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Renewal of an extinguished behavior in the context of a preceding response

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Abstract

Instrumental behavior chains are sequences of responses that minimally involve procurement behaviors that enable consumption. Recent studies suggest a fundamental role for context in controlling the acquisition and extinction of simple operant responding and instrumental behavior chains. Experiments on the extinction of behavior chains reveal that context affects procurement and consumption responding differently, such that procurement responding is directly affected by physical context changes, but consumption responding seems only to be affected by the amount of preceding procurement responding. Separately extinguished consumption responding renews when returned to the “context” of procurement preceding it. The present experiment was designed to determine the nature of this relationship. Rats learned two different discriminated heterogeneous chains in which a discriminative stimulus set the occasion for a procurement response (e.g., pulling a chain), which led to a second discriminative stimulus that occasion-set a consumption response (e.g., pressing a lever) that produced a food-pellet reinforcer. After learning both chains and performing them concurrently, both consumption responses were extinguished outside their respective chains. Consumption responding was only renewed when preceded by its associated procurement response and not when preceded by a procurement response that led to a different consumption response in acquisition. The results support the view that procurement is influenced by the physical context while consumption is controlled primarily by the response that precedes it in the chain. Theoretical and applied implications are discussed.

Many problems that people and societies face are behavioral problems. Behavioral problems can be excesses like smoking, overeating, and drug use, and they can also be behavioral deficits such as not exercising sufficiently or not eating enough. In the United States alone, \$209.7 billion a year is spent on healthcare costs due to obesity (Cawley & Meyerhoefer, 2012), and another \$289 billion a year is spent on healthcare costs due to smoking (U.S. Department of Health and Human Services, 2014). These are all problems of what is typically considered voluntary behavior. The behavior is voluntary in the sense that a person has the choice of whether or not to perform that behavior or some other behavior.

Modeling Behavior in the Lab

In the laboratory, voluntary behavior is modeled through operant conditioning (Skinner, 1956; Thorndike 1927). Operant conditioning can be done in a free-operant scenario (Ferster, 1953). In this scenario, an animal in an operant training chamber may perform any behavior it wishes, and there is typically some response like a lever press that will lead to reinforcement based on some scheduled rate. For example, a rat may have the option to make a lever press with every fifth lever press producing a food reinforcer (a fixed ratio 5, FR 5 schedule).

Alternatively, operant conditioning may be discriminative in nature (Hull, 1950). This means that a selected response, e.g. a lever press, will be rewarded only if performed during some discriminative stimulus (SD), e.g. a tone. This may more closely model the real-life behavior of humans, as there are usually signs or cues that a given behavior will be reinforced at a particular time (Skinner, 1965). Such behaviors are said to be under stimulus control, such that the presence or absence of stimuli control whether or not a response is made and will lead to reinforcement. An extremely common example is that of encountering a stoplight in traffic. A green light is an SD that one should drive, whereas a red light is an SD that one should press the

brakes and come to a stop. In terms of a more problematic behavior like smoking, a pack of cigarettes is an SD to actually smoke a cigarette.

Extinction

One method used to reduce levels of responding in the lab is that of extinction (Rescorla & Wagner, 1972). In an operant extinction paradigm, an animal is first trained to perform a response to earn some reinforcer. In the second extinction phase, reinforcement is withheld, regardless of the animal's responding. The new lack of reinforcement will cause animals to lower responding until they essentially no longer respond at all. There have been many studies of the extinction of many different kinds of operant and Pavlovian responses, in both behavioral and neurobiological terms (Bouton, 2004; Milad & Quirk, 2012).

It should be noted that laboratory studies on extinction have implications for some therapies used in clinical psychology. Cognitive behavior therapies (CBT) are designed to eliminate unwanted thoughts and/or behaviors, like those occurring in Post-traumatic Stress Disorder (PTSD) and Obsessive Compulsive Disorder (OCD). CBT has been found to be effective for many psychological problems, from reducing unwanted fear reactions in PTSD to reducing unwanted thoughts and compulsive behaviors in OCD (Rothbaum, Meadows, Resick, & Foy, 2000; Whittal & McLean, 1999). The goal of CBT is typically to provide new information that can compete and interfere with old memories and behaviors. Exposure therapy is a major component of these therapies. In exposure therapy, a cue or thought that evokes distressful thoughts or maladaptive behaviors is repeatedly presented in a neutral setting until it no longer evokes such thoughts and behaviors. This is essentially an extinction procedure meant to extinguish any connections between the cue and the maladaptive thoughts and behaviors. Thus, it is a process that produces new, interfering learning. The new learning is designed to

interfere with and hopefully “replace” the old. Basic research on the extinction paradigm may therefore have novel clinical implications (e.g., Bouton & Swartzentruber, 1991).

Relapse after Extinction

However, as many know, changing or eliminating problematic behaviors often proves to be very difficult. Many types of rehabilitation do not work for everyone, and relapse is extremely common following any type of rehabilitative behavior change. This is a major cause for concern for any type of treatment or rehabilitation as maintaining the behavior change is the over-arching goal of any therapy. It has been suggested that the decrease in responding following extinction is due to a loss of the original learning, a result of “unlearning” (Rescorla & Wagner, 1972). However, as discussed by Bouton (e.g., 1991), there are a number of effects to suggest that extinction does not result in unlearning and that at least some of the original learning still exists to some extent.

After successful extinction, responding may return for a number of reasons. For the spontaneous recovery effect, the mere passage of time is enough to cause extinguished responding to return. Rapid reacquisition refers to the phenomenon that an extinguished response will be acquired at a faster rate than it was originally learned when reinforcement is again presented for the response or the US is again presented with the CS. Reinstatement is another such relapse effect, and it refers to the return of extinguished responding following a non-contingent presentation of the reinforcer or an unconditioned stimulus originally associated with the response. Resurgence refers to a specific paradigm and is another mechanism for the return of extinguished behaviors. In resurgence, an animal acquires a response in one phase, that response is put on extinction in a second phase while a different response becomes available for reward, and finally in a third phase, the new response is then put on extinction. Responding on

the original response returns, or resurges, when the alternative reinforcement from the second phase is removed. The renewal effect is another well-studied relapse effect, and it refers to the return of responding that occurs when the animal is removed from the context in which responding was extinguished.

Context and New Inhibitory Learning in Extinction

The Bouton laboratory has done extensive work on the renewal of operant or instrumental behaviors (Bouton, 2014; Todd, 2013; Todd, Vurbic, & Bouton, 2014). This and other research revealed that rather than “unlearning,” extinction results in learning a new inhibitory response (Bouton, 1993; Bouton, 2002; Bouton & Todd, 2014; Bouton, Trask, & Carranza-Jasso, 2016). This “learning to inhibit a response” tends to be very context-specific, and this is why behavior renews when the animal is removed from the context where extinction was learned. Without the context-dependent inhibition of the response, the response will still be controlled by its original excitatory association with the reinforcer, and responding will return. Renewal was found in ABA, AAB, and ABC paradigms (Bouton, Todd, Vurbic, & Winterbauer, 2011; Todd, 2013). Each letter refers to a different context, so in an ABA paradigm, a behavior is learned in context A, extinguished in context B, and behavior is found to renew upon returning to context A in a test phase. AAB and ABC renewal are particularly interesting because extinguished responding renews even in a context in which the behavior was never previously performed. This suggests that a mere removal from the context of extinction is sufficient to cause renewal. The extinction context was found to serve as a discriminative stimulus which signals to the animal that the response will no longer be rewarded in that context (Todd, Vurbic, & Bouton, 2014).

The context that controls behavior and extinction can refer to a great number of things. Contexts may be either exteroceptive or interoceptive in nature (as discussed in Bouton, 2004). Often, exteroceptive stimuli like visual cues, olfactory cues, tactile cues, and physical location are used as contexts in animal experiments (Bouton, 1993). The passage of time can serve as a context as well. Spontaneous recovery is then explained by a shift from the “time” context in which extinction occurred causing the recovery of extinguished behaviors (Rosas & Bouton, 1998). At other times, interoceptive cues like mood state (Bower, 1981), drug state (Bouton, Kenney, & Rosengard, 1990), and even deprivation state (Davidson, 1993) serve as contexts. Smith (1979) famously showed that human memory is partly controlled by the context in which it was learned. Student participants had better memory for word lists when tested in the same context in which a word list was learned compared to a novel context. Some of the work in the Bouton lab is done in efforts to define context, determine what may contribute to context, and determine how contexts can influence learning and behavior.

Context also appears to play a role in driving operant behavior to some extent as well. While the extinction of instrumental and Pavlovian extinction learning are both context-dependent, recent studies suggest a role for the context in controlling instrumental responding more generally. Whereas Pavlovian conditioned responses often transfer very well across contexts (e.g., Bouton & King, 1983; Bouton & Peck, 1989; Hall & Honey, 1989; Harris, Jones, Bailey, & Westbrook, 2000), recent evidence suggests that instrumental responses do not transfer completely (Bouton, Todd, & León, 2014; Thrailkill & Bouton 2015b). For example, in an experiment reported by Bouton et al. (2014) in which rats learned that pressing a lever delivered a reinforcer only in the presence of a distinct SD, there was a substantial loss of responding when rats were tested with the response and its SD in a different context. A further experiment (Bouton

et al., 2014, Experiment 3) found that an SD for a response trained in one context could transfer perfectly to a different context, in which it had not been presented before, if it could set the occasion for that context's usual response (that had been occasioned there by a different SD). However, a response could not transfer to a different context even if its usual SD had occasioned another response there. Thus, the context controls the discriminated operant response, though not the effectiveness of its associated SD. A context-switch effect is thus seen when an operant (free or discriminated) response is extinguished in a context different from that in which it was acquired such that responding in the first trials is lower if the response is extinguished in a new context.

Behavior as Chains

Our lab has recently become interested in chains of behavior. A behavior chain minimally involves at least two behaviors: a response that directly leads to the reinforcer (a consumption response) and a response that provides access to the consumption response (a procurement response; Collier, 1981; Thraillkill & Bouton, 2015a). We and others (Thraillkill & Bouton, 2016a; Ostlund & Balleine, 2008) have argued that an understanding of behavior chains has both theoretical and translational relevance. Most human behavior occurs as part of behavior chains; it is not discrete events that lead to reinforcement. For example, a smoker must first buy cigarettes (procurement) in order to smoke (consumption). Each behavior takes place in its own set of discriminative stimuli (e.g., buying cigarettes in a minimart, and smoking outside on the sidewalk), and is of a different topography (e.g, handing over money in exchange for cigarettes, and lighting and smoking a cigarette).

Research on heterogeneous behavior chains has often been done in attempts to uncover the associative structure underlying these chains. The Balleine laboratory has repeatedly

discovered that outcome devaluation or other shifts in motivational state have dissociable effects on the distal (procurement) and proximal (consumption) responses of behavior chains (Balleine, 1992; Balleine, Garner, Gonzalez, & Dickinson, 1995; Corbit & Balleine, 2003; Balleine, Paredes-Olay, Dickinson, 2005). These studies all suggest that performance of the proximal action was affected by change in motivational state (from food deprived to non-deprived), but performance of distal action required incentive learning while in the new motivational state. This means that although a shift from a food deprived to a non-deprived motivational state was sufficient to lower proximal (consumption) responding, the animals needed to previously experience the reinforcer in the lowered motivational state (non-deprived) in order to reduce distal (procurement) responding for that reinforcer while in a non-deprived state. This suggests that in the Balleine lab's behavior chain paradigm, proximal responses are controlled by a more stimulus-outcome Pavlovian association, and distal responses are controlled by a more response-outcome instrumental association.

A lot of this research has been in terms of drug use. Ostlund and Balleine (2008) discuss the possibility that Pavlovian and instrumental processes are both acting at all times when learning a behavior, and they may have dissociable effects on different behaviors involved with drug use. Drug use was first viewed as a heterogeneous behavior chain with separate procurement (seeking) and consumption (taking) responses in an experiment done to determine if drug procurement is goal-directed (Olmstead, Lafond, Everitt, & Dickinson, 2001). It was found that cocaine procurement is indeed goal-directed in the sense that the procurement response decreases following extinction of the consumption response. Thus, when an animal "knows" that consumption is no longer rewarded, the animal no longer performs a procurement response. Zapata, Minney, and Shippenberg (2010) replicated this result but also found that with extensive

training, the procurement response becomes habitual and is not affected by devaluation of the consumption response through extinction. Veeneman et al. (2012) found that decreasing reward size, omitting the reward, or adding α -flupenthixol (a dopamine antagonist that is thought to decrease the neurological mechanisms of reward and motivation) reduced cocaine procurement. However, drug consumption was not reduced by reducing reward size, but it was reduced by omitting the reward or adding α -flupenthixol. These results further suggest some difference between the processes underlying procurement and consumption responding.

Behavior Chains in the Bouton Laboratory

With such considerations in mind, the Bouton laboratory recently developed a discriminated heterogeneous instrumental chain procedure for rats and began to address the extinction of behavior chains (Thraillkill & Bouton, 2015a). Our behavior chains differ in some important ways from behavior chains used in other labs. In the Bouton laboratory, a heterogeneous behavior chain consists of two responses of different topography, e.g. a lever press and chain pull, and we call these the procurement response and the consumption response. Each of these responses is occasion-set by its own distinct SD, e.g. a tone and a panel light. Response manipulanda (i.e., literally the physical lever and chain) are available to the animals at all times. The behavior chain paradigm is represented in Figure 1. Once an animal is fully trained, any given trial in a rewarded heterogeneous chain session consists first of the presentation of the procurement SD (S1) after some inter-trial interval (ITI). Responses on the procurement manipulandum (R1) during the procurement SD (S1) then cause the initiation of a consumption SD (S2) and the termination of the procurement SD. Consumption responding (R2) during the consumption SD (S2) will result in the termination of the consumption SD and presentation of a food reward. Having the manipulanda consistently available allows us to

measure baseline responding, study the change in responding throughout extinction, and more deeply look into the associative structures of the various responses and stimuli in this type of heterogeneous chain.

Recent research in the Bouton laboratory has found that separate extinction of the procurement response of a chain selectively also decreases the strength of the consumption response that followed it in the chain (Thraillkill & Bouton, 2015a). Similarly, extinction of the consumption response of a chain selectively lowers the strength of the procurement response that preceded it in the chain (Thraillkill & Bouton, 2016b; see also Olmstead, Lafond, Dickinson, & Everitt, 2001). In both cases, the opportunity to make the response in extinction was essential for the effect to occur; simple exposure to the SD without the ability to make the response had no effect (Thraillkill & Bouton, 2015a, 2016b). This has implications for therapies intended to reduce problematic behavior in that addressing and reducing one behavior that occurs as part of a chain may have beneficial effects at reducing other behaviors within that chain. This may be helpful for behaviors within a chain that cannot be extinguished directly, such as smoking or drug taking. Addressing and reducing the procurement behaviors leading to these consumption behaviors should help to reduce the problematic consumption behaviors as well. It also emphasizes the importance of making sure to extinguish the response directly, not just its associated cues.

Procurement as the “Context” for Consumption

Other more recent experiments have examined the contextual control of behavior chains. In the first of these experiments, it was found that procurement and consumption responding both separately renew when tested outside of their extinction contexts (Thraillkill, Trott, Zerr, & Bouton, 2016). This was true whether the responses were extinguished individually or as a unit

of the whole chain. However, a context switch affected each response differently during extinction. Specifically, in Experiment 1, when procurement responding was extinguished in a different context (B), responding was reduced compared to when it was extinguished in the context in which it had been trained (A). This is the expected context-switch effect as discussed above. However, the same effect was not seen when consumption responding was extinguished individually; extinguishing consumption in B led to the same amount of responding compared to when consumption was extinguished in A. Interestingly, in Experiment 2, when the chain was extinguished as a complete unit, the context-switch effect during extinction was seen for both procurement and consumption responding.

These results from the extinction phase when responses are extinguished individually suggest that procurement responding was sensitive to the effects of the first context switch in extinction. In contrast, consumption responding was not affected by the context. To our knowledge, this is the first attempt to compare the context specificity of individual responses following training in a chain. The results suggest that procurement responding, but perhaps not consumption responding, is weakened when first removed from the acquisition context in a manner similar to that which occurs with a singularly trained instrumental response (Bouton et al., 2011, 2014).

Also, in extinction of the chain as a complete unit, there was an immediate decrement in both the procurement and consumption response in groups that were switched to Context B (Thrailkill et al., 2016). The effect of context change on procurement is consistent with Experiment 1. However, the effect of context change on consumption is new. When consumption was extinguished by itself in Experiment 1, there was no evidence of weakened responding after the switch to Context B. However, when consumption was preceded by procurement in

extinction in Experiment 2, a strong context-switch effect was observed. The procurement response was itself decremented by the context switch. The difference between experiments thus suggests that although the operant chamber context does not control consumption responding (Experiment 1), the “stimulus” provided by engaging in the procurement response (Experiment 2) might do so. Recall that Thraikill and Bouton (2015a, 2016b) reported evidence that procurement and consumption responses can be strongly associated. Therefore, I examined the possibility that the procurement response could be acting as a “context” for consumption responding in Experiment 3.

Experiment 3 tested whether a consumption response extinguished outside the “context” of the chain would be renewed when it was returned to the chain. Rats learned the same chain as in the previous experiments. They then received extinction of the consumption response separately outside the context of the chain (i.e., the consumption SD was repeatedly presented, but responding no longer earned a reinforcer). The physical context was not changed in this experiment. Two groups then received a test in which the procurement SD now preceded the consumption SD [Groups S1-R1 and S1-], whereas the remaining groups [Groups No S1-R1 and No S1-] simply received further consumption extinction trials. The design is summarized in Table 1.

The performance of Groups S1-R1 and S1- allowed us to examine whether a return to the “context” of the chain caused a recovery of consumption responding. This is because the consumption response was tested (in the final test) after allowing earlier parts of the chain (the procurement SD and/or the presence of the procurement response). However, only Group S1-R1 was able to make the procurement response during the test. This is because Group S1-R1, but not group S1-, had the procurement manipulandum present during the test. The differential presence

of the manipulandum (Group S1-R1 vs. S1-) allowed us to assess the role of the opportunity to make the procurement response in the renewal of consumption. In order to control the novelty of the procurement manipulandum during testing, all groups also received extinction with the procurement manipulandum present or absent in the way it was present or absent during test. The results indicate that consumption renewed following presentations of the procurement SD as long as the rats were allowed to make the procurement response that had preceded the consumption response in the chain. The results thus provided new information about the contextual control of acquisition and extinction of heterogeneous behavior chains, and further enhanced our understanding of context.

The Present Experiment

However, there are a number of possible explanations for this effect. The animals could be making a specific association between the two behaviors, as other experiments suggest is the case (Thrailkill & Bouton, 2015a, 2016b). It remains possible, however, that making the procurement response led to a general increase in behavior near the front of the chamber that indiscriminately caused more responding on the consumption manipulandum. The present experiment was therefore designed to test whether renewal of consumption depended more specifically on the occurrence of the procurement response that was directly associated with the consumption response. This experiment, (Thrailkill et al., 2016, Experiment 4) was conducted as my Honor's thesis project and will be discussed in detail below.

The design of the present experiment is summarized in Table 1. Rats first learned two separate chains (cf. Thrailkill & Bouton, 2015a, 2016b) that consisted of sequences of different procurement and consumption responses ($R1 \rightarrow R2$ and $R3 \rightarrow R4$). Following acquisition of both chains, the rats received extinction of both consumption responses ($R2$ and $R4$) in the presence

of their SDs. In a final test, one consumption SD was preceded by separate presentation of both procurement SDs. On half of the trials, the consumption SD was preceded by the procurement SD that had been associated with it during acquisition (Congruent trials; $R1 \rightarrow R2$ or $R3 \rightarrow R4$), and half were preceded by the other procurement SD (Incongruent trials; $R1 \rightarrow R4$ or $R3 \rightarrow R2$). In Group With, the procurement manipulanda were available, so procurement responding was allowed and expected to occur; for Group Without, the procurement manipulanda were removed. If renewal of consumption is specific to the associated procurement SD/response combination, then renewal of consumption should only occur on congruent test trials. Also if the effect again depends on making the procurement response (as in Thrailkill et al., 2016, Experiment 3), Group Without was not expected to show renewal.

Method

Subjects

A total of 32 female rats Wistar rats (75-90 days old) were housed individually in suspended wire-mesh cages and maintained at 80% of their free-feeding weights. The rats had unlimited access to water in their home cages and were given supplementary feeding approximately 1 hr after each session when necessary.

Apparatus

The apparatus consisted of two unique sets of four conditioning chambers (Model ENV-008-VP; Med Associates) housed in separate rooms of the laboratory. Each chamber was in its own sound attenuation chamber. All boxes measured 30.5 x 24.1 x 23.5 cm (Length x Width x Height). The side walls and ceiling were made of clear acrylic plastic, whereas the front and rear walls were made of brushed aluminum. A recessed food cup measured 5.1 x 5.1 cm and was

centered on the front wall approximately 2.5 cm above the level of the floor. Two retractable levers (Model ENV-112CM, Med Associates) were located on the front wall on either side of the food cup. The levers were 4.8 cm long and 6.3 cm above the grid floor. The levers protruded 1.9 cm from the front wall when extended. The chain pull (14.5 cm long) and nose poke (2.5 cm in diameter and 2 cm deep) were located directly across from the two levers on the back wall and 6.3 cm (to the bottom of the chain and to the center of the poke) above the chamber floor. The nose poke was near the side of the chamber that acted as the chamber door, and the chain pull was near other side of the chamber that acted as a wall. Two 28-V (2.8 W) panel lights (diameter = 2.5 cm) were mounted on the walls above the retractable levers, 10.8 cm above the floor and 6.4 cm from the center of the front wall. On the middle panel of the back wall between the chain pull and the nose poke were a tone and a clicker. The center of the tone (model ENV-223HAM, Med Associates, 4500 Hz, 75 dBA) was located beneath the clicker and 6.3 cm above the grid floor. The center of the click (model ENV-135M, Med Associates, 75 dBA, 0.4s-on; 0.4 s-off) was 15.3 cm above the grid floor.

The chambers were illuminated by two 7.5-W incandescent bulbs mounted to the ceiling of the sound attenuation chamber, 34.9 cm from the grid floor. Ventilation fans provided background noise of 65 dBA. The two sets of boxes had unique features that allowed them to serve as different contexts in other experiments, but they were not used for that purpose here. In one set of boxes, the grids of the floor (diameter = 0.5 cm) were spaced 1.6 cm apart (center to center). In the other set of boxes, the floor consisted of alternating stainless steel grids with different diameters (0.5 and 1.3 cm, spaced 1.6 cm apart). No other features distinguished the two sets of chambers. Reinforcement consisted of the delivery of a 45-mg food pellet (MLab

Rodent Tablets; TestDiet, Richmond, IN) into the food cup. The apparatus was controlled by computer equipment in an adjacent room.

Procedure

Training was conducted seven days a week with one session a day lasting approximately 30 – 50 min. On the two days prior to response training, rats received one 30-min session of magazine training in which 30 food pellets, on average, were delivered to the food cup according to an RT 60-s schedule. All rats experienced each training phase, and were given brief remedial training in a separate session if they failed to respond during the main session.

Individual chain training. After magazine training, rats were trained to perform each of two chains individually. Procurement responses (R1 and R3) consisted of a chain pull or a nose poke (counterbalanced). Consumption responses (R2 and R4) consisted of pressing either the left or right lever (counterbalanced). Individual chain training was conducted with only two manipulanda present in the chamber at one time (one for procurement and one for consumption). The rats first learned to perform one of the consumption responses (counterbalanced) over the next two days. At this time, only the consumption manipulandum was present. In the first session, the first 20 consumption responses were reinforced on a continuous reinforcement (CRF) schedule, and then the consumption stimulus was presented on 20 trials with a 45-s variable intertrial interval (ITI). The consumption stimulus was always the panel light near the consumption manipulandum. A consumption response turned the SD off and immediately produced a food pellet according to a CRF schedule. A trial was terminated if a response was not made within 60 s of SD onset. The second session consisted of 20 more presentations of the consumption SD.

In Session 3, a procurement manipulandum was added to the chamber. Procurement responses were counterbalanced such that half of the rats were required to travel along the side walls to reach the consumption response, and half had to cross the chamber diagonally. The SDs for the procurement responses (tone and click) were counterbalanced across manipulanda (chain and poke), the chain that was trained first, and the linked consumption response. Single chain sessions consisted of 20 presentations of the procurement SD. Initially, if a single procurement response was made within 60 s, the procurement SD terminated, and the consumption SD was initiated, allowing consumption responding to be reinforced. Presentations of the procurement SD that did not lead to a procurement response ended after 60 s without presentation of the consumption SD or a food pellet. The ITI was variable with a mean of 45 s.

There were six training sessions (Sessions 3-8) with the full behavior chain. In Sessions 3-4, procurement and consumption responding were reinforced according to CRF (as described previously). In Sessions 5-6, the response requirement for procurement and consumption was random ratio (RR) 2, and in Sessions 7-8, the response requirement for both was RR 4. Random ratio schedules specify the probability of reinforcement for any given response. With an RR 2 schedule, each response has a 50% chance of producing reinforcement (every two responses on average); with an RR 4 schedule, each response has a 25% chance of producing reinforcement (every four responses on average). Increasing the response requirement allows for the rate of responding to increase across the experiment to a robust level. The second chain was then trained in an identical manner with the manipulanda used for the first chain removed from the chamber. As before, there were two sessions of training the new consumption response and then 6 sessions of training the new procurement-consumption chain.

Multiple chain training. Following training of the second chain, the rats received one reminder session of the first chain (RR 4) with the manipulanda for the second chain removed. The following day, all four manipulanda were present, and trials with the opportunity to perform each chain were presented in a pseudorandom order. There were 40 chain trials in each session (20 with each chain). The response requirement for both procurement and consumption was initially reduced to CRF and increased first to RR 2 and then to RR 4 over two sessions. The maximum stimulus durations that were allowed when there was no response were decreased from 60 s to 20 s over the first four sessions. The stimulus period was decreased to further increase the rates of responding for all responses. Rats then received 12 sessions of training with the terminal schedule parameters (RR 4 during a 20-s SD in all links on both chains). Sessions lasted approximately 40 min.

Extinction. Following acquisition, the rats were assigned to two groups. One group received three sessions of extinction training with all response manipulanda available (Group With), and the other group received identical sessions with the two procurement manipulanda removed (Group Without). Sessions consisted of 20 presentations of each consumption SD (40 total trials) separated by a variable ITI with a mean of 45-s. The first 16 extinction trials were intermixed trials for each consumption SD in an ABBA or BAAB manner (counterbalanced). The next 16 trials consisted of two blocks of eight extinction trials for each of the consumption SDs (counterbalanced). The blocked trials were used to reduce the novelty of similarly blocked trials during testing (see below). The final 8 trials were again intermixed trials of both consumption SDs in the manner described above. The trial order within a session was counterbalanced between groups and in terms of what chain was learned first. Consumption responding during consumption SD presentations resulted in termination of the stimulus

according to an RR 4 schedule without reinforcement. If the response requirement was not met, the stimulus terminated after 20 s. Procurement responding in the group with procurement manipulanda present was recorded, but it otherwise had no effect during extinction.

Consumption test. All rats then received a test session in which one of the consumption responses (counterbalanced across groups and chain trained first) was tested following presentations of each procurement SD. Both consumption manipulanda were present in the chamber and both procurement manipulanda were present only in the group that had them available during extinction (Group With). The test session started with 8 trials of continued extinction of the selected consumption SD, followed by 16 trials of congruent and incongruent trials intermixed in an ABBA or BAAB order (counterbalanced). Congruent trials included presentations of the procurement SD that had been linked with the consumption SD during training, and incongruent trials consisted of the presentation of the procurement SD that had led to the other consumption SD. In Group With, procurement responses during a procurement SD turned off the SD and turned on the consumption SD according to RR 4; the procurement SD otherwise terminated noncontingently and initiated the consumption SD after 20 s if the response requirement was not met. Consumption responses during a consumption SD turned off the stimulus according to RR 4, but did not produce food. Consumption SDs were otherwise terminated after 20 s on each trial.

Data Analysis

To describe procurement and consumption responding occasioned by the corresponding SD, we calculated elevation scores by subtracting the response rate on the response manipulanda during the 30 s immediately before the procurement stimulus was presented (the preprocurement period) from the response rate during the procurement and consumption stimuli, respectively.

The elevation scores and preprocurement response rates were evaluated with analyses of variable (ANOVAs) using a rejection criterion of $p < .05$. Effect sizes are reported where appropriate.

Results

Rats acquired both discriminated instrumental behavior chains, and they performed each response in its appropriate SD. Consumption responding decreased over extinction. In the group that could make the procurement responses (Group With), procurement SD presentations caused renewal of consumption responding during the subsequent congruent consumption SD only. Rats in Group Without did not renew consumption responding following procurement SD presentations, and there were no differences between congruent or incongruent trials in this group.

Acquisition

Figure 2 presents consumption and procurement responding during each of the last 12 days of training for each chain. Consumption responses on the left and right levers and procurement responses that led to the left and right levers (nose poke and chain, counterbalanced) are shown separately. [Focusing on left (chain 1; R2) and right (chain 2; R4) was a convenient way to distinguish between each animal's two chains; recall that the various manipulanda were counterbalanced.] Statistical analysis of the acquisition was restricted to the final 12 sessions in which the final training parameters were in effect.

Consumption responding. Figure 2a presents consumption responding as an elevation score in responses per min. The elevation score was calculated by subtracting the rate of responding in the 30 s prior to procurement SD onset from the rate of responding during the consumption SD. Each group (With and Without) increased consumption responding over

training and responses on left and right levers (chains 1 and 2) were similar. Procurement responding in each group for each response was compared in a Group (With, Without) by Chain (1, 2) by Session (12) ANOVA. Responding increased across sessions, $F(11, 330) = 13.32$, $MSE = 88.85$, $p < .001$, $\eta_p^2 = .31$, and there were no other differences or interactions, largest $F = 1.21$. Average consumption response rates during the preprocurement SD period were 1.1 and 1.1, 1.9 and 0.8 on the first RR 4 session, and 2.0 and 0.8, 0.7 and 0.5 on the last RR 4 session for Groups With and Without on consumption responses in chains 1 and 2, respectively. A Group by Chain by Session ANOVA found no difference in consumption during preprocurement SD periods, largest $F(1,30) = 1.69$, $MSE = 1.21$.

Procurement responding. Figure 2b similarly presents procurement responding as an elevation score in responses per min. The elevation score was calculated by subtracting the rate of responding in the 30 s prior to procurement SD onset from the rate of responding during the procurement SD. Each group (With and Without) increased procurement responding over training and procurement responses that led to left and right levers (chains 1 and 2) were similar. In an identical statistical analysis, procurement responding in each group for each response was compared in a Group (With, Without) by Chain (1, 2) by Session (12) ANOVA. Responding increased across sessions, $F(11, 330) = 47.60$, $MSE = 115.50$, $p < .001$, $\eta_p^2 = .61$, and there were no other differences or interactions, $F_s < 1$. Average procurement response rates during the preprocurement SD period were 3.6 and 6.2, 5.9 and 7.2 on the first RR 4 session, and 1.6 and 5.4, 6.8 and 7.7 on the last RR 4 session for Groups With and Without on procurement responses for chains 1 and 2, respectively. A Group by Chain by Session ANOVA did not find any significant differences, largest $F(1,30) = 3.05$, $MSE = 550.87$.

Discrimination. Figure 3 shows procurement and consumption response rates during the preprocurement, procurement, and consumption stimulus periods in the final session of acquisition. There is clear evidence of excellent stimulus control; i.e., the animals' responding is low in the pre-stimulus period, procurement responding but not consumption responding is elevated during the procurement SD, consumption responding but not procurement responding is elevated during the consumption SD, and incongruent responding (e.g., if R1 is performed during S3, the incorrect procurement SD) is close to zero during all stimulus periods. The animal is thus responding on the appropriate response during all stimulus periods.

Neither Group nor Chain factors differed across sessions of acquisition; therefore separate Response (procurement, consumption) by Status (reinforced chain, nonreinforced chain) ANOVAs for each stimulus period were applied to response rates collapsed over Group and Chain factors. In the preprocurement period, procurement responding was higher than consumption responding, $F(1,63) = 37.97$, $MSE = 41.62$, $p < .001$, $\eta_p^2 = .38$, and there were no effects of status or interaction, $F_s < 1$. In the procurement SD, procurement responding was also higher than consumption, $F(1,63) = 305.82$, $MSE = 172.90$, $p < .001$, $\eta_p^2 = .83$. The procurement response associated with the reinforced chain was performed at a higher rate than that of the nonreinforced chain. This was confirmed by a significant status effect, $F(1,63) = 218.60$, $MSE = 192.27$, $p < .001$, $\eta_p^2 = .78$, and a Response by Status interaction, $F(1,63) = 207.59$, $MSE = 203.57$, $p < .001$, $\eta_p^2 = .77$. Similarly, there was significantly higher consumption responding than procurement responding during the consumption SD, $F(1,63) = 463.76$, $MSE = 105.60$, $p < .001$, $\eta_p^2 = .88$. Effects of status, $F(1,63) = 752.88$, $MSE = 77.73$, $p < .001$, $\eta_p^2 = .92$, and a Response by Status interaction, $F(1,63) = 463.76$, $MSE = 105.60$, $p < .001$, $\eta_p^2 = .88$, further confirm strong discrimination of the reinforced chain in the presence of the consumption SD.

Extinction

Extinction of the consumption response in both groups proceeded without incident. Figure 4 summarizes the decline in consumption responding in each extinction session as a function of 4-trial consumption SD blocks for consumption responses (chains 1 and 2) for Groups With and Without respectively. A Group (With, Without) by Chain (1, 2) by Block (10) by Session (3) ANOVA confirmed that responding decreased within each session, $F(4,120) = 191.57$, $MSE = 69.66$, $p < .001$, $\eta_p^2 = .86$, and across sessions, $F(2,60) = 218.64$, $MSE = 117.41$, $p < .001$, $\eta_p^2 = .88$. There was no significant effect of chain, $F(1,30) = 2.70$, $MSE = 78.23$, $p = .11$, revealing that both responses extinguished similarly. A significant Session by Block interaction further confirmed that spontaneous recovery decreased across sessions of extinction, $F(8,240) = 40.73$, $MSE = 73.65$, $p < .001$, $\eta_p^2 = .58$. The Chain by Session interaction was not significant, $F(2,160) = 3.13$, $MSE = 49.59$, $p > .05$. There was a significant Session by Block by Group interaction, $F(8,240) = 2.44$, $p = .02$, $\eta_p^2 = .08$. There was no group difference, $F(1,30) = 3.09$, $MSE = 385.54$, $p > .05$, and there were no other significant effects or interactions, $F_s < 1$.

Mean consumption response rates in the pre-SD period were 1.6 and 1.0, 1.3 and 0.9 in the first session of extinction, and 0.7 and 0.7, 1.0 and 0.6 in the last session for Groups With and Without on consumption responses in chains 1 and 2, respectively. A Group (With, Without) by Chain (1, 2) by Block (10) by Session (3) ANOVA found that consumption responding in the pre-SD periods decreased within sessions, $F(4,120) = 11.23$, $MSE = 4.32$, $p < .001$, $\eta_p^2 = .27$, and across sessions, $F(2,60) = 4.37$, $MSE = 5.48$, $p = .02$, $\eta_p^2 = .13$. There was a significant Session by Block interaction, $F(8,240) = 7.59$, $MSE = 3.14$, $p < .001$, $\eta_p^2 = .20$. There was also a Chain by Session by Block interaction, $F(8,240) = 2.08$, $MSE = 3.41$, $p = .04$, $\eta_p^2 = .06$. There were no other significant effects or interactions, largest $F(4,120) = 1.87$.

For Group With, mean procurement response rates in the pre-SD period were 3.0 and 6.8 in the first session of extinction, and 1.1 and 2.5 in the last session on procurement responses from chain 1 and 2, respectively. A Chain (1, 2) by Block (10) by Session (3) ANOVA found that procurement responding in the pre-SD periods decreased within sessions, $F(4,60) = 5.95$, $MSE = 23.08$, $p < .001$, $\eta_p^2 = .28$, and across sessions, $F(2,30) = 9.31$, $MSE = 42.14$, $p = .001$, $\eta_p^2 = .38$. A significant effect of Chain was found, $F(1,15) = 5.44$, $MSE = 169.76$, $p = .03$, $\eta_p^2 = .27$. No other effects or interactions were significant, largest $F(4,60) = 1.53$.

Consumption Test

Figure 5 shows the result of the critical renewal test of extinguished consumption responding. Recall that the first 8 trials of the test session were continued extinction presentations of the consumption SD from the two chains. A Group (With, Without) by Chain (1, 2) by Block (4) ANOVA revealed that responding decreased over blocks of continued extinction, $F(3, 84) = 12.99$, $MSE = 48.86$, $p < .001$, $\eta_p^2 = .32$. No other significant effects or interactions were found, largest $F(1, 28) = 1.80$, $MSE = 90.40$.

Consumption responding in Group With during the test is presented for congruent and incongruent trials in Figure 5a. There was significant renewal of consumption responding in congruent trials when the last block of extinction trials was compared to the first block of test trials, $F(1, 15) = 4.47$, $MSE = 38.94$, $p = .05$, $\eta_p^2 = .23$, and no renewal of incongruent responding, $F < 1$. A Status (Congruent, Incongruent) by Block (4) ANOVA further revealed that consumption responding was higher following the congruent SD than the incongruent SD over blocks in the test, $F(1,15) = 7.64$, $MSE = 7.15$, $p = .01$, $\eta_p^2 = .34$. There were no other significant effects or interactions, largest $F(3,45) = 1.95$.

Consumption responding in Group Without during the test session is similarly presented for congruent and incongruent trials in Figure 5b. In contrast to Group With, there was no evidence of renewal of consumption responding on congruent trials, $F(1,15) = 2.02$, $MSE = 11.97$, $p = .17$, or incongruent trials, $F(1, 15) = 1.56$, $MSE = 9.09$, $p = .23$. Importantly, a Status (Congruent, Incongruent) by Block (4) ANOVA found no difference between congruent and incongruent responding over test trials, $F(1, 15) = 0.63$. Responding on both congruent and incongruent trials decreased over the test session, $F(3,45) = 5.57$, $MSE = 9.94$, $p < .01$, $\eta_p^2 = .27$, but did not differ based on Status or interact with Block, largest $F(3, 45) = 1.17$.

Mean consumption response rates during the preprocurement SD period were 0.3 and 0.1 on the first 2-trial block of the test, and 0.1 and 0.0 on the last 2-trial block of the test for Group With during congruent and incongruent trials, respectively. A Status (Congruent, Incongruent) by Block (4) ANOVA found that consumption responding before congruent trials was higher than responding before incongruent trials, $F(1,15) = 5.79$, $MSE = 0.265$, $p = .03$, $\eta_p^2 = .28$, and no other significant effects or interactions, largest $F(3,45) = 1.44$. Responding in the pre-period was generally low; taken with the fact that the congruent consumption elevation was higher the incongruent elevation, this suggests that the effect was not because of the higher pre-SD responding but rather despite it. In Group With, mean procurement response rate during the pre-SD periods were 0.7 and 0.6 in the final block preceding the introduction of the procurement SD, and 1.9 and 1.1 in the first block of the test of procurement manipulanda in chains 1 and 2, respectively.

Mean consumption response rates during the preprocurement SD period were 0.1 and 0.3 on the first 2-trial blocks of the test, and 0.4 and 0.1 on the last 2-trial blocks of the test for

Group Without during congruent and incongruent trials respectively. A Status (Congruent vs. Incongruent) X Block (4) ANOVA found that no significant effects or interactions, $F_s < 1$.

Discussion

In the present experiment, described in detail here as my thesis, we asked whether the renewal of consumption responding is specific to the presentation of the procurement stimulus-response combination linked with that consumption response in the chain. Rats learned two separate discriminated heterogeneous behavior chains with distinct responses and SDs. All rats learned to perform two chains consisting of $R1 \rightarrow R2$ and $R3 \rightarrow R4$ in the same sessions, each leading to the same food pellet reinforcer. Following acquisition of the behavior chains, all rats received extinction of both consumption responses ($R2$ and $R4$). The rats from each group then received a test with both procurement SDs ($S1$ and $S3$) presented before one consumption SD. Therefore, half of the test trials were congruent trials with the procurement SD leading to the same consumption SD as acquisition ($S1 \rightarrow S2$ and $S3 \rightarrow S4$). The other half were incongruent trials with the procurement SD leading to the different consumption SD as acquisition ($S1 \rightarrow S4$ or $S3 \rightarrow S2$). If presentation of the procurement stimulus-response combination renews consumption responding generally, both congruent and incongruent test trials should show renewal of consumption responding in the group with procurement manipulanda available. However, if the procurement stimulus-response combination renews only the specific consumption responding that has been linked in the chain, consumption trials should only have renewed on congruent test trials.

This is exactly what was found. Similar to a prior experiment (Thrailkill et al., 2016, Experiment 3), this effect was again dependent on the ability to make the procurement response in the presence of its SD. In Group With, only congruent trials led to the renewal of extinguished

consumption responding. In Group Without, neither congruent nor incongruent trials renewed consumption, and there was no difference between consumption responding following congruent and incongruent trials. The results allow us to rule out some alternative interpretations of the previous results. First, because renewal of consumption only occurred when the response was tested with the procurement link with which it was trained, it was not merely due to some nonspecific effect in which making a procurement response generally brought the rat near the consumption manipulanda. Second, the fact that renewal was so specific also rules out a possible theoretical mechanism. Engagement in any procurement response was not sufficient to create renewal on the incongruent trials; thus, renewal was not due to some general change of “context” between extinction in the absence of a procurement SD (and response) and testing with those events. Instead, it was necessary to return the consumption response to its specific acquisition context. The specificity of the results of Experiment 4 suggest that the renewal of consumption depended on a direct association between the procurement response and the next link in the chain.

As noted earlier, there seems to be a dissociation between procurement and consumption responding during extinction following a switch out of the physical context (the specific operant chamber) in which training occurred. When consumption is extinguished by itself, there is no context-switch effect from extinguishing in context B compared to extinction in context A (Thraill et al., 2016, Experiment 1). However, when consumption is preceded by procurement in extinction of the entire chain (Experiment 2), there is a strong context-switch effect from extinction in context B compared to extinction in context A. This is likely to be due to lowered extinction procurement responding when extinguished in B, leading to similarly lowered consumption responding, as we know these two responses are strongly associated from prior

experiments (Thrailkill & Bouton, 2015a; 2016b). These results led to the current hypothesis that the procurement stimulus-response combination preceding consumption behavior is serving as the context for consumption behavior, more so than the physical context in which the behavior occurs (A or B).

To assess whether procurement is functioning as the context for a consumption response, I performed an experiment (Thrailkill et al., 2016, Experiment 3) to ask whether consumption responding extinguished by itself renewed upon return to the context of the chain (procurement preceding consumption). Rats were first trained to perform the discriminated heterogeneous behavior chain, and all rats had consumption responding extinguished. In a test session, half of the rats received a procurement SD before the consumption SD (returning consumption to the “context” of procurement). Consumption responding renewed when preceded by the procurement SD, but this effect was dependent on the ability to actually perform the procurement response. Only the rats that received the procurement stimulus during the test and were able to make the procurement response went on to renew consumption responding. This suggested that procurement is indeed functioning as the “context” for consumption in some way.

The results of this and previous experiments suggest that although the physical context did not have strong control over consumption prior to extinction (Experiment 1), such control was exerted by the preceding procurement response (Thrailkill et al., 2016). Thus, in a sense, the procurement response provided the “context” for making the consumption response, and this context could have competed with and decreased the effectiveness of the physical context in controlling the consumption response (Experiment 1). In addition to increasing our understanding of contextual control of chained consumption behavior, the findings may further expand our conceptualization of context. Contexts have been broadly defined, and may take

several forms including physical, exteroceptive, interoceptive, and temporal characteristics (Bouton, 1993, 2004). Recent studies examining the extinction of singularly trained instrumental responses suggest that the identity of reinforcers for a new response, as well as types of noncontingently delivered outcomes function as contextual stimuli to control extinction learning (Bouton & Trask, 2016; Trask & Bouton, 2016; Trask, Schepers, & Bouton, 2015). The present results are consistent with the perspective that many things can function as contexts. Even responses—or perhaps their proprioceptive stimulus correlates—can play the role of context.

An integrative understanding of the associative structure learned in discriminated behavior chains has potential to contribute information or methods for clinically reducing instrumental behavior. One clear new implication of the results of the present experiment is that when consumption responses (e.g., smoking or drug taking) are inhibited outside the full behavior chain, they can renew (i.e., relapse) when there is an opportunity to make them after engaging in behaviors that precede them in the chain (e.g. buying cigarettes or drugs). Thus, an implication is that treatments should endeavor to address all behaviors in a chain.

Recent studies from this laboratory have shown that, consistent with the results of this experiment, mere exposure to the SD is ineffective to produce inhibition of chained, as well as singularly trained, instrumental responses (Bouton et al., 2016; Thraillkill & Bouton, 2015a, 2016b). Such results are consistent with clinical studies suggesting that simple Pavlovian exposure to drug-associated cues can be ineffective for reducing smoking or drug taking (e.g., Conklin & Tiffany, 2002). The ineffectiveness of simple cue-exposure therapy for treating addictive behaviors can be explained partly by the idea that any addictive behavior is not only driven by Pavlovian influences (cues) but also by instrumental behaviors performed during those and other cues. These cues may then be functioning as SDs for instrumental behaviors driving

the addiction. Discriminated operant behavior does not extinguish through mere exposure to the SD; rather, the response needs to be made during the SD without leading to reinforcement for the behavior to properly extinguish. Thus, in instrumental situations, it seems especially important for the organism to learn specifically to inhibit the response.

A focus on suppression of procurement behaviors may be especially effective: They may be easier to extinguish directly than more proximal (consumption) behaviors. Extinction of consumption directly would be procedurally difficult if not unlikely; drug users do not inject saline, and smokers rarely smoke denicotinized cigarettes. However, the inhibition of procurement may directly weaken consumption to some extent (Thrailkill & Bouton, 2015a) as well as potentially reduce the potential for the kinds of renewal demonstrated in the present experiment. In future experiments, extra procurement extinction will be included before testing consumption responding to determine if extinguishing each component of the chain separately can reduce or abolish the renewal effect seen in Experiments 3 & 4 (Thrailkill et al., 2016).

In summary, procurement and consumption responding in the present heterogeneous behavior chain are both influenced by the context, though in different ways. Whereas procurement responding is decremented by a physical context change in a manner similar to singularly trained instrumental responses, consumption responses seemed to be controlled to a greater extent by the preceding procurement response. Although this was true when responses were extinguished separately (Experiment 1), it is important to remember that consumption was sensitive to the context switch when it extinguished as part of a chain (Experiment 2; Thrailkill et al., 2016). The difference is due to the fact that the procurement response, which is decremented by physical context change, provides a context for the following consumption response. The fact that procurement behavior can function as a contextual stimulus and renew a separately

extinguished consumption response in a specific manner suggests an important role for the response association in the control of chained responses. Indeed, as we have noted (Thrailkill & Bouton, 2015a), the present results also suggest the importance and value of extinguishing procurement; left uninhibited, procurement responding can cause renewal of consumption when extinguished consumption is returned to the chain. This could be one mechanism by which some problematic behaviors relapse following their initial cessation.

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Figure 1. Representation of a Heterogeneous Behavior Chain. The figure presents the process for any one trial of the heterogeneous behavior chain. Following a variable ITI, the procurement SD (S1) is initiated. Procurement responses (R1) during the procurement SD (S1) then cause the termination of the S1 and initiation of the consumption SD (S2). Consumption responses (R2) during the consumption SD (S2) then may produce a reinforcer (+).

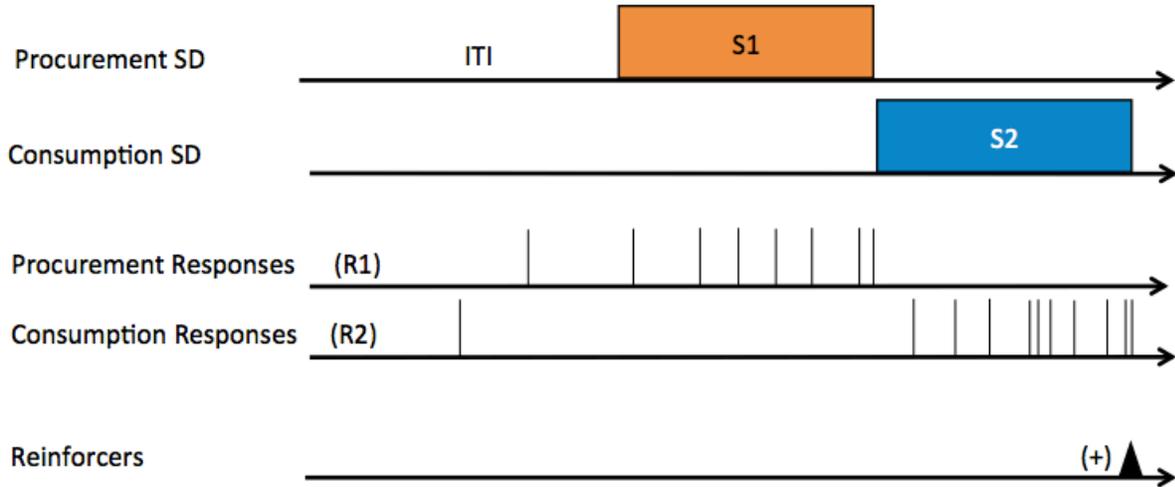


Table 1
Experimental Designs

Group	Acquisition	Extinction	Test
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Experiment 3

<i>S1-R1</i>	S1:R1 → S2:R2 + (1, 2)	S2:R2 - (1, 2) S2:R2 - (2)	<i>S1:R1</i> → S2:R2 - (1, 2)
No S1-R1			S2:R2 - (1, 2)
S1-			S1: → S2:R2 - (2)
No S1-			S2:R2 - (2)

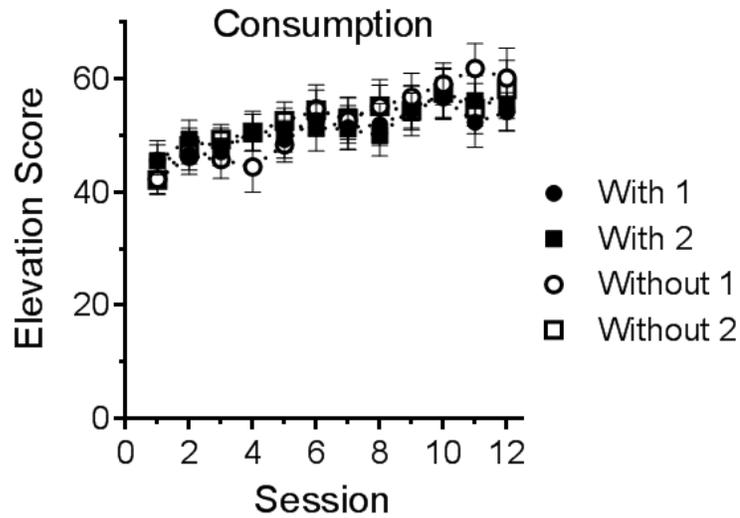
Experiment 4

With	S1:R1 → S2:R2 + (1, 2, 3, 4) S3:R3 → S4:R4 +	S2:R2 - (1, 2, 3, 4) S4:R4 -	S1:R1 → S2:R2 - S3:R3 → S2:R2 - (1, 2, 3, 4) S3:R3 → S4:R4 - S1:R1 → S4:R4 -
Without		S2:R4 - (2, 4) S4:R4 -	S1: → S2:R2 - S3: → S2:R2 - (3, 4) S3: → S4:R4 - S1: → S4:R4 -

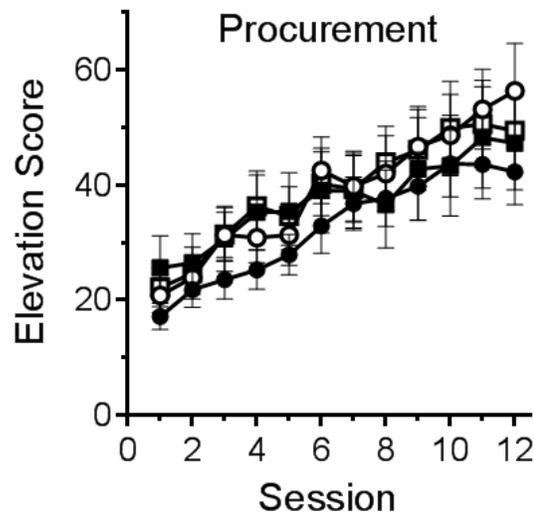
Note. Groups are presented in the far left column, and each column to the right refers to the phases of the experiment in chronological order. R1 and S1; R3 and S3 refer to procurement responses and their respective discriminative stimuli. R2 and S1; R4 and S4 refer to consumption responses and their respective discriminative stimuli. “+” designates reinforcement, “-“ designates nonreinforcement (extinction), and parentheses indicate which response manipulanda were present. Differences between groups are highlighted with bold text. The important group from Experiment 3 (S1-R1) that showed renewal of consumption responding is italicized. Congruent trials from the test session of the present experiment are shown in red text.

Adjusted from: Thrailkill et al. (2016). Contextual control of chained instrumental behaviors. *Journal of Experimental Psychology, manuscript in revision for publication*

Figure 2. Results of Acquisition. a.) Consumption elevation scores during acquisition. b.) Procurement elevation scores during acquisition. Responses on Chains 1 and 2 for Groups With and Without are both represented. Chain 1 refers to S1:R1→S2:R2, and Chain 2 refers to S3:R3→S4:R4. Error bars are the standard error of the mean and only appropriate for between-group comparisons.



a.)



b.)

Figure 3. Discrimination at the end of Acquisition. Procurement and consumption response rates are presented for Groups With and Without in the Pre-S1 stimulus period, the S1 stimulus period, and the S2 stimulus period. Responding on the congruent and incongruent response during the SDs is presented (e.g. an incongruent response would be if R3 was performed during S1).

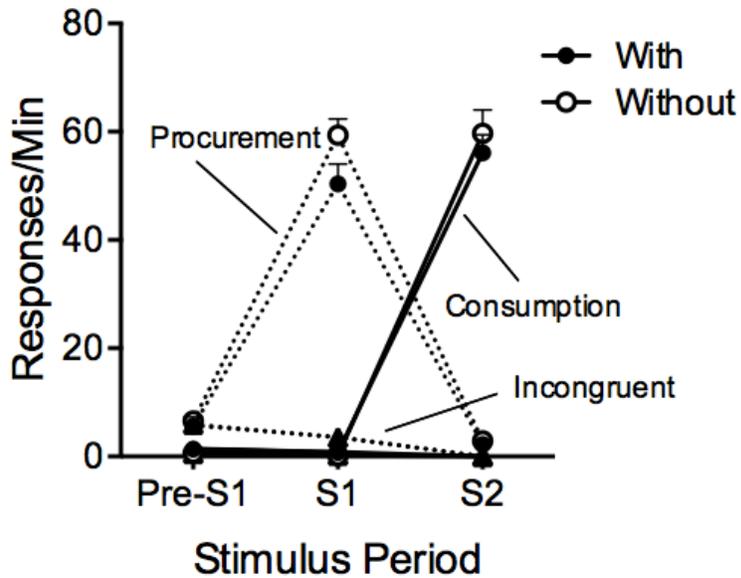


Figure 4. Results of Extinction. Consumption elevation scores during extinction in 4-Consumption SD trial blocks. Responses on Chains 1 and 2 for Groups With and Without are both represented. For extinction of consumption, Chain 1 refers to S2:R2, and Chain 2 refers to S4:R4. Error bars are the standard error of the mean and only appropriate for between-group comparisons.

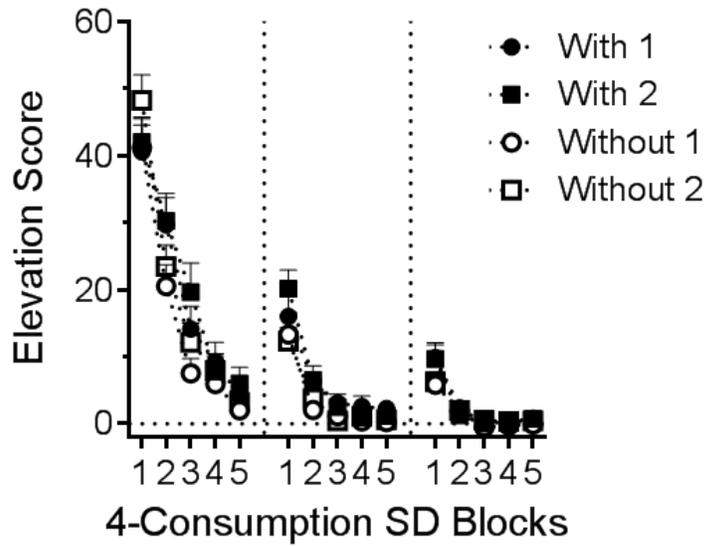


Figure 5. Results from Consumption Test. a.) Consumption elevation scores in 2-trial blocks during the last 4 extinction trials and first 8 test trials with the procurement SD presentations for Group With. b.) Consumption elevation scores in 2-trial blocks during the last 4 extinction trials and first 8 test trials with the procurement SD presentations for Group Without. For both groups, responses on congruent and incongruent trails are represented.

