

See discussions, stats, and author profiles for this publication at: <https://www.researchgate.net/publication/6575625>

# Stimulus–outcome interactions during instrumental discrimination learning by rats and humans

Article in *Journal of Experimental Psychology Animal Behavior Processes* · February 2007

DOI: 10.1037/0097-7403.33.1.1 · Source: PubMed

---

CITATIONS

48

---

READS

141

5 authors, including:



**Sanne de Wit**

University of Amsterdam

47 PUBLICATIONS 1,734 CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:



Alcohol dependence across the brain; from vulnerability to compulsive drinking [View project](#)

# Stimulus–Outcome Interactions During Instrumental Discrimination Learning by Rats and Humans

S. de Wit, D. Niry, R. Wariyar, M. R. F. Aitken, and A. Dickinson  
University of Cambridge

The associative structure mediating goal-directed action was investigated using congruent and incongruent conditional discriminations. The stimulus was the same as the outcome in each component of the congruent discriminations, whereas the stimulus of one component of the incongruent discriminations was the same as the outcome of the other component. Humans, but not rats, learned the congruent discrimination more rapidly than the incongruent discrimination, a difference that the authors attribute to the fact that outcome–response associations caused response conflict in the incongruent discrimination. Moreover, responding was resistant to outcome devaluation following incongruent, but not congruent, training, suggesting that both humans and rats adopted a stimulus–response strategy to resolve the incongruent discrimination.

**Keywords:** instrumental learning, response conflict, humans, rats, discrimination

Although it is well established that instrumental actions can be mediated by a representation of the reinforcer or outcome (Adams & Dickinson, 1981; Colwill & Rescorla, 1985), what is far from certain is the associative structure by which outcome representations exert their control over behavior. The simplest structure is that invoked by associative two-process theories, which assume that reinforcing a response (R) with an outcome (O) in the presence of a stimulus (S) establishes an  $S \rightarrow O \rightarrow R$  associative chain. According to these theories, a stimulus retrieves a memory of any associated outcome, which in turn activates the response that in the past has procured this outcome. Associative two-process theories argue that the  $S \rightarrow O$  association is brought about by the Pavlovian or predictive relationship between the stimulus and outcome, whereas the  $O \rightarrow R$  association is either a direct product of the instrumental contingency between the response and the outcome (Asratyan, 1974; Pavlov, 1932; see Gormezano & Tait, 1976, for a review) or arises from the reinforcement of the response in the presence of an activated representation of the outcome through the classic stimulus–response–reinforcement mechanism (Trapold & Overmier, 1972). However, the distinction between these two mechanisms is not relevant to the present studies, and we shall refer to both accounts as *outcome–response theory* because both assume that an  $O \rightarrow R$  association mediates instrumental responding.

Although outcome–response theory has been extensively evaluated by a variety of procedures (see Urcuioli, 2005, for review), one prediction of the theory that has received relatively little attention is that performance of biconditional discriminations should depend on the congruency of the stimuli and the outcomes. Specifically, the performance of an incongruent discrimination in which the stimulus assigned to one response is the same as the outcome of another response should be degraded by conflict or interference according to outcome–response theory. Figure 1 illustrates the component contingencies of an incongruent discrimination and the resulting associative structures. Event A, when presented as a stimulus,  $S_A$ , signals that one response,  $R_X$ , will be reinforced by Event B as an outcome,  $O_B$ , and that the other response,  $R_Y$ , will be nonreinforced,  $\emptyset$ . According to outcome–response theory, this contingency should set up an associative structure of the form  $A \rightarrow B \rightarrow R_X$ . On trials from the other component contingency, Event B as the stimulus,  $S_B$ , signals that  $R_Y$  will be reinforced with Event A as the outcome,  $O_A$ , and that  $R_X$  will be nonreinforced, resulting in a  $B \rightarrow A \rightarrow R_Y$  structure. To the extent that the encoding of an event as a stimulus overlaps with its encoding as an outcome, the two component contingencies of the incongruent discrimination should engender response conflict. This conflict arises from the fact that although Event A, when presented as  $S_A$ , will activate the correct response indirectly through the  $A \rightarrow B \rightarrow R_X$  structure, it will also directly activate the incorrect response through the  $A \rightarrow R_Y$  link of the  $B \rightarrow A \rightarrow R_Y$  structure established in the other component of the discrimination.

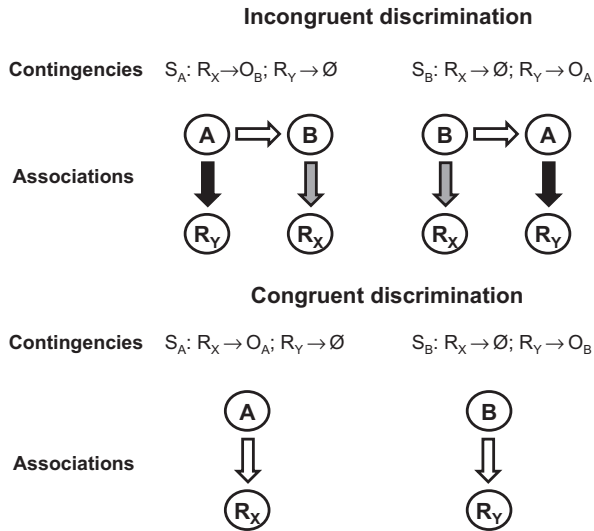
The acquisition of this incongruent discrimination can be contrasted with learning a congruent discrimination in which the stimulus and outcome assigned to a response are the same type of event (see Figure 1). The learning of this discrimination simply requires the acquisition of two nonconflicting single associations,  $A \rightarrow R_X$  and  $B \rightarrow R_Y$ , and a congruent discrimination should therefore be acquired faster than an incongruent discrimination. However, the extant studies of stimulus–outcome congruency within discrimination learning have failed to provide strong sup-

---

S. de Wit, D. Niry, R. Wariyar, M. R. F. Aitken, and A. Dickinson,  
Department of Experimental Psychology, University of Cambridge, Cambridge, England.

This research was supported by Merck, Sharp, and Dohme's Educational Program and the University of Cambridge Behavioural and Clinical Neuroscience Institute, supported by a joint award from the Medical Research Council and the Wellcome Trust.

Correspondence concerning this article should be addressed to S. de Wit, Department of Experimental Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, England. E-mail: sd322@cam.ac.uk



*Figure 1.* The component contingencies of the incongruent and congruent discriminations and the associative structures engendered by these contingencies according to outcome–response theory. Arrows with the same shading represent the same associations. S = stimulus; R = response; O = outcome;  $\emptyset$  = no outcome; A = Event A; B = Event B; X = one response; Y = other response.

port for this prediction of outcome–response theory. Peterson, Linwick, and Overmier (1987) used food and nonfood events as the stimuli and outcomes with pigeons, whereas Dickinson and de Wit (2003) trained rats with different types of foods: mixed diet pellets and sucrose solution. In neither study was there a reliable difference in the acquisition of the two discriminations, although Peterson et al. (1987) reported that discriminative control declined more rapidly in the incongruent discrimination relative to the congruent one, with increments in the delay between the presentation of the stimulus and the opportunity to respond (but see Linwick, Overmier, Peterson, & Mertens, 1988).

However, the absence of a congruency effect is only problematic for outcome–response theory under two conditions. The first is that the associative structures underlying the incongruent discrimination encodes the outcome representations, because to the extent that discriminative performance is mediated by direct  $S \rightarrow R$  associations, the commonality of stimulus and outcome should not interfere with performance. Although Peterson et al. (1987) did not assess the role of the outcome, Dickinson and de Wit (2003) found that devaluing an outcome by specific satiety reduced performance of the corresponding response during an extinction test in both the congruent and incongruent groups, thereby establishing mediation of responding by an outcome representation.

The second condition is that an event receives the same encoding in its roles as a stimulus and as an outcome. To the extent that the same event is differently encoded when represented as a stimulus (A and B) and as an outcome ( $\alpha$  and  $\beta$ ), the incongruent associative chains,  $A \rightarrow \beta \rightarrow R_X$  and  $B \rightarrow \alpha \rightarrow R_Y$ , will not interfere. Although Dickinson and de Wit (2003) demonstrated that the outcome event of one trial would act as an effective stimulus event for the next trial, they did consider the possibility that the stimulus and outcome received differential encoding. They

noted that their events, presentations of a food pellet and a sucrose solution, differed not only in their sensory properties, such as their flavors, but also in their motivational properties, with the sucrose solution being relevant to both hunger and thirst and the food pellets being relevant to hunger alone. As there is good evidence that the representations of food pellets and sucrose solution activated by associated stimuli encode their differing motivational properties (Dickinson & Dawson, 1987), the incongruent discrimination may have been solved by encoding the stimuli in terms of their sensory properties and the outcomes in terms of their motivational properties. The differential motivational properties of the events used by Peterson et al. (1987), reinforcement and nonreinforcement, are even more clear.

The implication of this analysis is that incongruent interference should be observed when stimuli and outcomes differ only in their sensory properties, because such events would not support differential encoding in terms of motivational properties. There is some evidence that this may be so. Eenshuistra, Weidema, and Hommel (2004) have recently reported that young (4-year-old) but not older (7-year-old) children made more errors in performing the incongruent discrimination relative to the congruent one, using purely sensory stimuli and outcomes. However, in this study, the children did not have to learn which response was correct for each stimulus on the basis of whether the response produced an outcome. Rather, the children were instructed about the correct response to each stimulus. Our aim was to reexamine the effect of stimulus–outcome congruency on discrimination learning using events that differed primarily in their sensory properties with both rats (Experiment 1) and adult humans (Experiment 2).

## Experiment 1

Rats were trained on either an incongruent or congruent discrimination using food events that only differed in their sensory properties as stimuli and outcomes, specifically starch solutions with either a coffee or a lemon flavor. In the incongruent group, half of the trials started with a drop of coffee-flavored solution that signaled, for example, that pressing the right lever would be rewarded with a drop of the lemon-flavored solution, whereas pressing the left lever would not be rewarded. The remaining trials started with a drop of lemon-flavored solution, signaling that left, but not right, lever presses would be rewarded in this component by the coffee-flavored solution. In contrast, the stimulus and outcome solutions had the same flavor within each component of the congruent discrimination.

Outcome–response theory offers two predictions: first, the performance of the incongruent discrimination should be impaired relative to the congruent discrimination and, second, to the extent that the rats successfully acquired the incongruent discrimination, responding should have been mediated by  $S \rightarrow R$  associations and, therefore, should have been impervious to outcome devaluation. We initially assessed sensitivity to outcome devaluation using a specific satiety procedure but failed to find any evidence for a devaluation effect, even in the congruent group. Therefore, we reexamined resistance to outcome devaluation using an aversion conditioning procedure.

## Method

### Subjects and Apparatus

Twenty-four naive male Lister hooded rats (*Rattus norvegicus*; Charles Rivers, United Kingdom), approximately 2 months of age, were housed in groups of 3 on a 12-hr reversed light–dark cycle and trained during the dark phase in two replications.

Training and testing took place in six operant chambers (26.5 cm long  $\times$  22 cm wide  $\times$  20 cm high) that were housed in sound-attenuating shells (MED Associates, St. Albans, VT). Head entries into a recessed magazine (5 cm  $\times$  5 cm) in the center of the intelligence panel were detected by interruption of an infrared photobeam. The magazine contained two adjacent wells in which  $\sim$ 0.08 ml of 20% (w/v) maltodextrin starch solution (Myprotein, Stockport, United Kingdom) were delivered by two software-operated syringe pumps (MED Associates, St. Albans, VT) for 2 s. The starch solutions were flavored with either 1.5% decaffeinated instant coffee (Sainsbury Supermarkets, London, United Kingdom) or 5% lemon juice (Crazy Jack, London, United Kingdom). Each chamber also contained two 4.8-cm-wide retractable levers that were placed symmetrically on either side of the magazine and could be illuminated by an overhead houselight. The experiment was controlled by software written in Visual Basic using the Whisker control system (Cardinal, 2000).

The rats were prefed for the specific satiety tests in 12 plastic feeding–drinking boxes (29 cm  $\times$  12 cm  $\times$  12 cm) in a separate room, and the starch solutions were presented in inverted 100-ml drinking cylinders. For aversion conditioning, Lithium Chloride (LiCl; Sigma-Aldrich Company, Dublin, Ireland) was dissolved in distilled water to yield a 0.15-M solution. The injection volume of LiCl was 20 ml/kg.

### Procedure

All animals were kept on a 22.5-hr food-deprivation schedule, with tap water always freely available, by being fed their maintenance diet in their home cages for 1.5 hr after each day's training was complete. The rats were randomly assigned to a congruent and incongruent group ( $N = 6$ ) at the start of each of two replications and received two training sessions per day in the first replication but only one session per day in the second.

**Pretraining.** Initially, all rats received two sessions of magazine training in each of which 15 presentations of coffee and lemon solutions were given on a random-time 60-s schedule, with the levers withdrawn. In the next two sessions, the rats were trained to lever press for the solutions on a discrete-trial schedule. Each trial started with the insertion of one lever, and the first press was rewarded with the appropriate solution. The first magazine entry after outcome delivery marked the end of the trial and caused the levers to retract. Trials were separated by an intertrial interval (ITI) that varied randomly between 5 and 30 s. Each session consisted of 15 trials with each lever, which were presented in random order. During the final two sessions of pretraining, responding was rewarded on a discrete-trial, fixed-interval schedule under which the first lever press that occurred 10 s after the start of the trial was rewarded. For half of the rats in the congruent and incongruent groups, presses on the right and left levers were rewarded with the lemon and coffee solution, respectively, with the remaining animals receiving the opposite lever–outcome assignment. Through-

out the experiment, a session began with the onset of the house-light and terminated with its offset.

**Discrimination training.** During each of 12 sessions of discrimination training, 15 trials starting with the delivery of the lemon solution were randomly intermixed with 15 trials starting with the delivery of the coffee solution. The presentations of these solutions were not explicitly signaled except by the sound generated by the operation of the delivery pump. These foods acted as discriminative stimuli signaling which lever press would be rewarded on that trial, and each rat was trained with the same lever press–outcome assignments as in pretraining. The first departure from the magazine after the delivery of the stimulus led to the insertion of both levers. In the congruent group, the stimulus signaled that lever presses rewarded with the same solution were correct, whereas presses rewarded with the different solution were correct in the incongruent group. On each trial, responding on the correct lever was rewarded on a discrete-trial, fixed-interval, 10-s schedule, whereas responding on the incorrect lever was never rewarded and engaged a 2-s changeover delay. The first magazine entry following outcome delivery caused both levers to be retracted and initiated an ITI that varied randomly between 60 and 180 s. In all other respects, the procedure was the same as that used during pretraining. The experiment terminated following the final discrimination training session for the rats in the first replication, whereas those in the second replication received the following training and tests.

**Specific satiety tests.** Immediately following the last discrimination training session, the rats received their maintenance diet and tap water in the feeding–drinking boxes for a 1-hr familiarization period. On the next day, half of the animals in each group were prefed coffee solution, and the other half were fed lemon solution for 1 hr. All rats then received a 5-min extinction test, during which both levers were available but responding was never rewarded. Subsequently, the animals were retrained on the discrimination schedule for one session, before being prefed the other solution and receiving an additional extinction test.

**Aversion conditioning.** Following one more retraining session with the discrimination schedule, each rat received 5 two-session cycles, consisting of a session with the to-be-devalued solution, which was followed the next day by a session with the other solution. All sessions took place in the operant chambers, with both levers retracted. During each session, the appropriate solution was presented on a random-time 30-s schedule, which was suspended whenever an outcome was delivered and only was restarted by a magazine entry. This contingency minimized the accumulation of unconsumed starch solution in the magazine. The sessions ended after 30 outcomes had been delivered or after 30 min had elapsed, depending on which criterion was met first. Immediately following the sessions with the to-be-devalued solution, the rats were removed from the operant chambers and received an interperitoneal injection of LiCl, before being returned to their home cages. Half of the animals in each group received aversion conditioning with the coffee solution, and the other half received aversion conditioning with the lemon starch solution.

**Devaluation tests.** On the following day, all animals were tested in a 5-min extinction test, with both levers concurrently available. All animals then received one more aversion conditioning two-session cycle followed by an additional 5-min extinction test.

**Reacquisition tests.** In order to confirm that the aversion conditioning had devalued the lithium-paired solution as an outcome, we gave the rats two separate single-lever reacquisition sessions during each of which responding was rewarded with the appropriate food type on a fixed-interval, 30-s schedule. For all animals, the coffee solution was the food outcome during the first session, and the lemon solution was the outcome during the second session. There was no ITI scheduled, but the levers were retracted and inserted again after each outcome delivery. The sessions ended after 30 outcomes had been delivered, or after 30 min, depending on which criterion was met first.

## Results and Discussion

### Discrimination Training

One rat in the congruent group of the first replication failed to learn to press the levers and was therefore dropped from the experiment. The acquisition of the discrimination was analyzed by the number of correct responses as a ratio of the total number of responses. The effect of replication on the discrimination ratios did not interact with that of group when assessed against a Type I error rate of .05, which was the criterion against which we assessed significance. Consequently, the ratios were collapsed across replications for their presentation in Figure 2. Although the rats failed to discriminate during the first four sessions with ratios around 0.5, thereafter both groups progressively acquired the discrimination with the terminal discrimination ratios lying between 0.7 and 0.8. Although the graphic data suggest that the rats acquired the congruent discrimination, if anything, more rapidly than the incongruent discrimination, there was no evidence for the reliability of this effect. Neither the main effect of group,  $F(1, 19) = 2.55$ , nor the Group  $\times$  Session interaction ( $F < 1$ ) was significant. Therefore, the relative rates of acquisition of the two discriminations provided no support for the prediction of outcome–response theory that the performance of the incongruent discrimination should have been impaired relative to that of the congruent one. However, according to outcome–response theory, this impairment should have been manifest only to the extent that the outcomes were encoded in the associative structures controlling responding. The

subsequent outcome devaluation tests in the second replication assessed the encoding of the outcomes.

### Specific Satiety Tests

Prefeeding did not appear to affect instrumental performance during the extinction tests. The average number of lever presses per minute for responses trained with the nonprefed and prefed foods were 3.0 and 2.5 in the congruent group and 2.8 and 3.2 in the incongruent group, respectively. There was no significant effect of prefeeding the outcome with which the response was trained ( $F < 1$ ) nor did the effect of this prefeeding interact with group,  $F(1, 10) = 2.01$ . Therefore, in contrast to Dickinson and de Wit's (2003) finding of a specific satiety outcome devaluation effect following both congruent and incongruent training with a sucrose solution and food pellets, we failed to find any impact of prefeeding. There are at least two possible reasons for the null result. Although prefeeding flavored starch solutions can induce an outcome devaluation effect (Balleine & Dickinson, 1998), it is possible that the change in outcome value was not sufficient to be manifest following discrimination training. Alternatively, it is possible that responding following both types of discrimination training was controlled by  $S \rightarrow R$  associations. The more profound outcome devaluation produced by aversion conditioning distinguished between these alternatives.

### Aversion Conditioning

As assessed by the rates of magazine entries during aversion conditioning, a selective aversion was conditioned to the food paired with LiCl in both groups. There was a significant interaction between the effect of the LiCl pairing and the cycles of training,  $F(4, 32) = 22.53$ ,  $MSE = 9.53$ , and simple main effects analyses established that the rats entered the magazine less on sessions with the LiCl-paired food than on sessions with the unpaired food on each of the last four cycles,  $F_s(1, 8) > 14.3$ . The fact that effects of LiCl pairing did not enter into any reliable interactions with group established that aversion conditioning proceeded indistinguishably in the congruent and incongruent groups:  $F_s < 1$ ;  $F_s(4, 32) < 1.80$ . The mean number of magazine entries per minute during the cycles immediately preceding the first devaluation test were 17.7 and 5.9 for valued and devalued outcomes, respectively, for the congruent group and 13.8 and 2.4, respectively, for the incongruent group. The corresponding values on the cycle immediately preceding the second devaluation test were 18.5 and 1.9 for valued and devalued outcomes, respectively, for the congruent group and 17.3 and 1.2, respectively, for the incongruent group.

### Devaluation Tests

Figure 3 presents the data of prime interest: the rates of responding during the first (left panel) and second (right panel) devaluation tests. A clear devaluation effect was evident for the congruent group in that these rats performed the response trained with the still-valued outcome more than the one trained with the outcome that had been devalued by aversion conditioning. This devaluation effect established that responding by the congruent group was mediated by representations of the outcomes. This did not appear to be the case for the incongruent group, however, because re-

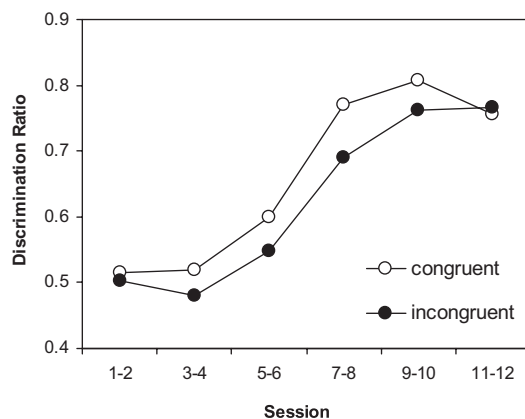


Figure 2. Experiment 1: Mean discrimination ratios of the congruent and incongruent groups during discrimination training.



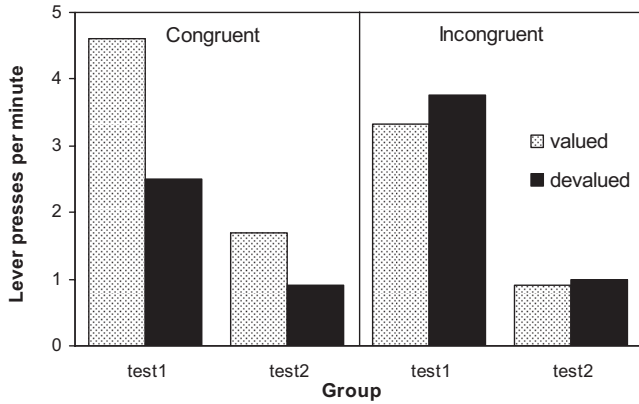


Figure 3. Experiment 1: Mean lever presses per minute during the first (Test 1) and second (Test 2) outcome devaluation tests for the congruent (left) and incongruent (right) groups.

sponding by these animals was impervious to devaluation in that the two responses were performed at comparable rates.

An overall analysis established that the rats responded at a higher rate in the first test than in the second test,  $F(1, 8) = 36.33$ ,  $MSE = 1.94$ , although, more important, there was no significant Test  $\times$  Devaluation interaction ( $F < 1$ ) nor a three-way Group  $\times$  Test  $\times$  Devaluation interaction,  $F(1, 8) = 1.19$ . The significant Group  $\times$  Devaluation interaction effect,  $F(1, 8) = 5.50$ ,  $MSE = 1.67$ , confirmed that the devaluation treatment had differential effects in the two groups, and simple main effects analyses confirmed that whereas there was a significant outcome devaluation effect in the congruent group,  $F(1, 8) = 7.55$ ,  $MSE = 1.67$ , there was no effect in the incongruent group ( $F < 1$ ).

### Reacquisition Test

Responding during the reacquisition test, which is illustrated in Figure 4, shows that the absence of a devaluation effect in the incongruent group was not due to a failure of the aversion treatment to abolish the reinforcing properties of the devalued outcome for these animals. Although the incongruent group performed the responses reinforced by the devalued and valued outcomes at comparable low levels at the outset of the test, responding was reestablished for the valued outcome but not the devalued outcome by the end of the test. Moreover, the differentiation between the two responses was as great in the incongruent group as in the congruent group. Overall, both groups responded more for the valued than for the devalued outcome,  $F(1, 8) = 36.67$ ,  $MSE = 22.66$ , and this devaluation effect did not interact with group,  $F(1, 8) = 2.78$ .

In summary, this study did not substantiate the prediction of outcome–response theory that performance of the incongruent discrimination should be inferior to that maintained by the congruent contingencies. However, the fact that incongruent responses, unlike those acquired by congruent training, were resistant to outcome devaluation and therefore mediated by  $S \rightarrow R$  associations was predicted by outcome–response theory.

### Experiment 2

The aims of the second experiment were threefold. The first was to reexamine the predictions of outcome–response theory concern-

ing the relative acquisition rates of congruent and incongruent discriminations and the underlying associative structures but using human participants.

The second aim was to address a confound in the contrast between the congruent and incongruent contingencies. Not only do these contingencies differ in the congruency of the stimuli and outcomes, which is the important difference according to outcome–response theory, but also in whether the stimulus and outcome in each component contingency are the same or different. The congruent discrimination can be solved by the acquisition of simple  $O \rightarrow R$  associations for each component contingency, whereas the incongruent discrimination requires the acquisition of two  $S \rightarrow O \rightarrow R$  associative chains. Therefore, to control for the effect of associative complexity, we included in this experiment a standard biconditional discrimination. In this discrimination, the stimuli and outcomes were different sets of events. For example, Event A, when presented as a stimulus, signals that one response,  $R_X$ , produces Event C as an outcome and that the other response,  $R_Y$ , is incorrect. According to outcome–response theory, this contingency should set up an associative structure of the form  $A \rightarrow C \rightarrow R_X$ . In the trials with the other component contingency, Event B as stimulus signals that  $R_Y$  will yield Event D as the outcome, with  $R_X$  being incorrect, which results in a  $B \rightarrow D \rightarrow R_Y$  structure. Even though this biconditional discrimination requires an associative structure of comparable complexity to that of the incongruent discrimination, outcome–response theory predicts that it should be readily learned because there is no overlap between the stimulus and outcome elements of the associative structures. In the absence of this overlap, the stimulus of one component of the discrimination does not elicit the incorrect, competing response via the  $O \rightarrow R$  association established in the other component. Moreover, outcome–response theory predicts that this standard biconditional discrimination should be mediated by knowledge of the response–outcome contingencies and therefore be sensitive to outcome devaluation. In summary, to control for the effect of stimulus–outcome overlap, in the present experiment we compared the performance of the incongruent discrimination not only with a congruent one but also with a biconditional discrimination.

The third and final purpose of this experiment was to assess control by  $O \rightarrow R$  associations using a further outcome devalua-

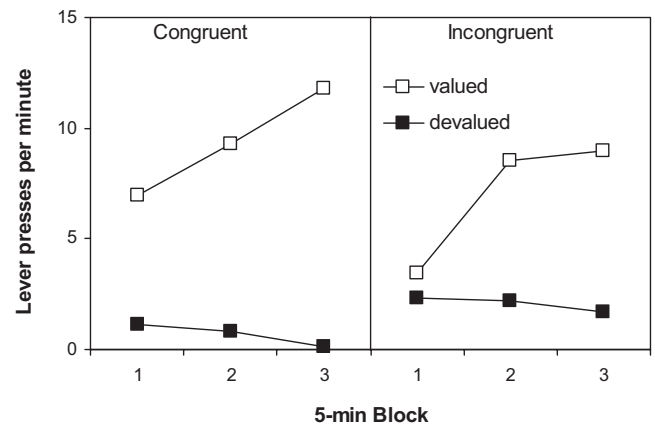


Figure 4. Experiment 1: Mean lever presses per minute during the reacquisition tests for the congruent (left) and incongruent (right) groups.

tion test. In Experiment 1, knowledge of the response–outcome contingency was evaluated by presenting the animals with the opportunity to perform the two responses following devaluation of one of the outcomes but in the absence of the discriminative stimuli. Although the omission of the discriminative stimuli ensured that any effect of the devaluation was mediated by the outcome representations, it also rendered the test conditions very different from those in training. Therefore, it is possible that the knowledge acquired during incongruent training suffered greater generalization decrement than that acquired during congruent training when assessed without the discriminative stimuli. Consequently, half of the participants received a stimulus–cued outcome devaluation test in which the stimuli associated with the two responses were presented to assess outcome–response knowledge. The remaining participants received an outcome–cued test that was analogous to the one used with the rats in Experiment 1. In summary, outcome–response theory again predicts that both discriminative performance and sensitivity to outcome devaluation should have been worse for the incongruent discrimination than for the congruent discrimination and, additionally, the biconditional discrimination.

### Method

#### Participants, Apparatus, and Stimuli

Thirty-two undergraduate and graduate student volunteers (*Homo sapiens*; age = 21–29 years) from the University of Cambridge were tested individually. The stimuli consisted of colored icons representing the eight different fruits: orange, pineapple, pear, apple, bananas, cherries, grapes, and coconut. Grayscale examples of these icons are shown in Figure 5. The stimuli were presented on a standard PC monitor, and responses were recorded on a standard keyboard using a program written in Visual Basic 6.0.

#### Procedure

The experiment was divided into two stages: discrimination training and devaluation tests.

**Discrimination training.** This stage was introduced using the following written instructions:

In this game, you will get the chance to earn points by collecting fruit from inside a box on the screen by opening the box by pressing either the right *m* or left *z* key. If you press the correct key, the box will open to reveal a fruit inside and points will be added to your total score. However, if you press the incorrect key, the box will be empty and no points will be added to your total. Your task is to learn which is the correct key to press. Sometimes it will be the left-hand one and sometimes it will be the right-hand one. The picture on the front of the door should give you a clue about which is the correct response. The quicker you make the correct response the more points will be added to your total. Your accumulated points will appear at the top of the screen. You should try to learn the types of fruits that are found inside the boxes following left-hand and right-hand responses because later on you will be asked to gather some types of fruit but not others.

Having read these instructions, each participant was presented with the first trial. Each trial started with the presentation of the front face of a brown box on the monitor, with the top surface of the box represented in depth so that the apparent viewpoint was from slightly above the box. The left-hand panel of Figure 5 shows a grayscale illustration of the image of the box, although at this stage only a single box was present without the surrounding fruit icons. A stimulus fruit icon appeared on the front face, and above the box was a panel with the words *Total Points* followed by the number of points currently earned. Either a left (*z* key) or a right (*m* key) response replaced this display with one designed to illustrate the inside of the box, with the front face removed. This display represented the internal surfaces of the bottom, sides, and rear wall of the box in apparent depth, as illustrated in the right-hand panel of Figure 5. If the correct response had been performed, a fruit icon appeared within the box and the points total was incremented, whereas the box appeared empty following the incorrect response without a change in the total points. The number of points awarded for correct responses within the following latency ranges were as follows: 0 to 1 s (5 points), 1 to 1.5 s (4 points), 1.5 to 2 s (3 points), 2 to 2.5 s (2 points), and 2.5 s (1 point). This outcome display remained present for 1 s before being replaced by the stimulus display of the next trial after a 1.5-s ITI.

The three discriminations were trained concurrently, with two fruit icons being assigned to the congruent discrimination, two to the incongruent discrimination, and four to the biconditional discrimination. Performing the correct response to a fruit stimulus yielded the same fruit icon as the outcome in the congruent discrimination but the other fruit icon in the incongruent discrimination. In the biconditional discrimination, two fruit icons acted as the stimuli and the other two as the outcomes, with the assignment of stimulus–outcome pairs remaining constant across training. So, for example, the correct response to a pineapple stimulus consistently yielded a grape outcome, whereas a correct response to the cherry stimulus yielded an apple outcome. To deconfound the identity of the icons from the contingencies, in each discrimination we arbitrarily paired the icons, and the left response was correct for one icon and the right response was correct for the other icon of a pair. These four pairings and response assignments were the same for each participant, but the four possible assignments of these icon and response pairings to the different discriminations were permuted across participants. For example, if the apple and grape icons acted as the outcomes of the biconditional discrimination for 1

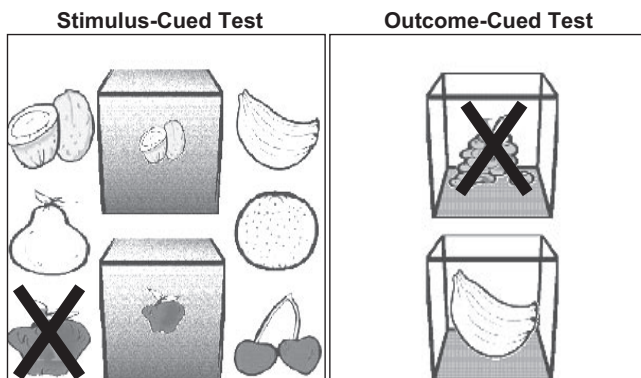


Figure 5. Experiment 2: A grayscale representation of the screen display during the stimulus–cued (left) and outcome–cued (right) devaluation tests. The devalued food for each trial is shown with a cross on it.

participant, they would act as the stimuli and outcomes of the congruent discrimination for another participant, with a corresponding permutation of the roles of the other icon pairs.

Discrimination training consisted of four 12-trial blocks. Within each block, there were 2 trials with each of the component contingencies from each of the 3 discriminations, which were presented in a random order that varied across participants. Therefore, every participant received a total of 8 trials with each component of the 3 discriminations.

**Outcome devaluation tests.** Following discrimination training, half of the participants received a stimulus–cued outcome devaluation test and the remainder an outcome–cued test. Both devaluation tests consisted of 4 trials from each of the 3 discriminations, 2 with one of the outcomes devalued and 2 with the other outcome devalued. These 12 trials were presented in a different random order for each participant.

The stimulus–cued test was introduced with the following written instructions:

Now two boxes will appear on the screen with different pictures on them. One box gave a fruit for a left response in the first stage and the other gave a fruit for a right response. Although all the fruits were valuable previously, one of them is now devalued on each trial and earns no points. The other fruit is still valuable and will gain you points. The devalued food for each trial is shown with a cross on it. You should respond by pressing the key that earns a valued fruit. The points you earn now will not be shown on the screen but you will see your final total at the end of the game.

As can be seen in the left-hand panel of Figure 5, on each trial, the display presented two closed boxes in the center of the screen, one above the other. The fruit icons on the front face of the boxes were a pair of stimuli from one of the three discriminations. In addition, the six fruit icons that had acted as the outcomes during training were also displayed, three on the left of the boxes and three on the right of the boxes, arranged in vertical columns. One of the two fruit icons that had acted as outcomes for the stimuli displayed on the boxes had a red cross superimposed on it, signifying that this outcome was devalued on this trial and therefore that performing the response that had previously yielded this outcome would earn no points. So, for example, the left-hand panel of Figure 5 might represent the display for the incongruent discrimination in which the coconut and apple were the stimuli and outcomes, with the apple outcome devalued. Consequently, when participants were faced with this display, the correct response, either left or right presses, would have been the one that had produced the coconut outcome to the apple stimulus during training. The panel showing the total points score was not present. Performing either response terminated the display without opening the boxes and replaced it with the display for the next trial after an ITI of 1.5 s.

The instructions for the outcome–cued test were the same except that the first three sentences were replaced by the following:

Now two open boxes will appear on the screen with different fruits inside them. One fruit was earned by a left response in the first stage and the other by a right response. Although both the fruits were valuable previously, one of them is now devalued and earns no points, whereas the other is still valuable and gains points. The devalued food will have a cross on it.

On each trial of this test, the display presented two open boxes, each containing one of the two fruit icons that had acted as the outcomes in one of the discriminations. These boxes were identical to those presented with the outcomes during discrimination training except for the fact that one of the fruit icons had a red cross superimposed on it, signifying that performing the response that had earned this outcome during training would not earn any points. The right-hand panel of Figure 5 contains an example of a screen display during the outcome–cued test. In other respects, the procedure during this test was the same as during the stimulus–cued test.

## Results and Discussion

### Discrimination Learning

As the top panel of Figure 6 illustrates, humans acquired the congruent discrimination more rapidly than the incongruent discrimination. Moreover, this difference was not due to use of different stimuli and outcomes in each contingency of the incongruent discrimination because the biconditional discrimination was also learned more rapidly than the incongruent discrimination. An overall analysis revealed a significant main effect of discrimina-

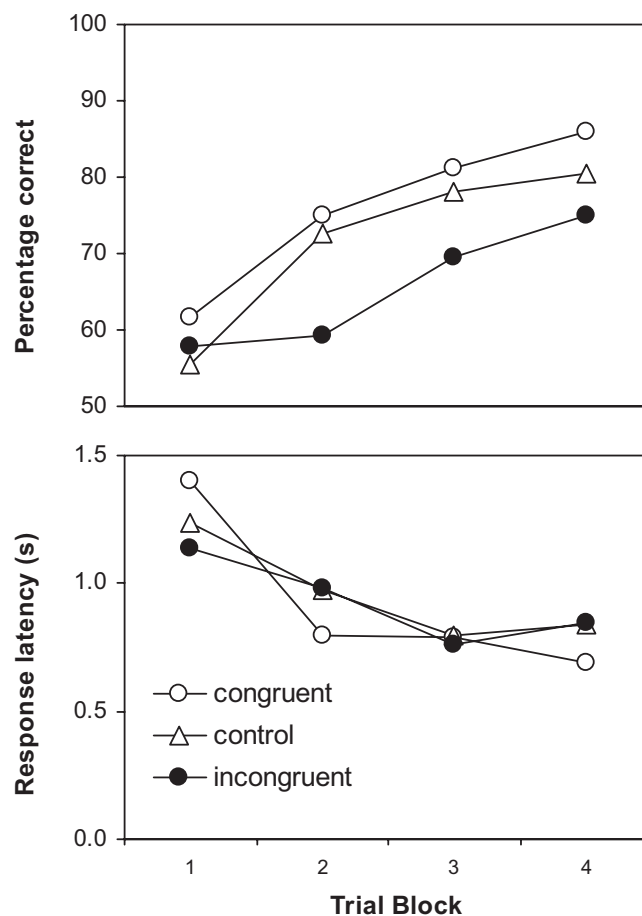


Figure 6. Experiment 2: Mean percentage correct responses (top) and mean latency to perform the correct response (in seconds; bottom) during training of the congruent, incongruent, and biconditional discriminations.



tion type on the percentage of correct responses,  $F(2, 62) = 5.17$ ,  $MSE = 697.0$ , and although this effect did not interact reliably with trial block,  $F(6, 186) = 1.06$ , inspection of the means prompted an analysis of simple main effects. These analyses revealed significant effects of discrimination type on Trial Blocks 2, 3, and 4,  $F_s(2, 62) = 5.04, 3.14, \text{ and } 3.23$ ,  $MSE_s = 450.9, 305.2 \text{ and } 365.2$ , respectively, and pairwise comparison using the Newman-Keuls procedure showed that both the congruent and biconditional discriminations were performed more accurately than the incongruent discrimination on Trial Block 2, with this difference persisting into Trial Blocks 3 and 4 for the congruent discrimination.

In spite of the retarded acquisition, the participants acquired the correct responses under the incongruent discrimination. There was a significant effect of trial block on percentage of correct responses for this discrimination,  $F(3, 93) = 9.25$ ,  $MSE = 441.3$ , which was performed significantly above the 50% chance levels on Trial Block 3,  $t(31) = 4.13$ ,  $SEM = 4.7$ , and Trial Block 4,  $t(31) = 5.95$ ,  $SEM = 4.2$ .

The differential acquisition did not reflect a speed-accuracy trade-off because, as the bottom panel of Figure 6 illustrates, responding after the first trial block tended to be fastest for the congruent discrimination, with similar response latencies for the incongruent and biconditional discriminations. Simple main effects analyses of the significant interaction between discrimination type and trial block for the response latency,  $F(6, 186) = 3.24$ ,  $MSE = 0.116$ , confirmed effects of discrimination type on Trial Blocks 2 and 4,  $F(2, 63) = 10.70 \text{ and } 4.65$ ,  $MSE = .034 \text{ and } .053$ , respectively, with Newman-Keuls pairwise comparisons establishing that responding under the congruent contingencies was more rapid than in the other discriminations on both of these trial blocks.

### Outcome Devaluation Tests

Figure 7 displays the percentage correct responding during the outcome devaluation tests, with the correct response defined as the one that would have produced the valued outcome as opposed to the devalued one during training. The overall pattern of responding

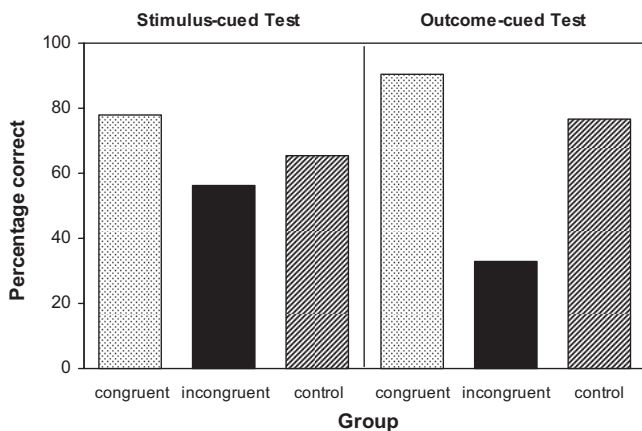


Figure 7. Experiment 2: Mean percentage correct responses for the congruent, incongruent, and biconditional discriminations during the stimulus-cued (left) and outcome-cued (right) devaluation tests.

was similar in both tests, with performance being best with stimuli and outcomes from the congruent discrimination, intermediate for those from the biconditional discrimination, and worst with those from the incongruent discrimination. These differences were more pronounced in the outcome-cued test (see Figure 7, right) than in the stimulus-cued test (see Figure 7, left), an effect confirmed by a significant interaction between discrimination and test types for the percentage of correct responses,  $F(2, 60) = 4.57$ ,  $MSE = 721.8$ , which prompted separate analyses of performance in the two tests.

Both the stimulus-cued and outcome-cued tests yielded a significant main effect of discrimination type,  $F(2, 30) = 3.58$  and  $16.06$ ,  $MSE = 538.2$  and  $905.4$ , respectively, and pairwise comparisons by the Newman-Keuls procedure confirmed that the percentage correct responses for the incongruent discrimination was lower than that for the congruent discrimination in both tests and lower than that for the biconditional discrimination in the outcome-cued test. Moreover, in neither test did the selection of the correct response differ from the 50% chance level for the incongruent discrimination: outcome-cued,  $t(15) = -1.70$ ,  $SEM = 10.1$ ; stimulus-cued,  $t(15) = 0.72$ ,  $SEM = 8.7$ . By contrast, the correct responses were selected significantly above chance in both tests for the congruent discrimination: outcome-cued,  $t(15) = 10.50$ ,  $SEM = 3.9$ ; stimulus-cued,  $t(15) = 5.08$ ,  $SEM = 5.5$ , as well as for the biconditional discrimination: outcome-cued,  $t(15) = 3.78$ ,  $SEM = 7.0$ ; stimulus-cued,  $t(15) = 2.18$ ,  $SEM = 7.2$ .

These devaluation tests suggest that responding established by the congruent and biconditional discriminations was goal directed in the sense that performance was controlled by the current value of the outcomes. As the outcomes were not presented contingent on the response during the test, the sensitivity of responding to the outcome value cannot have reflected the direct impact of the outcomes at the time of testing. Moreover, in the case of the biconditional discrimination, the selection of the correct response must have been mediated by a representation of the fruit in its role as an outcome because the stimuli and outcome were different fruits. As in Experiment 1, however, we cannot be certain in the case of the congruent discrimination whether this representation encoded the relationship between the response and the relevant fruit in its role as the stimulus or as the outcome, because this fruit played both roles in this discrimination. However, given that the fruit was presented explicitly as the outcome in the outcome-cued test, the fact that performance was, if anything, better in this test (90% correct) than in the stimulus-cued test (78% correct) suggests that the contingency between the response and the fruit as an outcome was encoded. If test performance was mediated by a representation of the stimulus-response contingency, we would have expected to observe some generalization decrement in the outcome-cued test relative to the stimulus-cued test, given that the fruit was presented explicitly as a stimulus in the latter test.

Finally, in contrast to the congruent and biconditional discriminations, there was no evidence that responding maintained by the incongruent discrimination was goal directed in the sense that the participants failed to select the response that had procured the currently valued outcome under these contingencies during training. The lack of discrimination during the outcome devaluation tests was not due to a failure to acquire the incongruent discrimination, which was reliably above chance and statistically indis-

tinguishable from the biconditional discrimination on the last two blocks of training. This finding suggests that the acquisition of the incongruent discrimination during training was mediated by learning the correct response to each stimulus or, in other words, by a  $S \rightarrow R$  association that did not encode the identity of the outcome.

In summary, the results of this experiment confirmed both predictions of outcome–response theory. The participants were slower to acquire the incongruent discrimination than the congruent and biconditional discriminations. The inferior performance of the incongruent discrimination relative to the biconditional discrimination provides strong support for outcome–response theory, as the associative complexity underlying these discriminations should have been comparable, the only difference being that the incongruent discrimination should have induced response conflict. Furthermore, the performance of the incongruent discrimination, unlike congruent and biconditional discriminations, was insensitive to outcome devaluation and therefore based on the learning of  $S \rightarrow R$  associations.

### General Discussion

Taken together, the results of our experiments support the associative analysis of goal-directed behavior offered by outcome–response theory within the context of conditional discrimination learning. To recap, according to outcome–response theory, the difficulty in performing an incongruent discrimination arises from the fact that the overlap in the representations of the stimulus and the outcome compromises performance that is mediated by a  $S \rightarrow O \rightarrow R$  associative chain. Because the stimulus of one component of the discrimination functions as the outcome of the other component, the presentation of a stimulus should always induce response conflict (see Figure 1). In accord with this analysis, Experiment 2 found retarded acquisition of the incongruent discrimination by human participants relative to two nonconflicting discriminations: a simple congruent discrimination, in which the stimulus and outcome of each component of the discrimination were the same, and a biconditional discrimination of the same associative complexity as the incongruent discrimination but without overlapping stimuli and outcomes. In accord with previous animal studies (Dickinson & de Wit, 2003; Peterson et al., 1987), however, Experiment 1 failed to find a reliable difference in the rates at which rats learned the congruent and incongruent discriminations. In contrast to these studies, the absence of a congruency effect cannot be explained in terms of the differential encoding of the stimuli and outcomes in terms of their sensory and motivational properties because these events had the same motivational properties of the starch solution.

The acquisition of the incongruent discrimination can be explained within an associative framework that is compatible with outcome–response theory if discriminative performance was controlled by  $S \rightarrow R$  associations that did not encode the identity of the outcome. Evidence for this form of control came from the outcome devaluation tests. Neither rats in the first experiment nor humans in the second could select between alternative responses on the basis of the current value of their incongruent outcomes, which suggests that either the response–outcome contingency was not encoded during incongruent training or, if it was encoded, it did not control response selection. Therefore, it is reasonable to assume that incongruent discriminative performance was based on

stimulus–response learning. The fact that reliable devaluation effects were observed following congruent training in both experiments and biconditional training in Experiment 2 shows that the general parameters of the discriminations and the nature of the responses and outcomes did not preclude response–outcome learning.

These conclusions raise at least two issues. The first concerns the absence of an effect of congruency on discriminative performance by the rats in Experiment 1. There are a number of reasons why the discriminative procedure used with the rats might have minimized any impairment of the acquisition of the incongruent discrimination. First, unlike the human participants in Experiment 2, the rats experienced the contingency between the correct response and the outcome on every trial because each trial always terminated with the correct response. Consequently, the  $S \rightarrow R$  association for the correct response would have been strengthened on each trial for the rats but not for the human participants. Second, the repetition of a particular flavored starch solution, first as a stimulus and then as the outcome on congruent trials, may have reduced reinforcing properties of the outcome (Wagner, 1981). Any short-term habituation effect would have reduced acquisition of the congruent discrimination relative to the incongruent one, thereby masking an effect of congruency.

Finally, there is evidence that the incongruent contingency engages a process that resolves the conflict generated by the competing  $O \rightarrow R$  associations by inhibiting the control of responding by these associations. The ability to resolve conflict has received most attention in the field of primate cognition, which has identified a role for the dorsal prefrontal cortex (Botvinick, Cohen, & Carter, 2004). Evidence that the incongruent discrimination used in Experiment 1 engages a conflict resolution process comes from a study by de Wit, Kosaki, Balleine, and Dickinson (2006), who found that inactivating the rodent dorsomedial prefrontal cortex following incongruent training disrupted discriminative performance by elevating incorrect responding relative to the biconditional control. The contribution of this conflict resolution process may have been minimized for the human participants by the high task demands of their discrimination procedure. Not only were they required to learn all three discriminations concurrently, the payoff contingency for correct responding highly favored rapid responding, which may have precluded executive control over responding.

The engagement of this conflict resolution process may also explain why the response–outcome contingency failed to control response selection by the rats in the devaluation tests following incongruent training. If the incongruent rats learned to inhibit control by the  $O \rightarrow R$  associations with the result that discriminative performance was mediated primarily by the  $S \rightarrow R$  associations, then it is not surprising that the animals were insensitive to outcome devaluation. Furthermore, in the case of human participants in Experiment 2, it is possible that they never had the opportunity to acquire strong  $O \rightarrow R$  associations in the first place. Relative to the other discriminations, fewer correct responses were performed during training on the incongruent discrimination, and therefore there was less opportunity to learn about the response–outcome relationship, an effect compounded by the greater number of incorrect responses, which would have extinguished any  $O \rightarrow R$  associations that were acquired.

The incongruent performance deficit observed in Experiment 2 concurs with the results of other procedures that have varied the congruency of stimuli and outcomes. In these procedures, however, the congruency was varied across different stages rather than during the training of a biconditional discrimination. For example, Meck (1985) arranged that presses on one lever by rats produced a brief tone, and presses on another lever produced a brief light, in the first stage of training, before teaching a biconditional discrimination using the tone and light as discriminative stimuli. The rats learned a congruent discrimination, in which the correct responses to the tone and light were those with which they were previously associated, more rapidly than an incongruent discrimination, in which these stimuli signaled that the other response would be reinforced. This finding is a straightforward prediction of outcome–response theory. The first stage of training should have established, for example, a tone  $\rightarrow$  right press association and a light  $\rightarrow$  left press association, which should then have immediately yielded appropriate responding in the congruent discrimination. In contrast, the  $O \rightarrow R$  associations established during the first stage would have elicited the incorrect response in the incongruent discrimination.

Elsner and Hommel (2001) used a similar design to demonstrate the operation of  $O \rightarrow R$  associations in human response priming. In the initial outcome training phase, different auditory stimuli were presented contingently on the occurrence of each of a set of responses. Elsner and Hommel then presented these tones as imperative stimuli for the responses while varying the stimulus–response mapping. In accord with Meck’s (1985) findings, responses were faster if the stimulus–response mapping in the imperative test was congruent, rather than incongruent, with the previous outcome training. Subsequent studies have replicated the effect of outcome–response congruency on human response priming and selection using a variety of outcomes (e.g., Beckers, De Houwer, & Eelen, 2002; Kunde, Koch, & Hoffmann, 2004). Moreover, like standard forms of conditioning, response priming by outcomes is sensitive to the temporal contiguity and contingency between the response and outcome (Elsner & Hommel, 2004) and to cue interactions (Flach, Osman, Dickinson, & Heyes, 2006). The present study is in line with these previous demonstrations of response priming through  $O \rightarrow R$  associations but, of note, also demonstrates that these associations can create response conflict among goal-directed actions.

The present experiments were founded on an associative analysis of goal-directed behavior. There are, however, a gamut of action theories (see Greve, 2001) that assume that human goal-directed actions are mediated by explicit, propositional or rulelike representations of instrumental contingencies. Within the context of the present discriminations, performance would therefore be based on representations of the component contingencies with something like the following content: When the stimulus is an apple, the left response produces a coconut, and the right response produces nothing. However, as this content could represent a component contingency from either the incongruent or biconditional discrimination, there is no obvious reason why it should be more difficult to acquire this representation under the incongruent contingencies. Because such representations explicitly mark the different functional roles of the stimulus and outcome, there is no reason why interference should occur when the same event is encoded in these different functional roles, as was the case for the

incongruent discrimination. Indeed, we have no doubt that humans, at least, could acquire such explicit contingency representations, either by instruction or by more extended or less demanding training, thereby enabling them to perform the incongruent discrimination in a goal-directed manner. However, the absence of a reliable outcome devaluation effect for the incongruent discrimination in the second experiment suggests that the performance of this discrimination was not mediated by explicit contingency representations under the present training conditions. Again it is possible that the high task demand of our human discrimination procedure prevented the acquisition of representations that encoded the component contingencies in propositional form just as it appears to have prevented the engagement of conflict resolution processes.

In summary, the retarded acquisition of the incongruent discrimination by humans supports the claim that instrumental contingencies establish  $O \rightarrow R$  associations and that these associations can cause response conflict when they are incongruent with the responses signaled by these same events as discriminative stimuli. Moreover, the resistance to outcome devaluation in both humans and rats following incongruent training accords with the prediction of outcome–response theory that the incongruent discrimination can only be solved through a stimulus–response mechanism. The implication of these findings is that  $O \rightarrow R$  associations make an important contribution to the control of the goal-directed behavior of both humans and other animals.

## References

- Adams, C. D., & Dickinson, A. (1981). Instrumental responding following reinforcer devaluation. *Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology*, 33(B), 109–122.
- Asratyan, E. A. (1974). Conditioned reflex theory and motivational behaviour. *Acta Neurobiologiae Experimentalis*, 43, 15–31.
- Balleine, B., & Dickinson, A. (1998). The role of incentive learning in instrumental outcome revaluation by sensory-specific satiety. *Animal Learning and Behavior*, 26, 46–59.
- Beckers, T., De Houwer, J., & Eelen, P. (2002). Automatic integration of non-perceptual action effects features: The case of the associative Simon effect. *Psychological Research*, 66, 166–173.
- Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Science*, 8, 539–546.
- Cardinal, R. N. (2000). Whisker (Version 1.0) [Computer software]. Cambridge, United Kingdom: Cambridge University Technical Services.
- Colwill, R. M., & Rescorla, R. A. (1985). Postconditioning devaluation of a reinforcer affects instrumental responding. *Journal of Experimental Psychology: Animal Behavior Processes*, 11, 520–536.
- de Wit, S., Kosaki, Y., Balleine, B. W., & Dickinson, A. (2006). Dorsomedial prefrontal cortex resolves response conflict in rats. *Journal of Neuroscience*, 26, 5224–5229.
- Dickinson, A., & Dawson, G. R. (1987). Pavlovian processes in the motivational control of instrumental performance. *Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology*, 39(B), 201–213.
- Dickinson, A., & de Wit, S. (2003). The interaction between discriminative stimuli and outcomes during instrumental learning. *Quarterly Journal of Experimental Psychology: Comparative and Physiological Psychology*, 56(B), 127–139.
- Eenshuistra, R. M., Weidema, M. A., & Hommel, B. (2004). Development of the acquisition and control of action–effect associations. *Acta Psychologica*, 115, 185–209.

- Elsner, B., & Hommel, B. (2001). Effect anticipation and action control. *Journal of Experimental Psychology: Human Perception and Performance*, 27, 229-240.
- Elsner, B., & Hommel, B. (2004). Contiguity and contingency in action-effect learning. *Psychological Research*, 68, 138-154.
- Flach, R., Osman, M., Dickinson, A., & Heyes, C. (2006). The interaction between response effects during the acquisition of response priming. *Acta Psychologica*, 122, 11-26.
- Gormezano, I., & Tait, R. W. (1976). The Pavlovian analysis of instrumental conditioning. *Pavlovian Journal of Biological Sciences*, 11, 37-55.
- Greve, W. (2001). Traps and gaps in action explanation: Theoretical problems of a psychology of human action. *Psychological Review*, 108, 435-451.
- Kunde, W., Koch, I., & Hoffmann, J. (2004). Anticipated action effects affect the selection, initiation, and execution of actions. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 57(A), 87-106.
- Linwick, D., Overmier, J. B., Peterson, G. B., & Mertens, M. (1988). Interactions of memories and expectations as mediators of choice. *American Journal of Psychology*, 101, 313-334.
- Meck, W. H. (1985). Postreinforcement signal processes. *Journal of Experimental Psychology: Animal Behavior Processes*, 11, 52-70.
- Pavlov, I. P. (1932). The reply of a physiologist to psychologists. *Psychological Review*, 39, 91-127.
- Peterson, G. B., Linwick, D., & Overmier, J. B. (1987). On the comparative efficiency of memories and expectancies as cues for choice behavior in pigeons. *Learning and Motivation*, 18, 1-20.
- Trapold, M. A., & Overmier, J. B. (1972). The second learning process in instrumental learning. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning: II. Current research and theory* (pp. 427-452). New York: Appleton-Century-Crofts.
- Urcuioli, P. J. (2005). Behavioral and associative effects of differential outcomes in discrimination learning. *Learning and Behavior*, 33, 1-21.
- Wagner, A. R. (1981). SOP: A model of automatic memory processing in animal behavior. In N. E. Spear & R. R. Miller (Eds.), *Information processing in animals: Memory mechanisms* (pp. 5-47). Hillsdale, NJ: Erlbaum.

Received October 5, 2005

Revision received May 30, 2006

Accepted June 14, 2006 ■

## ORDER FORM

Start my 2007 subscription to the *Journal of Experimental Psychology: Animal Behavior Processes*! ISSN: 0097-7403

\_\_\_\_\_ \$50.00, APA MEMBER/AFFILIATE \_\_\_\_\_  
 \_\_\_\_\_ \$104.00, INDIVIDUAL NONMEMBER \_\_\_\_\_  
 \_\_\_\_\_ \$273.00, INSTITUTION \_\_\_\_\_  
 In DC add 5.75% / In MD add 5% sales tax \_\_\_\_\_  
**TOTAL AMOUNT ENCLOSED** \$ \_\_\_\_\_

**Subscription orders must be prepaid.** (Subscriptions are on a calendar year basis only.) Allow 4-6 weeks for delivery of the first issue. Call for international subscription rates.



AMERICAN  
PSYCHOLOGICAL  
ASSOCIATION

**SEND THIS ORDER FORM TO:**  
 American Psychological Association  
 Subscriptions  
 750 First Street, NE  
 Washington, DC 20002-4242

Or call **800-374-2721**, fax **202-336-5568**.  
 TDD/TTY **202-336-6123**.  
 For subscription information, e-mail:  
**subscriptions@apa.org**

☒ **Check enclosed** (make payable to APA)

**Charge my:** ☐ VISA ☐ MasterCard ☐ American Express

Cardholder Name \_\_\_\_\_

Card No. \_\_\_\_\_ Exp. Date \_\_\_\_\_

\_\_\_\_\_  
 Signature (Required for Charge)

### BILLING ADDRESS:

Street \_\_\_\_\_

City \_\_\_\_\_ State \_\_\_\_\_ Zip \_\_\_\_\_

Daytime Phone \_\_\_\_\_

E-mail \_\_\_\_\_

### MAIL TO:

Name \_\_\_\_\_

Address \_\_\_\_\_

City \_\_\_\_\_ State \_\_\_\_\_ Zip \_\_\_\_\_

APA Member # \_\_\_\_\_ XANA17