8-2007

Effect of Extinction across Multiple Contexts on Renewal of Responses within a Functional Response Class

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Recommended Citation

Sobie, Jennifer L., "Effect of Extinction across Multiple Contexts on Renewal of Responses within a Functional Response Class" (2007). *Dissertations*. 919.
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EFFECT OF EXTICTION ACROSS MULTIPLE CONTEXTS ON RENEWAL OF RESPONSES WITHIN A FUNCTIONAL RESPONSE CLASS

by

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A Dissertation
Submitted to the
Faculty of The Graduate College
in partial fulfillment of the
requirements for the
Degree of Doctor of Philosophy
Department of Psychology
Dr. Lisa E. Baker, Advisor

Western Michigan University
Kalamazoo, Michigan
August 2007

EFFECT OF EXTINCTION ACROSS MULTIPLE CONTEXTS ON RENEWAL OF RESPONSES WITHIN A FUNCTIONAL RESPONSE CLASS

Jennifer L. Sobie, Ph.D.

Western Michigan University, 2007

Resistance to extinction in applied settings is a common problem seen in behavior excess scenarios including those that deal with dangerous responding such as high-intensity aggressive responding, or drug dependence—where relapse is discouragingly high and is acknowledged as the most significant challenge in treatment—or eating disorders, or those that include simple reduction of common but undesired behavior in adults, children, and even pets. Behavior reappearance (i.e., the untargeted return of a learned response following extinction) implicates the physical context in which learning occurs as having a critical influence on what is learned and how, when and where this learning will be expressed. Often, responding may include multiple topographies of behavior with distinct evoking discriminative stimuli that share a reinforcer, i.e., multiple members of a functional response class. The studies described in this dissertation evaluated the contribution of extinction of three members of a functional response class, all reinforced by food pellet delivery, on renewal of extinguished responding within the acquisition context. Results showed that extinction of multiple members of a functional response class increased resistance to extinction and did not attenuate renewal, but that reinforcement and subsequent extinction of a single response within the class can attenuate renewal of other previously preferred responses within that response class.

ACKNOWLEDGMENTS

I would like to take this opportunity to thank my committee members, Dr. Lisa Baker, Dr. Kennon A. Lattal, Dr. Cynthia Pietras, Dr. Jack Michael, and Dr. Galen Alessi, for their forbearance and guidance.

I would also like to acknowledge the contributions of my research assistants, Lauren Zverina, Damicah Dawson, Scott Taylor, Cait Meyer, Larry Morgan, and Jennifer Eubanks for their help in caring for the subjects, running the subjects, recording data and caring for the equipment.

Thanks to Dave, my husband, for being Dave, my husband.

Lastly, I would like to recognize Dr. Lisa Baker's steadfast support throughout. While she is technically my advisor, her support has gone well beyond any academic role. Thank-you Lisa.

Jennifer L. Sobie

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CHAPTER I

INTRODUCTION

Behavioral excess and relapse in applied settings is a common problem seen in clinical psychology across a myriad of behavioral disorders including eating disorders (Cautela, 1972), obsessive-compulsive disorder (Eddya et al., 2004), impulsivity (MacKillop, Anderson, Castelda, Mattson, & Donovick, 2006; Reynolds, 2006; Verdejo-García, Rivas-Pérez, Vilar-López, & Pérez-García, 2007), attention-deficit hyperactivity disorder (Fabiano et al., 2000), and anger and impulse management disorders (Connor et al, 2004). Perseveration of maladaptive behavior outside of treatment settings and across applied settings has been described as one of the greatest challenges facing clinical psychologists today (Childress, 2006). Accordingly, one area of focus of pre-clinical behavioral studies is examination of the etiology and mechanisms behind behavior perseveration and relapse.

Response perseveration encompasses a broad array of research models. Pre-clinical studies under the general umbrella of perseveration include resistance to extinction, response recovery, behavioral history (e.g., reinforcement and reinforcement schedule history, punishment history, etc.) and momentum, resistance to change, occasion setting, conditioned suppression, and equivalence conditioning and expression. Experimental exploration into these and related aspects of response perseveration has generated a number of treatment hypotheses that have been successfully extrapolated to clinical treatment conditions. The etiology and treatment of fears and anxiety disorders has been the focus of the particularly large and successful area of study referred to as response recovery. Response recovery is the untargeted return of a learned response following extinction, and pre-clinical data generated in study of response recovery have guided many suggestions for adaptations and additions in treatment of fears and phobias as well as other perseverant behaviors (Naugle & Donohue, 1998).

The treatment of drug addiction is another area where perseveration and response recovery is particularly relevant (Marlatt & Gordon, 1985; Mendelson & Mello, 1996; O'Brien, 1997). Here, relapse rather than the attainment of initial abstinence has been noted as the most significant challenge in treatment (Litt & Mallon, 2003; Marlatt & Gordon, 1985). Recovery related to environmental cues associated with drug taking and the reinforcing effects of drugs are thought to play an important role in relapse following abstinence (Rohsenow, Niaura, Childress, & Abrams, 1991; Jaffe, 1989). Accordingly, a pre-clinical paradigm that has become popular in the study of drug dependence acquisition, maintenance, and treatment is the animal model of self-administration (SA), where the animal subject is able to deliver a bolus of drug to itself through jugular catheterization. Response recovery has received increasingly attention as a phenomenon for study within the SA protocol (Shalev, Grimm, & Shaham, 2002), and paradigms that explore the effects of extinction of drug-reinforced behavior are progressively becoming the basis for development and refinement of addiction treatment (Conklin & Tiffany, 2002).

Yet another area of study associated with response perseveration and recovery of extinguished responding is resurgence. Resurgence is the recovery of extinguished responding upon extinction of a second response. Pre-clinical resurgence studies indicate that resurgence is mediated by a relative loss of reinforcement (Lieving & Lattal, 2003). Resurgence has been evaluated in clinical settings as well, most often in regards to its expression in members of a common response class (Harding, Wacker, Berg, Barretto, Winborn & Gardner, 2001; Horner & Day, 1991; Lalli, Mace, Wohn, & Livezey, 1995). It has been noted that responses that share consequences co-vary in expression according to the reinforcement rate engendered by any one or more than one member of that response class (Repp & Horner, 1999; Sprague & Horner, 1992). Such response classes are referred to as functional response classes (FRC) because all members share a common consequence-producing function (Catania, 1992).

Project Aims

The specific aims of this project were to evaluate a method for attenuation of response recovery in an experimental preparation. The hope was that by combining concepts elucidated in differing response recovery paradigms, a technique might be developed that could reduce recovery of extinguished responding. Such a technique could then be further evaluated in pre-clinical models of relapse.

CHAPTER II

LITERATURE REVIEW

As mentioned above, response perseveration is a phenomenon that has generated numerous areas of study with correspondingly numerous assessment models for evaluation of each specific area. One model of study that is common to most response perseveration studies is extinction of trained responding. Extinction phases in any paradigm allow for non-confounded measurement of conditioned or existing effects. The examination of extinction and those models that evaluate response recovery following extinction are elemental building blocks in development of a treatment designed to attenuate perseveration.

Extinction

Extinction in both operant and respondent paradigms is defined as responding weakened to its pre-reinforcement level (Catania, 1992). Pavlov introduced the term extinction (1927) regarding respondent conditioning and noted that presentation of a conditioned stimulus (CS) numerous times in the absence of the unconditioned stimulus (US) with which the CS had been paired served to reduce conditioned responding (CR) to the CS. Operant extinction procedures can include both responding in the absence of the reinforcing consequence (Skinner, 1938) or by response-independent (non-contingent) reinforcer delivery (Rescorla & Skucy, 1969), although in studies evaluating resurgence effects it has been seen that response-independent food delivery is not functionally equivalent to conventional extinction (Lieving, 2000) in that although the target response may decrease, the resurgence effect mentioned earlier does not occur under such conditions.

As demonstrated by the existence of the resurgence phenomenon, extinction tends not simply to decrease responding but also to generate responding (Galbicka, 1994). Given a reinforcement history, generated responding appears to be sensitive to that history (Franks & Lattal, 1976; Reed & Morgan, 2006). Choice of response in the face of extinction has been found to be differentially correlated with reinforced responding in the previous session in both basic experimental settings (Williams, 1996) and in applied animal behavior settings (Sobie, 1995).

Response Recovery

Recovery investigations have shown that the weakening effects of extinction tend to be restricted to the context in which the extinction treatment was implemented. When tested outside of the extinction context and in particular in the acquisition context, the weakened behavior recovers, often to its pre-extinction strength (Bouton, 2002; Bouton & Bolles, 1979; Bouton & Nelson, 1998). The fact that extinguished responding is subject to recovery suggests extinction does not return the subject to its preconditioning state (McAllister & McAllister, 2006), and that extinction is not un-learning and does not erase what had been learned about the original contingency (Bouton & Nelson, 1998). Rather, extinction is a separate learning experience, and the original learning experience is differentially available under those conditions in which it was learned and reinforced (Bouton & Swartzentruber, 1991). Given that therapy for behavior disorders tends to be conducted in a context distinct from the one in which the response is commonly expressed, studies regarding experimental extinction have notable clinical implications (Bouton & Nelson, 1998; Rauhut, Thomas & Ayres, 2001; Thomas & Ayres, 2004). Behavioral recovery phenomena and their study paradigms include renewal, reinstatement, spontaneous recovery, and resurgence.

Renewal. One form of response recovery is renewal. Renewal refers to the recovery of an operant or respondent CR when extinguished in one context and tested in another. The phenomenon of renewal implicates the physical context in which learning occurs as having a critical influence on what is learned and how, when, and where this learning will be expressed (Bouton & Nelson, 1998). While most of the research on renewal has focused on manipulations involving Pavlovian extinction studies, there are also a number of such studies that have evaluated the effects of context on operant responding and extinction. Both procedures share a number of relevant conditioning principles (see Bouton & Swartzentruber, 1991), and the results found in operant conditioning studies have basically paralleled those found in Pavlovian conditioning studies.

The phenomenon of renewal has been studied under a variety of protocols. In "ABA" studies, conditioning occurs in one context (A), is extinguished in a second context (B), and is then tested by a return to context A. Testing in context A generally "renews" measured responding to the CS (Bouton & King, 1983; Bouton & Peck, 1989; Harris, Jones, Bailey, & Westbrook, 2000). Some studies have reported renewal with ABC protocols, wherein conditioning occurs in context A, extinction in context B, and testing in context C (Bouton & Bolles, 1979; Bouton & Brooks, 1993; Bouton & Swartzentruber, 1986; Harris et al, 2000), and with AAB protocols (Bouton & Ricker, 1994), although others have not found renewal effects when testing occurs in the acquisition context without the introduction of extra variables such as non-contingent exposure to the reinforcer or the passage of time since extinction (Bouton & King, 1983; Crombag & Shaham, 2002; Goddard, 1999; Nakajima, Tanaka, Urushihara, & Imada, 2000). In regards to these conflicting results, Bouton and Ricker (1994) have speculated that for renewal to occur, the conditioning contexts must be equally familiar, equally associated with reinforcement, or equally associated with both reinforcement and extinction.

As with other contextual control effects, ABA operant renewal has been observed as well as Pavlovian renewal (Bouton & Ricker, 1994; Nakajima, Tanaka, Urushihara, & Imada, 2000; Nakajima, Urushihara & Masaki, 2002; Tamai & Nakajima, 2000). Nakajima, Urushihara and Masaki (2002) found evidence for operant renewal of a lever press following two different response elimination procedures in context B, one by the delivery of food for withholding responding (reinforced omission), and the other by non-contingent delivery of food. In both cases, responding was renewed by returning the rats to the original acquisition context.

Renewal under ABA conditions has also been reported in paradigms other than those of conventional extinction procedures. Peck and Bouton (1990) showed that appetitive conditioning followed by aversive conditioning (and vice versa) could be restored by a return to the original context, and positive/negative discrimination reversals (X+ and Y− in Context A, followed by X− and Y+ in Context B, then testing X and Y in Context A) show context-dependent performance in both Pavlovian discrimination (Bouton & Brooks, 1993) and operant discrimination (see Thomas, 1985, and Thomas, 1993, for reviews). Early studies on what was then referred to as "latent reacquisition" showed renewed maze running following extinction by re-exposure to the reinforcer in the goal box (Barch, Ratner, & Morgan, 1965). In studies evaluating the effects of heroin infusion associated stimuli, McFarland and Ettenberg (1997), and Gracy et al. (2000) found that, following extinction, a single re-exposure to the heroin-predictive discriminative stimulus renewed responding. Likewise, cocaine self-administration following extinction has also been found to be subject to the effects of renewal by exposure to the conditioning context and/or to discrete stimuli associated with the drug experience (Anagnostaras & Robinson, 1996; Crombag & Shaham, 2002; Davis & Smith, 1976; Ettenberg, MacConell, & Geist, 1996; Grimm et al., 2001; Grimm & See, 2000; McFarland & Ettenberg, 1995, 1997; Meil & See, 1997; Robinson, Browman, Crombag, & Badiani, 1998; Weiss et al., 2000). These effects have been found to be relatively resistant to the passage of time (i.e., they are subject to recovery), and in fact Grimm et al. (2001) found that, following cocaine withdrawal, renewal-type response-frequency evoked by exposure to discrete cues such as the lights and lever manipulandum associated with responding showed a linear increase across the 60-day withdrawal period maintained during the experiment.

Reinstatement. Reinstatement is similar to renewal, but describes the return of extinguished responding to a CS following non-contingent presentation of the US (Bouton & King, 1983; Bouton & Peck, 1989; Pavlov, 1927). Reinstatement is context dependent in that for reinstatement to occur, testing must take place in the context in which the US was presented (see Bouton, 2002). However, it should be noted that the salient features of the context may be few, and therefore the individual stimuli that may function as background to the conditioning as well as the collective condition that makes up the context must be considered in pre-clinical as well as clinical applications. This suggestion is supported by a recent McAllister and McAllister investigation (2006) that found that post-extinction shock delivered in a context distinct from the conditioning chamber but containing certain similar salient features, such as the shock-producing floor, reinstated avoidance of the shock chamber, and this avoidance was greater even than a no-extinction group.

Reinstatement of conditioned fear has been seen in non-human animals by non-contingent US presentation (Dirikx, et al., 2006; LaBar, & Phelps, 2005, Morris, Westbrook, & Killcross, 2005; Westbrook et al., 2002), and in humans (Dirikx, Hermans, Vansteenwegen, Baeyens, & Eelen, 2004; Hermans, Dirikx, Vansteenwegen, Baeyens, Van den Bergh, & Eelen, 2005). All investigations indicate that the effect is dependent on the physical context in which the reinstating event was experienced.

As with renewal, reinstatement has been shown in operant conditioning paradigms as well as Pavlovian paradigms (de Wit & Stewart, 1981; Self & Nestler, 1998). Operant reinstatement is the recovery of reinforced responding following extinction upon non-contingent presentation of the reinforcer. Reynolds (1964) illustrated that reinstatement can occur through contingent reinforcement for responding to a stimulus that differs from the discriminative stimulus correlated with the reinstated responding; he first trained pigeons to peck in the presence of red, green, or yellow illumination of a key until responding across conditions was stable. He then extinguished responding first to the yellow light, then to the red light, and then the green, eliminating all responding. When he next resumed reinforcement for only red light key pecks, both yellow and green key illumination showed pecking reinstatement. Therefore, presentation of a common reinforcer in the presence of a distinct discriminative stimulus consequent to its discriminated response can reinstate other discriminated responding to other discriminative stimuli in that context.

Recent studies have extended the findings on reinstatement to include not simply reinstatement by non-contingent presentation of the US or reinforcer, or contingent US or reinforcer presentation for an alternative response, but also by trauma or stress (Ahmed & Koob, 1997; Erb et al., 2000; Shalev, Finnie, Quinn, Tobin, & Wahi, 2006), and by drugs that induce stress and anxiety-like behavior in humans and non-humans (Ghitza, Gray, Epstein, Rice, & Shaham, 2006; Nair & Gray, 2006). In addition, reinstatement has been seen across reinforcer classes. That is, cocaine has been found to reinstate responding for food (Dias, Lachize, Boilet, Huitelec, & Cador, 2004), as has d-amphetamine (Odum & Shahan, 2004). Odum and Shahan found that amphetamine reinstated lever-pressing previously reinforced with food in rats with no prior exposure to amphetamine, while rats with exposure to amphetamine but not as a predictive cue for food did not show significant reinstatement of lever pressing.

Reinstatement has also been seen in operant drug self-administration studies by exposure to drug-relevant discriminative stimuli (McFarland & Ettenberg, 1997; Tsiang & Janak, 2006; Yan, Yamada, Nitta, & Nabeshima, 2007; and see Koob, 2000, and Kalivas & McFarland, 2003 for reviews).

Interestingly, under discrete trial paradigms where responding for cocaine under a tone or light discriminative stimulus was extinguished, responding reinstated when the stimuli were presented in compound (Kearns & Weiss, 2005).

Spontaneous recovery. Yet another paradigm of context-dependent behavior reappearance is "spontaneous" recovery, or the spontaneous reappearance of an extinguished response following an elapse in time. Given an AAA design (conditioning, extinction, and test in the same context), recovery occurs upon return to the context with no additional preparation but the passage of time. The phenomenon was first discovered by Pavlov (1927) but has since been demonstrated in virtually every conditioning method, and has been summarized by Bouton (2002) as a failure to retrieve extinction after a delay. Bouton suggests that delay creates a new temporal context (Bouton, 1991, 1993), and that spontaneous recovery and renewal are caused by similar failures to retrieve extinction outside the extinction context. This interpretation is supported by ABA studies that show that presenting discrete stimuli paired with extinction cues just prior to the final test preserves extinction under both recovery and renewal protocols (Brooks & Bouton 1993, 1994), and that a return to the conditioning context coupled with a delay has an additive effect on response renewal (Rosas & Bouton, 1997). It should be noted that although spontaneous recovery is a relatively reliable phenomenon, it has not been seen in all preparations. However, clinical treatments for phobic reactions in animals in applied situations which have incorporated measures to combat spontaneous recovery, such as periodic exposure to the feared stimulus, appear to have a higher success rate than treatments that do not address the possibility of spontaneous recovery (Voith & Borchelt, 1996). Similar results have been seen in applied animal behavior therapy with other types of eliciting stimuli (Sobie, 2001).

Latent Learning

In addition to behavior reappearance studies, latent learning studies also support the notion that context plays an important role in learning and that this role concerns conditional expression and/or retrieval of learning (Bouton, 1993). Latent learning is learning in the absence of the target behavior that is being manipulated. Described as "covert" learning (see Fantino & Logan, 1979), latent learning is learning that occurs without an observed change in behavior. For instance, non-reinforced pre-exposure to a maze facilitates later reinforced performance as measured by latency to a goal (Tolman & Honzik, 1930). Likewise, pre-exposure to a chamber such as a T-maze goal-box facilitates extinction, i.e., produces latent extinction (Barch, Ratner, & Morgan, 1965; Clifford, 1964; Jones, Sytsma, & Bridges, 1970), and this effect is contingent on the number of exposures (Dyal, 1962). Non-reinforced pre-exposure to a conditioned stimulus—a latent inhibition protocol (Lubow & Moore, 1959)—serves to retard subsequent Pavlovian acquisition. Like other latent learning, latent inhibition is context dependent in that testing in a context different from the pre-exposure context attenuates pre-exposure inhibition.

Conditional Establishment of the Role of the CS

Supported by his extensive research into the modulating effect of context on responding, Bouton proposed that contexts function as conditional determiners, imparting information regarding the immediate functional value or meaning of a discrete stimulus that has become ambiguous as a result of having been paired both with reinforcement and nonreinforcement (see Bouton & Nelson, 1998, for an overview). This role then would be similar to that of an occasion setter, which, unlike conditioned and discriminative stimuli, does not elicit behavior; it functions instead to modulate the behavioral or eliciting effects of conditioned stimuli (Holland, 1992). Reversal studies, where reinforced responding such as a behavior chain or a match-to-sample 4-term contingency is learned and then the arrangement of component behaviors or correct comparison stimuli are reversed, tend to support this theoretical role of the context as an occasion-setter since 1) reversal responding has been found to be disrupted when the reversal was learned under separate background contextual stimuli and the original contextual stimuli were then returned, but 2) adjustment to the contexts is more rapid than original learning of the task (Dibbets, Maes, Boermans, & Vossen, 2001), and reversal is more rapid in novel contexts (McDonald, King, & Hong, 2001; McDonald, Ko, & Hong, 2002). Studies that distinguish context effects from discrete stimulus effects (e.g., Martin-Iverson & Reimer, 1996; Harris & Westbrook, 1999) also serve to support the condition-establishing role of the context as distinct from the specific response-eliciting role of discrete stimuli, as do "state-dependent" learning studies. In state-dependent learning studies, rats undergoing fear extinction while under the influence of a benzodiazepine such as diazepam, chlordiazepoxide or midazolam show renewed fear responses when tested outside the drug state (Bouton, Kenney, & Rosengard, 1990; Harris & Westbrook, 2001), suggesting that the internal state of the animal acts as a conditional context (Bouton, 2002; Harris & Westbrook, 1999).

Resurgence

Even as behavior analysis was in its infancy and the phenomenon of extinction a novel concept, studies were undertaken that sought to produce both faster and more complete response suppression (Boe, 1964; Estes, 1944; Skinner, 1938). Much of this early work evaluated both punishment and extinction altering variables, and a popular variable of study was the reinforcement of an alternative response during the extinction or punishment component (see Rawson & Leitenberg, 1973). What was found was that, indeed, extinction of the original response (R1) occurred more rapidly and with greater suppression of responding during reinforcement of the alternative response (R2). However, also soon apparent was that when reinforcement for R2 was discontinued, R1 recovered at least partially (Leitenberg, Rawson, & Bath, 1970), and occasionally seemingly unaffected (Richman, Wacker, Asmus, Casey, & Andelman, 1999). Rawson and Leitenberg (1973) concluded the suppression of R1 by R2 protects R1 from actual extinction, and that the extinction procedure needs to be encountered in order for the behavior to be eliminated. Epstein and Skinner (1980) referred to this temporary suppression effect as "resurgence" in their 1980 paper, "Resurgence of responding during the cessation of response-independent reinforcement." The term came to represent the effect of response recovery following discontinuation of reinforcer delivery concurrent with extinction.

Although procedurally distinct, resurgence and reinstatement share certain controlling effects such as reinforcement rate prior to extinction. For instance, Richman et al. (1999) found that while reinforcement of a low frequency alternative behavior reduced expression of both a previously high frequency response and a mid-frequency response, discontinuation of reinforcement resulted in greater subsequent recovery of the high-frequency response. Similar findings were seen by Franks and Lattal (1976) in a reinstatement design when response-independent food delivery reinstated behavior previously reinforced on a differential low rate schedule (DRL) at a lower rate than behavior that had been maintained on a variable ratio (VR) schedule; reinstatement reflected the prior response rate of the two groups rather than the reinforcement rate, since the reinforcement rate had been relatively equal. Also, just as food responding has been seen to reinstate by exposure to non-contingent drug delivery (Dias et al., 2004; Odum & Shahan, 2004), resurgence has been seen between reinforcement classes (Podlesnik, Jimenez-Gomez, & Shahan, 2006). Podlesnik et al. reinforced lever presses with alcohol, then extinguished lever pressing and reinforced chain pulls with food pellets. Subsequent extinction of chain pulls resulted in resurgence of lever pressing.

Resurgence has also been seen in a number of clinical applications. Hanley, Iwata and Thompson (2001) found resurgence of attention-maintained undesired behavior when attempting to thin reinforcement delivery for an alternative response in functional communication training. They found that increasing reinforcement delays resulted in extinction of the alternative response which in turn resulted in resurgence of the problem behavior. Likewise, Lalli et al. (1995) reported that in treatment of a child's three disruptive behaviors maintained by escape, reinforcement of one response while the other two were placed on extinction resulted in almost immediate attenuation of the two non-reinforced responses but increased expression of the third. Placing the third response on extinction typically resulted in a resurgence of all three responses. This result was replicated by Richman et al. (1999).

Functional Response Classes

Another possible contributor to relapse in applied settings may be control exerted on individual responses as members of a functional response class. As defined by Catania (1992), a functional response class (FRC) is a class of operant behaviors identified by modification by a common consequence. For example, if both a lever press and a nose poke produce cocaine infusion and the consequent cocaine infusion increases the frequency of responding, then these two behaviors belong to the same functional response class. Likewise, if both running with scissors and slapping your sister gains attention and lack of attention is the establishing operation, these seemingly disparate responses belong to the same FRC. Catania suggests that when a targeted response seems insensitive to its consequences, the response may be a part of a larger functional response class where reinforcement of remaining members may serve to weaken the effects imposed on the targeted behavior. This weakening action could be similar to the extinction-protective effect of an alternative behavior trained during extinction in resurgence paradigms; when reinforcement is discontinued for the alternative response, the original response returns comparable to its original rate. Research into functional response classes that include problem behavior supports this idea, and has shown that manipulation of response class member behaviors has a non-targeted effect on remaining members and can serve not just to exacerbate responding but in some cases to protect or suppress responding (Richman, Wacker, Asmus, Casey, & Andelman, 1999).

Resurgence is a common phenomenon in treatment by extinction or counter-conditioning in FRCs (Repp & Horner, 1999). In fact, the predictability of resurgence has been incorporated into functional analysis of problem behavior within a FRC. Analyses of response class hierarchies by Richman et al. (1999) for subsequent treatment design indicate that resurgence of member responses follows a hierarchal sequence that they suggest is not necessarily the result of differential reinforcement or of reinforcement scheduling. What they found was a response bias with less severe problem behavior frequently occurring prior to more severe topographies. In addition, only one of the subjects differentially allocated responding specific to the topography that was producing reinforcement when one of three responses produced reinforcement. The authors mentioned that the mechanism for the bias was unknown, but is it is possible that the resurgence hierarchy reflected unknown reinforcement history; Reed and Morgan (2006) have shown that resurgence behavior follows an orderly pattern of emergence during extinction reflecting a primacy effect, with first learned response patterns emerging first and second-learned patterns emerging second, etc. It is possible that the less severe responding had been reinforced before the more severe responding in the participants' lifetimes.

The relationship between members of an FRC has been described as one of response covariation (Sprague & Horner, 1992). Response covariation refers to changes in the probability of behavior being emitted as a function of changes in the probability of other behaviors. In 1985, Carr and Durand published behavioral data that showed that reinforcement in the form of attention from adults for socially acceptable behaviors reduced inappropriate attention-seeking behavior. Their treatment, labeled by the authors as "functional communication training," was based on the concept of covariation and the idea that reinforcing alternative behavior effective in gaining adult attention would serve to reduce less appropriate behavior in the same FRC. Horner and Day (1991) expanded on Carr and Durand's findings by evaluating the role of response efficacy in the application of functional equivalence training, i.e., the training of a response designed to produce the same reinforcer currently produced by some other less desirable response. They found evidence for covariation within functional response classes; behaviors that were functionally equivalent but less efficient in terms of effort, schedule of reinforcement, or latency to reinforcer delivery did not compete well with existing behaviors within the response class and had little effect on the rate of those existing behaviors. However, more efficient behaviors did successfully compete, and the increase in these behaviors was concurrent with dramatic reductions in the problem behavior.

Covariation often describes resurgence, and it has been found that in applied settings, just as in experimental preparations, extinction of individual member responses of a response class results in an increase in responding of the remaining members. Lalli, Mace, Wohn, and Livezey (1995) reported that in treatment of three disruptive behaviors in a child, all having differing topographies but all maintained by escape, reinforcing one response while placing the other two on extinction resulted in almost immediate attenuation of the two non-reinforced responses while increasing expression of the third. Furthermore, placing the third response on extinction typically resulted in a resurgence of all three topographies. This result has been replicated by others (Harding, et al. 2001; Lieving, Hagopian, Long, & O'Connor, 2004; Richman, Wacker, Asmus, Casey, & Andelman, 1999).

Differential outcomes effect. Common reinforcers for corresponding discriminative stimuli have been found to positively influence performance on discrimination tasks. Termed the differential outcomes effect (DOE), correlating a specific outcome with one class of stimuli has been shown to improve stimulus class formation such as matching to position in aged rats (Savage, Pitkin, Careri, 1999), and discrimination tasks in a horse (Miyashita, Nakajima, & Imada, 2000) as well as in pigeons and dogs (see Goeters, Blakely, & Poling, 1992, for a review). Similar results have been found with humans in arbitrary matching-to-sample procedures (Estévez et al., 2001; Dube, McIlvane, Mackay, & Stoddard, 1987; Dube, McIlvane, Maguire, Mackay, & Stoddard, 1989). Dube et al. and Dube et al. concluded that the data showed that reinforcers may become members of stimulus classes, and that stimulus classes can be expanded via stimulus-reinforcer relations as new stimuli become class members through relations with reinforcers.

Stimulus equivalence. In verbally competent adult humans, when stimulus classes are expanded so that the choice of A in the presence of B produces reinforcement (i.e., $B \rightarrow A \rightarrow S^{R+}$), and B in the presence of C produces reinforcement ($C \rightarrow B \rightarrow S^{R+}$), relationships emerge (i.e., relationships appear without specific training) that include reflexivity (i.e., the choice of A as a match for A produces reinforcement, or $A \rightarrow A \rightarrow S^{R+}$, and $B \rightarrow B \rightarrow S^{R+}$, and $C \rightarrow C \rightarrow S^{R+}$), symmetry (i.e., $A \rightarrow B \rightarrow S^{R+}$ therefore $B \rightarrow A \rightarrow S^{R+}$, etc.), and transitivity (i.e., if $A \rightarrow B \rightarrow S^{R+}$ and $B \rightarrow C \rightarrow S^{R+}$, then $A \rightarrow C \rightarrow S^{R+}$) (Hayes, 1989). Such relationships are known as stimulus equivalence (Sidman, 1971), because any stimulus can be replaced with any other stimulus in the class and produce the same outcome (i.e., same reinforcer). Importantly, as with FRCs, resurgence of equivalence classes has been documented (Wilson & Hayes, 1996), when, following extinction, participants exhibited a resurgence of responding consistent with their earlier training.

Reliable stimulus equivalence emergence was thought to be reserved for verbal adults (Hayes, 1989; Pilgrim, Chambers, & Galizio, 1995). However, it was discovered that use of a DOE procedure, where differential choice within a stimulus class was reinforcer specific (i.e., class-specific reinforcement), produced stable equivalence responding in sea lions (Schusterman & Kastak, 1993), normally developing children (Bartholomew et al., 2003; Jacome, Pilgrim, Galizio, Wilson, & Aro, 2004), and developmentally disabled children (Ashford, Pilgrim, & Stanley, 2003; Pilgrim, 2004). These results suggest that multiple stimulus elements can become equivalence class members through their function as reinforcers (Ashford et al.), a conclusion that is further supported by findings that stimuli initially used as reinforcers can function as sample stimuli or comparison stimuli, and that stimuli that initially functioned as sample and/or comparison stimuli can function as reinforcers (Pilgrim, 2007). In addition, it has recently been shown that use of class-specific reinforcers in three-term contingencies (i.e., discrimination training, or discriminative stimulus→response→S^{R+} and delta stimulus→response→no S^{R+}) is sufficient for the emergence of four-member equivalence classes (Veenstra, Pilgrim, Aro, Kolb, & Linville, 2007); Veenstra et al. found that during simple discrimination training with children aged six through ten, all seven participants demonstrated the emergence of relations between the class-specific reinforcers and the stimuli for which they served as consequences, and one participant also showed emergence of conditional discriminations and four-member equivalence classes based solely on reinforcement of three-term contingencies inter-related by class-specific reinforcers.

Differential outcomes equivalence effects indicate that stimuli within a FRC are related and may function as equivalence members. This relationship may offer information regarding the basis of co-variation within a FRC, and may suggest that effects imposed on one discriminative stimulus might also impact other discriminative stimuli in the FRC.

Behavior and the Brain: Possible Clues to Treatment Design

In addition to the information provided through evaluation of extinction studies, brain activity under reinforcement, extinction, and stimulus-change conditions may provide data relevant to treatment of relapse. Neuroscience has advanced to the degree that reliable information is available on a variety of neurotransmitter systems within the brain. Although it would be premature—and superfluous to behavior analysis—to attempt to explain the etiology and maintenance of behavior in terms of neural mechanisms, some tentative inferences may be drawn from temporal correlations of neural activity and stimulus and/or response events experienced by the behaving organism, particularly regarding reinforcement. Neural events do not by themselves offer explanation, but they may provide small bits of information relative to interpretation of observable behavioral events in much the same way that variations in operant paradigms can elucidate potentially ambiguous data (e.g., as in the case where the functional equivalence of response independent food delivery to conventional extinction was elucidated by resurgence studies that showed that non-contingent food delivery attenuated resurgence whereas conventional extinction did not). Neural activity during presentation of discriminative stimuli, reinforcers and conditioned reinforcers may offer some information relevant to stimulus saliency which may in turn be relevant to increasing exposure to extinction and thereby possibly decreasing recovery.

The mesolimbic dopamine pathway has been studied extensively with respect to reinforced behavior (Contreras-Vidal and Schultz, 1999; Hassani, Cromwell and Schutz, 2001). A considerable amount of research has established that DA release in this neural pathway is involved in learning and reinforcement and in particular in stimulus-reward associations (Carlson, 2001; Waelti, Dickinson and Schultz, 2001). However, studies that evaluate the impulse activity from single DA neurons while animals learn and behave as opposed to studies that infer DA activity from post-event DA-marker expression, indicate that DA neurons are differentially activated not simply by reinforcement presentation but by consequence change.

Dopamine neurons in the ventral tegmental regions that project to the nucleus accumbens and frontal cortex, as well as the intermediate and lateral sections that project to the caudate nucleus and the putamen (see Schultz, 1999 for a review) are activated by nerve impulses received from axonal varicosities in the striatum and the frontal cortex, and these impulses are correlated with the presentation of novel, unexpected stimuli that have the capacity to elicit orienting responses (Romo & Schultz, 1990). Activation is also elicited by unexpected reinforcer delivery itself (Romo & Schultz), and by conditioned reinforcer presentation (Schultz, Apicella, & Ljungberg, 1993). As stimulus presentation becomes predictable—particularly appetitive stimuli, such as the continuous presentation of primary reinforcers at regular intervals both in operant and non-operant conditions—dopaminergic responses decrease progressively (Ljungberg, Apicella, & Schultz., 1992) and have been found to disappear completely upon completion of learning (Ljungberg et al. 1992; Mirenowicz & Schultz, 1994). Ljungberg et al. speculate that dopaminergic responses to conditioned stimuli attenuate with extensive overtraining because stimuli become predicted by events in the preceding trial.

Importantly, in concert with this decrease of activation upon presentation of the primary reinforcer, a progressively increasing negative correlation in activation can be seen upon presentation of the conditioned stimulus (CS); activation decreases at the time of the primary reinforcer presentation and increases at the time of the CS presentation (Schultz, 1998). This transfer of responding occurs regardless of whether the presentation of CS and reinforcer are predictable or whether they occur together in a random fashion. In other words, primary reinforcers are only effective in eliciting dopaminergic neuronal activity if they are unpredicted. At the same time, when a fully predicted reinforcer delivery fails to occur, dopamine neurons actually show a depression in activation at the time in which the reinforcer should have been delivered (Hollerman & Schultz, 1998). Such depression is also seen in response to presentation of generalized stimuli that resemble conditioned reinforcers that are not followed by a reinforcer. In addition, novel stimuli elicit DA neuron activation, but if the stimulus is not then followed by a reinforcer, an activity depression will occur.

Schultz (1998) concludes that dopamine neurons basically report reinforcer delivery relative to their prediction by reinforcement history, rather than signaling reinforcer presentation unconditionally. He further suggests that since dopamine neurons fail to discriminate between different reinforcing stimuli, rather than serving as a reinforcing mechanism themselves, they appear to function as a mechanism of stimulus congruity in regard to previous stimulus-reinforcer or stimulus-response-reinforcer contingency history.

The relevance of the activity of DA neurons to design of treatment to reduce response perseveration and relapse regards the relevance of DA neuron activation in basic learning. As mentioned, extinction is not un-learning, rather, it is new learning (Bouton & Nelson, 1998), and it is learning that must compete with existing context/SD→response→reinforcer learned associations. The neurophysiological studies just discussed indicate that dopamine-mediated learning involves not simply delivery of reinforcement (or no delivery of reinforcement), it involves or at least is enhanced by unexpected delivery. This suggests that greater learning occurs when the learning contingency is modulated in some way. Such a view is supported by the findings that repeated extinction in the same context does not necessarily attenuate renewal (Tamai & Nakajima, 2000), but that extinction in multiple contexts can attenuate renewal (Chelonis, Calton, Hart, & Schachtman, 1999; Gunther, Denniston, & Miller, 1998). Together these findings suggest that stimulus changes augment learning.

It is possible that procedures that augment responding during extinction promote extinction because responding under conditions with numerous incongruent stimulus-reinforcer events (i.e., stimulus A→no reinforcer events when the organism's history includes stimulus A→reinforcer A) is more salient to the behaving organism, and therefore provides more experience with non-consequence. Accordingly, procedures that augment responding during extinction might be expected to reduce recovery.

Summary

The differential expression of behavior described in the discussion of context and behavior reappearance in the paragraphs above implies that extinction—or any form of subsequent learning—is not an absolute guarantee of performance or nonperformance. That extinction in a context other than that in which it was learned has been found not to generalize to the acquisition context has obvious clinical implications regarding relapse; however, that the effect has been shown to be reliable in pre-clinical investigations offers investigators a number of paradigms in which to manipulate variables that may be relevant to maximizing extinction exposure and generalization. Renewal, spontaneous recovery and reinstatement are all paradigms that can be employed with relatively minor set-up changes to measure response recovery. An evaluation that involves reinforcing responding in one context, extinguishing it in second, and then testing for recovery in the acquisition (renewal), can be also used to test for spontaneous recovery by allowing a passage of time (at least 7 days), and reinstatement by non-contingent presentation of the reinforcer.

Data suggest that stimulus change may facilitate extinction. Equivalence data indicate that functional response class members share not simply functional relations (i.e., reinforcer producing relations), but perhaps evoking relations as well, such as occurs when attention-producing responses co-vary through extinction but can each occur in the presence of similar or shared discriminative stimuli such as different caregivers. It is possible that extinction of multiple responses within a functional response class may attenuate response recovery. It is also possible that extinction across multiple contexts may attenuate both resurgence and ultimately recovery.

The experiments described in this document attempted to assess these possibilities by evaluation of 1), the effect of extinction in a novel context of multiple discriminated responses within a response class on renewal, spontaneous recovery, and reinstatement within the acquisition context, and 2), the effects of differential reinforcement of a single response and subsequent extinction in a novel context on renewal and possibly resurgence in the acquisition context, in the hopes of supplementing our understanding of relapse in varied settings.

CHAPTER III

EXPERIMENTAL OBJECTIVES

Relapse and response recovery are behaviorally relevant issues that share features (i.e., the return of responding following abstinence or extinction) and possibly controlling variables. As an animal model of relapse, renewal preparations offer a basic protocol for manipulation of variables that may contribute to response recovery and, in particular, to variables that may facilitate extinction.

One variable that can be manipulated in renewal studies that has been shown to facilitate learning is exposure of the response to extinction in multiple contexts. Gunther, Denniston, and Miller (1998) and Chelonis, Calton, Hart, and Schachtman (1999) found that extinction across multiple contexts attenuated renewal, although others have not been able to replicate these findings (Bouton, Garcia-Guttierez, Zilski, & Moody, in press). And, importantly, multiple context exposure has been reported in the clinical literature to attenuate recovery of phobias (Earlbaum, 1990; MacDonald, 1975). Other forms of multiple exposures have also facilitated learning. Smith (1982) found enhancement of word recall in humans by exposure to multiple contexts during learning, a procedure that attenuated the context specificity of recall, and Wheeler, Chang and Miller (2003) found that pre-exposure to multiple contexts attenuated contextual control of latent inhibition and facilitated generalization to novel contexts.

The prevailing view on extinction is that it is new learning regarding previously learned information. Context specificity in extinction may occur when discriminative stimuli that once predicted reinforcement availability become incongruent through extinction; when the contextual stimuli that are present in extinction differ from those that are present in acquisition, the extinction-context stimuli may become occasion setters for the differential delta or no-reinforcer function of the stimuli correlated with reinforcement in the acquisition context (i.e., the acquisition discriminative stimuli). Exposure to multiple contexts may increase contact of a response to extinction, not simply by trial number where nothing new may be learned, but rather by the addition of stimulus conditions. Each exposure to a novel but related stimulus condition may serve to increase stimulus→response→no-reinforcement trials and decrease the evoking strength of the context as an occasion setter. This view supports the idea that the greater the exposure of a salient stimulus-response contingency to extinction, the more thorough the extinction.

As mentioned, the hypothesis behind this project is that it may be possible to increase exposure of a salient stimulus-response contingency to extinction not simply by exposure to multiple contexts, but by exposure through multiple discrete response members of a FRC. Since FRC members share function, extinction through all members may work functionally to increase exposure to extinction and thereby attenuate renewal. Two experiments were conducted to address this hypothesis. The first experiment compared the effects in Sprague-Dawley rats of extinction of one 3-

term contingency response (i.e., discriminative stimulus→response→outcome) consisting of either a left-right lever press, a left-right nose poke, or a 1-1 chain-pull, or three 3-term contingency responses (left-right lever press, left-right nose poke, and 1-1 chain-pull) belonging to the same functional response class (food-pellet acquisition), on renewal of responding when extinction and testing were carried out in different contexts. The second assessment evaluated the effects of differential reinforcement of one of the previously trained FRC member responses, followed by extinction of this response and resurgence of responses two or three in a novel context on subsequent renewal in the acquisition context.

CHAPTER IV

EXPERIMENT 1: EFFECT OF MULTIPLE RESPONSES WITHIN A RESPONSE CLASS ON ABA RENEWAL OF RESPONDING

Experiment 1 was designed to evaluate the effect of extinction of multiple responses within a functional response class on renewal. This experiment compared the outcome in rats of extinction in context B of one or three food-pellet maintained behaviors (FMB) learned in context A on the renewal of FMB when tested in context A. Table 1 shows the design of the experiment.

Table 1

Experimental Design of Experiment One

Group	Training	Extinction	Testing	
RCG	$(S^{D}_{all}[R_{all}]S^{R}+)_{A}$	$(S^{D}_{all}[—])_{B}$	$(S^{D}_{all}[—])_{A}$	n=9
CG	$(S^{D}_{1}[R_{1}]S^{R}+)_{A}$	$(S^{D}_{1}[—])_{B}$	$(S^{D}_{1}[—])_{A}$	n=14
	$(S^{D}_{2}[R_{2}]S^{R}+)_{A}$	$(S^{D}_{2}[—])_{B}$	$(S^{D}_{2}[—])_{A}$	
	$(S^{D}_{3}[R_{3}]S^{R}+)_{A}$	$(S^{D}_{3}[—])_{B}$	$(S^{D}_{3}[—])_{A}$	

Legend
$S^{D}{}_{1,\ 2,\ \text{or}\ 3}$ = discriminative stimulus 1, 2, or 3
$S^{R}+$ = 45 mg food pellet
$S^{D}{}_{all}$ = that group received $S^{D}{}_{1,\ 2,\ \text{and}\ 3}$
$R_{1,\ 2,\ \text{or}\ 3}$ = response 1, 2, or 3
R_{all} = that group emitted responses $_{1,\ 2,\ \text{and}\ 3}$
— = no consequence (extinction)
A, B or C = specific context

For example, $(S^{D}{}_{3}[R_{3}]S^{R}+)_{A}$ means that in the presence of the discriminative stimulus 3, response 3 is reinforced by a food pellet in context A. Extinction then occurs in context B, where, in the presence of discriminative stimulus 3, response 3 is not reinforced. Then the animal is tested in context A for renewal in the presence of discriminative stimulus 3.

Method

Subjects. A total of 24 naïve male Sprague-Dawley rats (Charles River, Portage, MI) aged six to 12 months at the start of the study were used in all assessments. Subjects were maintained on a 12/12 hr dark/light cycle (lights on at 7:00 A.M.) in the animal facility at Western Michigan University, at a relatively constant temperature (20 ± 2 °C) and humidity (50 ± 5%). Subjects were housed singly with water available *ad libitum*, while food was limited so as to maintain the animals at 80% normal weight. The experimental protocol was approved by the Institutional Animal Care and Use Committee of Western Michigan University (see Appendix D), and the subjects were maintained according to the general principles of animal husbandry outlined in the *Guidelines of the Committee on Care and Use of Laboratory Animal Resources* (National Research Council, 1996).

Conditioning chambers and contexts. Four modular rat chambers (MED Associates, Inc., Georgia, VT, USA), measuring 32-cm long, 24-cm wide, and 29.5-cm high, and housed in individual sound- and light-attenuating shells were used as operant conditioning chambers. The shells were equipped with fans to provide both ventilation and masking noise. Each chamber was constructed of aluminum front and back panels, clear acrylic sidewalls, an acrylic ceiling, and a grid floor. Two retractable levers were situated 4 cm above the floor on the front panel. Stimulus lights were located 2 cm above each lever and a pellet magazine receptacle was centered between the levers. A house-light was attached to the top of the sound-attenuating cubicle and was operated independent of the experimental program. The back panel was equipped with two nose-poke holes located 2 cm above the floor, each with light disks centered at the back of the holes, and a non-functional water reservoir centered between the nose-poke holes. A white-noise generator was attached to the back of the top right corner of the back panel so that the sound resonated from holes in the top right of the panel. Hanging from the ceiling of the center of the chamber was a 27-cm chain.

From these basic chambers, two contexts were created that differed in visual, olfactory and tactile cues. Both left and right levers, both nose-poke holes and the chain-pull chain were present in all contexts under all conditions. The chambers were housed in a 5' by 10' room with the computer where they were located adjacent to one another on a rack against one wall of the room, stacked so that they were two high and two wide. All experimental events and data collection were controlled with MED-PC instrumentation and software version 4.0 (MED Associates, Inc., Georgia, VT, USA) interfaced to a computer.

Context 1 was the basic conditioning chamber as described above. In addition, a Petri dish filled with water containing 0.05 mL of peppermint extract to impart scent was placed on the waste tray beneath the grid floor; concentrations were selected based on prior experience. Two of the four basic chambers served as Context 2. Distinct from Context 1, in Context 2 a ceramic floor tile covered the grid floor, opaque construction paper was placed on the outside of the back wall of the chamber, and 0.05 mL of citrus extract was placed in the Petri dish beneath the grid floor. These two contexts were used in all response acquisition sessions and ABA extinction and renewal (acquisition and renewal in one context, extinction in a separate context).

Procedures. The experiment was conducted in three phases: response acquisition (acquisition + 7 days stable responding), extinction phase (3 days at $\leq$10 responses on any response and $\leq$5% of total responding during the seven days of stable responding), and testing for renewal (9 days), recovery (1 day) and reinstatement (1 day). Rats were assigned to either the Response Class Group (RCG, n = 9, 3 responses) or the Control Group (CG, n = 15, single response). The CG group contained more subjects than the RCG so that if any of the three responses produced significantly higher or lower responding than the other two and had to be assessed separate from the other response groups, comparisons with the experimental group would still be feasible. As training progressed, one of the initial RCG subjects became ill and had to be euthanized before response acquisition was complete. Therefore, following initial response acquisition training, one of the original 15 CG animals (subject CL2A1) was put into the RCG (CG n = 14).

Two contexts were used in this experiment, one for conditioning and testing and one for extinction. The contexts were referred to as A and B, where A was the context where response acquisition and testing occurred and B was the context in which extinction occurred. For half of the animals in each group, A was Context 1 and B was Context 2. For the remaining animals in each group, A was Context 2 and

B was Context 1. Five animals assigned to the CG were trained to lever-press (subject CL2A1 was then immediately assigned to the RCG, reducing the lever-press CG group to n = 4), five were trained to nose-poke, and five were trained to chain-pull for food pellet delivery in Context A during a 45-min session (see Table 1 for design).

Operant responding. The rats were submitted to daily 45-min training sessions between 8:00 A.M. and 6:00 P.M. and trained to respond on a chained fixed ratio 1, fixed ratio 1 schedule of reinforcement (one response terminated its correlated discriminative stimulus [S^D] and activated the second S^D, one response on that operandum terminated that S^D and produced a reinforcer). Operant chamber house lights were on and all operanda were present but not active when the animals were placed in the chambers. Sessions commenced when the active response S^D was initiated. RCG sessions included presentations of the three different response conditions (S^D and its active operandum) in random order with the restriction that none of these response conditions had more than three consecutive presentations. RCG sessions terminated when either 45-minutes passed or 30 food pellets were delivered per response condition per animal. If 45 minutes passed before 30 food pellets were delivered, the program terminated. This procedure was used throughout all phases. For the CG animals, the relevant response program was activated for the entire 45-minute session or until 90 food pellets were delivered per animal, at which time the program terminated.

Response 1. When the S^D light centered above the left lever was illuminated, the lever-press program was active. One depression of the left lever turned off the left lever S^D light and illuminated the light centered over the right lever. When this light was illuminated, a depression of the right lever turned off the S^D light and resulted in delivery of one 45 mg food pellet (chained fixed ratio 1, fixed ratio 1; chained FR1 FR1). This chained response was chosen to better reflect what may be responding type in applied settings. Pellet delivery initiated a variable inter-trial interval 10″ (VITI 10″) time-out period. Subsequent lever presses or responding on any operandum during time-out periods had no programmed consequences. The total number of lever presses at any time, the number of successful left→right lever press responses, and pellet deliveries were recorded.

Response 2. When the S^D light centered within the left nose-poke hole was illuminated, the nose-poke program was active. Nose poking in the left hole terminated the light and illuminated the light centered in the right hole, activating the right hole indefinitely until a nose-poke in that hole resulted in delivery of one 45 mg food pellet (chained FR1 FR1). Pellet delivery terminated the hole illumination and initiated a VITI 10″ time-out period, and subsequent nose pokes in either hole during this time-out had no effect. Nose pokes in either hole alone had no programmed consequence. The total number of nose pokes in any hole under any condition, the number of successful left→right nose pokes, and pellet deliveries were recorded throughout the experiment.

Response 3. When the S^D of the absence of white-noise occurred, the chain-pull program was active. A pull of the chain resulted in a 0.5 sec blip of white noise, at which time a second pull resulted in delivery of one 45 mg food pellet (chained FR1 FR1) and initiation of white noise for the duration of a VITI 10″ time-out period. Chain pulls during the time-out period were recorded but had no effect. The total number of chain pulls under any circumstance, the number of successful one→blip→two chain pulls, and pellet deliveries were recorded throughout the experiment.

Response acquisition. Training the acquisition of a single response or the three responses began the day immediately following context exposure with magazine training. Magazine training was considered complete when a subject made at least 15 head entries with food pellet consumption. Responses were introduced one at a time on a random basis (see table 2) with only the relevant discriminative stimulus (S^D) active. All subjects were introduced to a response through manually reinforced successive approximations (hand shaping). S^Ds for both components of the chain (i.e., left and right lever S^Ds for the lever press, or left and right nose-poke S^Ds for the nose-poke, or absence of white noise for the chain pull). Once an animal had emitted >20 responses without assistance during a session, it was run on the acquisition program (see Appendix B). The response was considered acquired when the rat emitted ≥10 correct complex responses for three consecutive sessions. If the subject was a single-response subject (control group, CG) it was begun on the maintenance program (see Appendix C). The maintenance program differed from the acquisition program only in that it made programmed deliveries of food pellets whereas the acquisition program also allowed for researcher-delivered food pellet delivery during hand shaping. If the animal was a 3-response subject (RCG), the S^D for the response it had learned was no longer activated and a new S^D and response were conditioned. Once all three responses were acquired, the RCG subject began the maintenance program and was exposed to all three discriminative stimuli. CG subjects were run on the maintenance program until they emitted 90 responses for three days in a row. RCG subjects were run on the maintenance program until they emitted 30 responses per each of the three responses for three days in a row. So as not to introduce an over-training effect any subject that met the maintenance criteria was kept on food limitation but was not again exposed to the training chamber until all subjects had met all training criteria.

Once all animals had met maintenance criteria, all subjects were run on their respective programs for seven days.

Extinction training. During the extinction phase, all procedures were identical to those used during the acquisition phase, except that the food pellets were not dispensed. Accordingly, correct nose-poke responses terminated the active nose-poke hole S^D, lever presses terminated the lever-press S^D, and chain-pulls closed the circuit triggering an audible click and turned on the white noise, but pellets were not delivered. Animals that were trained to respond for pellets in Context 1 underwent extinction in Context 2, and animals that were trained to respond for pellets in Context 2 underwent extinction in Context 1.

Extinction conditions for the RCG were initiated serially across discriminative stimuli so that the each condition had been in effect for two days before the start of extinction for the next response. Behavior for all animals was considered extinguished when total responding fell to less than 5% and 3 days of ≤ 10 occurrences of any response under all conditions. When a subject met both criteria, it was left in its home cage on food limitation until all subjects had met criteria. When all subjects had met criteria, they were returned to their extinction contexts for an additional three consecutive days of extinction exposure before the first renewal test.

Tests for renewal. The testing phase began 24 hours after the final extinction session. During three 45-minute sessions, rats were tested for renewal by exposure to the context paired with food pellet delivery. The protocol for renewal tests was identical to that used for the extinction tests with the exception that the tests were performed in the context where responding to the S^Ds had been reinforced. Test sessions were conducted every third day, and on the intervening days the animals were exposed to regular extinction conditions in their regular extinction contexts to provide comparison data between tests (Crombag & Shaham, 2002).

Test for recovery. One week and one day after the final renewal test, subjects were re-exposed to the acquisition context. During the intervening seven days, the rats had been in their home cages on regular food limitation. On the eighth day, they were placed in the acquisition context and their regular programs run for one 45-minute extinction session to evaluate spontaneous recovery effects between groups.

Test for reinstatement. The day after the recovery test, animals were tested for reinstatement in their extinction contexts. Protocol was identical to the extinction protocol with the addition that reinstatement was facilitated by placement of five 45-mg food pellets (i.e., the reinforcer used throughout acquisition and maintenance), present in the food magazine when the subject was loaded into the operant chamber.

Results

Acquisition required 12-32 days (Tables 2 & 3). The CG met acquisition criteria significantly faster than the RCG as compared by Mann-Whitney U (0.0004). Acquisition of the initial response was no different between groups ($p= 0.49$), with the RCG taking an average of 13.22 ±1.94 days and the CG taking an average 15.00 ±0.84 days to meet the criterion of ≥ 10 correct complex responses for three consecutive sessions. Extinction was conducted over 8-36 days (Tables 2 & 3). Again there was a significant difference between groups in reaching criterion ($p < 0.001$), with the CG taking a mean 15 days to reach acquisition and the RCG a mean 23 days. The RCG showed no difference between the number of days to meet acquisition criteria and the number of days to extinction criteria, meeting extinction in a mean 22.5 days, whereas the CG took significantly longer to attain acquisition than extinction ($p < 0.05$), taking a mean 12 days to extinction criteria.

Table 2

Experimental Group Response Acquisition and Extinction

	Acquisition		Extinction	
ubject	Order	Days to Complete Acquisition (30 responses per response per trial for 7 sessions)	Order	Days to Complete Extinction (<10 responses per operandum per trial)
1A1	LCN	19	LNC	21
3A2	LNC	18	LNC	19
2B2	LNC	20	LNC	21
4B2	LCN	32	NLC	21
5A2	NLC	32	NLC	16
L2A1	LCN	19	CLN	18
6B1	LNC	29	CNL	27
7A1	NLC	20	CLN	36
8A2	NLC	19	NLC	24

Note. L = lever press, C = chain pull, N = nose=poke.

Table 3

Control Group Response Acquisition and Extinction

	Acquisition	Extinction
Response	Days to Complete Acquisition (90 complex responses per trial for 7 sessions)	Days to Complete Extinction (<10 total responses per operandum per trial)
Lever-press	12	15
Nose-poke	12	9
Nose-poke	17	8
Chain-pull	13	15
Nose-poke	16	9
Lever-press	18	12
Chain-pull	13	15
Chain-pull	13	14
Nose-poke	14	8
Chain-pull	15	16
Chain-pull	15	9
Lever-press	14	14
Nose-poke	14	16
Lever-press	24	13

Mean baseline response frequency, including non-reinforced responding under S^D conditions, was 345.9 ± 37.00 for RCG and 261.8 ± 26.46 for CG (see Figure 1). An unpaired t test indicated that baseline responding was not significantly different between groups.

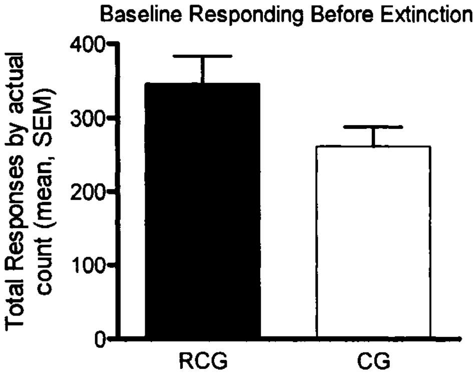


Figure 1. Total baseline responding, including non-reinforced responding under S^D conditions, for the 3-response response class group (RCG) and the control group (CG).

Extinction responding is shown in Figures 2-8. As can be seen from Figures 2-5, the CG subjects showed a dramatic decrease in responding almost immediately, while Figures 6-8 show that the RCG showed continued responding for a number of days. The lack of a statistical difference between the CG and RCG groups in days-to-extinction reflects the requirement that responding be ≤ 10 occurrences of any recorded topography for 3 days under all conditions; responding in the CG fell to below 5% of maintenance total responding by the 3rd day of extinction but subjects continued to respond marginally (equal to or above 10 recorded responses) for a number of days. As can be seen from Figures 2-5, nose-poking showed an almost immediate decrease upon termination of pellet delivery, followed by lever pressing and finally chain pulling. However, there was no difference in total days to extinction for CG lever press, nose-poke or chain pull subjects and the data from all CG subjects were pooled for all comparisons.

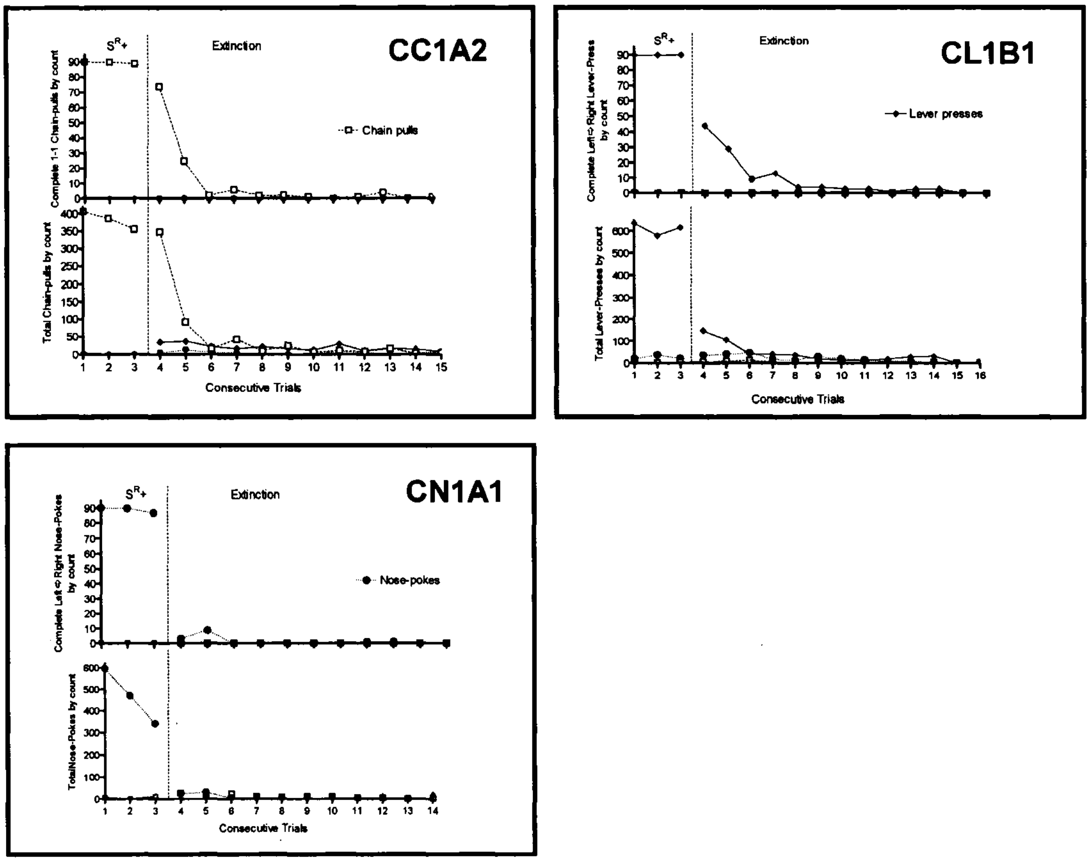


Figure 2. Performance during extinction of subjects CC1A2, CL1B1, and CN1A1 from the Control Group (CG). Phases (reinforcement and extinction) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows complex response frequency (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; bottom graph per subject shows total responding during each session.

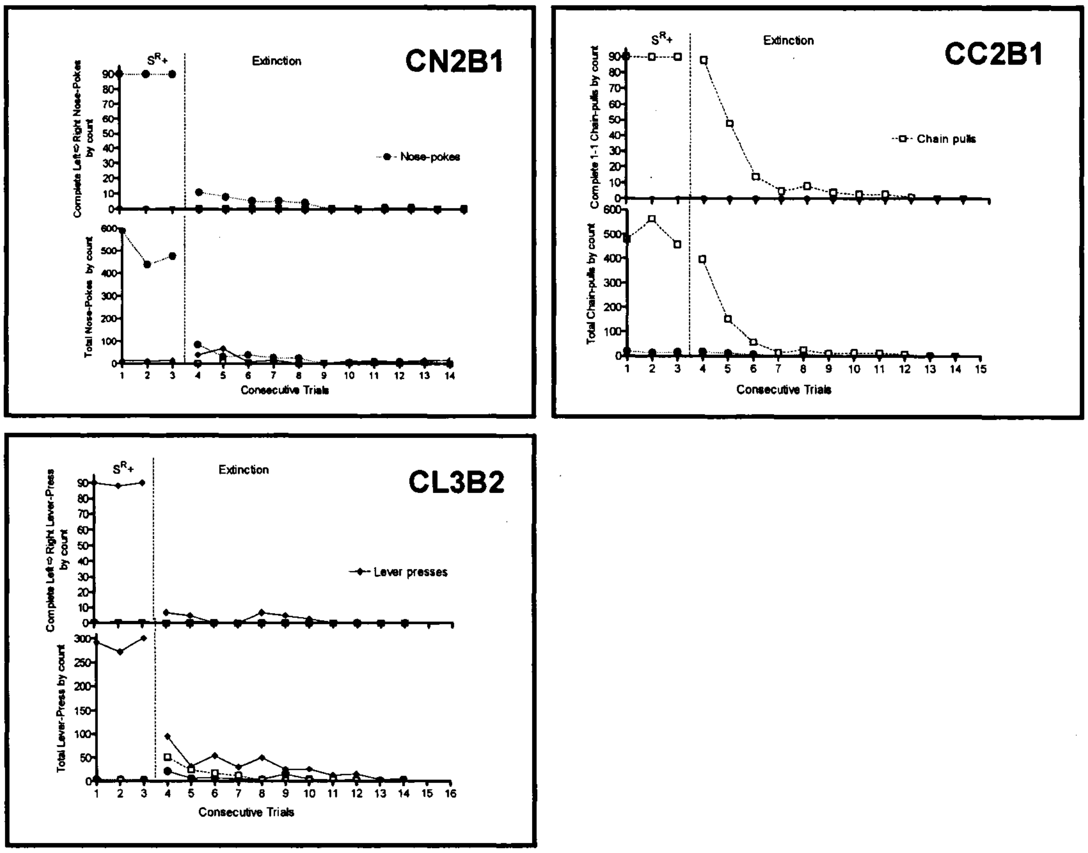


Figure 3. Performance during extinction of subjects CC2B1, CL3B2, and CN2B1 from the Control Group (CG). Phases (reinforcement and extinction) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows complex response frequency (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; bottom graph per subject shows total responding during each session.

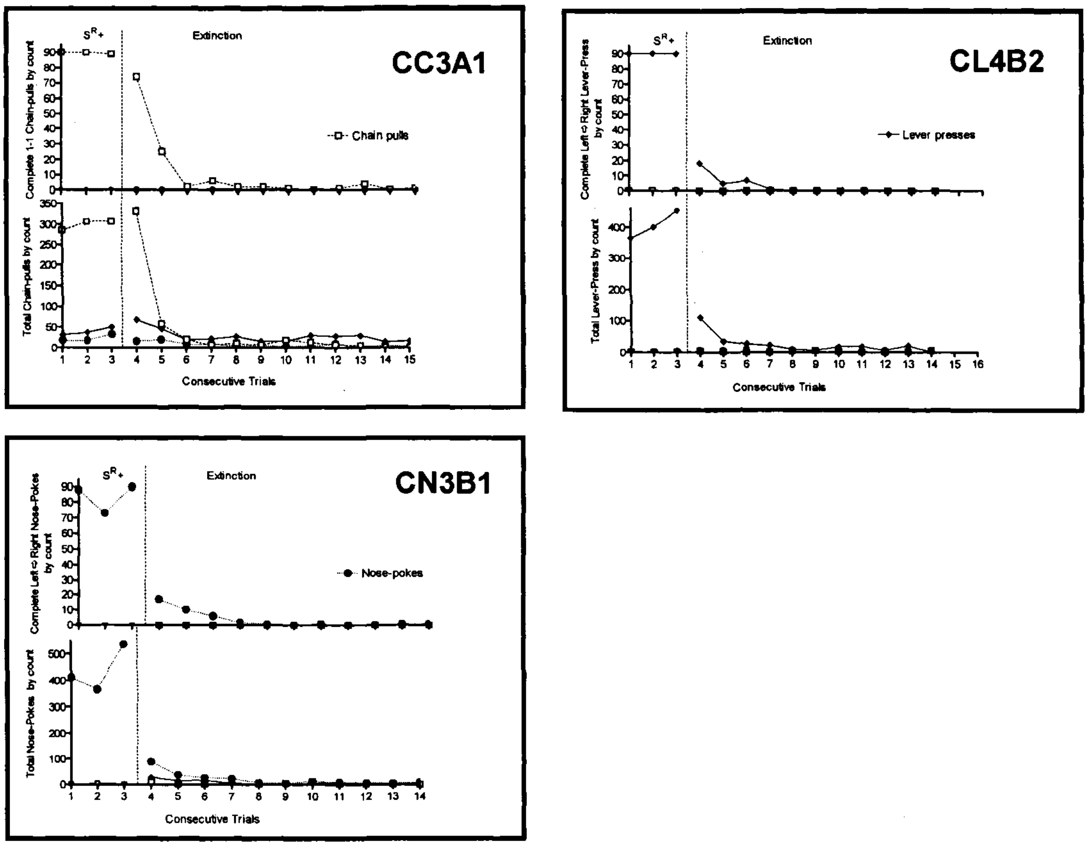


Figure 4. Performance during extinction of subjects CC3A1, CL4B2, and CN3B1 from the Control Group (CG). Phases (reinforcement and extinction) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows complex response frequency (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; bottom graph per subject shows total responding during each session.

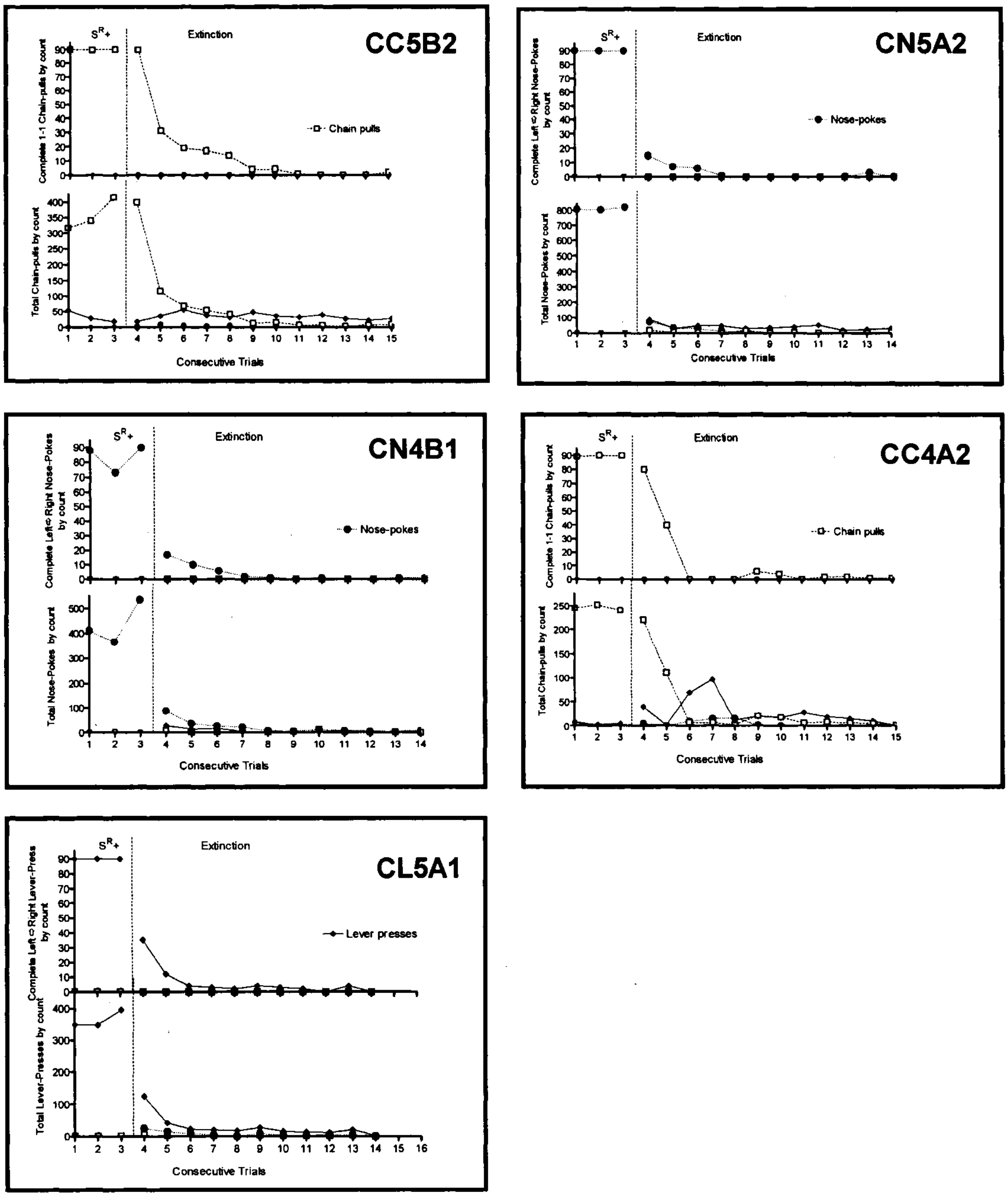


Figure 5. Performance during extinction of subjects CC5B2, CN5A2, CN4B1, CC4A2, and CL5A1 from the Control Group (CG). Phases (reinforcement and extinction) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows complex response frequency (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; bottom graph per subject shows total responding during each session.

As mentioned, Table 2 lists the order of initiation of extinction of responses in the RCG. Figures 6-8 show RCG performance during extinction; these figures illustrate the effect of extinction for two days of one response on both or any response that was already undergoing extinction and/or the remaining response(s).

Total-response graphs indicate some response covariation resulting from the serial extinction of responses in 7 out of the 9 RCG subjects. This covariation is reflected as an increase in one or both of the responses not yet placed on an extinction schedule, or a resurgence of one of the responses placed on extinction. For instance, Figure 6 shows that for subject E1A1 and E2B2, nose-pokes increased when lever pressing was put on extinction, and chain pulls increased for E2B2 when nose-pokes were put on extinction. Figure 7 indicates that for subject E4B2, chain pulls showed some increase when lever presses were put on extinction, while nose-pokes first increased when chain pulls were put on extinction and then resurged when lever presses were put on extinction.

Figure 8 shows that both lever presses and nose-pokes increased for subject E7A1 when chain pulls were put on extinction. Figure 8 also shows that subject E8A2 increased lever pressing when nose pokes were put on extinction, and that chain pulls resurged for CL2A1 when lever pressing was put on extinction.

The total response graphs in Figures 6-8 show that responding far exceeded reinforcement delivery. Also evident is greater head-entries than reinforcer delivery. Both of these outcomes indicate a lack of stimulus control.

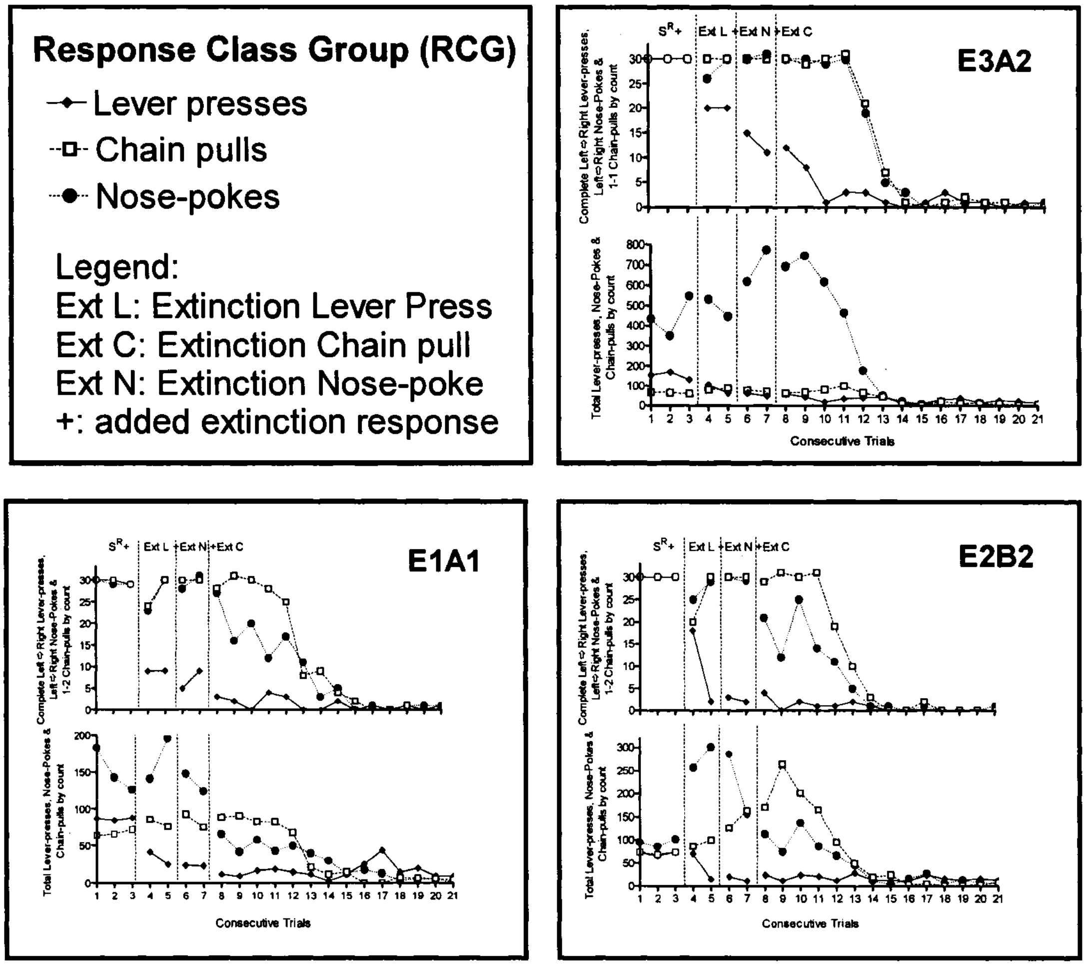


Figure 6. Performance during extinction of subjects E3A1, E1A1 and E2B2 from the Response Class Group (RCG). Phases (reinforcement and serial extinction of the three responses) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows complex response frequency (i.e., frequency of left→right lever presses and nose-pokes, and 1-1 chain pulls) per session; bottom graph per subject shows total responding during each session.

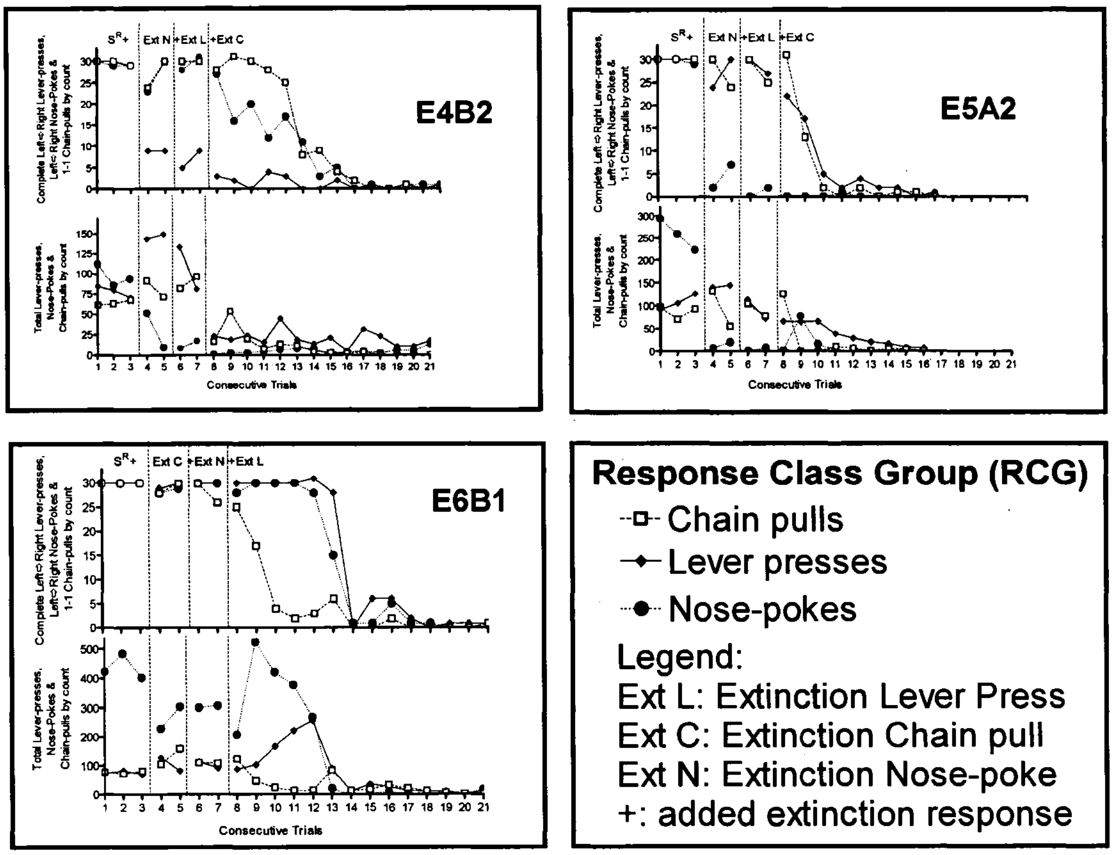


Figure 7. Performance during extinction of subjects E4B2, E5A2 and E6B1 from the Response Class Group (RCG). Phases (reinforcement and serial extinction of the three responses) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows total complex responses (left→right lever presses and nose-pokes, 1-1 chain pulls); bottom graph per subject shows total responding during each session.

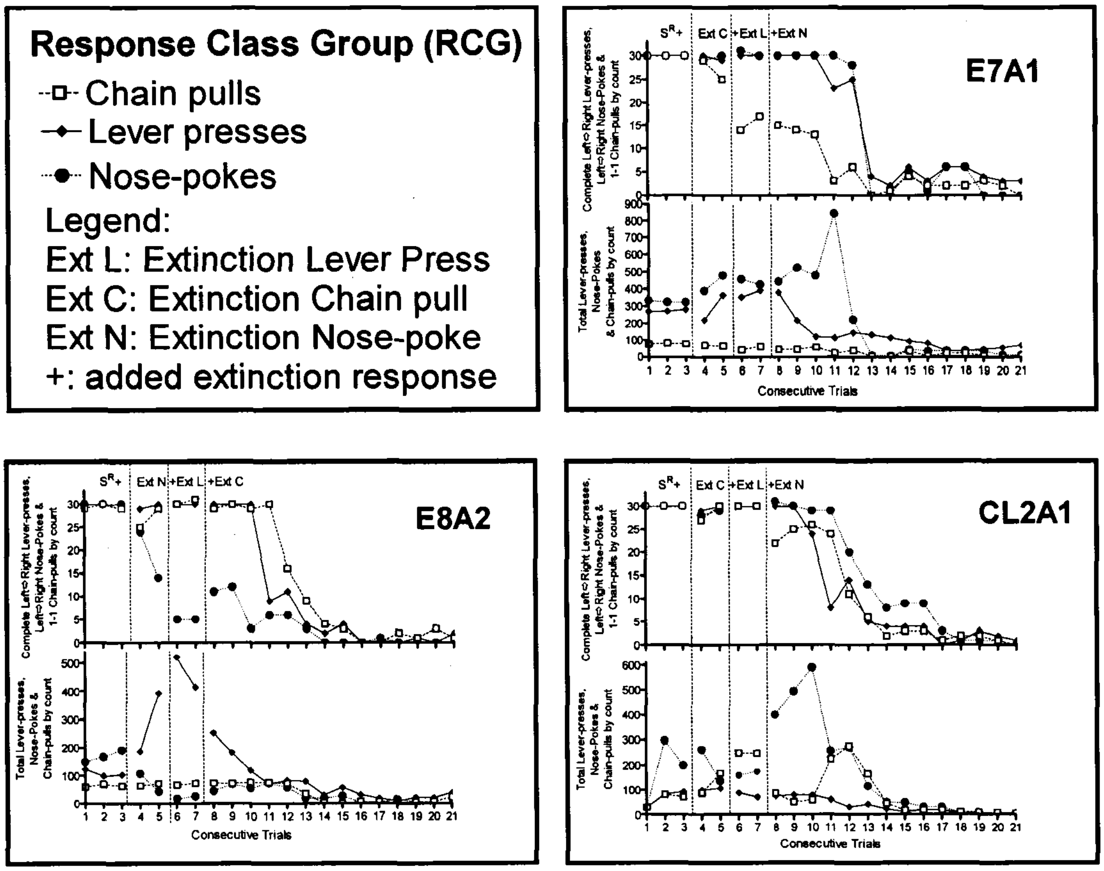


Figure 8. Performance during extinction of subjects E7A1, E8A2 and CL2A1 from the Response Class Group (RCG). Phases (reinforcement and serial extinction of the three responses) are defined by the dotted line. X-axis ticks represent 45 minute training/testing sessions. Top graph per subject shows total complex responses (left→right lever presses and nose-pokes, 1-1 chain pulls); bottom graph per subject shows total responding during each session.

Figure 9 shows the results of the response recovery texts. The main finding in Experiment 2 was that renewal was evident in both groups. As compared by Mann-Whitney U, there was a significant increase in responding during renewal for each group ($p < 0.01$). There was also a significant drop in responding for each group at each successive test ($p < 0.05$), indicating that successive exposure to extinction in the acquisition context (A) following extinction in Context B attenuated renewal in both groups.

Total responding during renewal testing is shown in Figure 9. As mentioned, performance did not vary significantly by response topography in either group at any time during renewal testing, and data are shown pooled across subjects in both the CG and the RCG. Although there was no significant difference between groups during specific renewal testing, the RCG did produce significantly more total responses ($p < 0.05$) when returned to the extinction context after the first renewal exposure. Inspection of Figure 9 shows that this effect resulted both from increased responding in the RCG and decreased variability of responding in the CG upon return to the extinction context.

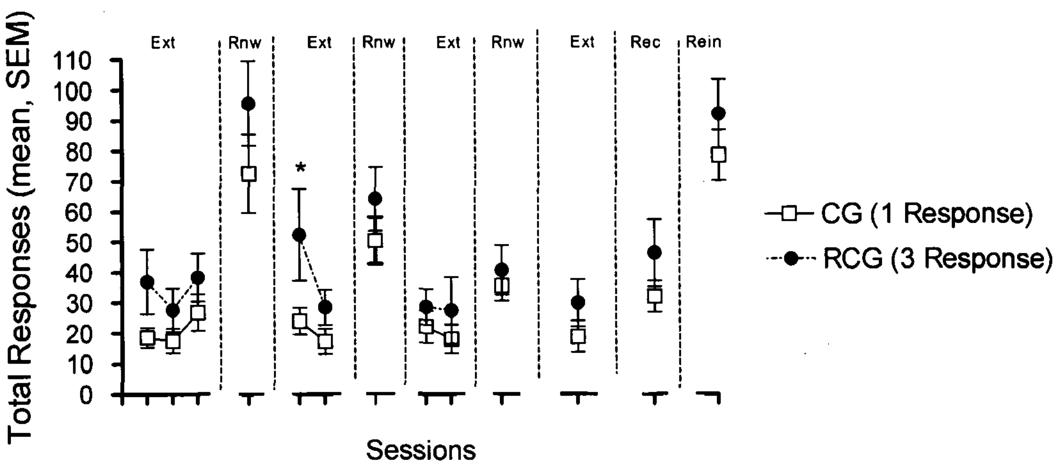


Figure 9. Total responding during renewal, spontaneous recovery and reinstatement tests. Phases are shown across the top: Ext: extinction, Rnw: Renewal, Rec: recovery, Rein: reinstatement. Y-axis ticks represent 45 minute training/testing sessions. * indicates a significant difference ($p < 0.05$) in responding between groups for that session.

Although responding increased marginally for each group during the spontaneous recovery test, robust time-mediated recovery in Context A was not evident in either group. Responding during the spontaneous recovery test was not significantly different from the final renewal test, but neither was it different from the last extinction exposure.

Reinstatement by non-contingent pellets set in the food magazine before placement of the animals in the operant chambers in Context B was evident in both groups. Responding was significantly different from both the recovery and final extinction session ($p < 0.001$), but not from the first renewal test.

Discussion

The specific aim of Experiment 1 was to evaluate the effect of extinction of more than one appetitive behavior within a functional response class in a context other than that of training on renewal in the training context. Although extinction of three topographies (i.e., FR1 FR1 chained lever-pressing, nose-hole poking, and chain-pulls) within a functional response class (i.e., all reinforced by delivery of a 45 mg food pellet) did not attenuate renewal as compared to extinction of a single response, this study did show that extinction in a novel context can facilitate extinction in the acquisition context. This conclusion is based on the fact that extinction in the novel context required an average of 23 days in the RCG and 12 days in the CG, and yet the three days of renewal testing—three days of extinction conditions in the acquisition context—coupled with extinction in Context B, effectively attenuated renewal and time-mediated spontaneous recovery in the acquisition context.

Experiment 1 also provided information regarding resurgence and covariation effects within a FRC in training and extinction contexts. Specifically, it showed that implementing extinction conditions for a single response (or, more precisely, a single $S^D \rightarrow$response relation) can produce an increase in responding in remaining reinforced responses, and that implementing extinction conditions for one or two responses can produce resurgence of responding that previously had decreased in frequency due to differential extinction conditions for that $S^D \rightarrow$response relation.

The total-response graphs in Figures 6-8 show that programmed differential reinforcement in the presence of the correlated S^D and programmed extinction in the absence of the S^D was not sufficient to produce stimulus control. This assumption is based on the fact that total response counts for all responses were much higher than counts for complex responses (i.e., reinforced FR1 FR1 chained responses). This was likely due to adventitious reinforcement. As described by Dinsmoor (1950), a stimulus delta condition (S^Δ; i.e., extinction) that is followed directly by a S^D condition increases the possibility that responding under the S^Δ will be adventitiously reinforced by the appearance of the S^D condition. In this particular experiment, it was not simply the possibility that responding under a S^Δ condition would be reinforced, but also that a response correlated with a different stimulus would be reinforced if it was emitted after the reinforcer-producing response was emitted and before the reinforcer was consumed. This circumstance was actually observed but not specifically recorded or measured; subjects were observed to occasionally perform one or both responses not correlated with the S^D→response that produced pellet delivery before returning to the food magazine to collect the pellet. Head-entries exceeding the number of pellet deliveries could also be taken as an indication that there was little stimulus control.

The covariation and resurgence results seen in the RCG are interesting in consideration of the lack of stimulus control. For instance, these data show that responding within a FRC acquired under S^D→response→reinforcer correlation conditions can be sensitive to a single-response extinction condition even when there is a lack of stimulus control. This interpretation is supported by non-discriminated resurgence studies (Lieving, 2001), where resurgence was evident when responding was expressed in the presence of the manipuladum but in the absence of a specific discriminative stimulus. In consideration of applied clinical conditions, such findings may be relevant to resurgence of responding across different stimuli, such as different care-givers.

Experiment 1 showed that extinction across three members of a FRC did not attenuate renewal in comparison with extinction of one response. What was evident was that extinction of members of a FRC produced covariation of responding within remaining FRC members including resurgence. Experiment 2 was designed to further evaluate the effects of extinction and differential reinforcement of FRC members on resurgence and renewal by differential reinforcement of one of the previously trained

FRC member responses, extinction of this response in a novel context, and subsequent renewal in the acquisition context.

CHAPTER V

EXPERIMENT 2: EFFECT OF MULTIPLE RESPONSES WITHIN A RESPONSE CLASS ON ABA RENEWAL OF RESPONDING

Experiment 2 examined the effect of extinction on resurgence of members of a FRC as well as the effect of extinction in a novel context on renewal. This was done by selectively reinforcing in Context A one of the responses in the FRC examined in Experiment 1, examining the effects of one-day extinction exposure in Context B and then extinguishing responding in Context C and evaluating renewal with a one-day test in Context A. Table 4 shows the design of the experiment.

Table 4

Experimental Design of Experiment Two

Training	Extinction	Testing	
$(S^D_1[R_1]S^{R+})_A$	$(S^D_1[-])_B$	$(S^D_1[-])_C$	
$(S^D_2[-]-)_A$	$(S^D_2[-])_B$	$(S^D_2[-])_C$	n=9
$(S^D_3[-]-)_A$	$(S^D_3[-])_B$	$(S^D_3[-])_C$	

Legend

S^D $_{1,\ 2,\ \text{or}\ 3}$ = discriminative stimulus 1, 2, or 3
S^R+ = 45 mg food pellet
S^D_{all} = that group received S^D $_{1,\ 2,\ \text{and}\ 3}$
$R_{1,\ 2,\ \text{or}\ 3}$ = response 1, 2, or 3
R_{all} = that group emitted responses $_{1,\ 2,\ \text{and}\ 3}$
— = no consequence (extinction)
A, B or C = specific context

For example, $(S^D{}_3[R_3]S^R+)_A$ means that in the presence of the discriminative stimulus 3, response 3 is reinforced by a food pellet in context A. Extinction then occurs in context B, where, in the presence of discriminative stimulus 3, response 3 is not reinforced. Then the animal is tested in context A for renewal in the presence of discriminative stimulus 3.

Method

Subjects. Nine male Sprague-Dawley rats (Charles River, Portage, MI) aged nine to 15 months at the start of the study were used in all assessments. These subjects were the same animals trained as the three-response RCG in Experiment 1. Subjects were housed and maintained as indicated in Experiment 1.

Conditioning chambers and contexts. Three of the four modular rat chambers described in Experiment 1 were used in Experiment 2. From these basic chambers, three contexts were created that differed in visual, olfactory and tactile cues. As in Experiment 1, all operanda were present in all contexts under all conditions. The experimental room and computer set-up and chamber arrangement was the same as described in Experiment 1 with the exception that the forth chamber was not used in this experiment. Contexts 1 and 2 of Experiment 1 again served as contexts A and B for Experiment 2 as determined by subject acquisition and extinction exposure in Experiment 1. In addition, a third context was created from the basic conditioning chamber described in the *Conditioning Chambers and Contexts* section of Experiment 1. Distinct from contexts 1 and 2, this context included nine 3″ by 3″ white tiles set upon the grid floor. There was no construction paper on the outside walls of the chamber. Also unique, 0.05 mL of cinnamon extract was placed in the Petri dish beneath the grid floor. This third context served as a novel extinction context (i.e., Context C) for all subjects regardless of whether they acquired responding in Context 1 and had responding extinguished in Context 2, or vice-versa.

Procedures. The experiment was conducted in five phases: single response re-acquisition (13 days), Context B extinction exposure (1 day), one day reinforcement re-exposure in Context A, Context C extinction (4 days), and test for renewal (1 day). All subjects were exposed to the same basic protocol and procedure.

As mentioned, three contexts were used in this experiment, one for conditioning, one for evaluation of previous extinction effects on the differential reinforcement of a single response, and one for extinction in a novel context. The contexts were referred to as A, B and C, where A was the context where response acquisition and testing occurred, and B was the original extinction context, and C was the novel extinction context..

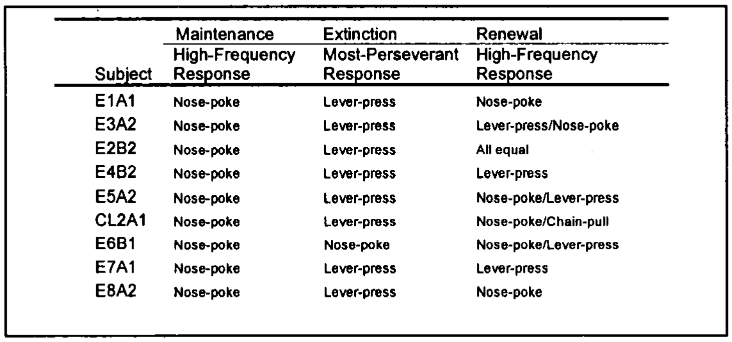
Operant responding. As in Experiment 1, subjects were submitted to daily 45-min training sessions between 8:00 A.M. and 6:00 P.M. In this experiment, only one response of the three previously learned was reinforced. As before, reinforcement was delivered on an FR1 FR1 chain schedule. Operant chamber house lights were on and all operanda were present but not active when the animals were placed in the chambers. Sessions commenced when one of the three S^Ds (i.e., light within the nose-poke hole, light above the lever, or absence of white noise) was presented. Although only one S^D was correlated with pellet delivery for responding on its operandum, sessions included presentations of all three S^Ds in random order with the restriction that none of the S^Ds had more than three consecutive presentations. Sessions terminated when either 45-minutes passed or 30 food pellets were delivered per animal. If 45 minutes passed before 30 food pellets were delivered, the program terminated. This procedure was used throughout all phases.

Response acquisition. Training the re-acquisition of a single response out of the three responses previously reinforced began six days after the reinstatement test in Experiment 1. During the six days between experiments, subjects were kept in their home cages on their regular food limitation feeding schedule. All subjects were run under the maintenance program (see Appendix C) used in Experiment 1.

Choice of the single response reinforced was based on individual pre-extinction responding in Experiment 1; responding patterns are shown in Table 5.

Table 5

Experiment 1 RCG Response Patterns



	Maintenance	Extinction	Renewal
Subject	High-Frequency Response	Most-Perseverant Response	High-Frequency Response
E1A1	Nose-poke	Lever-press	Nose-poke
E3A2	Nose-poke	Lever-press	Lever-press/Nose-poke
E2B2	Nose-poke	Lever-press	All equal
E4B2	Nose-poke	Lever-press	Lever-press
E5A2	Nose-poke	Lever-press	Nose-poke/Lever-press
CL2A1	Nose-poke	Lever-press	Nose-poke/Chain-pull
E6B1	Nose-poke	Nose-poke	Nose-poke/Lever-press
E7A1	Nose-poke	Lever-press	Lever-press
E8A2	Nose-poke	Lever-press	Nose-poke

For subjects E1A1, E2B2, E3A2 and E7A1, the reinforced response was the response that had generated the lowest frequency during the seven-day maintenance phase of Experiment 1. For subjects E6B1, CL2A1 and E4B2, the response was the one with a frequency relatively equal to the other responses, and for subjects E8A2 and E5A2, the response was the response with the highest frequency of the three prior to extinction. As previously stated, all S^Ds were active during the session but only responding under the selected stimulus was reinforced. All other responding was recorded and, as in Experiment 1 extinction, responding terminated the S^D, but no pellet was delivered.

Extinction training. All procedures during the Context B extinction phase were identical to those used during the single-response re-acquisition phase, except that the subjects were in Context B and food pellets were not dispensed. Accordingly, correct nose-poke responses terminated the active nose-poke hole S^Ds, lever presses terminated the lever-press S^Ds, and chain-pulls closed the circuit triggering an audible click and turning on the white noise, but pellets were not delivered. Animals that had been trained to respond for pellets in Context 1 underwent extinction in Context 2, and animals that had been trained to respond for pellets in Context 2 underwent extinction in Context 1.

Maintenance exposure. Following one day of extinction exposure in Context B, subjects were returned to Context A for one day of regular 1-response reinforcement.

Novel context extinction training. All procedures during the novel context extinction phase were identical to those used during the Context B extinction phase, except that the subjects were exposed to extinction conditions in Context C. Extinction exposure in Context C was in effect for four days for all subjects.

Tests for renewal. The renewal test was conducted 24 hours after the final extinction session. During one 45-minute session, rats were tested for renewal by exposure to the context paired with food pellet delivery. Protocol for renewal tests was identical to that used for the extinction tests with the exception that the tests were performed in the context where responding to the S^D associated with the differentially reinforced response had produced food pellets during acquisition and maintenance.

Results

Re-acquisition. Differential reinforcement produced responding in all nine subjects (see Figures 10-13).

Figure 10 and Figure 11 show that re-acquisition responding varied across those subjects that re-acquired the response that had previously generated the lowest frequency (i.e., E2B2, E7A1, E3A2, and E1A1); E2B2 showed immediate, relatively stable responding under the correlated S^D and had little expression of the other two responses; E7A1 responded immediately under the relevant S^D, but also continued to emit a large number of the other two responses—although it should be noted that subject E7A1 also failed to show differential responding during serial extinction in Experiment 1; E3A2 showed immediate reinforced responding (lever press), with relatively persistent nose-poking (prior high-frequency response); E1A1 did not begin responding until the eighth session because although the subject emitted some of the other responses, it didn't emit its low frequency response until the eighth session. Once responding and consequent pellet delivery began for E1A1, both of the other responses increased due possibly to reinstatement and/or adventitious reinforcement, but chain pull responding decreased by the second day (previous 2nd lowest frequency response) and nose-pokes (highest frequency response) decreased within five days.

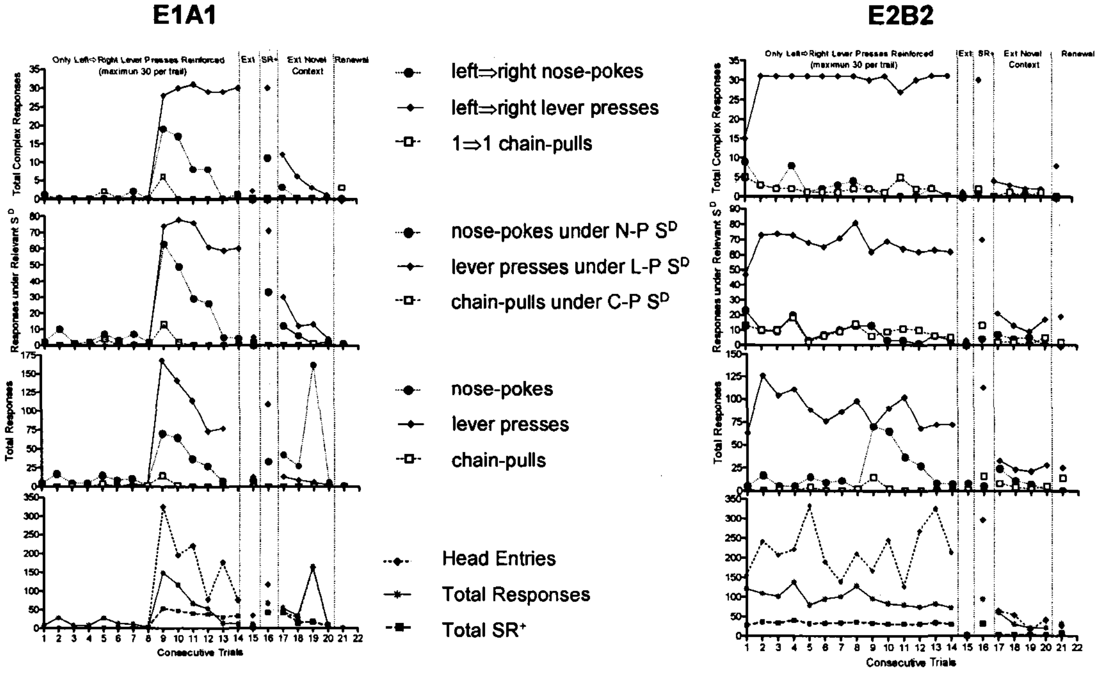


Figure 10. Performance of subjects that re-acquired the response generating the lowest frequency during the 7-day maintenance phase of Experiment 1. Shown is re-acquisition, 1-day extinction exposure in Context B (Ext), 1-day re-exposure to reinforcement in the training context (SR+), 4-day extinction in Context C (Ext novel context) and a 1-session test for renewal (Renewal). Phases are defined by dotted lines. X-axis ticks represent 30 minute training/testing sessions. Top graph per subject shows frequency of complex-responses (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; second graph per subject shows total responding under S^D conditions, third graph per subject shows total responding on each operandum during each session; bottom graph per subject shows head entries, total responses and total pellet deliveries.

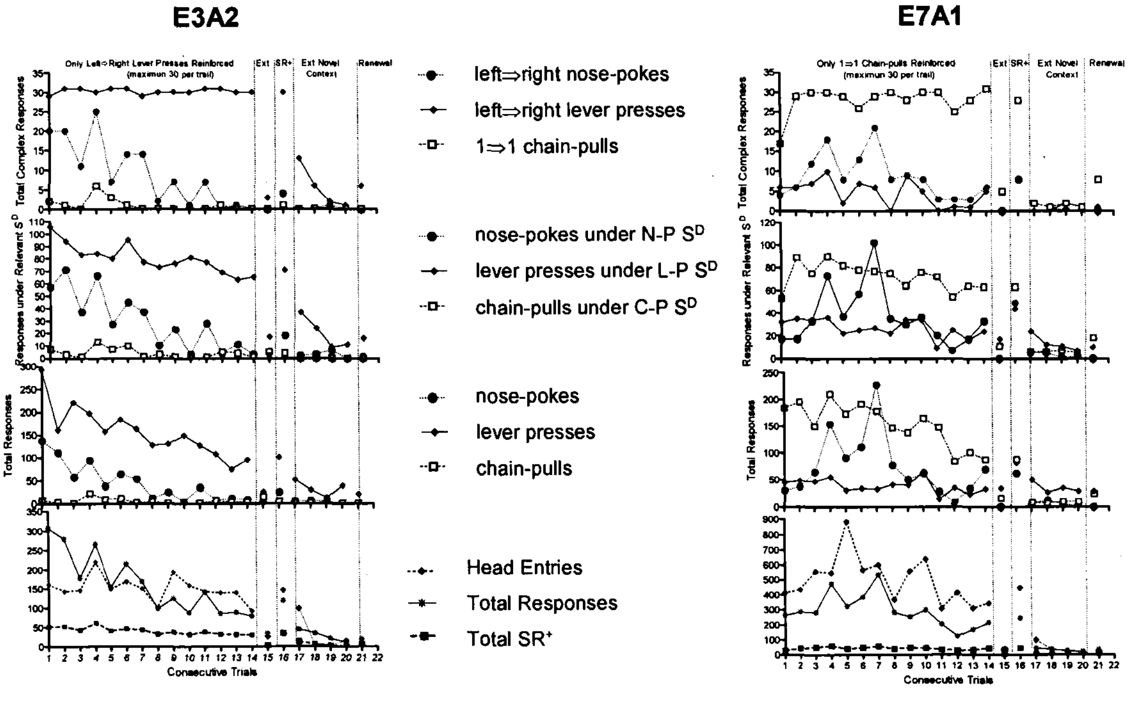


Figure 11. Performance of subjects that re-acquired the response generating the lowest frequency during the 7-day maintenance phase of Experiment 1. Shown is re-acquisition, 1-day extinction exposure in Context B (Ext), 1-day re-exposure to reinforcement in the training context (SR+), 4-day extinction in Context C (Ext novel context) and a 1-session test for renewal (Renewal). Phases are defined by dotted lines. X-axis ticks represent 30 minute training/testing sessions. Top graph per subject shows frequency of complex-responses (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; second graph per subject shows total responding under S^D conditions, third graph per subject shows total responding on each operandum during each session; bottom graph per subject shows head entries, total response and total pellet deliveries.

Figure 12 shows that re-acquisition of a medium frequency response produced almost immediate responding in all three subjects (i.e., E4B2, E6B1, and CL2A1).

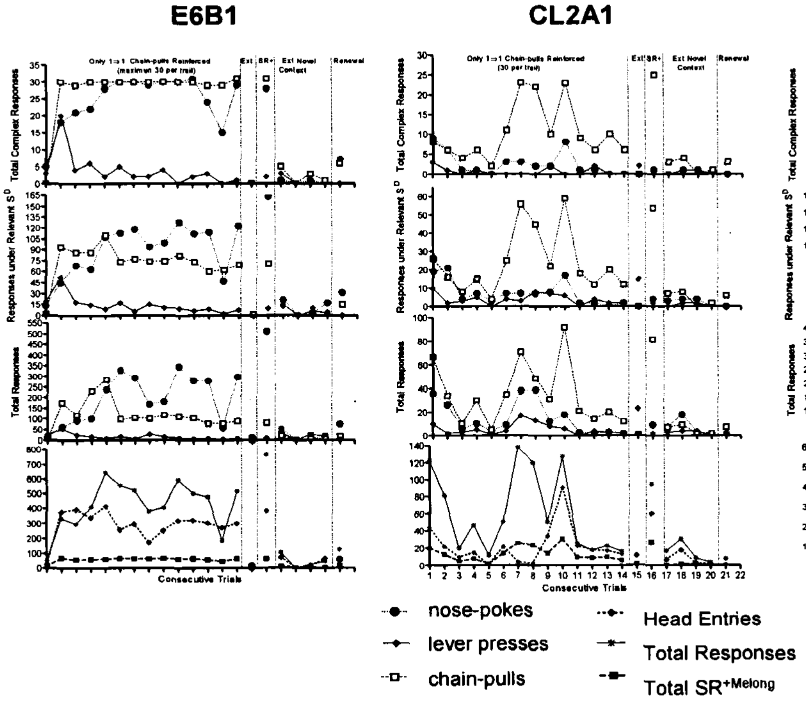


Figure 12. Performance of subjects that re-acquired a response generating a frequency relatively equal to the other responses during the 7-day maintenance phase of Experiment 1. Shown is re-acquisition, 1-day extinction exposure in Context B (Ext), 1-day re-exposure to reinforcement in the training context (SR+), 4-day extinction in Context C (Ext novel context) and a 1-session test for renewal (Renewal). Phases are defined by dotted lines. X-axis ticks represent 30 minute training/testing sessions. Top graph per subject shows frequency of complex-responses (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; second graph per subject shows total responding under S^D conditions, third graph per subject shows total responding on each operandum during each session; bottom graph per subject shows head entries, total responses and total pellet deliveries.

E4B2 showed a dramatic increase in reinforced responding on the third day of pellet availability; the other two responses reinstated at similar rates for one day. Subject CL2A1 showed minimal responding on all operanda for four days, but beginning with the fifth day responding was predominately on the operandum correlated with reinforcement (chain pulls). E6B1 showed both reinstatement and perseveration of nose-poking from the on-set of reinforcement, even though chain-pulls were the response actually correlated with pellet delivery.

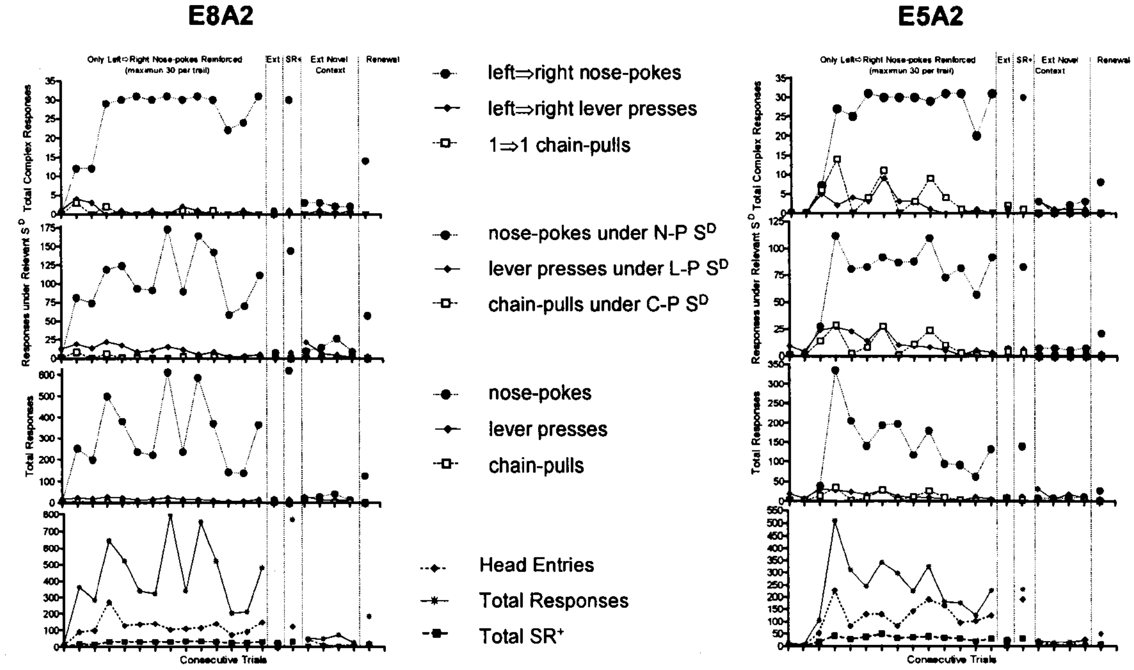


Figure 13. Performance of subjects that re-acquired the response generating the highest frequency during the 7-day maintenance phase of Experiment 1. Shown is re-acquisition, 1-day extinction exposure in Context B (Ext), 1-day re-exposure to reinforcement in the training context (SR+), 4-day extinction in Context C (Ext novel context) and a 1-session test for renewal (Renewal). Phases are defined by dotted lines. X-axis ticks represent 30 minute training/testing sessions. Top graph per subject shows frequency of complex-responses (i.e., frequency of left→right lever presses, or left→right nose-pokes, or 1-1 chain pulls) per session; second graph per subject shows total responding under S^D conditions, third graph per subject shows total responding on each operandum during each session; bottom graph per subject shows head entries, total responses and total pellet deliveries.

Figure 13 shows responding in subjects that re-acquired the highest-frequency response from Experiment 1. One of the subjects, E8A2, showed almost immediate resumption of responding when pellets were available, indicating that there was some responding occurring at the onset of placement in the chambers. The second subject, E5A2, began responding on the third day; pellet delivery for the re-acquisition response (nose-pokes) reinstated both lever pressing and chain pulls, and responding on those operanda lasted 9 days.

Context B extinction. Exposure to the extinction context used in Experiment 1 (Context B) resulted in attenuation of responding on all responses in all subjects. Subject CL2A1 (Figure 12) showed a slight resurgence of lever-pressing, a response that was not a high-frequency response in Experiment 1, but the re-acquisition response, chain pulls, did not occur during extinction in Context B; chain pull had been a mid-frequency response in Experiment 1. Subject E7A1 (Figure 11) showed marginal responding on all operanda, with only chain pulls (the re-acquisition response and a low-frequency response in Experiment 1) occurring under the relevant S^D.

One-day return to one-response reinforcement in Context A. One-day return to re-acquisition-response reinforcement produced responding in all subjects that was not significantly different by a Mann-Whitney U comparison from last day re-acquisition responding when counts were pooled across subjects. However, one subject, E1A1 (Figure 10), a low-frequency response re-acquisition subject, did show some renewal/reinstatement of its Experiment 1 high-frequency response, nose-pokes. Also, subject E6B1 (Figure 12), a mid-frequency re-acquisition subject with chain-pulls as the re-acquisition response, showed greater over-all frequency counts for nose-poking as well as greater correlated responding under the nose-poke S^D than correlated responding under the chain pull S^D.

Context C extinction. Extinction in a novel context, one of the conditions that was likely to produce a measure of interest in Experiment 2, produced some resurgence in four of the nine subjects. E1A1 (Figure 10) showed a dramatic increase in nose-poke responding that was not correlated with presentation of the nose-poke S^D; nose-poking had been the high-frequency response in Experiment 1. E7A1 (Figure 11) showed resurgence of lever pressing that, similar to the resurgence seen in E1A1, was not correlated with presentation of the lever press S^D. This resurgence was seen in concert with a dramatic decrease in responding of the re-acquisition response, chain-pulls. Chain pulls had been the low-frequency response in Experiment 1, however, lever pressing was not the high-frequency response, rather, the high-frequency response had been nose-pokes. Lever pressing had shown a relatively stable rate prior to extinction in Experiment 1, similar to nose-poking but lacking an increase in response to extinction. Nose-poking had been the last response placed on extinction in Experiment 1. Subject E2B2 (Figure 10) showed a marginal increase in nose-pokes but this increase did not co-vary with lever press, its re-acquisition response; its high-frequency response in Experiment 1 had been chain pulling.

Subject CL2A1 showed a slight one-day resurgence of nose-pokes, its Experiment 1 high-frequency response (Figure 12).

Renewal. As can be seen from inspection of Figures 10-13, some renewal was evident in all subjects when returned to the acquisition context following a four day extinction exposure in a novel context. However, as compared by Mann-Whitney U test, this renewal was not significantly different from the final-day extinction responding in the novel context, and was significantly different from final-day re-acquisition reinforced responding ($p<0.0001$). Observed renewal was not restricted to the re-acquisition response.

Of the subjects that had had their Experiment 1 high-frequency response reinforced during re-acquisition (Figure 13), E8A2 produced relatively pronounced renewal of the re-acquisition response (nose-poking), but did not show renewal of lever-pressing, a response that had shown a dramatic co-variation increase during Experiment 1 extinction. Subject E5A2 exhibited some renewal of the re-acquisition response and no renewal of other responses.

Experiment 1 mid-frequency re-acquisition response subjects in general showed little renewal responding (see Figure 12). E4B2 exhibited some marginal renewal of the re-acquisition response alone (nose-poke), and most of the responding was in the presence of the correlated S^D. Subject CL2A1 had the same pattern of slight renewal of chain pulling, the re-acquisition response; for the most part this responding was expressed in the presence of the correlated S^D. E6B1 exhibited renewal of both the re-acquisition response of chain pulling as well as nose-poking, but it should be noted that nose-poking persisted across re-acquisition and actually had a higher overall frequency during reacquisition than did chain pulls.

Subjects that had the response with the lowest frequency during Experiment 1 reinforced showed relatively minor but varied renewal (see Figure 10 and Figure 11). Interestingly, subject E1A1 exhibited some slight renewal of chain pulling, not correlated with the chain pull S^D, but no renewal of either the reacquisition response or the high-frequency response from Experiment 1 (i.e., lever presses and nose-pokes respectively). E3A2 showed some renewal of the re-acquisition response, lever pressing, in the presence of the lever press S^D. E2B2 also showed some renewal of the re-acquisition response, lever press, in the presence of the lever press S^D, and a very slight renewal of chain pulls that was not correlated with the chain-pull S^D; chain pulls had shown the greatest perseveration during extinction in Experiment 1 for this subject, while lever presses had shown no resurgence or co-variation increases during Experiment 1. E7A1 showed slight renewal of chain pulls, the re-acquisition response, and of lever presses; only the chain pulls were expressed in the presence of the correlated S^D. Although nose-pokes had perseverated along with lever presses during re-acquisition, nose pokes did not renew.

Discussion

Experiment 2 was designed to evaluate the effects of differential reinforcement of a single response within a FRC following extinction of three member responses on co-variation, resurgence and renewal within the FRC. Also evaluated was the effect of extinction in a second, novel context on renewal.

Three findings were most salient in Experiment 2. First, it appeared that subsequent reinforcement of one member of a FRC attenuated renewal of other members. This conclusion was based on the fact that the responses showing the highest renewal counts in Experiment 2 were the re-acquisition responses in eight out of nine subjects, including the subjects that had re-acquired their lowest-frequency response from Experiment 1; low-frequency responses had not been seen to show robust renewal in Experiment 1.

The second salient finding was that exposure to Context B evoked little or no recovery of any response, indicating that recent reinforcement in a context previously associated with both reinforcement and extinction—Context A, where reinforcement was delivered during acquisition and maintenance and extinction was evidenced from the attenuated renewal during the third renewal test in Experiment 1—does not attenuate the delta control (i.e., no reinforcement available) of a context associated only with extinction (Context B).

Lastly, Experiment 2 findings indicate that differential reinforcement of a target response within a FRC (i.e., re-acquisition of one member response), attenuates resurgence. There was opportunity for resurgence both in extinction exposure to Context B and in extinction exposure to Context C. As mentioned, there was little responding of any kind in Context B, and extinction in Context C produced minimal resurgence of any responses in all subjects, including in those subjects that had re-acquired a low-frequency response from Experiment 1.

CHAPTER VI

GENERAL DISCUSSION

Due to the fact that the subjects in Experiment 2 came with a reinforcement history gained in Experiment 1, it is difficult to separate the findings in Experiment 2 from those in Experiment 1. For instance, it was found that extinction in a novel context attenuated renewal of the reinforced response, but this effect may have been influenced by the repeated exposure to extinction in Context A during the three renewal tests in Experiment 1. Rather than conclude that extinction in multiple contexts other than the training context attenuates renewal, it can only be concluded that extinction in a novel context facilitates extinction in the training context (as seen in Experiment 1) and in a second novel context (i.e., extinction was rapid in Context C), and these exposures attenuate renewal in the training context.

However, considered together, results from Experiments 1 and 2 offer some insight into resurgence and renewal within a FRC. For instance, Table 5 from Experiment 1 indicates that, unlike resurgence effects where prior response rate appears to dictate response expression (Franks & Lattal, 1996), both response rate and response perseverance under extinction appeared to influence response renewal; this is inferred from the finding that the response with the highest-frequency during renewal was the response that had been generated with the highest frequency during maintenance in approximately a third of the subjects, and it was the response that had perseverated the longest during extinction in approximately a third of the subjects.

Other subjects showed renewal with equal counts in both of these responses, and one subject did show correlated renewal responding.

However, Experiment 2 renewal findings indicate that response perseveration has little influence on renewal, since it did not appear that resurgence responding during extinction in the novel context had any correlation with subsequent renewal in the training context. Rather, the responses generating the highest renewal counts in Experiment 2 were the re-acquisition responses in eight out of nine subjects, including the subjects that had re-acquired their lowest-frequency response from Experiment 1; low-frequency responses had not been seen to show robust renewal in Experiment 1. Two subjects in Experiment 2 inadvertently had the response with the highest renewal frequency in Experiment 1 reinforced as the re-acquisition response in Experiment 2 and this response remained the high-frequency renewal response in Experiment 2, but, most relevant are the response patterns of the remaining six subjects. Out of the six remaining subjects, five showed highest-frequency renewal of a different response in Experiment 2 than in Experiment 1, and, as mentioned, this response was the re-acquisition response. In the one subject that did show renewal of the same response in Experiment 2 as in Experiment 1 when this response was not a re-acquisition response (subject E6B1), the response had perseverated throughout re-acquisition in Experiment 2, indicating that it may have been supported by adventitious reinforcement. Since Figure 13 shows that both the perseverating response and the re-acquisition response renewed at similar counts during

Experiment 2, it is even possible that they had become a chained response and may have inadvertently shared not simply rate but also a reinforcement schedule.

Because this series of studies did not distinguish response rate from reinforcement rate, it can't be determined which variable most influenced renewal preference. However, it does appear that differential reinforcement of a single response may influence subsequent renewal expression. This finding could benefit practitioners working to attenuate response recovery in applied settings.

In addition, both basic studies evaluating resurgence (Lieving, 2000; Lieving & Lattal, 2003), and applied studies evaluating resurgence and co-variation in treatment settings (Harding, Wacker, Berg, Barretto, Winborn & Gardner, 2001; Horner & Day, 1991; Lalli, Mace, Wohn, and Livezey, 1995; Lieving, Hagopian, Long, & O'Connor, 2004; Richman, Wacker, Asmus, Casey, & Andelman, 1999) indicate that multiple exposures to extinction conditions do not attenuate resurgence. However, the data generated in this project indicate that differential reinforcement of a single response in the presence of its S^D combined with extinction of other member responses in the presence of their discriminative stimuli may attenuate resurgence in novel contexts, which may then facilitate attenuation in the training or home context. In such, it is hoped that this project may benefit recovery attenuation treatment, and that the data may support additional research into response recovery.

Appendix A

IACUC Approval

WESTERN MICHIGAN UNIVERSITY

Institutional Animal Care and Use Committee

Centennial
1903-2003 Celebration

Date: November 14, 2005

To: Lisa Baker, Principal Investigator

From: Robert Eversole, Chair

Re: IACUC Protocol No. 05-10-01

Your protocol entitled “Effect of Extinction Across Multiple Contexts on Renewal of Responses Within a Functional Response Class” has received approval from the Institutional Animal Care and Use Committee. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: November 14, 2006

Walwood Hall, Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276

Appendix B

Acquisition Program

```
\TRAINING LEVER PRESSES, NOSE POKES, AND CHAIN PULLS
\10/07/06 MATT PORRITT, WSG STAN RF
\ARRANGES 30 RESPONSES ON ONE LEVER/NOSE OR ONE CHAIN PULL THEN 20 LEFT
THEN RIGHT OR TWO CHAIN PULLS
\RUNS FOR 60-MIN OR 50 SR
\K-PULSES:
\K1 - LEVER TRAINING
\K2 - NOSE POKE TRAINING
\K3 - CHAIN PULL TRAINING
\K4 - SKIP THE SINGLE RESPONSE TRAINING GO TO 50 TANDEM RESPONSES


\THIS SECTION IS FOR OUTPUTS
^FOOD = 3
^RIGHTNPLIGHT = 7
^LEFTNPLIGHT = 6
^RIGHTLEVLIGHT = 5
^LEFTLEVLIGHT = 4
^WHITENOISE = 11
^FAN = 12
^RIGHTLEV = 2
^LEFTLEV = 1

\THIS SECTION IF FOR INPUTS
^LEFTLEVRESP = 1
^RIGHTLEVRESP = 3
^HEADENTRY = 5
^RIGHTNP = 7
^LEFTNP = 6
^CHAIN = 8



\THIS SECTION FOR Z-PULSES
^ZSR = 1



\HERE FOR CONSTANTS

\      (0) =
\      (1) =
\      (2) =
\      (3) =
\      (5) =
\      (6) =

\A = WORKING AND RECORDING DATA ARRAY
\      (0) =
\      (1) =
\      (2) =
\      (3) =  SR DELIVERIES
\      (5) =  SESSION SECONDS
\      (6) =  SKIP TWO
\        (7) =  LEFT FIRST
\B
```

```
\C
\D
\E
\F
\G
\H
\I
\J
\K
\L
\M
\N
\O
\P
\Q
\R
\S
\T
\U
\V
\W
\X
\Y
\Z

DIM A = 9

LIST B = 1, 1
LIST C = 0.5", 1.6", 2.9", 4.3", 6", 8", 10.5", 13.9", 19.2", 33"

DISKVARS = A

S.S.1,      \-----------------------------------------BOX CHECK --------
---------\
S1,
      1": ON, ^RIGHTLEV, ^LEFTLEV, ^LEFTLEVLIGHT --->S2
S2,
      2#R^LEFTLEVRESP: ON ^RIGHTLEVLIGHT; OFF ^LEFTLEVLIGHT --->S3
S3,
      2#R^RIGHTLEVRESP: ON ^LEFTNPLIGHT; OFF ^RIGHTLEVLIGHT --->S4
S4,
      2#R^LEFTNP: ON ^RIGHTNPLIGHT; OFF ^LEFTNPLIGHT --->S5
S5,
      2#R^RIGHTNP: ON ^WHITENOISE; OFF ^RIGHTNPLIGHT --->S6
S6,
      2#R^CHAIN: ON ^FOOD; OFF ^WHITENOISE --->S7
S7,
      #R^HEADENTRY: OFF ^FOOD; ON ^FAN, ^WHITENOISE --->S8
S8,
      1": SHOW 3, SR, A(3), 4, SECONDS, A(5) --->SX

S.S.2,      \-----------------------------------------LEVER TRAIN ------
---------\
S1,
      #K1: SHOW 1, LEVER, B(0) --->S2
S2,
      #START: ON ^WHITENOISE --->S3
s3,
```

```
        .1": RANDD A(0) = C --->S4
S4,
        A(0)#T: ADD A(1); IF (A(1) >= 30) OR (A(6) = 1) [@T3, @F3]
                              @T3: SET A(7) = 0 --->S5
                              @F3: IF A(7) = 0 [@T, @F]
                               @T: SET A(7) = 1 --->S5
                               @F: SET A(7) = 0 --->S6

S5,
        .5": ON ^LEFTLEVLIGHT --->S7
S6,
        .5": ON ^RIGHTLEVLIGHT --->S8
S7,
        #R^LEFTLEVRESP: OFF ^LEFTLEVLIGHT--->S9
S8,
        #R^RIGHTLEVRESP: OFF ^RIGHTLEVLIGHT--->S9
S9,
        .5": IF (A(1) >= 30) OR (A(6) = 1) [@T2, @F2]
                     @T2: ON ^RIGHTLEVLIGHT --->S10
                          @F2: ON ^FOOD; Z^ZSR --->S11
S10,
        #R^RIGHTLEVRESP: OFF ^RIGHTLEVLIGHT; ON ^FOOD; Z^ZSR --->S11
S11,
        .1": OFF ^FOOD --->S3


S.S.3,       \-----------------------------------------NOSE POKE TRAIN --
-----------\
S1,
        #K2: SHOW 1, NOSEPOKE, B(0) --->S2
S2,
        #START: ON ^WHITENOISE --->S3
S3,
        .1": RANDD A(0) = C --->S4
S4,
        A(0)#T: ADD A(1); IF (A(1) >= 30) OR (A(6) = 1) [@T3, @F3]
                              @T3: SET A(7) = 0 --->S5
                              @F3: IF A(7) = 0 [@T, @F]
                               @T: SET A(7) = 1 --->S5
                               @F: SET A(7) = 0 --->S6
S5,
        .5": ON ^LEFTNPLIGHT --->S7
S6,
        .5": ON ^RIGHTNPLIGHT --->S8
S7,
        #R^LEFTNP: OFF ^LEFTNPLIGHT--->S9
S8,
        #R^RIGHTNP: OFF ^RIGHTNPLIGHT--->S9
S9,
        .5": IF (A(1) >= 30) OR (A(6) = 1) [@T2, @F2]
                     @T2: ON ^RIGHTNPLIGHT --->S10
                          @F2: ON ^FOOD; Z^ZSR --->S11
S10,
        #R^RIGHTNP: OFF ^RIGHTNPLIGHT; ON ^FOOD; Z^ZSR --->S11
S11,
        .1": OFF ^FOOD --->S3
```

```
S.S.4,       \-----------------------------------------CHAIN TRAIN (HEY
THAT RHYMES)--\
S1,
      #K3: SHOW 1, CHAIN, B(0)--->S2
S2,
      #START: --->S3
S3,
      .1": RANDD A(0) = C --->S4

S4,
      A(0)#T: OFF ^WHITENOISE --->S5
S5,
      #R^CHAIN: ON ^WHITENOISE; ADD A(1); IF (A(1) >= 30) OR (A(6) = 1)
[@T1, @F1]
                              @T1: --->S7
                                        @F1: ON ^FOOD; Z^ZSR --->S6
S6,
      .1": OFF ^FOOD --->S3
S7,
      1": OFF ^WHITENOISE --->S8
S8,
      #R^CHAIN: ON ^WHITENOISE, ^FOOD; Z^ZSR --->S6




S.S.5,       \-----------------------------------------DATA RECORDS -----
---------\
S1,
      #Z^ZSR: ADD A(3) --->SX
      #K4: SET A(6) = 1; SHOW 2, SKIP1, B(0) --->SX

S.S.6,
S1,
      #START: --->S2
S2,
      1": ADD A(5); IF (A(5) >= 3600) OR (A(3) >= 50) [] --->S3
S3,
      .01": --->STOPABORTFLUSH
```

Appendix C

Maintenance Program

```
\MAINTAINING LEVER PRESSES, NOSE POKES, AND CHAIN PULLS
\10/07/06 MATT PORRITT, WSG STAN RF
\K1 = JUST LP
\K2 = JUST NP
\K3 = JUST CHAIN


\THIS SECTION IS FOR OUTPUTS
^FOOD = 3
^RIGHTNPLIGHT = 7
^LEFTNPLIGHT = 6
^RIGHTLEVLIGHT = 5
^LEFTLEVLIGHT = 4
^WHITENOISE = 11
^FAN = 12
^LEFTLEV = 1
^RIGHTLEV = 2


\THIS SECTION IF FOR INPUTS
^LEFTLEVRESP = 1
^RIGHTLEVRESP = 3
^HEADENTRY = 5
^RIGHTNP = 7
^LEFTNP = 6
^CHAIN = 8



\THIS SECTION FOR Z-PULSES
^ZSR = 1
^ZLEVER = 2
^ZNP = 3
^ZCHAIN = 4
^ZTIMEUP = 5
^ZSWITCH = 6
^ZEND = 7
^ZLISTENLEV = 8
^ZLISTENNP = 9
^ZLISTENCH = 10
^ZLISTENLEVSEC = 11
^ZLISTENNPSEC = 12
^ZLISTENCHSEC = 13
^ZTO = 14
^ZFOODM = 15

\HERE FOR CONSTANTS

\      (0) =
\      (1) =
\      (2) =
\      (3) =
\      (5) =
\      (6) =

\A = WORKING DATA ARRAY
```

```
\      (0) =  PROGRAM 1
\      (1) =  PROGRAM 2
\      (2) =  PROGRAM 3
\      (3) =  SR DELIVERIES
\      (5) =  SESSION SECONDS
\      (6) =  ADD CURRENT PROGRAM
\      (7) =  CURRENT SR
\      (8) =  CURRENT SECONDS
\      (9) =  CURRENT ITI
\B = RANDOMIZE PROGRAMS
\C = VI
\D = DATA RECORD ARRAY  \SHEESH THAT'S A LOT OF INPUTS!!
      ^LSR = 1    \LEVER SR
      ^NPSR = 2   \NOSEPOKE SR
      ^CHAINSR = 3      \CHAIN SR

      \LEFT LEVER
      ^LLEVCHAIN = 4    \LEVERPRESS DURING CHAIN
      ^LLEVNP = 5 \LEVERPRESS DURING NOSEPOKE
      ^LLEV = 6   \LEVERPRESS DURING LEVER

      \RIGHT LEVER
      ^RLEVCHAIN = 7    \LEVERPRESS DURING CHAIN
      ^RLEVNP = 8 \LEVERPRESS DURING NOSEPOKE
      ^RLEV = 9   \LEVERPRESS DURING LEVER

      \CHAIN PULLS
      ^CHAINLEV = 10    \CHAIN DURING LEVER
      ^CHAINNP = 11     \CHAIN DURING NP
      ^CHAINRESP = 12   \CHAIN DURING CHAIN

      \NOSE POKE LEFT
      ^LNPCHAIN = 13    \NOSEPOKE DURING CHAIN
      ^LNPLEVER = 14    \NOSEPOKE DURING LEVER
      ^LNP = 15   \NOSEPOKE DURING NOSEPOKE

      \NOSE POKE RIGHT
      ^RNPCHAIN = 16    \NOSEPOKE DURING CHAIN
      ^RNPLEVER = 17    \NOSEPOKE DURING LEVER
      ^RNP = 18   \NOSEPOKE DURING NOSEPOKE

      \HEAD ENTRIES
      ^HECHAIN = 19     \HEADENTRIES DURING CHAIN
      ^HELEV = 20       \HEADENTRIES DURING LEVER
      ^HENP = 21  \HEADENTRIES DURING NOSEPOKE

      ^SECLEV = 22      \TIME IN LEVER
      ^SECCHAIN = 23    \TIME IN CHAIN
      ^SECNP = 24 \TIME IN NOSEPOKE
      ^PROG = 25  \ORDER OF PRESENTATION

        ^TOLEV   = 26   \TIMED OUT LEVER TRIALS
        ^TONP    = 27   \TIMED OUT NP TRIALS
        ^TOCHAIN = 28   \TIMED OUT CHAIN TRIALS

\E
\F
\G
```

```
\H
\I
\J
\K
\L
\M
\N
\O
\P
\Q
\R
\S
\T
\U
\V
\W
\X
\Y
\Z

DIM A = 9
DIM D = 29
DIM F = 19
DIM G = 219

LIST B = 1, 2, 3
LIST C = 0.5", 1.6", 2.9", 4.3", 6", 8", 10.5", 13.9", 19.2", 33"


DISKVARS = A, B, D, F, G

S.S.1,      \---------------------------------------BOX CHECK --------
---------\
S1,
      1": ON, ^RIGHTLEV, ^LEFTLEV, ^LEFTLEVLIGHT --->S2
S2,
      2#R^LEFTLEVRESP: ON ^RIGHTLEVLIGHT; OFF ^LEFTLEVLIGHT --->S3
S3,
      2#R^RIGHTLEVRESP: ON ^LEFTNPLIGHT; OFF ^RIGHTLEVLIGHT --->S4
S4,
      2#R^LEFTNP: ON ^RIGHTNPLIGHT; OFF ^LEFTNPLIGHT --->S5
S5,
      2#R^RIGHTNP: ON ^WHITENOISE; OFF ^RIGHTNPLIGHT --->S6
S6,
      2#R^CHAIN: ON ^FOOD; OFF ^WHITENOISE --->S7
S7,
      #R^HEADENTRY: OFF ^FOOD; ON ^FAN, ^WHITENOISE; RANDD A(0) = B,
A(1) = B, A(2) = B; SET D(^PROG) = D(^PROG) + (A(0)*100) + (A(1)*10) +
A(2);  SHOW 1, KPULSE?, Z  --->S8
S8,
      #Z^ZEND:SHOW 1, LSR, D(^LSR), 2, NPSR, D(^NPSR), 3, CHAINSR,
D(^CHAINSR), 4, LRESP, (D(^LLEV)+D(^RLEV)), 5, NPRESP,
(D(^LNP)+D(^RNP)), 6, CHRESP, D(^CHAINRESP), 7, SECS, A(8) ---
>STOPABORTFLUSH

S.S.2, \--------------------------------------MAIN CONTROL------------
-----\
S1,
```

```
      #START: --->S2
        #K1: SET B(0) = 1, B(1) = 1, B(2) = 1; SHOW 1, LEVERONLY, Z ---
>SX
        #K2: SET B(0) = 2, B(1) = 2, B(2) = 2; SHOW 1, NOSEONLY, Z ---
>SX
        #K3: SET B(0) = 3, B(1) = 3, B(2) = 3; SHOW 1, CHAINONLY, Z ---
>SX
        #K4: SET F(0) = 1; SHOW 2, EXTLEVER, Z --->SX
        #K5: SET F(1) = 1; SHOW 3, EXTNOSE, Z --->SX
        #K6: SET F(2) = 1; SHOW 4, EXTCHAIN, Z --->SX
S2,
      1": RANDD E = B; IF E = 1 [@T1, @F1]
                              @T1: Z^ZLEVER --->S3
                  @F1: IF E = 2 [@T2, @F2]
                              @T2: Z^ZNP --->S3
                              @F2: Z^ZCHAIN --->S3
S3,
      #Z^ZSR: ADD A(7); IF A(7) >= 90 [Z^ZEND] --->SX
      #Z^ZTIMEUP: ADD A(6); SET A(7) = 0 --->S2
        #Z^ZSWITCH: --->S2

S.S.3, \----------------------------------------------COMPONENT TIMER --
-----------------\
S1,
      #START: --->S2
S2,
      1": ADD A(8); SHOW 5, SEC, A(8); IF A(8) >= 2700 [Z^ZEND] --->S1

S.S.4,  \---------------------------------------LEVER COMPONENT --------
---------------------\
S1,
      #Z^ZLEVER: ON ^WHITENOISE --->S2
S2,
      .01": RANDD A(9) = C --->S3
S3,
      A(9)#T: ON ^LEFTLEVLIGHT; Z^ZLISTENLEV --->S4
S4,
      #R^LEFTLEVRESP: OFF ^LEFTLEVLIGHT; ON ^RIGHTLEVLIGHT;
Z^ZLISTENLEVSEC --->S5
        20": OFF ^LEFTLEVLIGHT; ADD A(7); Z^ZTO --->S6
S5,
        20": OFF ^RIGHTLEVLIGHT; ADD A(7); Z^ZTO --->S6
      #R^RIGHTLEVRESP: OFF ^RIGHTLEVLIGHT; IF F(0) = 1 [@T, @F]
                                                  @T: Z^ZSR --->S6
                                                  @F: ON ^FOOD; Z^ZSR;
ADD F(15) --->S6
S6,
      1": OFF ^FOOD; Z^ZSWITCH --->S1


S.S.5,  \---------------------------------------NOSE POKE COMPONENT ----
-------------------------\
S1,
      #Z^ZNP: ON ^WHITENOISE --->S2
S2,
      .01": RANDD A(9) = C --->S3
S3,
      A(9)#T: ON ^LEFTNPLIGHT; Z^ZLISTENNP --->S4
```

```
S4,
      #R^LEFTNP: OFF ^LEFTNPLIGHT; ON ^RIGHTNPLIGHT; Z^ZLISTENNPSEC ---
>S5
        20": OFF ^LEFTNPLIGHT; ADD A(7); Z^ZTO --->S6
S5,
        20": OFF ^RIGHTNPLIGHT; ADD A(7); Z^ZTO --->S6
      #R^RIGHTNP: OFF ^RIGHTNPLIGHT; IF F(1) = 1 [@T, @F]
                                                  @T: Z^ZSR --->S6
                                                  @F: ON ^FOOD; Z^ZSR;
ADD F(16)  --->S6
S6,
      1": OFF ^FOOD; Z^ZSWITCH --->S1


S.S.6, \--------------------------------------------CHAIN PULL
COMPONENT -----------------------\
S1,
      #Z^ZCHAIN: ON ^WHITENOISE --->S2
S2,
      .01": RANDD A(9) = C --->S3
S3,
      A(9)#T: OFF ^WHITENOISE; Z^ZLISTENCH --->S4
S4,
      #R^CHAIN: ON ^WHITENOISE --->S5
        20": ON ^WHITENOISE; ADD A(7); Z^ZTO --->S7
S5,
      1": OFF ^WHITENOISE; Z^ZLISTENCHSEC --->S6
S6,
        20": ON ^WHITENOISE; ADD A(7); Z^ZTO --->S7
      #R^CHAIN: ON ^WHITENOISE; IF F(2) = 1 [@T, @F]
                                                  @T: Z^ZSR --->S7
                                                  @F: ON ^FOOD; Z^ZSR;
ADD F(17) --->S7
S7,
      1": OFF ^FOOD; Z^ZSWITCH --->S1

S.S.7, \-------------------------------------------DATA RECORDS -------
---------------------------\
S1,
      #Z^ZLEVER: SHOW 1, LEVER, A(A(6)) --->S2
      #Z^ZNP: SHOW 1, NP, A(A(6))--->S3
      #Z^ZCHAIN: SHOW 1, CHAIN, A(A(6))--->S4
S2,
      #R^LEFTLEVRESP: ADD D(^LLEV); SHOW 2, LEVLEFT, D(^LLEV) --->SX
        #R^RIGHTLEVRESP: ADD D(^RLEV); SHOW 3, LEVRIGHT, D(^RLEV) --->SX
      #R^HEADENTRY: ADD D(^HELEV) --->SX
      #R^RIGHTNP: ADD D(^RNPLEVER) --->SX
      #R^LEFTNP: ADD D(^LNPLEVER) --->SX
      #R^CHAIN: ADD D(^CHAINLEV) --->SX
      #Z^ZSR: ADD D(^LSR); SHOW 4, LEVSR, D(^LSR)--->SX
      #Z^ZSWITCH: --->S1

S3,
      #R^LEFTLEVRESP: ADD D(^LLEVNP) --->SX
        #R^RIGHTLEVRESP: ADD D(^RLEVNP) --->SX
      #R^HEADENTRY: ADD D(^HENP) --->SX
      #R^RIGHTNP: ADD D(^RNP); SHOW 3, NPRIGHT, D(^RNP) --->SX
      #R^LEFTNP: ADD D(^LNP); SHOW 2, NPLEFT, D(^LNP) --->SX
```

```
      #R^CHAIN: ADD D(^CHAINNP) --->SX
      #Z^ZSR: ADD D(^NPSR); SHOW 4, NPSR, D(^NPSR) --->SX
      #Z^ZSWITCH: --->S1

S4,
      #R^LEFTLEVRESP: ADD D(^LLEVCHAIN) --->SX
        #R^RIGHTLEVRESP: ADD D(^RLEVCHAIN) --->SX
      #R^HEADENTRY: ADD D(^HECHAIN) --->SX
      #R^RIGHTNP: ADD D(^RNPCHAIN) --->SX
      #R^LEFTNP: ADD D(^LNPCHAIN) --->SX
      #R^CHAIN: ADD D(^CHAINRESP); SHOW 2,CHAIN, D(^CHAINRESP) --->SX
      #Z^ZSR: ADD D(^CHAINSR); SHOW 4, CHAINSR, D(^CHAINSR) --->SX
      #Z^ZSWITCH: --->S1

\S.S.8,
\S1,
\     1": IF A(6) >= 3 [SHOW 1, LSR, D(^LSR), 2, NPSR, D(^NPSR), 3,
CHAINSR, D(^CHAINSR), 4, PROGRAM, D(^PROG)] --->STOPABORTFLUSH

S.S.8, \-------------LATENCIES
S1,
        #START: SET F(5) = 0, F(6) = 35, F(7) = 75, F(8) = 110, F(9) =
150, F(10) = 185--->S2
      #K1: SET F(5) = 0, F(6) = 95 --->S2
        #K2: SET F(7) = 0, F(8) = 95 --->S2
        #K3: SET F(9) = 0, F(10) = 95 --->S2
S2,
        #Z^ZLISTENLEV --->S3
        #Z^ZLISTENNP --->S5
        #Z^ZLISTENCH --->S7
S3,
        .1": SET G(F(5)) = G(F(5)) + .1 --->SX
        #Z^ZTO ! #R^LEFTLEVRESP: ADD F(5) --->S4
S4,
        .1": SET G(F(6)) = G(F(6)) + .1 --->SX
        #Z^ZTO ! #R^RIGHTLEVRESP: ADD F(6) --->S2
S5,
        .1": SET G(F(7)) = G(F(7)) + .1 --->SX
        #Z^ZTO ! #R^LEFTNP: ADD F(7) --->S6
S6,
        .1": SET G(F(8)) = G(F(8)) + .1 --->SX
        #Z^ZTO ! #R^RIGHTNP: ADD F(8) --->S2
S7,
        .1": SET G(F(9)) = G(F(9)) + .1 --->SX
        #Z^ZTO ! #R^CHAIN: ADD F(9) --->S8
S8,
        .1": SET G(F(10)) = G(F(10)) + .1 --->SX
        #Z^ZTO ! #R^CHAIN: ADD F(10) --->S2
```

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