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Review

Factors that influence the persistence and relapse of discriminated behavior chains

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ABSTRACT

Behavior chains are composed of sequences of behaviors that minimally include procurement and then consumption. This review surveys recent research from this laboratory that has examined the properties of discriminated heterogeneous behavior chains. In contrast to another review (Thrailkill and Bouton, 2016a), it discusses work examining what makes chained behavior persistent, and what makes it relapse. Results suggest that responses in a discriminated heterogeneous behavior chain may become associated, so that extinction of either one reduces the strength of the other. Evidence also suggests that the goal of the first (procurement) response may be the next (consumption) response (rather than the upcoming discriminative stimulus, a putative conditioned reinforcer, or the primary reinforcer at the end of the chain). Further studies suggest that methods that promote generalization across acquisition and extinction (partial reinforcement and delivery of noncontingent reinforcers during extinction) lead to greater persistence of the procurement response. A third set of studies analyzed the contextual control and relapse of chained behaviors. The context controls both the acquisition and extinction of chained behaviors. In addition, a separately-extinguished consumption response is renewed when returned to the context of the chain. The research expands our general understanding of the learning processes that govern instrumental behavior as well as our understanding of chains.

Operant behaviors are typically organized into chains of linked behaviors, as Skinner (e.g., 1934) observed many years ago. A behavior chain minimally involves a response that leads directly to the reinforcer (a consumption response) and at least one more response that provides access to the consumption response (a procurement response; terminology from Collier, 1981). Understanding behavior chains may have important translational implications, because unhealthy behaviors such as drug abuse, overeating, and smoking are all part of a chain. For example, smoking behavior involves not only inhaling smoke from a cigarette (consumption), but also seeking out and buying cigarettes (procurement). To stop smoking, one must quit buying the cigarettes in addition to inhaling them. Importantly, the procurement behavior (e.g., buying cigarettes in the minimart) and the consumption behavior (e.g., smoking outside by the street) often each take place in the presence of their own discriminative stimulus (SD). Clinical research also suggests an important role for procurement-related stimuli in the maintenance of unhealthy consumption behaviors (Conklin et al., 2008). On this view, because behavior is often part of a chain, understanding behavior chains will be relevant for developing approaches that address problematic operant behavior.

The term "behavior chain" has several possible meanings in the literature. In one, the term refers to a sequence of linked behaviors in which responses during one stimulus are followed by another stimulus that is thought to (a) reinforce the previous response and (b) set the occasion for the next one (Gollub, 1977; Kelleher and Gollub, 1962). In one example, a pigeon pecking a key on a so-called chained schedule of reinforcement pecks in the presence of different stimuli that signal different response requirements; because the pecking response in each component is the same, this is a *homogeneous* behavior chain. In another example, a rat may be required to press a lever in one stimulus and then pull a chain in another; because the chain involves topographically dissimilar responses, this is a *heterogeneous* chain. Either of these types of chains can be distinguished from other "chaining", or response-sequence tasks that do not involve distinct SDs for each response (e.g., Balleine et al., 1995; Ostlund et al., 2009). The term behavior chain can further refer to tasks that differentially reinforce different response patterns that involve distinct SDs to occasion the start of each pattern (e.g., Bachá-Méndez et al., 2007; Grayson and Wasserman, 1979). Such response patterns can function as a distinct operant unit; that is, the entire sequence can be sensitive to its reinforcement contingencies (e.g., Reid et al., 2001; Schwartz, 1982).

The present review focuses on the type of chain in which different

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behaviors are signaled by different SDs, which we call *discriminated heterogeneous chains* for even more precision. The main reason for this focus is that discriminated heterogeneous chains are the types of chains that are involved in smoking and drug taking, where, as described above, different procurement and consumption responses take place in different SDs. Our recent work has studied how extinction can reveal what holds such chains together and what takes them apart (see Thrailkill and Bouton, 2016a, for a review). We begin by briefly reviewing studies that address the associative content of discriminated chains. We then emphasize studies that extend this approach to address the applied questions of what makes chained behavior persistent and what makes it relapse. We address similarities and differences between simple behaviors and behaviors that occur as part of a chain. Overall, the work has revealed several important details about behavior chains with possible implications for the applied and theoretical understanding of operant behavior.

1. The associative structure of a discriminated behavior chain

Earlier research on heterogeneous chains suggested that organisms may learn an association between the responses in the chain (Olmstead et al., 2001; Zapata et al., 2010). For instance, Olmstead et al. (2001) trained rats to press a lever (R1) to insert a second lever (R2) on which a response led to an outcome (O) of an intravenous infusion of cocaine. (Notice that there were no SDs for either response other than the presence of the individual levers.) After learning this chain (R1-R2-O), the rats received sessions in which the R2 lever was presented by itself and either reinforced or not reinforced (extinguished). In a test, R1 responses were then measured in extinction. Responding on R1 was weaker after R2's extinction than after its reinforcement. This led the authors to suggest that rats decreased R1 because it no longer led to a valued outcome (the R2-reinforcement combination). However, it was unclear whether the strength of R1 reflected its relation to the R2 response, the R2 SD, the primary reinforcer, or some combination of the above. In addition, extinguishing R2 in one group and reinforcing it in the other made it impossible to know which was the active ingredient.

To address these concerns, Thrailkill and Bouton (2016b) studied whether extinction of R2 weakens R1 after training with a discriminated heterogeneous chain. Fig. 1 provides a diagram of the procedure. After an intertrial interval (ITI), a procurement SD (S1; e.g., a light) turned on and set the occasion for a procurement response (R1; e.g., lever press). Completing the procurement requirement (e.g., random ratio 4; RR 4) simultaneously turned off S1 and turned on S2. In S2, completing the response requirement (e.g., RR 4) on the consumption manipulandum (R2; e.g., chain pull) terminated S2, delivered the food-pellet reinforcer, and initiated the next ITI. After learning this discriminated chain, groups received either extinction of R2 in S2, or extinction of S2 without being able to make R2 (response manipulanda were removed from the chamber). After extinction, each group received a test with extinction presentations of S1 with both R1 and R2 manipulanda present. Groups that could perform R2 during extinction made the fewest number of S1R1 responses. In contrast, the group that received extinction of S2 without the ability to learn to not make R2 made a number of S1R1 responses that was similar to that in a nonextinguished control group. Thus, extinction of any Pavlovian excitatory value of S2 did not weaken R1 responding. Instead, although extinction of S2R2 could weaken R1, making R2 in extinction was critical. This result is consistent with other research showing that extinction of simple responses requires learning to inhibit the response when it is nonreinforced (Bouton et al., 2016; Rescorla, 1997).

Importantly, a further experiment established that the effect of R2 extinction on R1 was specific to the R1 with which it had been chained. Rats learned two separate chains (S1R1-S2R2-O and S3R3-S4R4-O), and then received extinction of S2R2. In a test, rats received extinction presentations of S1R1 and S3R3. Extinguishing S2R2 specifically weakened R1, that is, the response that had preceded it in its chain. Rats responded on the nonextinguished R3 response as much as did an untreated control group. Therefore, the effect of extinguishing R2 on R1 was not the result of generalization between responses, or perhaps a general state of frustration that inhibited all behavior.

Instead, the results suggest that the rats had learned to associate the two responses, and that the response association makes R1 sensitive to the current status of R2. Extinction of R2 (but not S2) seemed to weaken R1 in a manner analogous to how decreasing the value of the reinforcing outcome for a simple operant response can decrease performance of the response (Adams, 1982; Dickinson and Balleine, 2002). In an analogous way, our results suggest that R2 (but not S2) may be a goal of the procurement response (R1).

The results are reminiscent of findings from Pavlovian serial compound conditioning methods in which two CSs are conditioned in series, i.e., CS1 → CS2-US (Holland and Ross, 1981). In those studies, extinction of either conditioned stimulus (CS1 or CS2) weakened responding to the other CS. If this logic applies to a discriminated operant behavior chain, we would expect not only that extinction of R2 would weaken R1 (as above), but extinction of R1 should also weaken R2. Thrailkill and Bouton (2015a) therefore addressed this possibility using analogous designs. After training the discriminated heterogeneous chain (S1R1-S2R2-O), rats received extinction of R1 or S1 before testing R2. To be specific, in extinction, groups received extinction of R1 in S1, or S1 alone in the absence of the opportunity to make the response. After extinction, groups received extinction test presentations of S2 with both manipulanda present. Groups that were able to make R1 during extinction, but not the group that was merely exposed to S1, showed suppressed R2 responding relative to a no-treatment control. Clearly, extinguishing S1R1 weakened R2, but making the response (R1) was again required. A further experiment with the two-chain procedure found that the effect of R1's extinction was specific to the R2 with which it had been trained. Because the effects were specific to the associated response, the results suggest that R1 extinction may weaken R2 through some form of "mediated" extinction (Holland and Ross,

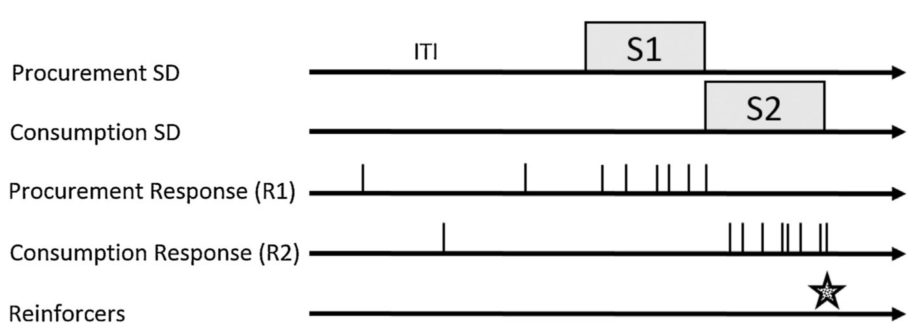

Fig. 1. Diagram of events in a discriminated heterogeneous instrumental chain. Procurement (R1; e.g., lever press) and consumption responses (R2; e.g., chain pull) can occur freely. After an intertrial interval (ITI), the procurement SD (S1) turns on. Procurement responses (R1) during S1 can produce the simultaneous offset of S1 and onset of the consumption SD (S2). Consumption responses (R2) during S2 can produce the simultaneous offset of S2, presentation of the reinforcer (food), and initiate the next ITI.