Pavlovian conditioning and signaling: Higher order conditioning and transfer in rats

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Five rats were trained to barpress for food and then a first-order Pavlovian task (CS₁-shock) was superimposed on this ongoing operant. Rapid suppression to CS₁ was found. In the next phase, a second-order task (CS₂-CS₁) was superimposed on the ongoing operant, followed by CS₁ extinction and then by CS₂ probe trials. Evidence of second-order conditioning was found even after CS₁ extinction, as has been previously reported. In the final phase, a third signal (CS₃) was followed by CS₁ and resulted in some suppression to CS₃, although the response rate to CS₁ during this phase was similar to that of the last day of CS₁ extinction. The data suggest that when the CS₁ was presented alone it resulted in behavior different from that when it followed a given signal.

One of the many phenomena Pavlov (1927) reported in his classic work was that of "higher order" conditioning. Specifically, he reported that a stimulus followed by food for a number of trials not only produces a conditioned salivary response, but also can be used as a "reinforcer" to establish conditioned salivation to some other neutral stimulus.

However, the literature on higher order conditioning has not been terribly successful, often revealing relatively low levels of conditioning. Recently, Rescorla (Rescorla, 1973; Rizley & Rescorla, 1972) developed a procedure that yields extremely rapid and high levels of second-order conditioning. Rats are trained to barpress for food on a variable-interval (VI) schedule. Then a Pavlovian task is superimposed on this ongoing operant [e.g., a 10-sec flashing light (CS₁) that terminates with a ½-sec 1-mA footshock], thus establishing first-order conditioning to the CS₁ since the barpressing behavior essentially ceases during the 10-sec flashing light. Subsequently, a 30-sec tone (CS₂) is followed by the 10-sec flashing light (the CS₁), and the suppression ratio to the tone goes from .5 (no suppression) to near zero (total suppression) in four to eight trials. Rizley and Rescorla (1972) also demonstrated that, once established, second-order conditioning appears to become independent of the conditions necessary for its occurrence, since extinction of CS₁ does not reduce the conditioning level of CS₂ after second-order conditioning is established. Further, Rescorla (1973) reported another extremely clever study in which, after CS₁ extinction, CS₂ is used as the "reinforcer" to reestablish suppression to CS₁. Rescorla (1973) points out that first- and second-order conditioning may reflect different independent associative processes.

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With regard to the nature of second-order conditioning, Shapiro, Sadler, and Mugg (1971) reported evidence of second-order conditioning using dogs in a salivary conditioning paradigm. However, the overall level was quite low and the acquisition function, instead of being negatively accelerated, was concave downward. That this latter finding was not the result of extinction of CS₁ was demonstrated by the result that subsequent extinction of CS₁ led to 0% salivation to CS₁ but left the level of conditioning (although low) to the CS₂ unaffected.

It may be that in Rescorla's studies he had not given enough trials to detect a concave downward function, plotting proportion conditioned response as a function of trials. Of course, if we are considering the suppression ratio as a dependent variable, the function would be concave upward, since acquisition when using the suppression ratio is a decreasing function. In the present study this possibility was explored.

METHOD

Subjects and Apparatus

The subjects were five female rats (Sprague-Dawley) about 100 days old at the start of the experiment. They were maintained throughout the experiment at 80% of their normal body weight.

The experimental chambers consisted of three identical operant boxes, 7¼ x 12 x 8¼ in. (18.4 x 30.5 x 21 cm). Each chamber had a recessed food magazine in the center of the end wall, a bar 2 in. (5.1 cm) and ¾ in. (1.9 cm) above the magazine, and two panel lights, 6 in. (15.2 cm) apart, 2 in. (5.1 cm) above the bar. A 2,900-Hz Sonalert was in the center of the end wall 5 in. (12.7 cm) above the food cup. The floor of the chamber was composed of 3/16-in. (.48-cm) stainless steel rods spaced ¾ in. (1.9 cm) apart. This grid could be electrified through a relay-sequence scrambler from a high-voltage high-resistance shock source. The two end walls of the chamber were aluminum; the side walls and top were clear Plexiglas. Each box was enclosed in a sound- and light-resistant shell. Mounted in the center of the side wall of the outer shell was a 6½-W light bulb and a speaker. Experimental events were controlled and recorded automatically by relay equipment located in an adjoining area.

Procedure

In the first session, each rat was magazine trained manually with 45-mg Noyes food pellets. This session continued until the subject had emitted about 30 barpresses. Starting with the second experimental day, all sessions were 2 h long and the animal was placed on a VI schedule of reinforcement. For the first 4 days of training the schedule was VI 1 min; throughout the remainder of the experiment a VI 2-min schedule was in effect.

After 22 days of VI training (18 days of VI 2 min), two pretest sessions were given during which the stimuli subsequently to be used in conditioning were presented. During each session two presentations of each of what were to be CS₁, CS₂, and CS₃ were superimposed on the barpressing behavior.

The next day began Phase 1 conditioning, designed to establish first-order conditioning to CS₁. During Phase 1 all five subjects received paired presentations of the CS₁ and a 1-mA ½-sec footshock on a variable-time schedule; shock onset coincided with CS₁ termination. Four such trials were given during each of the three 2-h sessions. Phase 2 was designed to produce second-order conditioning. A trial consisted of a 30-sec CS₂ followed immediately by a 10-sec CS₁. Four such trials were administered on each of 3 days of Phase 2. The next day began Phase 3, which was an extinction phase. Each day four nonreinforced presentations of CS₁ were superimposed on VI responding. The next three sessions assessed the conditioning of the second-order stimulus. During this session subjects continued to respond on the VI 2-min schedule. Superimposed upon this performance were four nonreinforced presentations of the 30-sec CS₂. The final 3 days were a final conditioning phase of a 30-sec CS₃ followed by the 10-sec CS₁. Four such trials were given each day.

The specific stimuli used for CS₁, CS₂, and CS₃ for each rat were: for one subject a flashing houselight (2/sec), a 2,900-Hz tone, and continuous panel lights, which served as CS₁, CS₂, and CS₃, respectively; for a second subject the CS₁, CS₂, and CS₃ were continuous panel lights, a flashing houselight, and a 2,900-Hz tone, respectively; for a third subject a white noise click (2/sec), a 2,900-Hz tone, and a flashing houselight served as the CS₁, CS₂, and CS₃, respectively. The last two subjects both had the 2,900-Hz tone as CS₁, while one had the panel lights and the flashing houselight as CS₂ and CS₃, respectively, and the other had the flashing houselight and a white noise click as the CS₂ and CS₃, respectively.

To achieve comparability with prior work, one measure of conditioning used was the amount of suppression of barpressing produced by a stimulus presentation. This is typically done to attenuate the effects of individual differences in overall rate of responding and, as a result, the results are typically presented in terms of a suppression ratio. This ratio has the form $A/(A + B)$, where A is the rate of responding during the CS and B is the rate of responding in a comparable period prior to CS onset. Thus, a suppression of 0 indicates no responding during the CS (100% conditioning), while one of .5 indicates similar rates of responding during the CS and pre-CS periods (little or no conditioning). In addition, to further examine overall effects of shock and subsequent second-order training, the mean response rates in the various phases were also analyzed.

RESULTS AND DISCUSSION

In Figure 1 is shown the mean suppression ratio and mean response rates for the various phases averaged across five subjects. The solid line represents the overall response rate per session for nonsignal periods. The overall rate was fairly stable prior to first-order conditioning (range .30-.34). During first-order conditioning,

the only phase during which the subjects were shocked, the overall response rate for *nonsignaled* periods decreased (range .19-.27). However, during all other phases the rate returned to the baseline level (range .26-.33).

Rapid first-order conditioning can be seen in Sessions 23-25, with the rate to CS₁ approaching zero. During the second-order conditioning phase, rapid conditioning can be seen but it appeared to dissipate over the 3 days of training (Sessions 26-28). At the end of second-order training the CS₂ rate was still below the overall nonsignal rate, which by this time had recovered from the generalized suppressive effects of shock during the first-order phase.

First-order extinction never resulted in a .50 suppression ratio, although by the last day of extinction (Session 31) the CS₁ response rate was very close to the overall nonsignal rate. The second-order probe trials revealed some suppression, although extinction seems evident. However, the CS₂ rate was still somewhat below that of the nonsignal periods (Sessions 32-34).

In the last phase the CS₁ response rate was quite variable, although it was below the overall nonsignal rate for Session 35, above it for Session 36, and slightly below for the last session (37). The CS₃ response rate shows a concave upward function, terminating only slightly below the overall rate. The suppression ratio is similar, although more variable, still showing evidence of suppression during the final session.

The response rates were presented here to reveal a well-known fact: Although the use of suppression ratio takes into account momentary fluctuations in responding over time, it may "overact" to the momentary fluctuation. On the other hand, comparing the signal response rate to the overall nonsignal rate may give a clearer indication of the level of control of the signal. Since the overall nonsignal rate was fairly stable after the first-order phase, we can then examine the response rates to the various signals for evidence of control.

As a result some interesting findings emerge. Although the CS₁ rate increases during extinction, the CS₂ rate remains unchanged, that is, the CS₂ rate during probe tests was about the same as it was at the end of second-order training. Further, although the CS₁ rate in the final phase was quite variable, and on the average similar to that at the end of CS₁ extinction, CS₃ exhibited some control, as evidenced by the lower rate relative to nonsignal periods. Control animals that never received shock had been run in this study. Although they generally showed reduced responding to a signal when it first appeared, this effect disappeared rapidly, while for the five experimental subjects the signal control appeared to be longer lasting.

These data are at best suggestive regarding the shape of the second-order acquisition function. However, they do suggest an important distinction: that the CS₁ when presented alone may result in behavior different from that when it is presented following a given signal. Thus,

Figure 1. Mean rate (per second) as a function of session number. The four data points for each session represent the mean rate for each of the four signal trials in a session.

although CS₁ during the final phase (CS₃-CS₁ conditioning) did not lead to response rates very different from the last day of CS₁ extinction, the signal preceding it, CS₃, which had previously shown no differential responding, appeared to acquire suppressive tendencies, as CS₁ had done during first-order conditioning.

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