the

number of schedule key responses made so far in the trial than to the number of seconds that had elapsed in the trial. For the other subjects and conditions, however, the current procedure does not allow a strong conclusion to be drawn about the extent to which the number of schedule key responses made and the passage of time each controlled the timing of subjects' escape key responses.

Discussion

The addition of stimulus changes signaling the transition between ratios reduced persistence for most subjects in most conditions. When this occurred during conditions that favored escaping, the presence of these stimulus changes therefore reduced instances of the sunk cost error. This effect was also observed by Navarro and Fantino (2005) in their Experiment 1. Navarro and Fantino suggested that this effect occurred because it made the long-term benefits of responding on the escape key more easily discriminated. The addition of stimulus changes may also have affected not only *whether* subjects used the escape key, but *when* they did so. That pigeons produced their escape responses after a smaller number of schedule key responses with stimulus changes present reduced the mean response requirement given escape, and therefore increased the difference between escaping and persisting—a variable Navarro and Fantino (2005) and the current Experiments 1 and 2 found to be a critical determinant of persistence.

Although signaling ratio transitions led to a reduction in the sunk cost error in conditions under which the contingencies favored escape, it had the opposite effect in conditions favoring persistence; that is, it led to a reverse sunk cost error—escaping when persistence was appropriate. Avila-Santibanez et al. (2010) also presented the condition here described as P1 with stimulus changes present. Two of their subjects

escaped consistently under these conditions in spite of the associated increase in mean response requirement. The other two subjects persisted on approximately half of the ratios larger than FR10. Therefore, the occurrence of this reverse sunk cost error has been observed across these two studies given the same persistence-favoring schedule arrangement. Navarro and Fantino (2005) also added stimulus changes to a (different) condition that favored persisting. Unlike the current subjects, however, their subjects persisted consistently and therefore minimized their obtained response requirements.

One explanation for these instances of the reverse sunk cost error points to order in which the conditions were experienced. More specifically, our pigeons first encountered the added stimulus changes during conditions in which escaping was favored by the contingencies- this was also the case for the Avila-Santibanez et al.'s (2010) subjects. However, this is unlikely to provide a complete explanation for these effects for two reasons. Firstly, Navarro and Fantino's (2005) pigeons also first encountered stimulus changes in a condition in which the contingencies favored escaping (during Experiment 1), but none made the reverse sunk-cost error. Additionally, when conditions were replicated without stimulus changes, performance was typically replicated, meaning that there was not elsewhere evidence for lasting effects of prior experience with stimulus changes. The possibility remains, however, that this reversed sunk cost error would have been less likely had the pigeons first encountered stimulus changes during a condition during which persistence was appropriate.

Another possible explanation for this reverse sunk-cost error when stimulus changes were introduced is that the flashing schedule key light may have acquired

conditioned aversive properties through its association with relatively high work requirements. Perhaps the termination of the flashing schedule key light upon using the escape key was negatively reinforcing, even at the expense of lower mean response requirements. This could be tested by using stimuli that occurred for only a brief time following the onset of the optimal escape point, or by including stimulus changes that terminated upon continued persistence on the schedule key as well as upon escape.

Arguing against the possibility that stimuli associated with high work requirements have aversive properties, however, Kacelnick and Marsh (2002) found that starlings preferred response alternatives that had previously been associated with higher work requirements. In Kacelnick and Marsh's study, however, the key color associated with a high work requirement was presented as an antecedent to, rather than as a consequence of, key pecking, and it is not known what effect it would have had if either its presentation or termination was made contingent upon responding. Future research might investigate whether subjects will respond to terminate stimuli associated with high work requirements in other procedural contexts, as well as the conditions under which reverse sunk cost errors are made by humans and animals. Given that in everyday life people often fail to persist with courses of action likely to produce benefits to them that outweigh the costs, investigating this reverse error is likely to be of applied relevance to humans.

Table 4-1. The sequence of conditions experienced by the experimental subjects in Experiment 3. See Figure 2-1 for complete condition descriptions. S indicates that stimulus changes were present. The number of sessions for which each condition was presented in order to establish stable responding is presented in parentheses.

Subject	1	2	3	4	5	6	7	8	9	10	11
250	R1 (10)	R1S (39)	R1 (46)	R4 (56)	R4S (23)	R4 (11)	P1 (13)	P1S (62)	P1 (37)	E (12)	ES (35)
457	R1 (20)	R1S (13)	R4 (58)	R4S (10)	P1 (27)	P1S (31)	E (20)	ES (37)	P2 (13)	P2S (13)	P2 (11)
1770	R1 (59)	R1S (28)	R1 (59)	P1 (33)	P1S (13)	R4 (16)	R4S (38)	R4 (27)	E (23)	ES (39)	E (23)

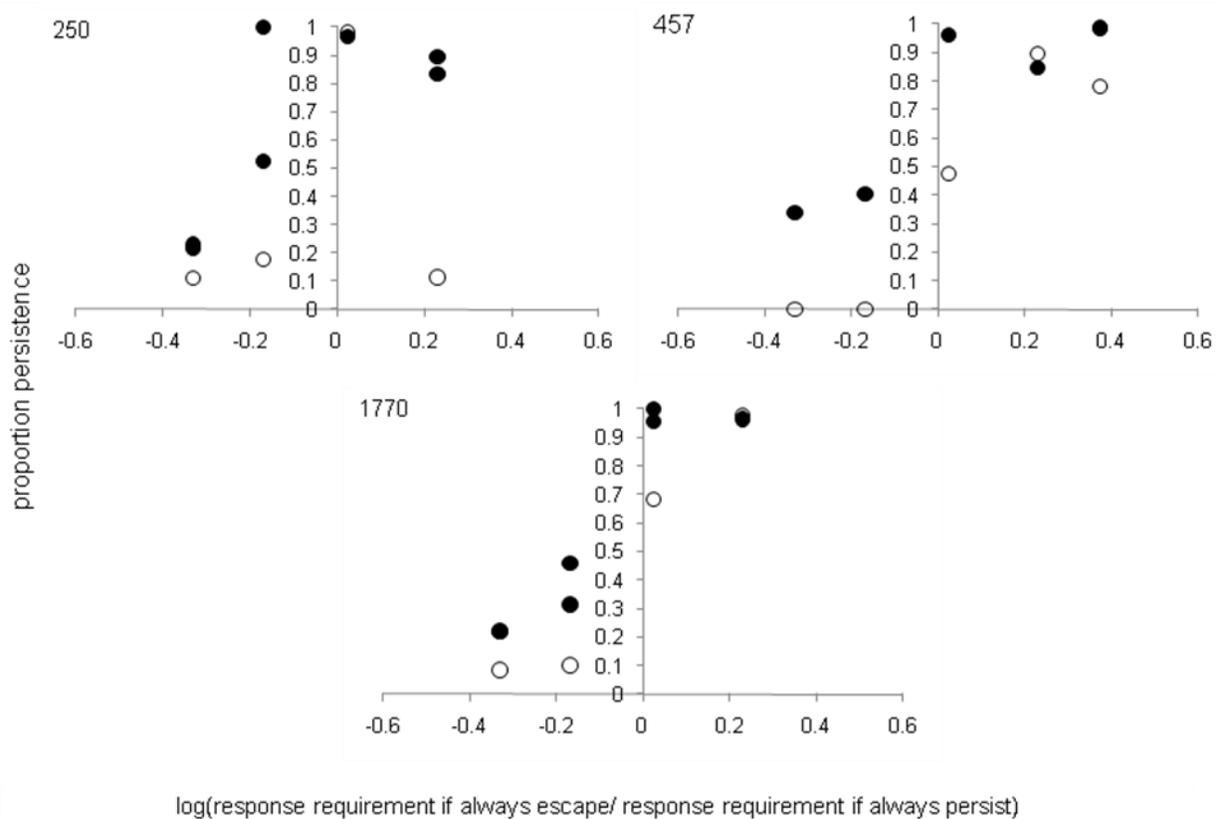


Figure 4-1. Mean proportion persistence for the last five sessions of each condition as a function of the ratios of the expected mean response requirements for persisting and escaping on every trial. Stimulus-changes-absent conditions are indicated with closed circles, and stimulus-changes-present conditions with open circles. The ratios are logged so that distance from the y-axis indicates the extent to which the optimal strategy is favored on a consistent scale. Conditions plotted to the right of the y-axis favor persisting, those to the left favor escaping.

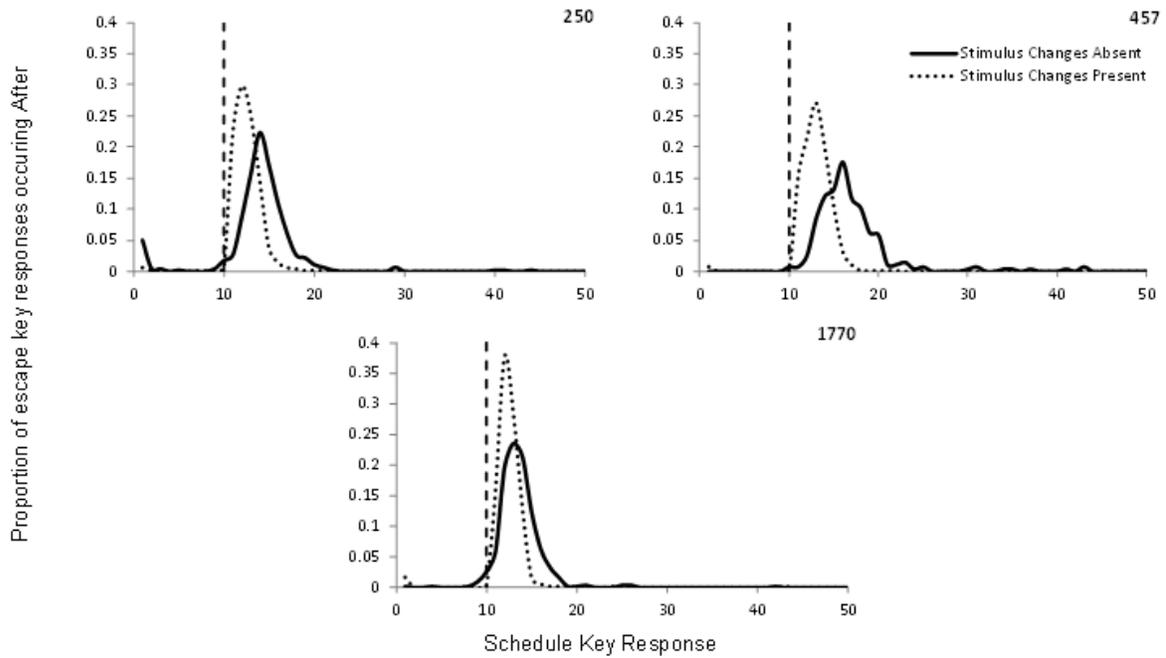


Figure 4-2. Distributions of the frequencies with which an escape key response occurred after exactly a given number of schedule key responses, for each subject. The dashed distributions are those when stimulus changes were present and the solid distributions when they were absent. The vertical dashed line indicates the optimal number of schedule key responses after which to make an escape key response (10).

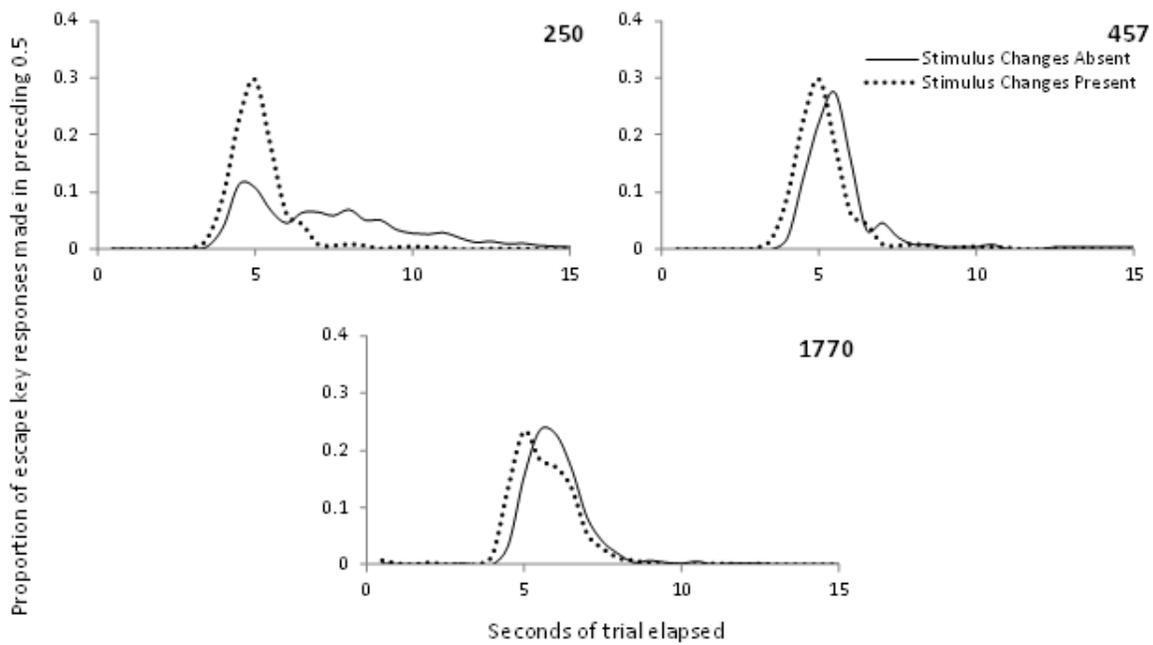


Figure 4-3. Distributions of the frequencies with which an escape key response occurred after a given number of second (in 0.5 s bins), for each subject. The dashed distributions are those when stimulus changes were present and the solid distributions when they were absent.

CHAPTER 5 THE CURRENT PERFORMANCE VERSUS MIXED-RATIO PERFORMANCE

In the current study, a mixed ratio schedule was programmed on the ratio key. In a mixed ratio schedule two or more ratio sizes alternate unpredictably from trial to trial. The current procedure differed from such standard mixed ratio schedules in the presence of the escape key, in the fact that it affected subjects' response requirements, and because that trials could begin following either an escape response or following food. Therefore it was of interest to investigate whether performance on the current task was similar to that observed on mixed ratio schedules.

Within-trial Response Patterns.

On mixed ratio schedules, the within-trial response pattern typically observed is a pause in responding at the beginning of the trial followed by a run in responding where inter-response times are shorter than the pause (Mazur, 1983). To investigate whether a similar pattern occurred on the current task, pause and subsequent inter-response times were calculated for each response. The pause was defined as the time between the end of the immediately preceding inter-trial interval (which could follow either a food presentation or an escape response) and the first response in the trial. For subsequent responses in the trial, inter-response time was defined as the time between that schedule key response and the most recently preceding schedule key response.

Figure 5-1 presents these inter-response times as a function of the number of responses that had occurred previous to that response in the trial. Data included are from the stable period of each condition in Experiments 1 to 3 that did not include stimulus changes and on which persistence occurred on more than half of the trials;

conditions with less persistence were excluded because insufficient numbers of schedule key responses occurred during typical trials.

Figure 5-1 indicates that trials began with a pause that was longer than subsequent inter-response times, and was followed by responding at a relatively constant rate. One exception to this was Pigeon 250. That subject showed an increase in inter-response times during the portion of the trial in which escape key responses were typically made. That is, there was some disruption in the rate of schedule key responding for that subject that coincided approximately with the point at which escape became optimal.

Experiment 3 found that conditions that included stimulus changes differed from those that did not both in proportion persistence and in the timing of the escape key responses. Therefore, the within-trial patterns of responding were also analyzed to investigate whether the presentation of these stimulus changes also affected the timing of schedule key responses within a trial. Figure 5-2 presents these inter-response time data as a function of the number of schedule key responses that had previously been made on the current trial with conditions including stimulus changes plotted separately. Conditions are all from Experiment 3 in order to hold the schedule arrangements constant across stimulus conditions. Figure 5-2 indicates that the onset of the first stimulus change was associated with increased inter-response times between schedule key responses in all three subjects that completed Experiment 3. That is, the onset of the stimulus change disrupted ongoing responding on the schedule key, even when it did not cause an escape response to be made immediately.

Control of Pause Length

In mixed-ratio schedules, pause lengths increase as the mean ratio increases (Mazur, 1983), and whether this pattern was also present on the current task was investigated. In conditions where persisting was the most frequent response pattern, the pattern of responding (receiving food, and then responding on the same key until the next food presentation) was most similar to that occurring under a simple mixed-ratio schedule. In contrast, performance on conditions with lower levels of persistence and more frequent escape diverged from that under simple mixed ratio schedules due to frequent use of the escape key. For this reason, conditions where persistence occurred on more than half the trials were analyzed separately from conditions on which persistence occurred on fewer than half the trials. Conditions with stimulus changes were not included. Mean (obtained) response requirement was defined as the total number of responses produced in the session including both escape and schedule key responses divided by the number of reinforcers presented during that session (typically 40). Pause lengths are presented as a function of mean response requirement in Figure 5-3.

Figure 5-3 indicates that mean pause increased as mean response requirement increased during conditions where persistence was the primary response pattern (filled circles). However, pauses remained approximately constant during conditions in which subjects escaped more than half of the large ratios they encountered (open circles). The pause lengths presented in Figures 5-3 include pauses occurring at the beginning of all trials: both those following a food presentation, and those following an escape response. Conditions with higher levels of persistence also include a greater proportion of pauses beginning immediately following a food presentation. This may account for

the observed differences in the relationship between response requirement and pause lengths associated with differences in levels of persistence observed here.

To investigate this possibility further, the pauses presented in Figure 5-3 were separated according to whether they occurred after food or after an escape key response (but combined across levels of persistence). These data are presented in Figure 5-4. As can be seen from the figure, pauses following food were longer than those following escape, and this difference was larger in conditions with relatively large mean response requirements. This suggests that it is likely pauses following food that drive the relationship between pause length and response requirement evident in the conditions during which subjects persisted. That is, pauses following food increase with mean response requirement under the current procedure as do pauses following food under a simple mixed ratio schedule.

Control of Run-Rate

Run-rate is negatively correlated with response requirements under simple mixed ratio schedules in the range presented here (Mazur, 1983). Therefore, it was of interest to investigate whether the same relationship was evident under the current modified mixed ratio schedule. To this end, Figure 5-5 presents run-rate as a function of mean response requirement for the stable period of each of the conditions (including replications, which are included as separate points) that did not include stimulus changes in Experiments 1 to 3. Run-rates were calculated by dividing the number of schedule key responses produced on a given trial by the length of the interval between the first response in the trial and the end of the trial (either a food presentation or an escape response). Escape responses were not included in run-rates.

Given that differences in levels of persistence were associated with differences in patterns of pause lengths, run-rate was also analyzed according to levels of persistence on each condition, as well as mean response requirement. Unlike pause, however, the pattern observed for the two types of conditions was similar: a decrease in run-rate as mean response requirement increased. Therefore, response rates were sensitive to the mean response requirement in a given condition, regardless of the likelihood that that run of responses began and/or ended with an escape response.

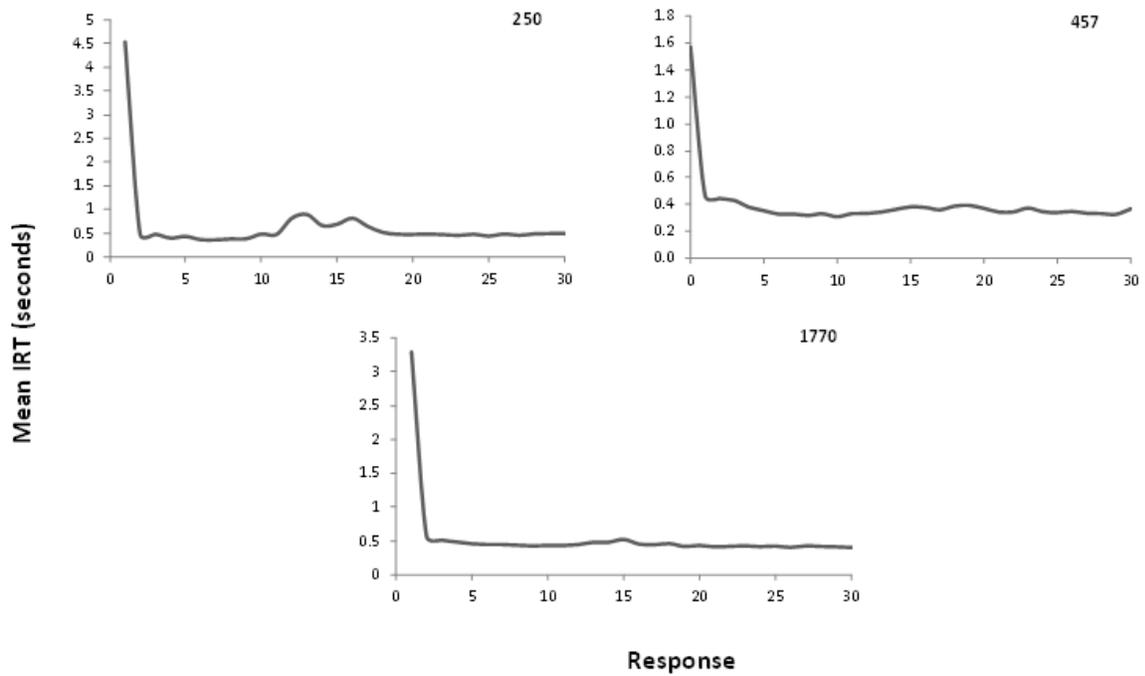


Figure 5-1. Mean pause and inter-response times for conditions included in Experiments 1 to 3 in which stimulus changes were absent and in which there was persistence on more than half the trials. Note the varying y-axes.

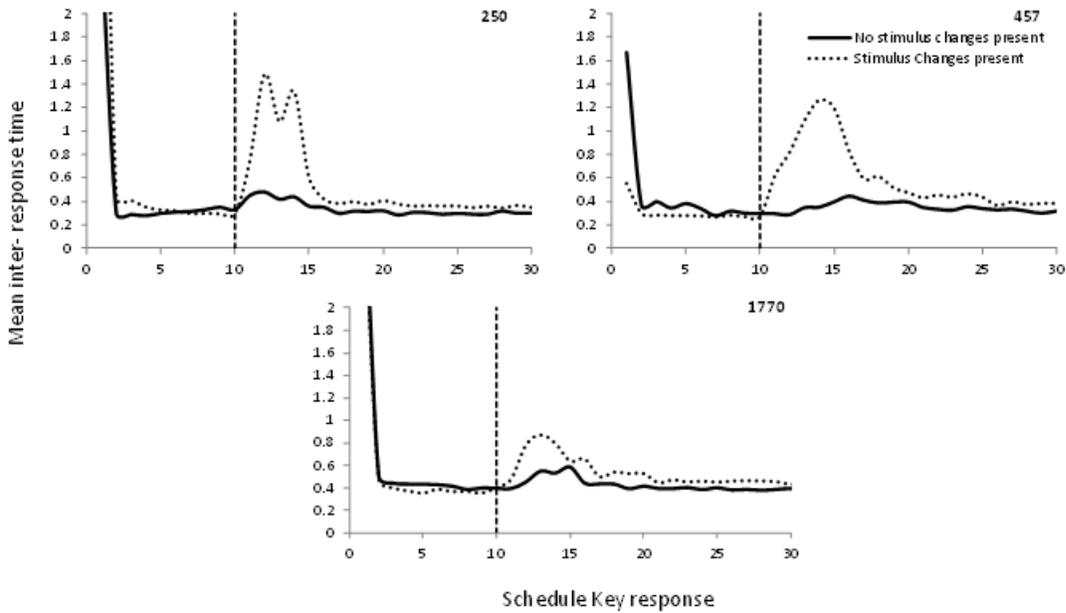


Figure 5-2. Mean inter-response time, by subject, as a function of the number of schedule key responses made since the beginning of the trial. Dashed function indicates data from conditions during which stimulus changes were present. Solid function indicates data from conditions during which stimulus changes were absent. The dashed vertical line indicates the onset of the first stimulus change.

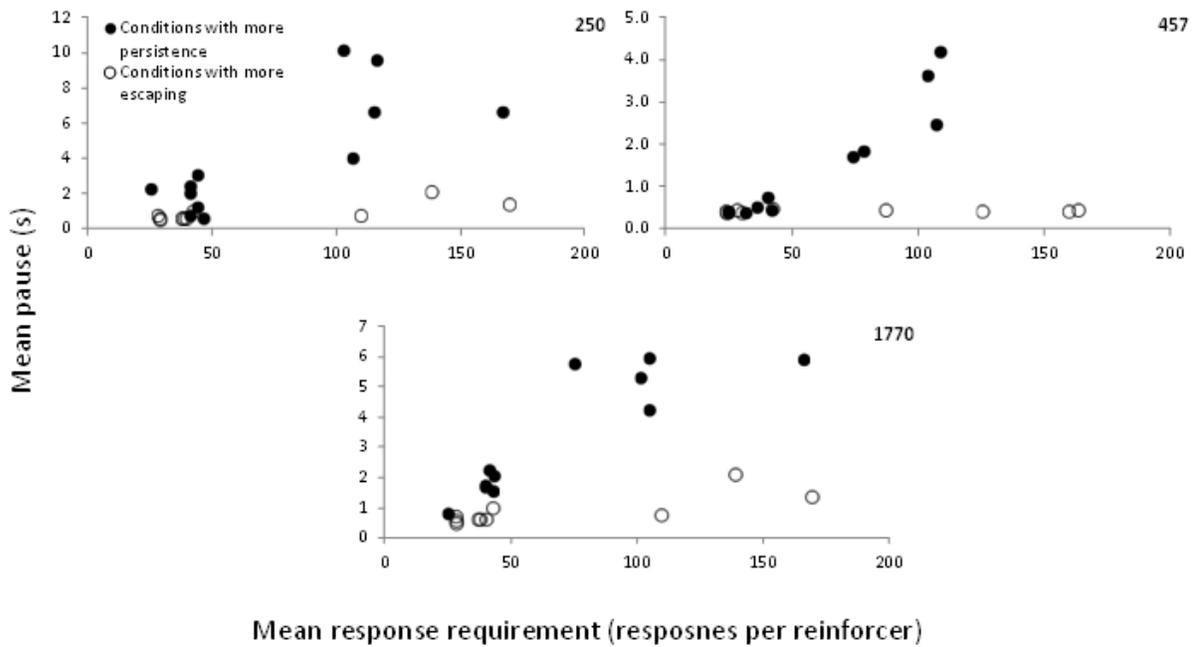


Figure 5-3. Mean pause length, as a function of the mean acquired response requirement, by subject. Solid points are conditions on which proportion persistence was greater than 0.5, open points are conditions on which proportion persistence was less than 0.5.

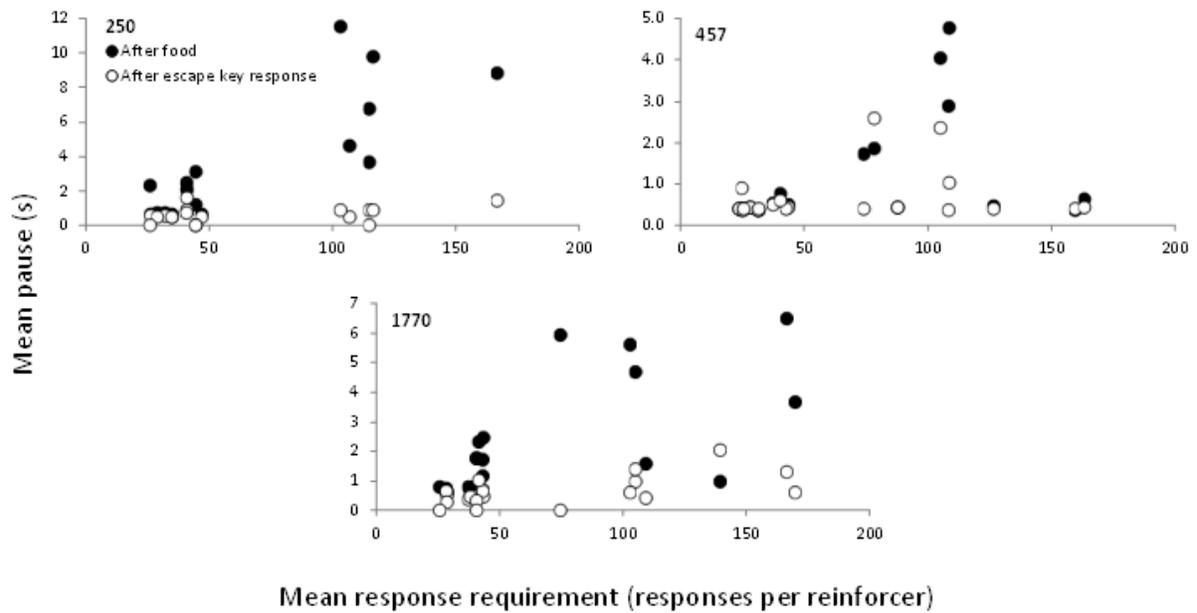


Figure 5-4. Mean pause length, as a function of the mean acquired response requirement, by subject. Solid points are mean pauses occurring immediately after a food presentation, and open circles are pauses occurring immediately after an escape response.

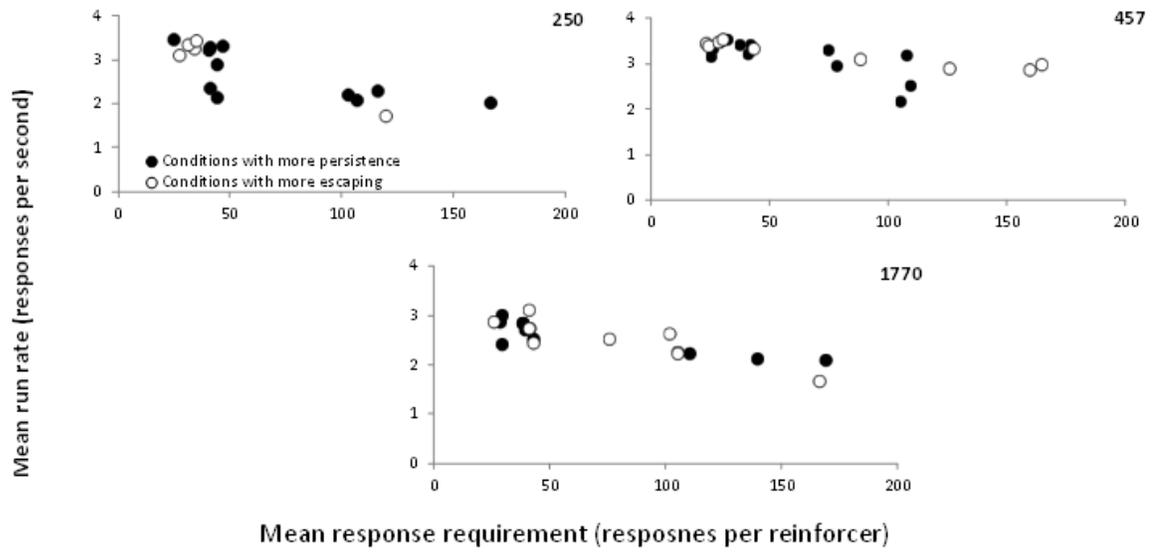


Figure 5-5. Mean run-rate as a function of mean response requirement. Closed circles are conditions for which proportion persistence was greater than 0.5. Open circles are conditions for which proportion persistence was below 0.5. Solidlines are the best fitting linear regression line for both sets of data.

CHAPTER 6

EXPERIMENT 4: MANIPULATING THE OPTIMAL ESCAPE POINT

In Experiment 2, neither the size nor the probability of the second ratio strongly predicted levels of persistence, suggesting again that the critical choice occurred after the initial ratio; the size of later ratios appeared to exert little control over escape. In Experiments 1 to 3, escape occurred either relatively soon after the initial (FR 10) ratio was completed, or not at all. Experiment 4 investigated whether consistent escape responses would occur after the second ratio if this pattern was favored strongly enough by the contingencies.

To this end, pigeons were exposed to a schedule arrangement under which it was optimal to escape after having completed the second to smallest ratio (FR 20). Two stimulus-changes-present conditions were also included. In one, the transitions between every ratio were signaled. Therefore, in order to make optimally timed escape responses, subjects had to disregard the stimulus change indicating that the smallest ratio had been completed, and continue responding on the schedule key until the completion of the next ratio, and the associated stimulus change. In the second stimulus changes condition, only the optimal escape point (here, FR 20) was signaled. This allowed a further investigation of the effects of varying how easily discriminated the optimal escape point was on the timing of escape responses.

It was predicted that the optimal escape point would be the most difficult to discriminate when it was not associated with any stimulus change, of intermediate discriminability when it was associated with a change in the key light flash rate (in the condition where all ratio transitions were signaled), and easiest to discriminate in the condition where it was signaled by a change from a static to a flashing key light. It was

further predicted therefore that these differences in levels of discriminability would be associated with differences in how close to the optimal point in the trial escape key responses were made.

Method

Subjects and Apparatus

For logistical reasons, it was only possible to include two subjects, 457, and 1770 in Experiment 4. These subjects' living conditions were as for Experiments 1-3. The apparatus were also as for the previous three experiments.

Procedure

During all three conditions in Experiment 4, four ratios were arranged on the schedule key as follows: FR 10 was programmed on 10% of trials, FR 20 on 70%, FR 200 on 10%, and FR 300 during the remaining 10% of trials. Although FR 10 was the smallest programmed ratio, because it was relatively rare and FR 20 was so frequently presented, the optimal response pattern was to complete 20 schedule key responses before escaping. Such a pattern effectively avoided the larger two ratios, thereby minimizing the mean overall response requirements. Specifically, escaping immediately after completing every FR 10 trial would result in a mean response requirement of 109 responses, while escaping consistently after completing the FR 20 trials without reinforcement would result in a much lower mean response requirement: 21.5 responses. Persisting on every trial would result in an intermediate response requirement of 65.

These schedule arrangements were held constant across three conditions. In one condition there were no stimulus changes. In a second condition, there were 3 stimulus changes— occurring following the non-reinforced completion of each of the smaller

three ratios. Stimulus changes took the form of alterations to the rate at which the schedule key light flashed. This arrangement was therefore similar to the stimulus changes condition presented during Experiment 2. In a third condition, only one stimulus change — after 20 responses (the optimal escape point) — was presented. Specifically, after 20 responses the flash key light changed from static white to alternating between off and lit white every one second. This was the stimulus change that followed the twentieth schedule key response during the three stimulus changes condition. Pigeon 457 completed the stimulus-changes-absent condition followed by the three stimulus changes condition, and the one stimulus change condition, while 1770 completed the stimulus-changes-absent condition, followed by the one stimulus change condition, and the three stimulus changes condition. The stimulus-changes-absent condition was then replicated for both pigeons to investigate any lasting effect of experience with these added stimulus changes.

Dependent Variables

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

Results and Discussion

In no condition did either subject make the sunk cost error by persisting to the extent of completing ratios after the optimal escape point. Pigeon 457 did not complete any of these larger ratios during any of the four conditions during the stable period. Pigeon 1770 completed 2% of such larger ratios during the one stimulus change condition, but did not complete any of them during any of the other conditions.

Neither did either pigeon make the reverse sunk cost effect of escaping too early (as occurred in some cases when stimulus changes were present during Experiment 3) when it was optimal to persist, for example escaping after the completion of the smallest (FR10) ratio. Rather, on average, the pigeons escaped somewhat soon after having completed the second-smallest ratio. This was similar to the timing of their escape key responses relative to the (earlier) optimal escape point in the previous three experiments.

Given the floor effect on proportion persistence in the no stimulus changes condition, it was not possible for the addition of stimulus changes to reduce persistence as it had in Experiment 3. However, the addition of stimulus changes did affect the accuracy of escape responses, as they had in Experiment 3. As can be seen from Figure 6-1, and as predicted, the timing of escape responses for both pigeons approximated the optimal point most accurately when only that point was signaled, and least accurately when there were no additional stimulus changes; signaling all transitions in expected ratio produced intermediate accuracy. Additionally, escape for both pigeons more closely approximated optimality the second time they experienced the stimulus-changes-absent condition, that is, after having experienced the two conditions with stimulus changes added. Experience with the stimulus changes thus appeared to produce long lasting improvements in optimal responding. Such effects were not observed when stimulus-changes-absent conditions were replicated during Experiment 3, however, so it is difficult to draw a firm conclusion regarding such history effects from the present data.

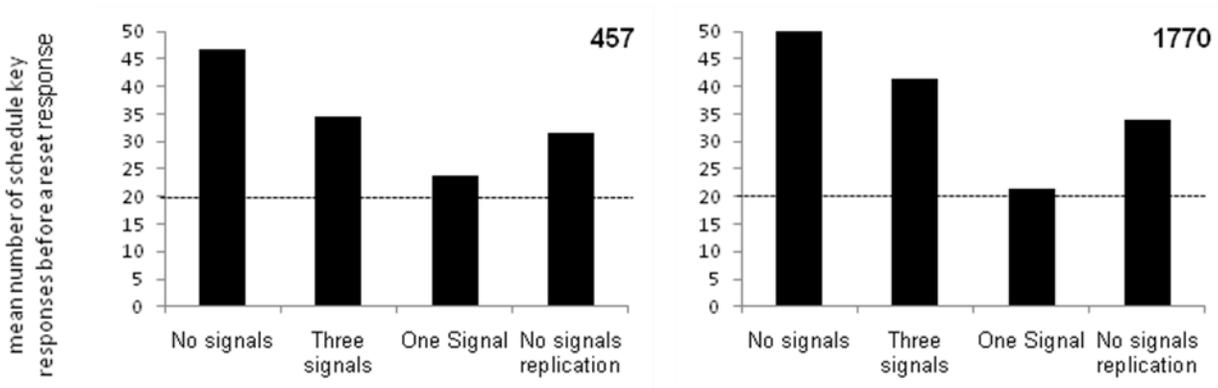


Figure 6-1. Mean number of schedule key responses made before an escape key response, by subject and condition. The horizontal line at 20 indicates the number of schedule key responses after which it was optimal, in terms of mean response requirement, to make an escape key response.

CHAPTER 7 GENERAL DISCUSSION

The Overall Contribution of the Current Study

In the present study, pigeons made two separable but inter-related decisions: (1) *whether* to persist or escape, and (2) *when* to do so. Both of these decisions are likely important to adaptive behavior in everyday contexts, and the current study suggests that both must be considered in accounting for the sunk cost error. The most significant finding from the present study is that decisions about whether to persist were related to their overall costs to some extent, but not to the extent of avoiding the sunk cost error. Experiments 1 and 3 showed that the tendency to persist varied as an orderly function of the ratio of the expected response requirements for persisting and escaping. This is consistent with Navarro and Fantino's (2005) conclusion that levels of persistence on the current task were sensitive to the extant contingencies for persistence and escape, a pattern also observed by Avila-Santibanez et al. (2010) during conditions in which stimulus changes were absent. It is also consistent with De La Piedad et al.'s (2006) finding that persistence occurred less frequently in the condition where it produced an extinction contingency.

The present study takes the analysis of the sunk cost effect a step further in three key ways. Firstly, it identified the features of the contingencies that most strongly control levels of persistence (in Experiments 1 and 2). This feature was the ratio of the global mean response requirements for persistence and escape. This suggested that the sunk cost effect may arise from the global contingencies, rather than the local contingencies acting at the choice point.

Secondly, the current study explored persistence over a wider range of contingencies, finding intermediate levels of persistence that did not occur in the conditions presented by Navarro and Fantino, and showing that the frequency of the error varies as a graded function of its costs. Therefore, although it appeared that behavior was sensitive to the global consequences for the two possible extreme response strategies, in some conditions pigeons adopted an intermediate pattern of behavior where they persisted on some trials and escaped on others. It is notable that the relative response requirements of the two global patterns that could be adopted (persisting on every trial and escape on every trial) apparently influenced pigeons' levels of persistence even while they adopted neither global response pattern.

The third contribution of the current set of experiments was to extend the analysis that had been previously conducted of the effects of added stimulus changes. Experiments 3 and 4 showed that when escape was the optimal behavior, choices became more optimal under conditions including an added stimulus change signaling the optimal escape point. This was consistent with prior results, and the present findings additionally demonstrated that these added stimulus changes affect the timing of escape responses. This improvement in subjects' approximation of the optimal escape point had the effect of increasing the obtained response requirement advantages of escaping. This might have, in turn, contributed to the increased frequency with which subjects escaped when stimulus changes were present.

Experiment 4 further demonstrated that when only one of several experienced stimulus changes signaled the optimal escape point, pigeons' behavior was controlled by that stimulus change in particular, making escape key responses approximately the

optimal time. All else being equal, therefore the sunk cost error may be seen as a tendency to persist as the default strategy in situations in which the response requirement for doing so is insufficiently different from the response requirement for escaping and/or the optimal escape point is difficult to discriminate.

The current findings are also consistent with research into two other decision making errors: base-rate neglect and the conjunction fallacy. Both have been found to occur in non-verbal analog tasks with humans (Fantino and Savastano, 1996; Goodie & Fantino), and, in the case of base-rate-neglect, with pigeons (Hartl & Fantino, 1996; Fantino, Kanevsky & Charlton, 2005). Together, this body of research demonstrates the utility of such an experimental approach to investigating these instances in which individuals consistently choose alternatives that do not maximize overall reinforcement rate. The current study found that choices about whether to persist were not completely unaffected by the contingencies, even while also demonstrating the sunk cost error in some instances. This imperfect sensitivity to the contingency (rather than completely arbitrary or completely optimal response patterns) has also been demonstrated in the case of base-rate neglect and the conjunction fallacy (Zizzo et al. 2000), with individuals demonstrating what has been referred to in some other domains as “bounded rationality” (e.g. Diamond, & Vartiainen, 2007; Kahneman, 2003)

Definition of persistence in the current study

In the current study proportion persistence was defined as the proportion of ratios completed larger than the smallest one. This was the same definition adopted by Navarro and Fantino (2005) and Avila-Santibanez et al. (2010). Completing the smallest ratio was always optimal and so trials on which the smallest ratio was programmed were not factored into the calculations of proportion persistence used here (for

Experiment 4, trials on which the smaller two ratios were presented were excluded from this calculation because it was optimal to complete them). Persistence defined in this manner reliably co-varied with changes in reinforcement contingencies in the current study, indicating that it captured a meaningful aspect of the pigeons' behavior.

This definition of persistence is less than ideal, however, for two reasons: firstly, because it defines persistence in part with reference to the current ratio, thus conflating aspects of the subjects' behavior with an aspect of the environmental manipulation. . Therefore, for example, completing 80 schedule key responses would be classified as persistence on a trial on which the ratio was FR80, but not when it was FR160. The second problem is that the current definition requires each of many possible response patterns to be classified as either persistence or escape. Therefore, for example on an FR160 trial, making an escape key response up to the 159th response would not be classified as persistence even given the amount of time the subject had spent making schedule key responses that were no longer optimal.

In spite of the potential for such classification problems, this definition of persistence was retained in the current study. This was in part for consistency and comparability with previous studies. Additionally, problems of the type described above did not arise in practice in the current study because pigeons either escaped relatively soon after doing so became optimal, or persisted to complete the ratio whatever its size. Therefore, there was clear separation in response pattern between trials classified as persistence and trials classified as escape. The inclusion of a second dependent variable-- the mean number of responses to escape—also allowed for a more graded assessment of subjects' patterns of responding that supplemented the proportion

persistence measure, and did not have the binary classification problem described above.

Sensitivity to Number

Decisions about when to cease persisting require sensitivity to the levels of investment already made. In the stimulus-changes-absent conditions of the present study pigeons escaped after approximately the optimal number of schedule key responses, suggesting perhaps that their behavior was under the control of the number of prior responses during that trial, albeit with the caveat that it is not known to what extent their behavior also reflected sensitivity to the passage of time. If the current subjects were sensitive to the number of key pecks they had recently made, then, this is consistent with previous research showing that pigeons' behavior can come under stimulus control by this feature of their own past behavior.

For example, Hobson (1975) presented pigeons with one of two sample ratios and then two comparison response alternatives. Responding on one comparison produced reinforcement when the sample ratio had been the shorter of the two possible and responding on the other comparison produced reinforcement when the sample had been the longer of the two possible ratios. On the condition most relevant to the discrimination required by the current task the pigeons chose the correct comparison at above chance when the two possible sample ratios were FR 9 and FR 10. This result is consistent with current speculation that our pigeons' escape responding was under the control of the number of prior responses on the current trial.

It is also notable that our pigeons consistently overshot the smallest ratio. This may be an additional manifestation of their overall tendency to persist. An additional explanation for this the slight overshooting is that the costs (defined in terms of

increased response requirement) for overshooting were small compared to the costs for undershooting. This is because undershooting errors had the potential to result in missing the small ratio, should it be programmed on the current trial.

This tendency to overshoot the optimal escape point can also be seen as subjects underestimating the number of responses they have made on the schedule key since the beginning of the trial. Such underestimation is consistent with the “choose small” effect observed by Fetterman and MacEwen (1989). This effect occurs on the procedure described above in which subjects are required to make responses indicating whether a sample ratio they recently completed was “small” or “large”. Specifically, if a delay is added between the sample and the presentation of the comparisons, subjects have a tendency to make errors in the direction of miss-classifying the large ratio as small, and therefore underestimating its size. It may be that the mechanisms underlying this effect also contribute to the current subjects’ tendency to overshoot the smallest ratio before they made an escape key response.

The conditions on which stimulus changes were present reduced the mean number of schedule key responses by which pigeons overshot the optimal escape point. This suggests that these exteroceptive stimulus changes in the form of a flashing light were more discriminable than the pigeons’ own recent past behavior in that they exerted stronger control over the timing of their escape responses. This is consistent with research comparing stimulus control by these two types of stimuli. For example, Ferster and Peele (1980) compared subjects’ performance on FR schedules in the presence and absence of an external stimulus correlated with the number of responses they had made so far in their ratio. Ferster and Peele’s conclusion was that “*the main difference*

between the control by the visual added counter and the bird's own behavior as a controlling stimulus is the imprecision of the latter compared with the former" (p103).

Reverse Sunk Cost Errors and Impulsivity

When making a decision about whether to persist, there are two errors that an individual can make. The first -- persisting when escaping is optimal -- is the sunk cost error. The second possible error is escaping when persistence is optimal, which Navarro and Fantino (2005) suggested might reflect impulsivity. Impulsivity is defined as choosing a smaller reinforcer that will occur after a shorter delay over a larger reinforcer that will occur after a longer delay. Although it is often to their overall advantage to wait to obtain a larger reinforcer, people and animals often choose to receive a smaller reinforcer after a shorter delay, behaving impulsively.

Navarro and Fantino (2005) discussed the possibility that escape may occur because it is the response with the potential to produce the shortest-ever-available delay to reinforcement (after the shortest ratio). Therefore, escape might be driven by impulsivity rather than the overall contingencies. Their initial suggestion was that all escape may be driven by the mere possibility of such relatively immediate reinforcement, even in conditions where it is also favored by the overall contingencies. Their finding (in Experiment 2) that subjects persist when doing so is optimal, even though such small ratios are still occasionally produced by escape suggests that this is not the case. This was confirmed by results in the current study, and Avila-Santibanez et al. (2010) where subjects also generally persisted in stimulus-changes-absent conditions where such persistence was optimal.

As Navarro and Fantino (2005) noted, however, their study did not rule out the possibility that escape in escape-optimal conditions was driven by the increased

probability of producing a small ratio following escape, rather than the overall contingencies. This was because, in their study, conditions favoring escape also had a higher probability of the smallest ratio than those favoring persistence. The current Experiment 2 found that the probability of FR10 trials during a given condition was less strongly predictive of escape than were features of the overall contingencies. This suggests that escape is not impulsive behavior driven by the probability of producing relatively immediate food.

The current study did find evidence for escape even when persistence was supported by the contingencies, however. This occurred during persistence-optimal conditions where stimulus changes were present. This effect was also observed by Avila-Santibanez et al. (2010), who suggested that escaping during a persistence-optimal condition could be described as impulsivity. The current results were insufficient to determine whether the frequency of escape when stimulus changes were present was associated with the probability of FR10 trials rather than with the overall contingencies because these two variables were correlated strongly in the conditions presented in Experiment 3. Replicating the conditions presented in Experiment 2 where the probability of FR10 was dissociated from the overall contingencies would test this possibility empirically. It is unclear why the presence of stimulus changes would affect the manner in which the frequency of FR10 trials controlled subjects' levels of persistence, however.

It may also be, as suggested above, escape in persistence-optimal conditions in which stimulus changes are present is actually maintained by (immediate) escape from the signals. That is, the signals may have acquired aversive properties due to being

paired with high work requirements. Although the value of escape from these stimulus changes is presumably smaller than that of food, subjects may choose to escape the signals because this occurs after a shorter delay (and, additionally occurs following after every escape while FR10 trials are of lower probability). If so, the reverse sunk cost effect should be reduced if both either the signals are brief or if persistence and escape both terminate the presentation of the signals.

De la Piedad et al. (2006) drew an additional connection between the sunk cost effect and impulsivity. In situations in which individuals are choosing between smaller, sooner reinforcers and larger later reinforcers, they may initially prefer the larger, later, reinforcer but switch their preference to the smaller, sooner reinforcer after time has elapsed and the delay to both reinforcers has decreased. This change from self-control to impulsivity is referred to as preference reversal. De la Piedad et al. speculated that the sunk cost effect may occur because it reduces the probability of preference reversal. That is, if an individual initiates and invests in a course of action leading to a larger, later reinforcer prior to undergoing preference reversal, then this investment and the sunk cost effect may work against preference reversal by increasing persistence on the response alternative producing the larger, later reinforcer, allowing the animal to achieve the larger, later reinforcer.

Siegel and Rachlin (1995) demonstrated that preference for larger, later reinforcers is increased if the ratio requirement is increased on both alternatives, an effect they termed soft commitment. Soft commitment increases preference for the larger, later alternative in spite of the fact that the smaller, sooner is also continuously available and the subject may switch to it at the point at which preference reversal is

typically observed when the ratio on both alternatives is FR1. De la Piedad et al. (2006) suggested that soft commitment “*may be interpreted as a manifestation of the sunk cost effect, and vice-versa*” (p. 20). Overall, it is likely useful to seek to explain instances of the reverse sunk cost effect by attempting to identify relatively immediate reinforcers that might be maintaining this behavior in spite of the apparently more valuable or overall more frequent reinforcers available for persisting.

Future Research: Type of Investment

In the current study, subjects had invested both time and effort in responding on the schedule key before the choice point. It was not possible to disentangle the contribution of each of these types of investment to the levels of persistence observed in the current procedure. Future research could usefully investigate the extent to which the sunk cost effect occurs, and is affected by the environmental factors identified here, for investments of time, effort, and investments of other resources such as money separately. Investments of effort could be manipulated independently of investments of time by, for example, varying the force required on a response manipulandum.

Investments of time could be isolated by using the current procedure but with a mixed fixed-time schedule programmed on the schedule key instead of the current mixed fixed-ratio schedule. That is, once the trial had begun there would be a set likelihood that non-contingent food would occur after some period of time. If this did not occur then subjects' response alternatives would be whether to persist with the trial, which would not produce food for a longer period of time, or abandon it in favor of a new trial. Whether or not the end of the smallest fixed time duration was signaled could be varied across conditions.

Additionally, token reinforcement schedules could be used as non-human animal analogs of human investments of money. Token schedules consist of a response requirement to produce tokens, followed by a response requirement to produce the opportunity to exchange, and then a response requirement to exchange tokens for other already-effective reinforcers such as food (see Hackenberg, 2008 for a discussion of such schedules) On such a schedule, tokens would first be earned, and then some portion of the earned tokens could be “invested” on a mixed exchange schedule. As in the current study, some such investments would pay off, but on other trials subjects would choose between investing additional tokens and escaping to begin investing in another exchange ratio using their remaining tokens.

Future Research: the Sunk Cost Magnitude Effect

In Navarro and Fantino’s (2005) study the conditions during which pigeons were most likely to persist were those on which this response pattern was favored by the contingencies, and on which they had invested more responses at the choice point (because the smallest ratio was larger). Therefore, based on their results alone it was not possible to determine the extent to which each of these features, alone or in combination, increased persistence. The current study found that pigeons persisted where this response pattern was favored by the contingencies, even when the amount of initial investment was held constant. This demonstrated that differences in the number of responses invested were not necessary to produce differences in levels of persistence.

Past research, however, has found that having invested more at the choice point does lead to a higher probability of persistence in humans (e.g. Garland, 1990; Navarro & Fantino, 2009). Additionally, De la Piedad et al. (2006) found that the longer the time

pigeons had spent responding on a response-initiated FI schedule the more likely they were to keep responding on that alternative, consistent with their behavior being influenced by the number of responses they had already invested. This variable has not been directly manipulated in studies with non-human animals, however; doing so would strengthen the conclusion that amount of past investment increases the likelihood of persistence in non-human animals as it does in humans. An alternative is that any past investment increases animals' future tendency to increase by the same amount.

Amount of past investment could be directly manipulated within the current task by varying the size of the smallest ratio from trial to trial, for example including some small investment trials with a relatively low smallest possible ratio and others with a relatively large smallest possible ratio. The opportunity to escape would only be presented upon the completion of this initial ratio. The size of the larger possible ratios beginning from this choice point would be held constant. This would hold the consequence of persistence constant across initial investment size. The consequence of escape would be held constant because the size of the smallest ratio would vary unpredictably from trial to trial meaning that the mean expected ratio at the beginning of a trial (and therefore following escape) was unaffected by the amount of initial investment made in the immediately preceding trial. Therefore, any difference in levels of persistence observed between the two ratio sizes would be evidence that the frequency with which animals make the sunk cost effect increases with the amount of initial investment made. Directly manipulating amount of past investment would provide an additional line of evidence that past investment is a variable that directly controls future persistence in non-human animals.

Conclusion

The sunk cost effect is of interest both as a decision-making error with applied relevance for humans, and as an instance in which an individual's own previous behavior is a variable that controls their future behavior. The current study demonstrated that whether subjects persisted to make the sunk cost error depended on the contingencies. Specifically, the sunk cost effect occurs in a contingency range where the cost of persistence is relatively low. Additionally, the frequency of the sunk cost effect is altered by variables enhancing the salience of the optimal point at which to cease persisting. Future research should therefore consider both whether and when subjects escape under conditions in which persistence is favored by the contingencies.

APPENDIX A
ABSOLUTE NUMBERS OF TRIALS WITH ESCAPE AND PERSISTENCE –
EXPERIMENT 1

Table A-1. Mean absolute numbers of ratios programmed and completed for Pigeon 250 during the last five sessions of the conditions presented during Experiment 1, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4	39.60	38.80	39.00	1.20	0.03
E	10.20	10.00	30.80	30.00	0.98
R1	14.00	14.00	26.00	26.00	1.00
R3	34.20	34.00	51.40	6.00	0.12
R2	17.40	17.40	26.40	22.60	0.86
R1	14.00	14.00	26.00	26.00	1.00

Table A-2. Mean absolute numbers of ratios programmed and completed for Pigeon 456 during the last five sessions of the conditions presented during Experiment 1, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4	43.00	38.80	44.00	1.20	0.03
E	10.80	10.80	31.20	29.20	0.94
R1	16.40	16.40	31.00	23.60	0.76
R2	37.00	35.40	54.80	4.60	0.08
P1	0.60	0.60	12.00	12.00	1.00

Table A-3. Mean absolute numbers of ratios programmed and completed for Pigeon 457 during the last five sessions of the conditions presented during Experiment 1, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4	26.40	26.20	25.80	13.80	0.54
E	10.20	10.20	30.40	29.80	0.98
R4	27.60	27.60	23.80	12.40	0.52
P1	3.20	2.80	41.80	37.20	0.89
R5	40.40	39.40	27.00	0.60	0.02
P1	3.20	3.20	42.40	36.80	0.87
R5	39.80	39.60	27.80	0.40	0.01
R4	37.80	37.80	36.40	2.20	0.06
R1	23.40	23.00	42.80	17.00	0.40

Table A-4. Mean absolute numbers of ratios programmed and completed for Pigeon 1770 during the last five sessions of the conditions presented during Experiment 1, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4	40.00	37.80	40.40	2.20	0.06
E	11.40	11.40	33.80	28.60	0.85
R1	24.60	24.40	43.80	15.60	0.36
P1	2.60	2.60	41.40	37.40	0.91
R1	31.20	30.00	56.80	10.00	0.18
P2	2.60	2.60	37.40	37.40	1.00
E	10.20	10.20	30.40	29.80	0.98

APPENDIX B
ABSOLUTE NUMBERS OF TRIALS WITH ESCAPE AND PERSISTENCE –
EXPERIMENT 2

Table B-1. Mean absolute numbers of ratios programmed and completed for Pigeon 250 during the last five sessions of the conditions presented during Experiment 2, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4 a	7.00	7.00	28.40	27.80	0.98
P1 a	10.00	10.00	30.00	30.00	1.00
R1 a	4.80	4.80	48.00	35.20	0.75
E a	13.40	12.40	117.40	27.60	0.24

Table B-2. Mean absolute numbers of ratios programmed and completed for Pigeon 457 during the last five sessions of the conditions presented during Experiment 2, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4 a	33.60	33.40	139.40	6.60	0.05
P1 a	10.00	10.00	30.20	30.00	0.99
R1 a	28.40	27.20	260.00	12.80	0.05
E a	14.60	14.00	131.40	26.00	0.21
P1 a	10.20	10.20	29.80	29.80	1.00
R1 a	37.00	36.00	325.00	4.00	0.01

Table B-3. Mean absolute numbers of ratios programmed and completed for Pigeon 1770 during the last five sessions of the conditions presented during Experiment 2, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R4 a	34.20	28.80	134.20	3.60	0.02
E a	5.00	4.80	43.60	35.20	0.81
R1 a	4.00	4.00	38.00	33.40	0.88
R4 a	29.60	26.40	120.40	13.00	0.13
R1 a	15.80	15.40	150.60	24.00	0.17
P1 a	10.00	10.00	30.00	30.00	1.00

APPENDIX C
ABSOLUTE NUMBERS OF TRIALS WITH ESCAPE AND PERSISTENCE –
EXPERIMENT 3

Table C-1. Mean absolute numbers of ratios programmed and completed for Pigeon 250 during the last five sessions of the conditions presented during Experiment 3, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R1	14.00	14.00	26.00	26.00	1.00
R1S	30.00	29.80	59.40	10.20	0.18
R1	20.60	20.60	37.00	19.40	0.53
R4	32.60	32.20	33.80	7.80	0.23
R4S	36.40	36.40	34.20	3.60	0.11
R4	34.40	33.20	31.60	6.80	0.22
P1	3.20	3.00	52.60	37.00	0.83
P1S	10.80	10.60	166.60	19.60	0.11
P1	2.60	2.60	42.00	37.40	0.89
E	10.40	10.40	30.60	29.60	0.97
ES	10.40	10.40	30.20	29.60	0.98

Table C-1. Mean absolute numbers of ratios programmed and completed for Pigeon 457 during the last five sessions of the conditions presented during Experiment 3, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R1	23.40	23.00	42.80	23.00	0.40
R1S	40.00	40.00	72.40	40.00	0.00
R4	30.40	30.40	28.40	30.40	0.34
R4S	40.00	40.00	39.60	40.00	0.00
P1	3.20	3.20	43.80	3.20	0.85
P1S	3.00	3.00	41.40	3.00	0.90
E	10.00	10.00	31.40	10.00	0.96
ES	17.00	17.00	49.40	17.00	0.48
P2	1.60	1.60	39.00	1.60	0.98
P2S	3.80	3.80	46.80	3.80	0.78
P2	3.00	3.00	37.40	3.00	0.99

Table C-1. Mean absolute numbers of ratios programmed and completed for Pigeon 1770 during the last five sessions of the conditions presented during Experiment 3, in the order in which the conditions were presented.

Condition	Mean FR10 trials programmed	Mean FR10 trials completed	Mean ratios larger than 10 programmed	Mean ratios larger than 10 completed	Mean proportion persistence
R1	22.80	22.20	39.40	17.80	0.46
R1S	33.80	33.80	63.60	6.20	0.10
R1	26.60	26.40	44.80	13.60	0.31
P1	2.40	2.40	39.00	37.60	0.96
P1S	2.60	2.60	38.20	37.40	0.98
R4	33.40	33.00	32.20	7.00	0.22
R4S	37.40	37.00	35.60	3.00	0.08
R4	33.40	33.00	32.60	7.00	0.22
E	10.00	10.00	30.00	30.00	1.00
ES	13.60	13.60	40.20	26.40	0.68
E	10.00	10.00	31.60	30.00	0.96

APPENDIX D
ABSOLUTE NUMBERS OF TRIALS WITH ESCAPE AND PERSISTENCE –
EXPERIMENT 4

Table D-1. Mean absolute numbers of ratios programmed and completed for Pigeon 457 during the last five sessions of the conditions presented during Experiment 4, in the order in which the conditions were presented.

Condition	Mean FR10 and FR 20 trials programmed	Mean FR10 and FR 20 trials completed	Mean ratios larger than 20 programmed	Mean ratios larger than 20 completed	Mean proportion persistence
No signals	40	40	8.8	0	0
Three Signals	40.4	40	9	0	0
No signals replication	40.2	40	10	0	0
One Signal	40.2	40	10.2	0	0

Table D-2. Mean absolute numbers of ratios programmed and completed for Pigeon 1770 during the last five sessions of the conditions presented during Experiment 4, in the order in which the conditions were presented.

Condition	Mean FR10 and FR 20 trials programmed	Mean FR10 and FR 20 trials completed	Mean ratios larger than 20 programmed	Mean ratios larger than 20 completed	Mean proportion persistence
No Signals	40.6	40	9.6	0	0
One Signal	41.8	39.8	9.4	0.2	0.02
Three Signals	40.4	40	10.2	0	0
No Signals Replication	40.6	40	10.6	0	0

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BIOGRAPHICAL SKETCH

Anne Macaskill completed her undergraduate degree, a Bachelor of Science with honors, in psychology at the University of Otago and Victoria University of Wellington, both in New Zealand. Anne then completed her Master of Science at Victoria under the supervision of Maree Hunt and Dave Harper. This project was an investigation of Evaluative Conditioning in adult humans. Anne then moved to the University of Florida to complete the dissertation presented here, and earn her PhD. During this time, she also completed other projects in basic behavior analysis and behavioral pharmacology.