Motivational State-Dependent Renewal of Operant Responding under Food and Water Deprivation States

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Psychology.

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May, 2021
THE GRADUATE SCHOOL

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Motivational State-Dependent Renewal of Operant Responding Under Food and Water Deprivation States

be accepted in partial fulfillment of the requirements for the degree of

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Abstract

Renewal and reinstatement are two different ways in which operant responding may recover following extinction. These and other forms of recovery following extinction have been described as relapse phenomena and demonstrate the context-specific nature of extinction learning. Most studies of relapse phenomena have utilized distinct exteroceptive stimuli as context (e.g., auditory, visual, and/or olfactory stimuli). However, there is growing literature on the role of interoceptive stimuli (e.g., deprivation and drug states) in the recovery of extinguished responding. Recent studies have demonstrated that events that function as motivating operations (MOs) may contribute to relapse following extinction both by a) eliciting interoceptive conditions that serve as a discriminative context for relapse (i.e., the discriminative function) and b) altering the evocative efficacy of discriminative stimuli associated with the reinforcer that originally established responding (e.g., the motivational function). The purpose of the current study was to further examine the extent to which the discriminative and motivational functions of MOs contribute to relapse following extinction. One group of mice was deprived of food for 24 h and the other was deprived of water for 24 h during the acquisition of an operant response. Following this, each group received extinction sessions under the other MO condition. Both groups then received renewal and reinstatement tests under both MO conditions. More renewal and reinstatement were observed in the motivational states in which acquisition of responding occurred. The implications of these results are considered in the context of state-dependent learning.
Acknowledgements

Matthew Lewon, Ph.D., thank you for your constant support and mentorship over the years. Your guidance has made me the scientist I am today. I will constantly strive to make you proud of me. I am grateful for every opportunity you’ve given me.

To my best friend and partner Jeff, thank you for every single time you picked up the slack while I worked into the night. Without your reassurance and support I couldn’t have gotten this degree. Thank you for doing this with me.

To my lab and program mates past and present, I cannot express how thankful I am for each of you professionally and personally. I want to especially thank Vanessa Willmoth, Staheli Meyer, Kim Henkle, Christina Peters, Melia Shamblin, Natalie Buddiga, Melanie Stites, and Courtney Smith for always showing up and helping me at a moment’s notice.

My research assistants, without your passion to learn and attention to detail I could not have completed this milestone. Thank you for showing up and committing yourselves to this research project.
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Statement on the Welfare of Animals

All research herein was conducted in accordance with guidelines approved by the University of Nevada, Reno’s Institutional Animal Care and Use Committee under protocol #20-07-1045.
Renewal and reinstatement describe two different ways in which conditioned responding recovers (i.e., begins occurring again or increases in frequency) following extinction (Bouton & Swartzentruber, 1991). Because both renewal and reinstatement describe the reoccurrence of a previously extinguished behavior, they have been referred to generally as *relapse phenomena* (Podlesnik, Kelley, Jimenez-Gomez & Bouton, 2017) (other relapse phenomena include spontaneous recovery and resurgence). Renewal and reinstatement have been observed in both Pavlovian and operant conditioning preparations, though most recent research has studied these phenomena using operant procedures. As the current study is concerned with the recovery of extinguished operant behavior, the discussion below will focus on operant procedures for studying renewal and reinstatement.

Renewal is the recovery of extinguished behavior that occurs when the context is changed following extinction. Renewal is most often observed when an organism is returned to the original context in which conditioning occurred, but it can also be observed with exposure to a context that is different from the one in which extinction occurred (Bouton & Swartzentruber, 1991). Three common procedures used to study operant renewal are AAB, ABC, and ABA designs. In an AAB preparation, conditioning and extinction occur in context A and recovery is observed in context B. In an ABC renewal preparation, conditioning occurs in context A, extinction occurs in novel context B, and recovery is observed in a second novel context C. Lastly, in ABA preparations, conditioning occurs in context A, extinction occurs in context B, and recovery of responding is observed when returned to context A (i.e., the conditioning or acquisition context). The ABA design generally results in the most robust renewal and will be
utilized in the current study (Bouton & Todd, 2014; Bouton, Vurbic, & Winterbauer, 2011; Nakajima, Tanaka, Urushihara, & Imada, 2000).

In the case of reinstatement, response-independent deliveries of the reinforcer that previously maintained responding are arranged following extinction of the response, and these reinforcer presentations occasion the recovery of the extinguished response. Like renewal procedures, the prototypical reinstatement procedure consists of three phases: a) acquisition of a response via a particular form of reinforcement, b) extinction of the response, and c) tests in which the response-independent delivery of the reinforcing stimulus that had established the response in phase a) is provided. Typically, these phases all occur in the same physical context. The response-independent delivery of reinforcers in phase c) is thought to contribute to the recovery of extinguished behavior due to the discriminative properties of the reinforcer acquired during initial training in phase a) (Bouton & Trask, 2016; Bouton & Swartzentruber, 1991; Franks & Lattal, 1976; Campbell, Phillips, Fixsen, & Crumbaugh, 1968; Lattal, St. Peter & Escobar, 2013).

Renewal, reinstatement, and other relapse phenomena have been the subject of a great deal of recent basic research because they are thought to be relevant to understanding the failure of generalization of extinction-related treatment effects (Podlesnik et al., 2017). For example, people may enter into a treatment facility for substance abuse. While there, they may acquire behaviors that serve as alternatives to drug-taking in a context that is much different from the one in which they began and continued to use drugs. Research on renewal and reinstatement suggests that when the individual returns to the original context in which they used drugs, there is an increased likelihood of relapse. The role of the recovery of extinguished behavior has been studied

**Context and its Role in Relapse Phenomena**

Understanding the role of context in learning is thought to be fundamental to the analysis of renewal, reinstatement, and other relapse phenomena (Bouton & Todd, 2014; Balsam & Tomie, 1985). In renewal preparations, the recovery of responding is thought to be due to exposure to a context that is different than the one in which extinction occurred. The implication of this is that the effects of extinction contingencies on the frequency of a particular response are somewhat confined to the contextual circumstances correlated with the discontinuation of reinforcement. Some have suggested that the effects of extinction are more context-specific than the effects of reinforcement and have offered this as an explanation for why responding is observed to recover in non-extinction contexts in AAB and ABC renewal designs (i.e., responding recovers in novel contexts in which neither reinforcement nor extinction has occurred) (Bouton, Todd, Vurbic, & Winterbauer, 2011). With respect to reinstatement, the presentation of the reinforcer that was used to initially establish responding is thought to reconstitute one of the original contextual conditions under which a particular performance was acquired,
thereby contributing to the recovery of extinguished responding (Franks & Lattal, 1976; Doughty, Reed, & Lattal, 2004; Balleine & Ostlund, 2007). Adding additional contextual stimuli that had been present during acquisition (i.e., adding a component of the renewal preparation) enhances the reinstatement effect (García-Gutiérrez & Rosas, 2003).

Context has been defined in many ways, but the term is used here broadly to describe any stimulation originating from inside or outside the body of an organism that comes to affect its behavior (Rosas, Aguilera, Alvarez & Abad, 2006; Bouton, 2010). The stimuli that may comprise context and affect learning may be separated into two classes: exteroceptive and interoceptive. Exteroceptive stimuli are those that originate from outside of the body of the behaving organism (i.e., stimulation arising from objects/events in the physical or social environment). The majority of studies on relapse phenomena have investigated the effects of exteroceptive contextual stimuli on the recovery of extinguished responding. In most experimental preparations, these typically include distinct visual, auditory, gustatory, and/or olfactory stimuli that are systematically manipulated by the experimenter. These are analogous to the exteroceptive features of contexts in which individuals acquire problematic behaviors (i.e., the places and/or people in the presence of which behavior to be treated is initially established).

Interoceptive stimuli are those that originate in the body of the behaving organism. These include stimulation arising from a variety of physiological events, including those induced by drug/alcohol intake, food/water/sleep deprivation or satiation, and events associated with emotions. Learning that is specific to interoceptive context has been described as state-dependent learning (Overton, 1985). A well-studied example of this is drug discrimination (Overton, 1991). In drug discrimination studies, an operant
response is reinforced in a particular drug state and extinguished either in a non-drug state or a different drug state. Evidence of state-dependent learning is observed when the response differentially occurs in the state in which it has been reinforced.

**Interoceptive Conditions Associated with Motivating Operations**

Many of the interoceptive conditions that may come to control behavior in the way described above appear to be elicited by events that function as motivating operations (MOs; Lewon, Thomas, Peters, & Hayes, 2020). MOs are environment-organism interactions that are described as altering the extent to which consequential events function as reinforcing and/or aversive. MO is an omnibus term for both establishing operations (EOs) and abolishing operations (AOs). EOs increase the reinforcing and/or aversive efficacy of some stimulus, while AOs decrease the efficacy of these consequential stimuli (Michael, 1982, 1993; Laraway, Sncyrski, Michael, Poling, 2003. Eating salty food, for example, could be considered an EO for water consumption because it increases the frequency of organisms’ behaviors that have been reinforced with water. Conversely, eating a substantial amount of food could serve as an AO that decreases food-seeking behaviors.

It is important to acknowledge that MOs affect behavior in a way that is different from discriminative stimuli (Michael, 1982; Poling, Lotfizadeh, & Edwards, 2020). Discriminative stimuli affect behavior through their correlation with response-outcome contingencies (i.e., the “availability” of a particular outcome contingent upon a response), while MOs are held to affect behavior by altering the evocative efficacy of discriminative stimuli that have been associated with a particular response-contingent outcome. Because MOs appear to serve multiple functions, this particular effect (i.e., altering the
effectiveness of discriminative stimuli associated with particular outcomes) will be referred to as the *motivational function* of MOs.

In addition to their motivational functions, many MOs appear to elicit physiological responses that serve as sources of interoceptive stimuli, and these stimuli may come to exert discriminative control over behavior under certain contingencies (Lewon, et al., 2020). For example, in a series of experiments, T. L. Davidson and colleagues used a conditioned fear paradigm to demonstrate how food deprivation and satiation conditions could be established as an interoceptive discriminative cue for conditioned freezing behavior (Davidson, 1987) In these experiments, a tone was presented to rats and followed by unavoidable shock only in specified food deprivation or satiation states (the state in which shock followed the tone varied across groups/experiments). The animals came to differentially freeze in the deprivation/satiation state that predicted shock, thereby demonstrating that the interoceptive conditions associated with these MOs came to function as discriminative cues for shock.

**Interoceptive Contextual Cues and Relapse Phenomena**

Researchers have begun to study the role of interoceptive contextual cues associated with MOs in the renewal of operant behavior. For example, Schepers and Bouton (2017) examined the use of food deprivation and satiation states as interoceptive contextual cues for the recovery of extinguished responding with rats. In the first phase of the experiment, satiated rats learned to lever press for food pellets. In the second phase, rats were deprived of food for 23 h prior to each session in which lever presses were extinguished in the same exteroceptive context. Lastly, counterbalanced tests for renewal
were conducted under satiation and 23-h deprivation states, again in the same
exteroceptive context. More responding was observed in the renewal tests conducted in
food satiation states, suggesting that the interoceptive stimuli associated with that
condition functioned as discriminative cues for the recovery of responding.

More recently, Lewon et al. (2020) used different combinations of food
derivation and satiation states to further study the role of interoceptive cues in renewal.
One group of mice (Group 24-0) acquired operant responding via reinforcement under
24-h food deprivation during the first phase and responding was then extinguished in the
same exteroceptive context under 0-h food deprivation (i.e., satiation). A second group
(Group 0-0) received the same acquisition training under 0-h deprivation conditions
followed by extinction also under 0-h food deprivation. A final group (Group 24-24)
received both acquisition and extinction sessions under 24-h food deprivation. All groups
were then tested for renewal in the same exteroceptive setting under both 0-h and 24-h
food deprivation conditions. Both Groups 24-0 and 0-0 exhibited renewal in the 24-h
derivation test, which represented ABA and AAB renewal, respectively. However, AAB
renewal was not observed for Group 24-24 in the 0-h deprivation test. On the basis of
these findings, the authors suggested that while the interoceptive stimuli associated with
0-h deprivation would have been expected to occasion AAB renewal for Group 24-24
because it was the state in which extinction had not occurred, this was not observed
because there was no EO in place for the reinforcer. In other words, the discriminative
functions of the interoceptive conditions associated with 0-h deprivation for Group 24-24
were insufficient for the recovery of responding in the absence of motivation for the
reinforcer that had been used to initially establish responding. This suggests that the
motivational functions of MOs interact with the discriminative functions of the interoceptive conditions associated with them in determining whether or not renewal is observed.

**Purpose**

The purpose of the proposed study was to further investigate the recovery of extinguished operant responding occasioned by interoceptive contextual stimuli associated with MOs. This study extended research in this domain in two ways. First, food and water deprivation states served as the acquisition, extinction, and testing contexts (previous studies used different levels of food deprivation/satiation only). One group (Food Group) received acquisition sessions under 24-h food deprivation and extinction sessions under 24-h water deprivation. Conversely, the second group (Water Group) received acquisition sessions under 24-h water deprivation and extinction sessions under 24-h food deprivation. Both then received two renewal tests: one under 24-h food deprivation and the other under 24-h water deprivation. In light of previous studies, was expected that greater renewal would be observed in the food deprivation renewal test for Food Group while more renewal would be observed in the water deprivation renewal test for Water Group.

This study also extended existing research by including two tests for reinstatement following the two renewal tests. In these tests, the reinforcer that was used to establish responding during acquisition sessions was presented in a response-independent manner as described above. As with renewal tests, one reinstatement test was conducted under 24-h food deprivation and the other was conducted under 24-h water deprivation. As such, the reinstatement tests may be considered to reflect the
additive effects of a) the discriminative properties of interoceptive context (i.e., food or water deprivation state) and b) the discriminative properties of the presentation of the reinforcer used in acquisition training. If the interoceptive conditions associated with food and water deprivation have acquired discriminative control over responding, it was expected that more reinstatement would be observed in the former for Food Group and more reinstatement would be observed in the latter for Water Group.

Method

Subjects

Twenty-eight experimentally naïve female BALB/c mice served as subjects. Subjects were assigned to two experimental groups with two subgroups within each for the purpose of counterbalancing the order of renewal and reinstatement tests (see Table 1).

Apparatus

Med Associates ENV-307A (St. Albans, VT) operant chambers were utilized for all phases of the experiment. The chambers measure 12.7 cm high Å~ 15.9 cm wide Å~ 14.0 cm deep and are mounted on a white polypropylene base. Chambers were placed in a sound-attenuating cubicle to reduce ambient noise. Each cubicle was equipped with a fan for air circulation and to further limit distractions from outside sounds. Cubicles were equipped with an aperture for visual inspection of the operant chamber. Within the chamber a 100-mA house light is mounted 10 cm above the grid floor. This is located on the center column of the back wall of the operant chamber opposite the dipper receptacle. The dipper receptacle (entry port measuring 2.5 cm high Å~ 2.9 cm wide Å~ 1.9 cm
deep) is located in the center column at the front of the chamber and is 0.5 cm above the grid floor and was equipped with head entry detectors (ENV-254) that recorded entries when subjects placed their heads at least 0.64 cm into the receptacle. One of two side walls include the loading door and opposite that is a solid wall made of clear polycarbonate where all activity could be monitored visually. A liquid dipper (ENV-302M-S) was used to deliver the reinforcer, which was a 25/75 mixture of sweetened condensed milk and water (SCM mixture). The operandum for the operant response was an illuminable nose poke (ENV-313M) measuring 1.3 cm in diameter x 1 cm deep. The nose poke was located 3 cm to the left of the dipper receptable. A response was defined as an animal’s snout breaking a beam 0.64 cm in the nose poke. MED-PC IV software was utilized to automatically count all responses and program stimulus presentations throughout the experiment.

**Experimental Design and Data Analysis**

Both groups received the same regimen of preliminary training, acquisition, extinction, and renewal and reinstatement tests. The independent variable was the MO condition under which they received acquisition and extinctions sessions. As shown in Table 1, Food Group received acquisition sessions under 24-h food deprivation and extinction sessions under 24-h water deprivation. Conversely, Water Group received acquisition sessions under 24-h water deprivation and extinction sessions under 24-h food deprivation. Both then received renewal and reinstatement tests under both MO conditions, and the order of these tests was counterbalanced across subgroups within each group to control for sequence effects.
The primary dependent variable was the number of responses during the renewal and reinstatement tests. Mixed ANOVAs were used to analyze the results. These allowed for comparisons of the within-subjects factor (i.e., differences in responding between the food and water deprivation renewal/reinstatement tests for individual subjects), the between-subjects factor (i.e., differences in responding between Groups Food and Water in the renewal/reinstatement tests), and a group/test interaction. \( p \)-values of 0.05 were used as the criterion for statistical significance for these comparisons.

**Motivating Operations**

Two MOs were employed in this experiment. These are described below.

**Food Deprivation.** The food deprivation MO was imposed by removing food from the home cage 24 h prior to an experimental session. During this time, subjects had free access to water. Following experimental sessions, animals then had free access to both food and water for 24 h prior to the next deprivation period.

**Water Deprivation.** The water deprivation MO was imposed by removing water from the home cage 24 h prior to an experimental session. During this time, subjects had free access to food. Following experimental sessions, animals then had free access to both food and water for 24 h prior to the next deprivation period.

**Pre-Experimental Training**

All subjects received 20 sessions of pre-experimental training to teach them to approach and consume the reinforcer from the dipper receptacle and establish operant nose poke responding for the reinforcer. For both groups, half of these sessions were conducted under the food deprivation MO and half were conducted under the water
deprivation MO (see Table 1). The MO in the first/last session in each phase was
counterbalanced across subgroups within Groups Food and Water. Preliminary training
consisted of 10 sessions of dipper training and 10 sessions of nose poke training. Each of
these are described below.

**Dipper Training.** During dipper training there was a concurrent variable-time 45
s (VT-45 s)/fixed-ratio 1 (FR-1) schedule of reinforcement. For the VT-45 s schedule, the
dipper was presented independently of responding on average every 45 s. When the
dipper was raised, it stayed up until subjects put their heads in the receptacle. Once that
occurred, subjects had 6 s to consume the SCM reinforcer. Additionally, there was an
FR-1 schedule in place for responses on the nose poke operandum. Each response was
reinforced with 6 s access to the SCM reinforcer. Each session ended after 15 minutes,
and subjects in both groups received 10 total sessions, five under food deprivation and
five under water deprivation.

**Nose Poke Training.** Nose poke training sessions were identical to dipper
training sessions with one exception. The VT schedule of reinforcement was discontinued
and only responses occurring on the nose poke operandum were reinforced on a FR-1
schedule with 6 s of access to SCM. Each session ended after 15 minutes, and subjects
received 10 total sessions. As during dipper training, five sessions were conducted under
food deprivation and five sessions were conducted under water deprivation for both
groups.

**Experimental Sessions**

**Acquisition sessions.** Following preliminary training, all subjects received five
acquisition sessions. During these sessions the nose poke was illuminated and responding
was reinforced with 6 s of access to SCM on a variable-interval 30 s (VI-30 s) schedule. A Fleshler-Hoffman (1962) constant probability procedure was used to select intervals for the VI schedule (range from 1.55 s to 99.08 s with replacement). Each session lasted 20 minutes, and all subjects received 5 total sessions. MOs implemented were 24-h food deprivation for Food Group and 24-h water deprivation for Water Group (see Table 1).

**Extinction sessions.** Following acquisition sessions, subjects received four extinction sessions. During these sessions the nose poke was illuminated and the SCM mixture was placed in the dipper but responding on the nose poke operandum was not reinforced: responses were recorded but had no programmed consequences. Each session lasted 20 minutes. Motivating operations implemented were opposite of that which each group experienced during acquisition sessions. As shown in Table 1, Food Group received extinction sessions under the 24-h food deprivation MO and Water Group received these sessions under the 24-h water deprivation MO.

**Renewal tests.** After extinction sessions, subjects received two renewal tests under the MO conditions under study (24-h food deprivation and 24-h water deprivation). Renewal tests were identical to extinction sessions except that they were 10 min in duration. The order of these tests was counterbalanced across subgroups within each group (see Table 1).

**Reinstatement tests.** Following the renewal tests, subjects experienced two reinstatement tests under the two MO conditions under study (24-h food deprivation and 24-h water deprivation). The order of these tests was counterbalanced across subgroups within each group (see Table 1). Each test lasted 10 minutes. The nose poke was illuminated and SCM was placed in the dipper. Responding on the nose poke was
counted but had no programmed consequence. Three response-independent deliveries of the SCM reinforcer were programmed to occur approximately every three minutes (i.e., VT-3 min) during the test sessions. If a nose poke response occurred within 10 s of when a reinforcer delivery is programmed on the VT schedule, the delivery of the reinforcer was delayed for 30 s in an attempt to prevent adventitious reinforcement of the response.

**Results**

**Pre-Experimental Training**

**Dipper Training.** Panel A of Figure 1 shows the mean latency to the dipper after the presentation of response-independent dipper presentations on the VT-45 s schedule under food versus water deprivation training sessions for all subjects. In both food and water deprivation conditions, there was a similar decrease in the time to approach the dipper across successive trainings. Panel B of Figure 1 depicts the mean total number of head entries into the dipper receptable. The instances of head entries increased across sessions, and this occurred at approximately the same rate under food and water deprivation conditions. Panel C of Figure 1 shows the mean number of nose pokes during dipper training under food and water deprivation. Following the first training session, there was a decrease in nose pokes to 1-2 per session. As with the other measures during this stage of training, there was no significant difference in the number of nose poke responses or the trend in this measure between food and water conditions.

**Nose Poke Training.** During nose poke training, the VT-45 s schedule operating during dipper training was discontinued and reinforcement was only provided for responding on the nose poke operandum on a FR-1 schedule. Panel A of Figure 2 shows
the mean number of head entries per session for all animals under both food and water deprivation conditions. There was a gradually decreasing trend in this measure across trainings, and again there was no significant difference between food and water deprivation conditions in terms of either level or trend. Panel B of Figure 2 displays the mean number of nose poke responses made per session for all animals in food and water deprivation conditions. There is a gradual and similarly increasing trend in the number of responses per session under both food and water deprivation. There was a higher mean rate of responses under food deprivation in sessions three and four, but otherwise the animals generally made the same number of responses under food and water deprivation. The large increase in mean rate of responding in session four under food deprivation conditions is due to a single mouse responding over 300 times. Nevertheless, there was otherwise not a significant difference in the acquisition of nose poke responding between food and water deprivation conditions.

**Experimental Sessions**

**Acquisition sessions.** Figure 3 shows the mean rate of responses for Groups Food and Water during acquisition, extinction and renewal/reinstatement testing phases of the experiment. As shown in Table 1, Food Group was deprived of food during acquisition sessions and Water Group was deprived of water. Differentiation between the effects of food and water deprivation was not observed during pre-experimental dipper training or when reinforcement was provided on a FR-1 schedule during initial nose poke training, but during acquisition sessions, animals deprived of food responded on average three times more than those deprived of water under the VI-30 s schedule. The mixed ANOVA analysis found no significant effects for session ($F_{4, 104} = 1.13, p = 0.35, \eta^2 = $
0.04) or the group/session interaction ($F_{4, 104} = 1.44, p = 0.23, \eta^2 = 0.05$). However, there was a strong, significant group effect ($F_{1, 26} = 20.82, p < 0.001, \eta^2 = 0.45$), suggesting that food deprivation is a substantially more effective EO when responding is reinforced on VI-30 s schedule of reinforcement.

**Extinction sessions.** Figure 3 shows an overall decrease in responding across extinction sessions for Groups Food and Water. There appeared to be an extinction burst (Lattal, Kuroda, & Cook, 2020; Lerman & Iwata, 1995) during the first extinction, session where subjects in both groups displayed more responding compared to their last acquisition session. While both groups exhibited this apparent extinction burst, when measuring the magnitude of this burst relative to the last acquisition session, the burst was larger for Water Group, (see Figure 4) which received acquisition sessions under water deprivation and extinction sessions under food deprivation. Data from acquisition sessions suggested that food deprivation is a more effective EO for SCM-reinforced responding, and it is possible that the larger extinction burst for Water Group was due to the shift from water deprivation during acquisition to food deprivation during extinction. On the other hand, the extinction burst for Food Group (which received acquisition sessions under food deprivation followed by extinction sessions under water deprivation) was smaller. The mixed ANOVA analysis revealed a statistically significant session effect ($F_{3, 78} = 78.64, p < 0.001, \eta^2 = 0.75$), but there were no statistically significant differences for the group factor or for the group/session interaction ($F_{1, 26} = 13.39, p = 0.08, \eta^2 = 0.12; F_{3, 78} = 1.73, p = 0.17, \eta^2 = 0.06$, respectively). As such, the significant group difference between Groups Food and Water observed during acquisition sessions was not observed during extinction when MO conditions were reversed.
**Renewal tests.** Renewal tests occurred under both food and water deprivation conditions (see Table 1). As shown in Figure 3, both groups made more responses in renewal tests in the motivational state under which acquisition occurred: Food Group engaged in more responding under food deprivation, and Water Group engaged in more responding under water deprivation. This suggests that the interoceptive stimuli associated with the MO conditions under which responding was acquired/extinguished exerted a degree of discriminative control over responding. This conclusion is supported by a relatively large significant test/group interaction effect ($F_{1, 26} = 22.54, p < 0.001, \eta^2 = 0.47$). Statistical analysis did not reveal significant effects for differences in deprivation test ($F_{1, 26} = 0.76, p = 0.39, \eta^2 = 0.03$) or group ($F_{1, 26} = 1.15, p = 0.29, \eta^2 = 0.04$). Counterbalancing the order of tests (food vs. water deprivation) appeared to be effective in that statistical analysis revealed no significant differences in terms of testing order for test, group, or test/group interaction.

**Reinstatement tests.** The results of the reinstatement tests showed the same general pattern as those observed in the renewal tests, but there was more responding in reinstatement tests relative to the renewal tests. As in the statistical analysis of renewal test results, the mixed ANOVA analysis for reinstatement tests revealed a significant test/group interaction ($F_{1, 26} = 11.61, p = 0.002, \eta^2 = 0.31$) but insignificant effects for test and group factors ($F_{1, 26} = 0.08, p = 0.93, \eta^2 < 0.001$ and $F_{1, 26} = 0.33, p = 0.57, \eta^2 = 0.01$, respectively). As with the renewal tests, there were no statistically significant differences with respect to test, group, or group/test interaction for analysis of testing order.


Discussion

This study extended recent findings of state-dependent renewal by using food and water deprivation states as contexts for the acquisition, extinction, and recovery of operant responding. In the renewal and reinstatement tests, both groups responded more in the motivational state in which acquisition occurred. As nothing about the exteroceptive context was changed during the experiment, it is likely that the patterns observed during the tests was due to the discriminative properties of the interoceptive states associated with food and water deprivation. (Lewon et al., 2020; Schepers & Bouton, 2017). The difference between responding of the two groups in the tests was more pronounced in the food deprivation tests. As the acquisition sessions phase demonstrated that food deprivation was a more effective EO for SCM-reinforced responding, the greater differentiation between groups in the food deprivation tests may have been due to a combination of the discriminative and motivational properties of the food deprivation MO (Lewon et al., 2020).

While the same general patterns of responding were observed in the renewal and reinstatement tests for both groups, the overall level of responding was higher in the latter. This is predicted by theoretical accounts of relapse phenomena that posit that the recovery of extinguished responding is due to the exposure to contextual variables under which responding was originally acquired (Franks & Lattal, 1976; Doughty, Reed, & Lattal, 2004; Balleine & Ostlund, 2007). In the present experiment, two contextual variables were correlated with the transition from acquisition to extinction contingencies. One was the change in motivational state (i.e., food to water deprivation or vice versa) and the other was the discontinuation of reinforcement. Renewal tests represented the
reconstitution of just one of these contextual variables: interoceptive conditions associated with MOs under which acquisition occurred. On the other hand, reinstatement tests conducted under the acquisition motivational state represent the reconstitution of two of the contextual circumstances of acquisition: a) the motivational state under which acquisition occurred and b) the presentation of the reinforcer that had followed responding during acquisition.

The SCM mixture utilized as a reinforcer in the current study ostensibly has some of the reinforcing properties of both food and water. Its sweet taste and caloric value are similar to those associated with food reinforcement, but it also contains a large proportion of water (75%). An interesting finding was that the differential effects of food and water deprivation EOs on SCM-reinforced responding was not observed until the schedule for the reinforcer was thinned to VI-30 s after pre-experimental training. In pre-experimental dipper and nose poke training under the FR-1 schedule, there was no systematic difference in any measure of reinforcer-related behavior under food and water deprivation. However, when the SCM reinforcer was contingent upon nose poking and the schedule changed to VI-30 s during acquisition sessions, there was significantly more responding for the SCM reinforcer under food deprivation. This observation was similar to those reported in other studies demonstrating that the effects of MOs on responding for a particular reinforcer depend in part upon the schedule of reinforcement for the reinforcer (Ferster & Skinner, 1957; Carlton, 1961; Shull, 2004). Future studies may examine the interactions between different concentrations of SCM reinforcement, food and water deprivation MOs, and schedules of reinforcement.
Extinction bursts have been defined as a temporary increase in the frequency, duration, or intensity of a response when reinforcement for the response is discontinued (Lattal et al., 2020). One of the conclusions suggested by the transition from reinforcement to extinction in the present study is that the relative magnitude of an extinction burst depends in part upon the relation between the MO conditions under which responding is reinforced and those under which it is extinguished. When each group experienced the transition to extinction, there was an increase in rate of responding in the first extinction session relative to the last acquisition session. However, as shown in Figure 4, the increase for Water Group was substantially larger than the increase for Food Group. As noted above, food deprivation was a more effective EO for SCM-reinforced responding relative to water deprivation. Because of this, the transition from reinforcement to extinction coincided with an increase in motivation for Water Group and a decrease in motivation for Food Group. This suggests that larger extinction bursts may be expected when transitioning from lower motivational conditions during acquisition to higher motivational conditions during extinction (see also Lewon et al., 2020).

The results of the present study provide further evidence that interoceptive states can be an important part of the context in which learning occurs. As many events that function as MOs (e.g., drug-taking/withdrawal, events associated with emotions, sickness, etc.) appear to both a) elicit physiological conditions that may acquire discriminative functions and b) alter the value of consequential events as measured by the amount of behavior expended to obtain them, more research on the discriminative and motivational functions of MOs and their interactions is warranted. A unique feature of interoceptive stimuli is that they may occur across a wide range of exteroceptive
contextual circumstances. If circumstances are such that interoceptive conditions are more reliably associated with certain contingencies, these interoceptive conditions may come to control behavior to a greater extent than exteroceptive conditions and/or interact with the control exerted by exteroceptive conditions. These possibilities will have important implications for deepening our understanding of many behavioral phenomena of clinical significance, especially those influenced by physiological variables.
References


Lattal, K. A., Kuroda, T., & Cook, J. E. (2020). Early extinction effects following


Balsam & A. Tomie (Eds.), *Context and Learning* (pp. 357-384). L. Erlbaum Associates.


Table 1

*Motivational Conditions across Experimental Phases for Each Group/Subgroup*

<table>
<thead>
<tr>
<th>Phase</th>
<th>Food Group (n = 14)</th>
<th>Water Group (n = 14)</th>
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<tbody>
<tr>
<td></td>
<td>Subgroup A (n = 7)</td>
<td>Subgroup B (n = 7)</td>
</tr>
<tr>
<td>Acquisition</td>
<td>Food dep</td>
<td>Food dep</td>
</tr>
<tr>
<td>Extinction</td>
<td>Water dep</td>
<td>Water dep</td>
</tr>
<tr>
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<td>Water dep</td>
</tr>
<tr>
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</tr>
<tr>
<td>Reinstatement 1</td>
<td>Food dep</td>
<td>Water dep</td>
</tr>
<tr>
<td>Reinstatement 2</td>
<td>Water dep</td>
<td>Food dep</td>
</tr>
</tbody>
</table>
A

Mean Latency from Free Dipper to Entry

B

Mean Number of Head Entries

C

Mean Number of Nose Pokes

Sessions
**Figure 1.** Pre-experimental training: dipper training results for each session under food and water deprivation conditions. Panel A shows the mean latency from a response-independent dipper presentation to head entry. Panel B depicts the mean number of total head entries into the dipper receptacle. Panel C displays the mean number of nose pokes. Error bars depict the standard error of the mean (SEM).
Figure 2. Depicts phase two of pre-experimental training: nose poke training results under food and water deprivation conditions. Panel A depicts mean number of head entries into the dipper receptacle. Panel B shows the mean number of nose pokes across sessions of dipper training. Error bars depict SEM.
Figure 3. Mean rates of responding +/- SEM during acquisition, extinction, renewal and reinstatement testing for Food and Water Groups.
Figure 4. Mean relative rates in responding +/- SEM for last acquisition and first extinction session for Food and Water Groups.