The Psychological Record, 2007, 57, 577–592

PURSUING THE PAVLOVIAN CONTRIBUTIONS TO INDUCTION IN RATS RESPONDING FOR 1% SUCROSE REINFORCEMENT

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The present study investigated whether Pavlovian conditioning contributes, in the form of the response operandum serving as a conditioned stimulus, to the increase in the rate of response for 1% liquid-sucrose reinforcement when food-pellet reinforcement is upcoming. Rats were exposed to conditions in which sign tracking for 1% sucrose was measured when a subsequent period would or would not provide food pellets. Upcoming food pellets produced an increase in the sign-tracking response, but several accounts could potentially explain that increase. In a second experiment, rats responded at a higher rate for 1% sucrose on a lever predictive of upcoming food pellets than on a lever reliably followed by nonreinforcement. A similar result occurred in concurrent-choice probe sessions. These results, consistent with those of the first experiment, cannot be accounted for by the same alternative explanations and therefore suggest that Pavlovian conditioning can contribute to the observance of positive induction.

Induction is said to occur when the rate of operant responding in one situation varies directly with changes in the conditions of reinforcement in another (e.g., Weatherly, Stout, McMurry, Rue, & Melville, 1999). For instance, Weatherly et al. (1999) showed that rats' rate of lever pressing for low-concentration liquid-sucrose reinforcers in the first half of an experimental session varied directly with the rate of food-pellet reinforcement available in the second half of the session. Subsequent studies have demonstrated that this increase in rats' responding for liquid-sucrose reinforcement (e.g., 1% or 5%) when a higher-valued reinforcer (e.g., food pellets) is upcoming is both robust and reliable (e.g., Weatherly, Himle, Plumm, & Moulton, 2001; Weatherly, Plumm, Smith, & Roberts, 2002).

A number of attempts have been made to determine why this increase in responding takes place, and the results suggest that several mechanisms (or procedural variables) likely contribute. One factor is the

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number of response operandi employed. When subjects respond on the same operandum (e.g., a single lever) in both halves of the session, an increase in responding for the low-valued reinforcer in the first half may occur when the high-valued reinforcer is upcoming because responses for the high-valued reinforcer occur prior to its availability (e.g., a fixed-interval scallop may occur in the first half of the session for the reinforcer that will become available at the midpoint of the session). If only one response operandum is used, then those "premature" responses are added to the responses being made for the currently available low-valued reinforcer, thus increasing overall response rates.

Evidence that such responses occur was provided by Weatherly et al. (2001, Experiment 3). In that experiment, rats pressed lever A for 1% sucrose reinforcement in the first half of the session. Across conditions, either 1% sucrose or food pellets served as the reinforcer in the second half. In some conditions, subjects also pressed lever A to earn reinforcers in the second half of the session. In other conditions, they pressed lever B to earn reinforcers in the second half. When food-pellet reinforcement would be earned in the second half of the session by pressing lever B, presses to lever B were observed in the first half of the session (i.e., "premature" responses), thus indicating that such responses occur. Results also showed, however, that despite these responses occurring on lever B, the rate of responding for the sucrose in the first half on lever A was still heightened by upcoming food-pellet reinforcement (i.e., induction was still observed). Weatherly et al.'s (2001) results therefore indicated that "premature" responses could potentially contribute to induction, but at least one additional explanation is needed to fully account for the effect.

Results from Weatherly, Arthur, Palbicki, and Nurnberger (2004) suggest that a change in reinforcer value is an additional explanation. In their first experiment, a between-group design was used to produce induction in responding for 1% sucrose in treatment rats relative to control rats. All rats were then presented with a new response that was reinforced with 1% sucrose. Results showed that the rats in the treatment group, which had been displaying induction, learned this new response more quickly and performed it at a higher rate than did rats in the control group, which had not been displaying induction. These results suggested that 1% sucrose had become a more effective reinforcer for the induction-displaying subjects than for the non-induction-displaying subjects. Subsequent experiments replicated this effect when the new response was learned in a context different from that in which induction was observed. Results also demonstrated that differences in responding between induction-displaying and non-induction-displaying rats were not observed if the new response was not reinforced at all or was reinforced with a substance other than the one used in the induction procedure (i.e., 1% sucrose). Together these results indicate that induction had led to an increase in the reinforcing value of 1% sucrose.

Other results support this increase-in-value explanation. First, Weatherly, King, and Uran (2003) had rats press a lever for sucrose delivered on a progressive-ratio schedule of reinforcement. They demonstrated that rats would complete more ratios on this schedule when a period of food-pellet reinforcement was upcoming than when it was not. In other words, upcoming food-pellet reinforcement increased the “price” rats were willing to pay for the same sucrose reinforcers, indicating that the sucrose had increased in value. Second, Weatherly, Lang, King, Beste, and Grove (2006, Experiment 3) showed that upcoming 32% sucrose reinforcement in the second half of the session increased operant rates of responding for 1% sucrose in the first half of the session, replicating previous results that used upcoming food-pellet reinforcement. In their study, however, reinforcement consisted of 10-s free access to the sucrose solution. The results showed that rats not only increased their rates of lever pressing for 1% sucrose in the first half of the session when 32% sucrose reinforcement was upcoming, they also increased their consumption of 1% sucrose in the first half relative to when 32% sucrose was not upcoming. The increase in consumption is consistent with the idea that induction leads to an increase in the value of the 1% sucrose.

Recent evidence suggests that this potential increase in value may be linked to where the reinforcers are delivered and consumed. For example, Weatherly, Nurnberger, and Kristiansen-Moen (2006; Experiment 2) had rats respond in sessions in which 1% sucrose reinforcement in the first half of the session was followed by, in different conditions, either 1% or 32% sucrose reinforcement in the second half. Upcoming 32% sucrose reinforcement produced induction, thus increasing responding for 1% sucrose in the first half of the session. However, the size of the increase was influenced by where the 32% sucrose was delivered. The largest induction effect was observed when the 1% and 32% sucrose reinforcers in the different halves of the session were delivered to the same location. Induction was still present but was reduced when the 32% sucrose was delivered to a location different from that of the 1% sucrose. The authors thus speculated that Pavlovian higher-order place conditioning may contribute to induction. However, they also reasoned that because a significant induction effect remained when the low- and high-valued reinforcers were delivered to different locations, at least one other explanatory mechanism must be invoked to explain the effect. In this instance, it is possible that the addition of “premature” responses for the upcoming reinforcer could be that explanation because Weatherly et al. (2006) had the rats press the same lever in both halves of the session.

Weatherly et al.’s (2006) idea that Pavlovian processes might be involved in the appearance of induction should not be surprising. In fact, some researchers (e.g., Williams, 2002) have noted that Pavlovian processes should promote induction rather than the more often reported contrast effects (e.g., behavioral contrast; Reynolds, 1961). One potential Pavlovian contribution comes from how the different reinforcers are temporally ordered (i.e., 1% sucrose reliably and repeatedly followed by food-pellet reinforcement). The impact of this temporal ordering on induction was questioned, however, by the results from several studies that indicated that induction was still observed in responding for 1% sucrose when the sucrose reliably followed, rather than preceded, the food-pellet reinforcement (e.g., Weatherly et al., 1999; Weatherly, Lang, & King, 2004).

Other results also appeared to question the role of Pavlovian conditioning. For instance, Weatherly et al. (2002, Experiment 4) had rats press one of two levers for sucrose reinforcement in the first half of the session. If lever A was used, then sucrose reinforcement would also be available in the second half of the session. If lever B was used, then food-pellet reinforcement would be upcoming. However, which lever (A or B) that was used in the second half to obtain the available reinforcer was randomly determined (i.e., at the midpoint of the session, the lever that had been in use was retracted and then one of the two levers was inserted for use in the second half of the session). Thus, the lever used in the first half served as a potential conditioned stimulus (CS) for the type of reinforcer in the second half, but both levers were equally correlated with sucrose and food-pellet reinforcement. Results showed that induction failed to develop in the first half of the session in this procedure. Furthermore, systematic differences in responding on the different levers were not observed during concurrent-choice probe sessions.

Weatherly, Tischart, and Palbicki (2003) also reported results that appeared to argue against a direct Pavlovian contribution. They had rats respond in two types of session that were presented pseudo-randomly. In one, rats pressed lever A in the first half of the session for sucrose reinforcement and lever B in the second half for food-pellet reinforcement. In the other, they pressed lever B in the first half of the session for sucrose reinforcement and lever A in the second half for sucrose reinforcement. Thus, although the presence of lever A in the first half of the session was predictive of upcoming food-pellet reinforcement, only lever B was ever used to obtain the food pellets. Results showed that response rates in the first half of the session were higher during sessions in which lever B, rather than A, was present despite the fact that food-pellet reinforcement would not be available during those sessions. Concurrent-choice probe sessions also showed higher response rates on lever B than on lever A.

The results of Weatherly et al. (2002, 2003) question the idea that a stimulus that predicts the upcoming high-valued reinforcer promotes the appearance of induction. However, these results do not completely rule out the possibility of a Pavlovian contribution to induction. In fact, they might highlight what that contribution may be. Specifically, Weatherly et al. (2002, Experiment 4) showed that when each lever was equally correlated with food-pellet reinforcement, differential responding did not appear. Weatherly et al. (2003) demonstrated that when the levers were differentially correlated with food-pellet reinforcement, then responding was heightened on the lever used to earn the food pellets, even in sessions in which food-pellet reinforcement would not be available. Together, these results suggest that a stimulus that signals differential reinforcement can contribute to the appearance of induction. However, it is not clear whether this outcome results from Pavlovian processes (i.e., the lever serving as a CS), operant processes (i.e., the lever serving as a discriminative stimulus), or both. The present experiments were designed to make this assessment.

Experiment 1 tested whether induction would occur in any of three different situations, one that measured unconditioned responding, one that tested Pavlovian responding, and one that tested operant responding. If Pavlovian processes contribute to induction by the lever becoming a CS, then induction should be observed under conditions that measure Pavlovian responding. If only operant processes are involved, then induction should only be observed when operant behavior is measured. Experiment 2 tested whether the lever could serve as a predictive stimulus for upcoming food-pellet reinforcement when the lever itself was not used to earn the food pellets. Pressing lever A or B in the first half of the session was predictive of the substance available in the second half. However, reinforcers in the second half were delivered noncontingently and no lever pressing was allowed. If the lever can become a CS for upcoming food-pellet reinforcement, then induction should be observed in this procedure. Because the lever was not serving as a discriminative stimulus, however, induction should not be observed if operant processes control induction.

Experiment 1

The goal of Experiment 1 was to determine whether induction could be observed for a Pavlovian response and how it would compare to induction in non-Pavlovian responding. To make this determination, a sign-tracking (Hearst & Jenkins, 1974) procedure was employed.[1] In the first half of the session, the lever was inserted 10 s prior to the delivery of 1% sucrose. The lever was then retracted and the sucrose delivered. Responses to the lever were recorded but had no consequence. Responses to the lever would be considered Pavlovian in this procedure because they are controlled by the stimulus-reinforcer relation, not the response-reinforcer relation. In the second half of the session, the lever was always retracted and either 1% liquid sucrose or a food pellet, in different conditions, was delivered by means of a random-time (RT) schedule of reinforcement. Induction in this procedure would be represented by a higher number of sign-tracking responses in the first half of the session when food pellets would be delivered in the second half than when 1% sucrose would be delivered in the second half.

[1]Sign tracking is said to occur when the organism approaches and contacts a CS that has been paired with an unconditioned stimulus (US), typically food. Under the current procedure, the lever served as the CS and the 1% sucrose served as the US. Sign-tracking is a relatively commonly studied phenomenon that continues to attract research attention (e.g., Rescorla, 2006), partially because of its potentially profound but largely unstudied contributions to human behavior (e.g., drug taking; Uslaner, Acerbo, Jones, & Robinson, 2006).

Method

Subjects

The subjects were 12 experimentally experienced male Sprague-Dawley rats originally obtained from Charles River Laboratories. The subjects were approximately 1 year of age at the start of the experiment, and each had experience pressing a lever for liquid sucrose and food pellets delivered by means of intermittent schedules of reinforcement. More specifically, each had experience responding in conditions in which sucrose reinforcement in the first half of a 50-min session was followed by either sucrose or food-pellet reinforcement, in different conditions, in the second half. Subjects were individually housed with free access to water in the home cage. Subjects were continuously maintained at 85% of their free-feeding body weight, which had been previously determined. Deprived weights were maintained via postsession feedings or daily feedings on days that sessions were not conducted. Subjects experienced a 12/12 hr light/dark cycle, with all sessions conducted during the light portion of the cycle. Care and maintenance of the animals was in accordance with the guidelines published by the National Research Council (1996).

Apparatus

Two identical Coulbourn Instruments, Inc., experimental chambers were employed. Each measured 30.5 cm long, 25.0 cm wide, and 28.5 cm high. On the left side of the front panel, 6.5 cm above the grid floor and 2.5 cm from the left Plexiglas wall, was a 3.5-cm-wide by 0.1-cm-thick response lever that extended 2 cm into the chamber. The lever required a force of approximately 0.25 N to depress and could be retracted so that it was flush with the front panel. Above the lever was a panel that contained three stimulus lights (red, yellow, and green from left to right). The lights were 0.6 cm in diameter, with the center light being 5 cm above the lever and the other lights 0.6 cm to the left and right. Centered on the front panel, 2 cm above the floor, was a 3.3-cm-wide, 3.8-cm-high, and 2.5-cm-deep opening. The opening allowed access to a trough into which reinforcers were delivered. Liquid reinforcers were delivered to the trough via a syringe pump outside the apparatus and attenuating cubicle. Food pellets were delivered to the trough via a pellet dispenser behind the front panel. A 1.5-cm-diameter house light, which provided general illumination, was centered on the back panel, 2.5 cm below the ceiling. Each experimental chamber was housed inside a sound-attenuating cubicle equipped with a ventilation fan to mask noise from outside.

Experimental events were programmed, and data were recorded, with a personal computer that was connected to Coulbourn Instruments Universal Lincs and that ran Graphic State software. The control equipment was in a room adjacent to the one housing the experimental chambers.

Procedure

The subjects were experimentally experienced and were therefore placed immediately on the experimental procedure. Each subject responded in a total of six conditions (i.e., a completely within-subject design was employed). Conditions differed in terms of the contingencies of reinforcement in the first half of the session and the type of substance delivered in the second half of the session.

All sessions were 50 min in length. In the first pair of conditions (RT-1% & RT–food pellet [FP]), the lever was inserted into the chamber during the first half of the session and 0.2 ml of 1% liquid sucrose (percent volume per volume mixed with tap water) was delivered by means of an RT 60-s schedule. Sucrose delivery was programmed at a probability of 0.01 every 0.6 s. The red/left light above the lever was illuminated continuously, except during sucrose delivery. This stimulus change was the only one during the 3.2 s required to deliver the sucrose reinforcer (i.e., the trough was not illuminated). These 3.2 s were not counted toward the 50-min session duration. In this pair of conditions, responses to the lever had no consequence. At the midpoint of the session, the lever was retracted and the light above the lever was extinguished. In the RT-1% condition, 0.2 ml of 1% sucrose was then delivered for the remainder of the session according to an identical RT 60-s schedule. In the RT-FP condition, a 45-mg food pellet (Research Diets, Formula A/I) was delivered for the remainder of the session by means of the RT 60-s schedule. The house light was illuminated throughout the session.

In the second pair of conditions (sign tracking [ST]-1% & ST-FP), a sign-tracking procedure was in effect during the first half of the session. Specifically, an RT 50-s schedule programmed when the lever would be inserted into the chamber. The lever was then inserted into the chamber for 10 s. After 10 s, the lever was retracted and 0.2 ml of 1% sucrose was delivered to the trough. Responses to the lever during the 10 s it was inserted into the chamber had no consequence. As with the RT conditions, at the midpoint of the session, the lever was retracted from the chamber and either 1% sucrose (ST-1%) or a food pellet (ST-FP) was delivered on an RT 60-s schedule for the remainder of the session.

The final pair of conditions (signaled response [SR]-1% & SR-FP) employed a signaled-response procedure. As in the sign-tracking conditions, an RT 50-s schedule programmed when the lever would be inserted into the chamber during the first half of the session. However, when inserted, a fixed-interval 10-s schedule was in effect (i.e., the first lever press that occurred after 10 s had elapsed was reinforced with 1% sucrose). Again, the SR-1% and SR-FP conditions differed in whether 1% sucrose or food pellets, respectively, were delivered noncontingently in the second half of the session.

Every subject experienced each of the above conditions, with conditions being conducted once per day, 5 days per week. Six of the subjects experienced the conditions in the following order: ST-1%, SR-FP, RT-1%, ST-FP, SR-1%, and RT-FP. The remaining 6 subjects experienced these conditions in the reverse order. Each condition was conducted for 20 consecutive sessions.

Results

Figure 1 presents the results from Experiment 1. The data used to construct Figure 1 were analyzed by conducting a two-way (condition by upcoming reinforcer) repeated-measures analysis of variance (ANOVA). Results showed that the main effect of condition was significant (F [2, 22] = 42.94, p < .001), indicating that different levels of responding were observed across the three pairs of conditions. The main effect of upcoming reinforcer was also significant (F [1, 11] = 9.09, p = .012), indicating that the more responses per reinforcer were observed when food pellets would be delivered in the second half of the session than when 1% sucrose would be delivered. The interaction between condition and upcoming reinforcer (F [2, 22] = 1.65) was not significant. Because determining whether induction was present during specific contingencies was the crux of the experiment, follow-up analyses were conducted. Results from one-way ANOVAs showed that responding was heightened

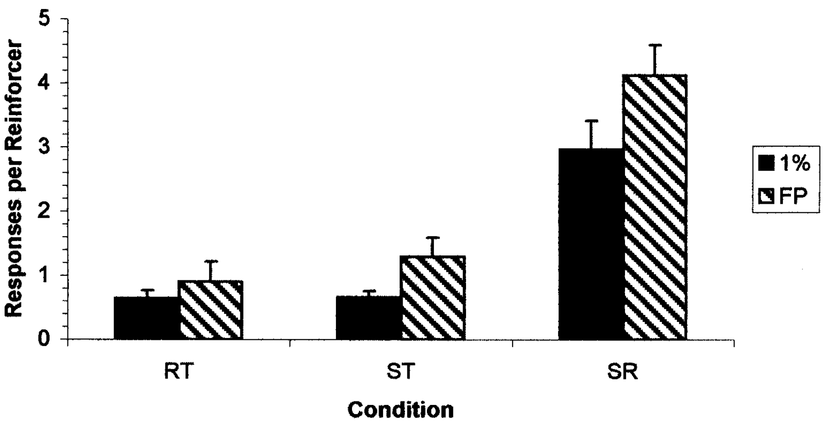

Figure 1. Results of Experiment 1. Presented are the lever presses per reinforcer in the first half of the session for the mean of all subjects in each pair of conditions. The solid bars represent responding when 1% sucrose would be delivered in the second half of the session, and the striped bars represent when food pellets would be delivered. The error bars represent 1 standard error of the mean across all subjects responding in each condition. The data were calculated from the final five sessions of each condition.

when food-pellet reinforcement was upcoming in the ST (F [1, 11] = 6.68, p = .025) and SR conditions (F [1,11] = 5.79, p = .035) but not in the RT conditions (F < 1). Results for these analyses, and all that follow, were considered significant at p < .05.

Discussion

The results of Experiment 1 are consistent with the idea that Pavlovian processes can contribute to positive induction. Induction was observed when a sign-tracking response was the dependent measure but not when a nonconditioned response was the dependent measure (i.e., RT conditions). As expected, given past research, induction was also observed in the operant, signaled-response conditions.

Although induction was observed for sign-tracking responses, this result does not provide concrete evidence that Pavlovian conditioning can contribute to induction. For instance, it is possible that generalization occurred from the signaled response to the sign-tracking conditions, thus accounting for the increased responding. It is also possible that existing explanations for induction can indirectly account for the present results. As noted above, research suggests that upcoming food-pellet reinforcement increases the value of the low-valued reinforcer (e.g., Weatherly et al., 2004), possibly due to both substances being delivered to the same location (Weatherly et al., 2006). If the 1% sucrose was increased in value when the food-pellet reinforcement was upcoming in the present procedures, then one might expect an increase in the number of sign-tracking responses when the stimulus (i.e., the lever) was predictive of a strengthened reinforcing stimulus (i.e., the 1% sucrose). Such a contention is supported by the fact that the different substances were delivered to the same location. If true, then one would not conclude that sign tracking can contribute to induction but rather that induction can contribute to sign tracking.

Experiment 2

Experiment 1 supported the idea that the response operandum (i.e., the lever) might become a CS for upcoming food-pellet reinforcement and thus contribute to induction.[2] However, the results leave open several alternative explanations. Experiment 2 was designed to determine whether a Pavlovian influence could still be detected when these alternative explanations were ruled out. To do so, rats were employed to press a lever for 1% sucrose reinforcement in the first half of the session using lever A or B. If lever A was used, then extinction would be in effect during the second half of the session. If lever B was used, then food pellets would be delivered noncontingently in the second half. These types of sessions alternated across sessions, with both substances being delivered to the same location.

If Pavlovian processes contribute to induction, then one would predict that heightened rates of responding would be observed on lever B relative to lever A during the first half of the session. Likewise, in concurrent-choice

[2]In the ST conditions of Experiment 1, the lever (CS) was paired with the delivery of 1% sucrose (US), which presumably maintained the sign-tracking response. However, when food-pellet reinforcement was upcoming in the second half of the session, sign-tracking responses increased in the first half. The question that arises is whether this increase was directly linked to the upcoming food pellets (e.g., the upcoming food pellets serving as an additional, distal US) or to some other factor (e.g., a change in the reinforcing value of the 1% sucrose, which in turn increased the sign-tracking responses). Because inserting the lever in the first half of the session was one of the few, and arguably the most salient, stimulus changes prior to availability of the food pellets, the former possibility is not out of the realm of reason. It is, in fact, an empirical question.

probe sessions, one would predict higher rates of responding on lever B than on lever A. This result would be expected, because the lever would be serving as a CS for the upcoming conditions of reinforcement. One would not predict to observe induction, however, according to the alternative explanations. If the 1% sucrose has increased in value, then one would expect equal increases in responding in both types of session for the 1% sucrose. Likewise, because the sucrose and food pellets were always delivered to one location, one would predict that any effect of location of delivery would be equal in the two types of session. Finally, any increase in responding on lever B relative to lever A would not be explainable as the outcome of the lever becoming a discriminative stimulus because the levers were retracted when the food pellets delivered and did not signal any operant contingency.

Method

Subjects

The subjects were 12 experimentally experienced male Sprague-Dawley rats originally obtained from Charles River Laboratories. The subjects were approximately 9 months of age at the start of the experiment and were not those used in Experiment 1. All subjects, however, did have experience pressing a lever for liquid-sucrose and food-pellet reinforcement delivered by means of a random-interval (RI) schedule, with their experimental history being similar to that described for subjects in Experiment 1. The subjects were housed and maintained as described in Experiment 1.

Apparatus

Two experimental chambers were used. They were identical to those described in Experiment 1, with two exceptions. A second retractable response lever was on the front panel to the right of the trough, symmetrical to the lever on the left. A three-light stimulus panel, identical to that described in Experiment 1, was also above the right lever.

Procedure

The subjects were experimentally experienced and therefore immediately placed on the experimental procedure. Subjects responded in 50-min sessions. During the first half of the session, lever pressing was reinforced with 0.2 ml of 1% sucrose programmed with an RI 60-s schedule. Reinforcers were scheduled at the probability of 0.01 every 0.6 s, unless a reinforcer had already been scheduled for delivery. At the midpoint of the session, the lever present during the first half of the session was retracted from the chamber and either extinction was in effect for the remainder of the session (i.e., a 25-min time-out) or food pellets were delivered by means of an RT 60-s schedule identical to that described in Experiment 1. Whether extinction or food-pellet reinforcement was available in the second half was determined by the lever subjects pressed in the first half. If they pressed lever A in the first half, then extinction was in effect in the second half (1%-EXT). If subjects pressed lever B in the second half, then food pellets would be delivered in the second half (1%-FP). For half of the subjects, the left and right levers served as levers A and B, respectively. This order was reversed for the other half of the subjects. When the left lever was used, the red light above that lever was illuminated. When the right lever was used, the green light above that lever was illuminated. The light above the lever was extinguished during reinforcer delivery. The house light was continuously illuminated.

These sessions alternated in strict succession for 40 sessions (i.e., 20 sessions of each type). The first session was a 1%-EXT session for half of the subjects. It was a 1%-FP session for the other half. Starting with session 41, four 25-min concurrent-choice probe sessions were conducted in which both levers were presented. In two of these sessions, extinction was in effect on both levers. In the other two sessions, independent RI 60-s schedules of 1% sucrose reinforcement were in effect for responding on both levers, with a 2-s changeover delay in effect during which reinforcement was not available. Twenty-five min sessions were employed because that equaled the length of the first half of the training sessions. Each probe session was separated by four additional training sessions, two of each type. The order of probe sessions varied across subjects.

After the fourth probe session was completed, subjects experienced 20 additional training sessions (i.e., 10 of each type). These additional sessions were conducted because differences in responding were apparent in the probe sessions but not in the initial training sessions. Previous research had shown similar results, with significant differences becoming apparent with additional training sessions (see Weatherly et al., 2003). These additional sessions again alternated in strict succession. All sessions in Experiment 2 were conducted once per day, 5 days per week.

Results

Figure 2 shows the results of Experiment 2. Data used to construct the top graph of Figure 2 were initially analyzed with a two-way (time by upcoming reinforcer) repeated-measures ANOVA. This analysis yielded no significant results. However, to determine whether induction was ever observed, follow-up one-way ANOVAs compared responding in the different types of session prior and subsequent to the probe sessions. These analyses showed that although responding did not differ in the first half of the training sessions prior to the probe sessions ($F < 1$), responding was significantly higher in sessions in which food pellets were upcoming than in sessions in which they were not (F [1, 11] = 8.19, p = .015) by the end of training.

Analysis of the probe sessions also indicated that a significant induction effect was observed. The data used to construct the bottom graph of Figure 2 were analyzed using a two-way (condition by upcoming

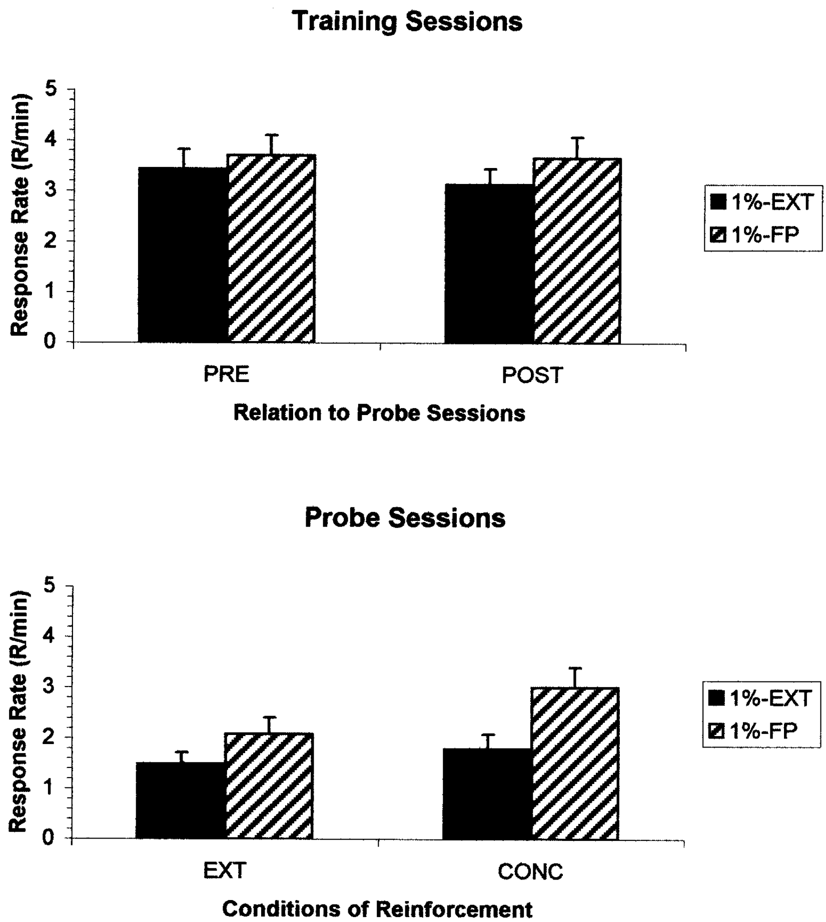

Figure 2. Results of Experiment 2. The top graph presents the rate of lever pressing during the first half of each of the final five training sessions that occurred prior (PRE) and subsequent to (POST) the concurrent-choice probe sessions. Results are presented for the mean of all subjects. The solid bars represent results from the 1%-EXT sessions. The striped bars represent results from the 1%-FP sessions. The bottom graph presents the mean rate of responding on each lever during the two concurrent-choice probe sessions in which extinction (EXT) or 1% sucrose reinforcement (CONC) was in effect. The solid bars represent responding on the lever used in the 1%-EXT training sessions. The striped bars represent responding on the lever used in the 1%-FP sessions. In both graphs, the error bars represent 1 standard error of the mean across subjects.

reinforcer) repeated-measures ANOVA. This analysis yielded a significant main effect of condition (F [1, 11] = 12.47, p = .005), indicating that subjects responded at higher rates when the concurrent schedules were in effect than when extinction was in effect. The main effect of upcoming reinforcer was also significant (F [1, 11] = 10.86, p = .007), indicating that subjects pressed the lever that preceded food pellet delivery in the training sessions at a higher rate during the probe sessions than they did the lever that preceded extinction. The interaction between condition and upcoming reinforcer did not reach significance (F [1, 11] = 3.52).

Discussion

In Experiment 2, the lever used in the first half of the training sessions was a potential CS for the upcoming conditions of reinforcement. If that Pavlovian process influenced the presence of induction, then induction should have been observed in the sessions in which food pellets were upcoming relative to sessions in which extinction was upcoming. A significant induction effect was ultimately observed in the training sessions. This effect was also present during concurrent-choice probe sessions in which both levers were present.

These results are not explainable by means of the alternative explanations available for the results of Experiment 1. Specifically, if upcoming food-pellet reinforcement had increased the value of the 1% sucrose, then similar rates of responding for 1% sucrose reinforcement in the first half of the session should have been observed on the different levers, because sessions alternated strictly and thus the effect of the increase in value would be expected to manifest in both types of session. If location of reinforcer delivery influenced responding, then it too would be expected to exert its influence equally in both types of session. Finally, the differences in responding also do not appear explainable in terms of one lever, rather than the other, becoming a discriminative stimulus for food-pellet reinforcement. One could make this argument because neither lever was present when the food pellets were delivered nor did either lever signal that the response of pressing the lever would now result in differential reinforcement.

However, several arguments could be made that operant, and not Pavlovian, processes explain the results of Experiment 2. One argument is that responding on lever B increased because it was serving as a discriminative stimulus for responding that was adventitiously reinforced by a period of food-pellet reinforcement. A second argument is that, because food-pellet reinforcement was delivered only after lever B was removed, pressing lever B was adventitiously reinforced by the removal of the lever at the midpoint of the session. Although possible, both of these arguments can be countered. If the upcoming period of food-pellet reinforcement was adventitiously reinforcing responding in the first half of the session, then induction should have also been observed in the RT conditions of Experiment 1. It was not. Next, if the absence or removal of lever B was serving as the reinforcing stimulus, then it would seem logical that the presence of lever B would serve as an inhibitory stimulus. If true, then responding on lever B should have decreased, not increased. Furthermore, if the removal of the lever that was predictive of upcoming food-pellet reinforcement contributed to induction by adventitiously reinforcing responding on that lever, then Weatherly et al. (2002, Experiment 4) should have observed induction in their procedure (see description in the general introduction above), but they did not.

General Discussion

Previous research on positive induction in rats that respond for a low-valued reinforcer when a high-valued reinforcer is upcoming had suggested that at least two mechanisms could contribute to the effect. One was the addition of “premature” responses for the yet unavailable high-valued reinforcer when the low-valued reinforcer was still available. A second was an increase in the value of the low-valued reinforcer, perhaps due to both the low- and high-valued reinforcers being delivered to the same location. The present experiments were assessments of whether a third process could also contribute to induction. They investigated whether the response operandum (a lever in the present case) could, through Pavlovian processes, come to serve as a CS for upcoming food-pellet reinforcement, with response rates increasing because subjects approached and contacted the CS. Both experiments provided support for this possibility.

The results of Experiment 1 showed that positive induction was observed when the lever was used as a CS in a sign-tracking procedure (Hearst & Jenkins, 1974) when food-pellet reinforcement was upcoming relative to when it was not. However, alternative explanations existed for why this increase in responding might have occurred. The results of Experiment 2 demonstrated that positive induction could be observed on a lever that was predictive of upcoming food-pellet reinforcement despite the lever not being used to earn the food pellets. The results of Experiment 2 were inconsistent with the alternative explanations that could potentially account for the results of Experiment 1. Together, the present results thus suggest that under some conditions, the presence or size of positive induction, or both, may be influenced by the Pavlovian process of the response operandum becoming a CS for differential reinforcement.

The question that now remains is whether these three identified mechanisms fully account for the occurrence of positive induction. If they do, then it should be possible to program conditions that systematically and predictably alter the size of induction. That is, if the high-valued reinforcer will be earned by responding on the same operandum used to earn the low-valued reinforcer and is delivered to the same location as the low-valued reinforcer, and the operandum used to earn the low-valued reinforcer serves as an excitatory CS for the upcoming high-valued reinforcer, then one would expect to observe a robust positive induction effect. However, as these factors are manipulated from optimal, induction should be reduced, if not eliminated altogether. Furthermore, by manipulating these factors independently, it should be possible to compare their overall contributions to positive induction.

As the reasons for why rats increase their rate of responding for a low-valued reinforcer when a high-valued reinforcer is upcoming are discovered, the study of positive induction should serve as yet another reminder of the complexities of relative reinforcement. What began as a somewhat surprising finding in a relatively straightforward procedure (Weatherly et al., 1999) has led to some unexpected and not-so-straightforward explanations. Easily overlooked procedural variables, such as whether one or two response operandi are used and whether the different reinforcers are delivered to the same or different locations, appear to have relatively profound effects on behavior. Likewise, both operant (e.g., "premature" responses) and Pavlovian processes (e.g., changes in reinforcer value, the response operandum becoming a CS) appear to be involved in altering behavior in what might be considered a fairly simplistic situation (i.e., one RI 60-s schedule in effect for a 25-min period). If anything, the study of positive induction demonstrates that the systematic study of behavior in controlled situations remains necessary if the field is ultimately to reach its goal of predicting and controlling behavior.

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