THE EFFECTS OF HIGH MAGNITUDE REINFORCEMENT AND REINFORCER DELAY:
A CONTINGENCY MANAGEMENT ANALOG STUDY

By

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Abstract

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Substance abuse has severe implications for individuals, families, and communities. Contingency management (CM) is an empirically validated treatment for drug abuse and is an effective component of treatments for many types of substance use disorders. CM arranges consequences to increase desired behavior and decrease undesired behavior. In most cases this is accomplished through reinforcement of drug-abstinent behavior using vouchers, opportunity to win a prize, money, or earning clinical privileges. Reinforcer magnitude and reinforcer delay are two important factors which contribute to CM efficacy. Reinforcers with greater magnitude are generally associated with greater clinical efficacy. Delay to reinforcement is generally associated with poor outcomes in clinical settings. The current experiment used an analog model of CM for the treatment of drug abuse to study the effects of reinforcer magnitude and reinforcer delay on abstinence from drug use. It was predicted that there would be no effect of delay in the high magnitude condition, and that delay would be associated with a decrease in target behavior in the low magnitude condition. Results indicate that high magnitude of reinforcement, both with and without delay, is associated with higher rates of abstinence when compared with the
rates of abstinence maintained by low magnitude of reinforcement. Delayed high magnitude reinforcement was associated with shorter intervals to relapse to smoking when compared to immediate high magnitude reinforcement. No effect of delay was detected in the low magnitude condition. Implications for CM based treatment of addiction are discussed.
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CHAPTER ONE

INTRODUCTION

Substance use disorders are a serious threat to the well-being of individuals, families, and communities. The results of a recent investigation estimate that in the United States 19.9 million Americans aged 12 and older (8% of the population) have used an illicit drug in the past 30 days (SAMHSA, 2010). This same study estimates that 22.3 million people in the U.S. aged 12 and older met the criteria for dependence or abuse of alcohol and/or an illicit substance. This rate is comparable to that of the previous five years, indicating a steady rate of abuse and dependence. Drug abuse and dependence have serious health, social, and economic implications, with estimates of the annual cost of drug abuse in the United States ranging from $180 – $246 billion (Holland & Mushinski, 1999; Office of National Drug Control Policy, 2004).

There are a number of approaches to the treatment of substance use disorders. Multiple studies support the efficacy of treatment and have typically shown that those who receive treatment have lower rates of drug use at follow-up assessments than those that do not (Gossop, Marsden, Stewart, & Kidd, 2003; Hubbard, Craddock, & Anderson, 2003; Inciardi, S. S. Martin, & Butzin, 2004). Contingency management (CM) is an empirically validated treatment for substance use disorders and has been successfully applied to a variety of substances and treatment populations (Higgins, Silverman, & Heil, 2008).

Foundations of Contingency Management

The theoretical foundation of CM derives from operant psychology (e.g., Skinner, 1938, 1961) and is based on the observation that abused drugs act as a reinforcer (i.e., that they can maintain behavior when offered contingently), and drug taking is subject to the rules of operant...
behavior such as: behavior is controlled by antecedent variables (e.g., state of drug deprivation or exposure history), response variables (e.g., the specific behavior required to receive drug), and variables that involve post-response events (e.g., delay to reinforcement) (Thompson & Schuster, 1968). CM emerged from the convergence of two independent lines of study that are founded on this theoretical foundation (Bigelow & Silverman, 1999): behavioral pharmacology, which has investigated the reinforcing effects of drugs, and clinical programs that applied behavioral principles in a therapeutic setting.

The basis in behavioral pharmacology comes from research indicating that the behavior of drug taking is influenced by environmental factors. This concept is central to CM. A relevant example of an environmental factor that can influence drug taking behavior is the introduction of an alternative, non-drug reinforcer. Typically, an alternative, non-drug reinforcer that is sufficiently large and available contingent on not using the drug will decrease the rate of drug use (e.g., Roll & Newton, 2008). The influence of a salient alternative reinforcer on drug taking behavior has been demonstrated in research with animals (e.g., M. E. Carroll, Lac, & Nygaard, 1989; Nader & Woolverton, 1991) and humans (Bickel, DeGrandpre, Higgins, Hughes, & Badger, 1995; Higgins, Bickel, & Hughes, 1994; Roll, Reilly, & Johanson, 2000). CM treatment of drug abuse builds on these findings by systematically providing alternative sources of reinforcement contingent on the occurrence of a target behavior (e.g., provision of a drug negative urine test) and withholding of those consequences in the absence of the target behavior (e.g., provision of a drug positive urine test). For example, a voucher redeemable for goods/services would be given to a person in treatment if a biological sample was provided that indicated drug abstinence. If the biological sample indicated drug use, the voucher would be withheld.
Initial application of behavioral principles to the treatment of drug abuse in a clinical setting was in the treatment of alcoholism (Hunt & Azrin, 1973) and benzodiazepine abuse (Stitzer, Bigelow, & Liebson, 1979). Hunt & Azrin (1973) used removal of social reinforcers such as job, family and social relations to reduce drinking. Stitzer et al. (1979) provided clinical privileges in a methadone clinic contingent on reduced use of diazepam. Despite evidence suggesting that behavioral principles could effectively treat substance use disorders, they did not initially gain widespread use. Not until the early 1990s, after CM was shown to provide significant results when used to treat cocaine addiction (Higgins, Budney, & Bickel, 1994a), did CM treatment of drug addiction begin to gain in popularity (Bigelow & Silverman, 1999). The success of CM in treating cocaine addiction has led to increased research into CM treatments for drug addiction, the application of CM to other drugs of abuse, the development of novel approaches of using CM techniques, and to the utilization of CM treatments with novel populations that historically have not responded well to existing treatment programs (Higgins, Heil, & Lussier, 2004; Higgins et al., 2008).

Contingency management is an effective treatment for drug addiction in terms of the number of supporting empirical studies, the variety of drugs and client populations with which it has been used, the client retention rate, and the relatively high mean effect size (see reviews and meta analyses by: Lussier, Heil, Mongeon, Badger, & Higgins, 2006; Petry, 2000; Prendergast, Podus, Finney, Greenwell, & Roll, 2006).

CM has been used successfully to treat drug addiction in a number of specific populations that are typically considered challenging, such as adolescents (Corby, Roll, Ledgerwood, & Schuster, 2000; O'Leary Tevyaw et al., 2007; Roll & Watson, 2006), college students (Correia & Benson, 2006; Irons & Correia, 2008), homeless (Milby & Schumacher, 2008; Schumacher et
al., 1999, 2003; however, see also: Milby et al., 2003, 2008), people with mental illness (Burgio,
Page, & Capriotti, 1985; Roll, Higgins, Steingard, & McGinley, 1998; Roll, Chermack, &
Chudzynski, 2004; Sigmon, Steingard, Badger, Anthony, & Higgins, 2000; Tidey & Ries, 2008;
Weinstock, Alessi, & Petry, 2007) pregnant women (Heil et al., 2008; Heil, Yoon, & Higgins,
2008; Rosado, Sigmon, Jones, & Stitzer, 2005) and unemployed persons (Wong, Dillon, Sylvest,

CM has also been used successfully to treat addictions to various substances including:
alcohol (M. Cohen, Liebson, Faillace, & Speers, 1971; Miller, 1972; Petry, B. Martin, Cooney,
& Kranzler, 2000; Wong, Silverman, & Bigelow, 2008), benzodiazepine (Chutuape, Silverman,
& Stitzer, 1999; Stitzer et al., 1979), cocaine (Higgins, Budney, & Bickel, 1994b; Higgins,
Budney, Bickel, Foerg, & et al, 1994; Kirby, Marlowe, Festinger, Lamb, & Platt, 1998; Petry et
al., 2004), marijuana (Budney, Higgins, Radonovich, & Novy, 2000; Budney, Moore, Rocha, &
Higgins, 2006; Budney & Stanger, 2008; Kadden, Litt, Kabela-Cormier, & Petry, 2007),
methamphetamine (Roll et al., 2006; Roll, 2007; Shoptaw et al., 2005) nicotine (Correia &
Benson, 2006; Irons & Correia, 2008; Sigmon, Lamb, & Dallery, 2008; Stitzer & Bigelow,
1984), and opioids (Higgins, Stitzer, Bigelow, & Liebson, 1986; McCaul, Stitzer, Bigelow, &
Liebson, 1984). In addition, CM has been successfully used to treat those that concurrently
abuse more than one type of drug (Dallery, Silverman, Chutuape, Bigelow, & Stitzer, 2001;
Iguchi, Stitzer, Bigelow, & Liebson, 1988; Peirce et al., 2006; Petry & B. Martin, 2002; Petry et
al., 2005; but also see Downey, Helmus, & Schuster, 2000). Combined, these findings support
CM as a powerful drug abuse treatment modality for facilitating change in drug use behaviors.
Reinforcement in Contingency Management

Contingency management arranges consequences to increase desired behavior and decrease undesired behavior. In most cases of CM treatments of substance abuse, the focus is on increasing a desired behavior through reinforcement (e.g., reinforcing biologically verified abstinence). However, there are examples in the literature of the use of punishment to decrease undesired behavior. For instance, in the criminal justice system CM has been used as a component of drug courts to systematically deliver negative consequences for non-compliance with court ordered treatment (Burdon, Roll, Michael L. Prendergast, & Rawson, 2001; Marlowe & Wong, 2008), and in the medical field a physician in treatment for drug-abuse might sign a contract stipulating that if drug use occurs a prepared letter stating that he/she is abusing drugs will be mailed to their medical licensing board (Anker & Crowley, 1982; Crowley, 1985, 1999; however, see Magura, Casriel, Goldsmith, Strug, & Lipton, 1988). In almost all cases when punishment is used in CM it is in conjunction with reinforcement. For example, the schedule of reinforcement that is often used in CM includes the punishment of a reset contingency in reinforcer magnitude if drug-use occurs along with an incrementing magnitude of reinforcement contingent on drug-abstinence (Roll & Higgins, 2000; Roll, Higgins, & Badger, 1996; Roll & Howard, 2008).

There are a variety of reinforcers that have been used in CM treatments to reinforce a target behavior. Vouchers redeemable for goods and services are frequently used (Higgins, Alessi, & Dantona, 2002; Higgins et al., 1994; Kirby et al., 1998). These are provided contingently to the person receiving treatment. When received, the person may use the voucher to purchase goods or services, with the approval of his/her counselor. Clinic staff facilitate
redeeming the vouchers by making all purchases, thus the person receiving treatment receives only vouchers and not money.

Opportunity to win a prize is another type of reinforcement used in CM based treatments (Petry, Alessi, Marx, Austin, & Tardif, 2005). The prize in these programs is often an item useful for everyday living (e.g., bus tokens, toiletries, pots, dishes, gift certificate to local restaurant or store). Participants earn opportunities to draw a token out of a bowl that contains many tokens. A prize is won by drawing a winning token. Typically half of the available tokens are “non-winners” that have a printed message, such as “Good Job,” while the other half of the tokens are “winners” worth a small, medium, or jumbo reward. While not all the tokens are “winners,” all can be considered reinforcers, because the non-winners have been shown to maintain the target behavior (Petry et al., 2000; Petry et al., 2004). In the cited studies, the small reward was worth $1.00, the medium prize worth $20.00, and the jumbo prize worth approximately $100.00, with the chance of winning a prize inversely related to its value.

The comparative efficacy of vouchers vs. that of prizes at maintaining abstinent behavior has been found to be equal, both in terms of initial abstinence and in terms of post-treatment abstinence at six and nine month follow-up (Petry, Alessi, Hanson, & Sierra, 2007; Petry et al., 2005).

While vouchers and opportunity to win a prize are the most common types of reinforcers used in CM treatments of drug abuse, other types reinforcers that have been used are: access to privileges (M. Cohen, Liebson, Faillace, & Allen, 1971; Kadden & Mauriello, 1991), take home methadone (Chutuape, Silverman, & Stitzer, 2001; Kidorf & Stitzer, 1999; Milby, Garrett, English, Fritschi, & Clarke, 1978; Schmitz et al., 1998; Stitzer, Iguchi, & Felch, 1992), and opportunity to work (Donlin, Knealing, & Silverman, 2008; Silverman et al., 2007). Take-home
privileges for patients in methadone maintenance programs are a highly desired type of reinforcement and some studies have shown that they are preferred to money (Amass, Bickel, Crean, Higgins, & Badger, 1996; Chutuape, Silverman, & Stitzer, 1998; Schmitz, Rhoades, & Grabowski, 1994; Stitzer & Bigelow, 1978). The finding that elements of the existing treatment can be used contingently to control behavior is encouraging, as the perceived cost of CM programs is often cited as a reason for this treatment technology not being widely adopted (Kirby, Benishek, Dugosh, & Kerwin, 2006; Petry & Alessi, 2008). Addressing this issue, researchers have identified a number of reinforcers available in a treatment clinic, such as take-home doses of methadone, which could be used in place of money or vouchers (Roll, Chudzynski, & Richardson, 2005; Schmitz et al., 1994)

Schedule Development

The schedules of reinforcement used in CM procedures vary in level of complexity. The ability of various schedules of reinforcement to control the rate of a behavior has been extensively studied (Catania, 1998; Ferster & Skinner, 1957). An example of a more simple schedule used in CM is one in which the magnitude of reinforcement does not change over the course of treatment. For example, Stitzer & Bigelow (1983) treated tobacco dependence by arranging conditions such that participants could earn a set amount of money per day contingent on providing a carbon monoxide (CO) sample that was 50% lower than baseline. CO is a biochemical marker of smoking measured in expired breath. Results of the study indicated that receiving money (i.e., alternative reinforcer) contingent on decreasing CO level (i.e., target behavior) was effective for decreasing the CO level, with higher magnitudes of reinforcement being associated with higher rates of abstinence.
A more complex schedule of reinforcement is typically employed in modern CM approaches to treatment. This schedule was developed to be used in a CM program for treating cocaine addiction in an outpatient setting (Higgins et al., 1994b). It was specifically designed to initiate and maintain continuous abstinence by providing an escalating magnitude of reinforcement, with each successive biological sample that tested negative for drug use, and awarded bonuses for consecutive abstinence. This schedule also includes a reset contingency such that if a specimen is submitted that tests positive for drug no reinforcement is given and the value of the next negative specimen is reset to the initial level. The purpose of the reset contingency is to discourage relapse. Thereafter, the magnitude of reinforcement escalates again with each successive negative sample until five consecutive drug-negative specimens are submitted. At that point the value of the reinforcer is returned to the highest prior value received.

This schedule of reinforcement has been the subject of continued refinement and validation through experimental analysis. Silverman et al. (1996) demonstrated that it was the contingent delivery of vouchers that resulted in drug abstinence, as opposed to the delivery of vouchers alone. Roll, Higgins, & Badger (1996) found that using an escalating magnitude of reinforcement resulted in higher rates of sustained abstinence, relative to a schedule in which the reinforcer value was unchanged over the course of treatment. Roll & Higgins (2000) replicated and expanded these findings and also demonstrated the importance of the reset contingency for maintaining in-treatment abstinence.

Roll et al. (2006) continued research on the schedule of reinforcement typically used in CM treatments by investigating variables that might lead to improved rates of abstinence. These include: having a high or low initial reinforcement level, a periodic bonus for sustained
abstinence, inclusion of a reset contingency, having a rapid, slow, or moderate rate of escalation of reinforcer value, and having a reinforcer value that increased or decreased. The relevant findings from this study suggest that a schedule that includes escalating reinforcer magnitude for consecutive instances of abstinence, bonuses for continuous abstinence, and a reset in voucher magnitude for failure to abstain is most efficacious in initiating and maintaining abstinence (Roll et al., 2006).

Further research on the schedule of reinforcement used in CM has focused on the manner in which a schedule programs reinforcement delivery. The findings of Roll & Howard (2008) indicated that a schedule that arranges reinforcement in an “economic gain” situation of providing reinforcement for samples that indicate abstinence rather than an “economic loss” situation of taking sums away from a lump sum to be awarded after treatment has important implications for the target behavior. These investigators demonstrated that providing reinforcers for biological samples that indicated abstinence resulted in better outcomes compared to taking money away for failure to abstain. While the amount of possible reinforcement was the same for the gain and loss groups, the manner in which it was distributed influenced the amount of control it had on the target behavior.

**Reinforcer Magnitude**

Regardless of the type of reinforcer used, be it vouchers, prizes, privileges, or something else, there are important factors that influence how efficacious the reinforcer will be. Magnitude of reinforcement is one such factor. Research on the effect of reinforcer magnitude on behavior has shown interactions between magnitude and rate of behavior. Empirical findings have not consistently shown that greater magnitude of reinforcement (whether defined in terms of volume, concentration, duration of access, or number of items) always results in more (or less) of a
behavior. There are examples in the basic research of higher magnitude reinforcers being associated with higher rates of behavior in terms of response rate, and breaking point (e.g., Hodos & Kalman, 1963; Kliner, Lemaire, & Meisch, 1988; de Villiers & Herrnstein, 1976). There are also examples in the basic literature that indicate greater reinforcer magnitude does not result in an increase of behavior (e.g., Bonem & Crossman, 1988; Reed, 1991). It is not clear that the cause for this discrepancy has been resolved, but the type of schedule of reinforcement used combined with the magnitude of reinforcement appears to be influential. For example, Reed (1991) reported that high magnitude of reinforcement resulted in a decrease in response rate on a variable-interval 30-s schedule, while an increase in response rate was observed with high magnitude reinforcement on a variable-ratio 30 schedule. Human research on the effect of reinforcer magnitude on behavior has largely found consistent results, with reinforcer magnitude being associated with higher rates of target behavior (Bennett & Samson, 1987; Champion & Leung, 1964; Higgins et al., 1994).

Research on the effects of reinforcer magnitude in CM clinical treatments for addiction have almost exclusively been done using treatments targeting cocaine addiction (Dallery et al., 2001; Garcia-Rodriguez et al., 2009; Higgins et al., 2007; Petry et al., 2004; Silverman, Chutuape, Bigelow, & Stitzer, 1999). These clinical treatment studies have consistently found that reinforcers of higher magnitude are associated with better treatment outcomes. For example, Dallery et al. (2001) found that higher reinforcer magnitude was associated with higher rates of abstinence. Increasing the magnitude of reinforcement in CM treatments has even led to increased rates of abstinence in patients that were considered treatment-resistant (Silverman et al., 1999). Higgins et al. (2007) found that higher magnitude of reinforcement is also associated with longer duration of continuous abstinence. A recent meta-analysis of voucher based CM
treatments found that the magnitude of the monetary value of vouchers was associated with larger effect sizes (Lussier et al., 2006a). Magnitude of reinforcement has also been shown to be important for treatment outcomes such as retention in treatment (Garcia-Rodriguez et al., 2009), rate of attendance in continuing care (Businelle, Rash, Burke, & Parker, 2009), and higher rate of abstinence at follow up (Higgins, Badger, & Budney, 2000; Higgins et al., 2007; Higgins, Wong, Badger, Ogden, & Dantona, 2000).

In addition to clinical research, CM analog studies have been conducted to analyze the effect of reinforcer magnitude in an analog of CM treatment of substance use disorders (Higgins et al., 1994; Lamb, Kirby, Morral, Galbicka, & Iguchi, 2004; Roll et al., 2000; Stitzer & Bigelow, 1983). These have also uniformly found that higher magnitude of reinforcement results in higher rates of drug abstinence. Higgins, Bickel, & Hughes (1994) showed that the number of choices for drug decreased as the magnitude of the alternative reinforcer increased. The results of Roll et al. (2000) indicated that choice for drug is lowest when the alternative reinforcer is at its highest magnitude and lowest delay.

Concerns have been raised by some that higher magnitude of reinforcement may result in adverse consequences, such as the patient may be more likely to relapse due to increased resources or that the patient may feel coerced (Dickert & Grady, 1999; Fry & Dwyer, 2001). While this issue has not been fully resolved there are data to suggest that using high magnitude reinforcement does not result in increased drug use or feelings of being coerced, but is instead associated with greater participant satisfaction with the study (Festinger, Marlowe, Dugosh, Croft, & Arabia, 2008; Festinger et al., 2005).
Reinforcer Delay

The effect of delayed reinforcement on behavior has been extensively studied (e.g., Catania, 1998; Renner, 1964). Reinforcer delay has been shown to influence the effectiveness of the reinforcer in controlling behavior of animals (Grice, 1948; Perin, 1943; Pierce, Hanford, & Zimmerman, 1972) and humans (Kirby et al., 1998; Vuchinich, Tucker, & Rudd, 1987). The study of the influence of delay to reinforcement on behavior has consistently shown that delay is associated with an increase in the amount of time and the number of trials needed to acquire the response (Pierce et al., 1972; Renner, 1964).

An example of the influence of delayed reinforcement in CM was demonstrated by Kirby et al. (1998). Exp. 2 investigated the influence of delivering vouchers after each sample that indicated abstinence vs. providing vouchers in a single lump sum at the end of treatment. Despite having an equal amount of total possible reinforcement, it was found that participants that were provided vouchers at each test had better treatment outcomes in terms of continuous cocaine abstinence, and total number of cocaine-free urine samples. In addition, participants who received reinforcement at each test had more urine samples submitted that were free from any drug, even though this was not a contingency for reinforcement. Thus, by changing the schedule of reinforcement to one with more frequent reinforcement, and less delay between the behavior and the reinforcement, the experimenters were able to dramatically improve the treatment outcomes.

The decrease in target behavior rate in CM treatments as a result of reinforcer delay was supported in a recent meta-analysis (Lussier et al., 2006a). This analysis found that across 30 journal articles delayed reinforcement was associated with an average effect size that was nearly half that of studies that provided immediate reinforcement. It was also found in multivariate
analysis that reinforcer delay was a significant predictor of effect size, with more delay associated with smaller effect size. This meta-analysis supports the large influence that delayed reinforcement has in CM treatments.

Contingency Management Analog Studies

As briefly mentioned above, an analog study is a laboratory procedure developed to study specific aspects of a behavior, or the influence on behavior of specific aspects of a clinical or applied procedure (cf. Roll et al., 1996). The use of analog studies has a rich history in the experimental analysis of behavior. For example, the experimental chamber developed by Skinner for use with rats and pigeons was a means of studying particular aspects of behavior in a simplified and controlled environment, an analog of the complex environments that are usually encountered (Skinner, 1965). Analog studies have played an important role in making refinements to the schedule of reinforcement used in CM treatments of substance abuse (Roll & Higgins, 2000; Roll et al., 1996; Roll & Howard, 2008). Cigarette smoking is often used as an exemplar of drug use in CM analog studies for a number of reasons. These include: most relapse to cigarette smoking occurs within 48 hours of a quit attempt (Cummings, Giovino, Jaén, & Emrich, 1985; Hughes et al., 1992) smokers are a relatively easier population to work with than users of illicit drugs, and smoking behavior is easily measured using a breath CO meter.

Roll, Reilly, & Johanson (2000) conducted a proof of concept study investigating the effect of reinforcer magnitude and delay on CM efficacy. To be eligible to participate on any given day cigarette smoking participants were required to meet the abstinence criteria of a CO sample that indicated 50% or less of their baseline CO level. The reinforcer (money) earned as an alternative to choosing drug (puffs on a cigarette) changed for each of 10 one hour sessions both in magnitude ($0.10, $1.00, or $2.00) and delay (no delay, 1 week, or 3 weeks).
Participants made 10 independent choices for drug or money in the course of the one hour session, one choice every five minutes. The importance of reinforcer magnitude and delay was shown in that both the amount of money offered as an alternative to a puff on a cigarette, and the amount of time until the money was delivered, significantly altered the number of times participants chose to consume a puff on a cigarette. Greater reinforcer magnitude and smaller delay intervals were associated with fewer puffs selected. While these findings are intriguing and have been widely disseminated (e.g., Higgins et al., 2004), the next logical step was to conduct an experiment that increased the external validity of these findings.

The Current Study

The current experiment aimed to increase the external validity of the findings of Roll et al. (2000) by using a CM analog study that more closely approximated CM treatment conditions. Specifically, the current experiment provided alternative reinforcement contingent on the provision of a biological sample that indicated drug abstinence, instead of offering an alternative to drug during the experimental session. Participants received either a high or low magnitude of reinforcement that was provided either immediately or after a delay. It was hypothesized that 1) participants receiving a high magnitude of reinforcement would have better outcomes than those that receive a low magnitude of reinforcement, 2) participants in the no-delay conditions would have better outcomes than participants in the delay condition of the corresponding level of reinforcer magnitude, and 3) based on the trend observed in Roll et al. (2000), that the effect of reinforcer delay would depend on the level of reinforcer magnitude such that outcomes for the high magnitude groups would be similar and those of the low magnitude groups would not.
METHOD

Screening

A screening interview was conducted to determine participant eligibility. This interview took place either over the phone, via email, or in-person (according to how the person responded to the advertisement). Following a prepared script, the interviewer asked participants if they currently smoked, the average number of cigarettes smoked per day, the number of years smoked, if they were currently trying or wanted to quit smoking, if they used smokeless tobacco, and if they were between 18 and 60 years old. To qualify for the study, participants were required to currently smoke $\geq 10$ cigarettes per day (Roll & Howard, 2008), have smoked for at least 2 years (Dallery, Meredith, & Glenn, 2008), be between the ages of 18 and 60, not pregnant, have no self-reported current use of smokeless tobacco, and answer in the negative to the question: “Are you currently trying to, or do you want to quit smoking?” Participants were required to not be currently trying to quit smoking to limit the influence of extraneous variables affecting smoking during the study. Those that met the inclusion criteria were scheduled for an in-person screening.

Participants

Participants were 103 adult volunteers (27 females, 76 males) recruited from the community using local online classified advertisements and via word-of-mouth (Packer, Roll, B. Banasik, & J. Banasik, 2010). All participants were between 18 and 60 years old ($M=30$, $SD=9.8$). 67% were single, and had an average of 12 years of education (range: 7 – 20). Measures of smoking history indicated that the participants smoked an average of 19 cigarettes per day (range: 10 – 35), had smoked for a mean of 14 years (range: 2 – 45), at intake had a
mean CO level of 18.8 ppm (range: 10 – 74 ppm), and had a Fagerstrom score of 5.4 (indicating moderate dependence on nicotine). On average 76% of the participants’ friends smoked. The racial makeup of the participants was 87.4% White/Caucasian, 1% Black/African American, 6.8% Native American, 4.9% Other/Multi-Racial, which is representative of the area in which the study was conducted. This study was approved by the local Institutional Review Board, and all subjects provided informed consent.

*Intake*

After signing the informed consent form participants submitted a breath CO sample using a CO meter. This handheld device is simple to use, with participants simply blowing through a disposable mouthpiece. For all qualifying participants, demographic information was collected including: age, sex, race, ethnicity, marital status, years of education, percent of friends that smoke, and extent of nicotine dependence as measured by the Fagerstrom Test of Nicotine Dependence (Heatherton, Kozlowski, Frecker, & Fagerström, 1991). Participants were not informed of the inclusion/exclusion criteria (except for the age limit) so as not to bias the participants’ self-reported smoking history and smoking habits.

Participants were instructed to not use any type of nicotine replacement therapy for the duration of the study, but to use "willpower" to refrain from smoking. Willpower was selected because when asked, participants in CM-based treatments typically attribute their success to their own willpower (Silverman et al., 1998).

Those participants that qualified for the study and signed the consent form were randomly assigned into one of the four groups. Randomization was determined by a postdoctoral fellow working in Dr. Roll’s Laboratory who placed the individual group
assignments into envelopes, sequentially numbered, prior to initiation of the study. The envelopes were opened as participants were enrolled in the study.

A saliva sample was collected from all participants immediately after randomization and again at the conclusion of the five day assessment period. These samples were used to assay levels of cotinine, a nicotine metabolite, using the Calbiotech cotinine ELISA kit that was adapted for use with saliva (Packer et al., 2010). Comparing cotinine level from the beginning of the study to levels at the end of the study provided an additional measure of nicotine abstinence. Cotinine has a half-life of 18 hr (Jarvis, Russell, Benowitz, & Feyerabend, 1988; Wall, Johnson, Jacob, & Benowitz, 1988), whereas CO has a much shorter half-life of 2 – 8 hr (Javors, Hatch, & Lamb, 2005; SRNT Subcommittee on Biochemical Verification, 2002). Cotinine can therefore detect exposure to nicotine up to three days after exposure.

**Apparatus**

A Bedfont CO meter was used to collect CO samples. The device was calibrated according to the manufacturer’s guidelines at the beginning of the study.

Saliva samples were collected for cotinine analysis using polypropylenes tube that were capped, labeled, and stored at –80 °C until the day of the cotinine assay, when samples were thawed in the refrigerator. Cotinine concentration was assayed using a high-sensitivity salivary cotinine quantitative enzyme immunoassay kit supplied by Calbiotech Inc. (Spring Valley, CA). The assay required 10 µL of saliva and had a detection limit of 5 ng/ml.

**Design**

The study used a 2 x 2 between subjects design, using combinations of high or low magnitude of reinforcement conditions and delay or no-delay of reinforcement conditions. By
providing a CO sample that indicated smoking abstinence at every opportunity participants in a high magnitude of reinforcement group could earn a total of $207.50, while those in a low magnitude of reinforcement group could earn a total of $70.00. The high magnitude amount was approximately two times the amount used in typical CM analog studies, while the low magnitude amount was approximately half the amount typically used in CM analog studies (e.g., Roll & Howard, 2008). Participants in a delay group received all reinforcers earned a week following the last test of the experiment, while those in a no-delay group received earned reinforcers at each test immediately after providing a CO sample. Thus, there was a high magnitude of reinforcement delay group (HMD), and a high magnitude of reinforcement no-delay group (HMND). Corresponding to these was a low magnitude of reinforcement delay group (LMD), and a low magnitude of reinforcement no-delay group (LMND).

The delivery of reinforcement was based on the procedure that has been previously used to model typical voucher-based reinforcement procedures (Roll & Higgins, 2000; Roll et al., 1996; Roll & Howard, 2008). This schedule incorporates elements that are typically included in CM treatment of drug addiction. These are: an escalating magnitude of reinforcement for successive samples that indicate abstinence, bonuses for three consecutive samples that indicate abstinence, and a reset of reinforcer magnitude to the initial low level following an instance of drug use. The current schedule programmed reinforcement delivery in the following fashion. For the High Magnitude of reinforcement groups, the initial abstinence was worth $7.00. Each consecutive instance of abstinence increased the magnitude by $0.50, and every three consecutive instances of abstinence resulted in the provision of a $10.00 bonus. Failure to abstain resulted in the withholding of the programmed reinforcer and reset the magnitude of the next available reinforcer to the original $7.00 value. At the next trial that indicated abstinence
the progression of reinforcer magnitude and delivery of bonuses began again. For example, if an individual was abstinent on Test 1, he or she received $7.00, abstinent on Test 2 he or she received $7.50, and abstinent on Test 3 he or she received $8.00 plus a $10.00 bonus. If he or she tested positive on Test 4, he or she would receive nothing, and the next abstinence would result in the delivery of $7.00. The Low Magnitude of reinforcement groups worked in the same manner, but with values of lower magnitude. The initial abstinence was worth $0.50 and the bonus for three consecutive abstinences being worth $2.00. The increment for successive abstinences was the same for both High and Low magnitude groups. All reinforcement was provided to the participant in cash.

Participants in the no delay conditions received earned reinforcers immediately after providing a sample that indicated abstinence. Participants in the delay conditions received reinforcers in a lump sum a week following the final test on day five of the study.

General Session Procedure

The experiment took place over the course of a five-day (Monday through Friday) span. Because the half-life of CO is 2-8 hr, CO samples were collected three times daily (morning, afternoon, and evening), with a minimum of 4 hr between assessment. Therefore, over the course of five days participants had 15 opportunities to earn money. Meeting with research personnel this frequently has been used successfully in previous studies (Corby et al., 2000; Roll & Higgins, 2000; Roll et al., 1996; Roll et al., 1998; Roll & Howard, 2008). Each visit was conducted in clinical laboratory facilities provided by the Washington State University College of Nursing. Not all participants took part in the experiment in the same five-day span, but were run in weekly cohorts over the course of six months.
At each assessment, participants provided a CO sample using a handheld CO meter. The criterion for smoking abstinence was a CO reading \(\leq 6\)ppm, a value was chosen based on current research that suggests this level of CO would reliably discern recent smoking activity (Cropsey, Eldridge, Weaver, Villalobos, & Stitzer, 2006; Javors et al., 2005). At each assessment participants also reported their subjective experience of current desire to smoke and current severity of any withdrawal symptoms using a Visual Analog Scale (VAS). VAS are frequently used to quantify the subjective experience of a participant, and been successfully used in smoking and nicotine addiction studies in the past to rate withdrawal symptoms and current desire to smoke (Dallery, Houtsmuller, Pickworth, & Stitzer, 2003; Donny, Houtsmuller, & Stitzer, 2007; Houtsmuller & Stitzer, 1999; Jarvik et al., 2000). The VAS was a 100mm line anchored by the terms “None” and “Very Strong.” The participant would mark with an intersecting line where on the continuum they felt they were with their current craving and withdrawal symptoms.

At each visit participants were given a receipt indicating the amount of money earned at that session, the total amount earned to date, when the next bonus would be available, and the time and place of next assessment. The purpose of the receipt was to remind the participant of the consequence of maintaining abstinence, and act as a reminder for the next appointment.

The data from each test (CO meter reading and VAS scores) was recorded, as was the amount of money earned at each test, any strategies used to abstain from smoking, and self-report data of cigarette use. The data was entered into a Microsoft Access 2007 database on the same day.

At the final assessment participants provided a second saliva sample for cotinine testing. An exit interview was conducted in which the participant was queried regarding any attempts to
quit smoking prior to the study. Questions included: 1) Have you ever tried to quit smoking in the past? 2) How many times have you tried to quit smoking? 3) What type of techniques did you use? 4) What was the longest amount of time you were able to maintain abstinence?

**Data Analysis**

Chi-square analysis was conducted to compare groups on demographic and smoking history variables that were nominal data. These included: marital status, gender, and race. ANOVA was used to analyze all other demographic and baseline measures, including: age, education, average cigarettes smoked per day, years smoked, baseline CO, and Fagerstrom score.

Outcome measures and method of analysis are listed in Table 1. Continuous variables were analyzed using ANOVA. An alpha level of .05 was used for all statistical tests. Pair-wise comparisons (Tukey HSD, $p < .05$) were used to identify specific between-group differences.

A dichotomous dummy variable (0=No, 1=Yes) was created to identify the participants that achieved total abstinence for the duration of the study, those that achieved a 24 hr period of abstinence, and those that resumed smoking after achieving a 24 hr period of abstinence. These dichotomous variables were analyzed using the Likelihood Ratio Chi-square analysis. An adjusted alpha level of 0.01 was used to account for the multiple comparisons. The method of analysis for each outcome measure is summarized in Table 1.

---

1 All CO outcome variables violated the parametric test assumptions of normal distribution and homogeneity of variances. Non-parametric statistical tests supported the conclusions of the equivalent parametric tests.
Table 1. Outcome measures and methods of analysis

<table>
<thead>
<tr>
<th>Outcome Measure</th>
<th>Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of trials abstinent</td>
<td>ANOVA</td>
</tr>
<tr>
<td>Longest duration of abstinence</td>
<td>ANOVA</td>
</tr>
<tr>
<td>Time to first negative test</td>
<td>ANOVA</td>
</tr>
<tr>
<td>Time to first positive test</td>
<td>ANOVA</td>
</tr>
<tr>
<td>Abstinent for the duration of the study</td>
<td>Chi$^2$</td>
</tr>
<tr>
<td>24 hr period of abstinence</td>
<td>Chi$^2$</td>
</tr>
<tr>
<td>Resumed smoking after achieving a 24 hr period of abstinence</td>
<td>Chi$^2$</td>
</tr>
<tr>
<td>Attendance</td>
<td>ANOVA</td>
</tr>
<tr>
<td>Money earned</td>
<td>ANOVA</td>
</tr>
</tbody>
</table>

The procedure for handling missing data was carefully considered as there are clear implications for the interpretation of the data. In the context of the current study a missed appointment was considered to reflect a failure of the reinforcer that was being offered contingent on providing a breath sample that indicated smoking abstinence. Therefore, in those instances when a participant missed an appointment the CO test result was coded as a positive test. It is possible that some of the missed appointments would not have tested positive. Therefore, by counting all missed appointments as positive the Type I error rate is knowingly inflated, and the manipulation’s influence is weakened. This is the most conservative method of interpreting missing data, and has been used in similar studies (Corby et al., 2000; Roll, 2005; Roll et al., 1998).

Cotinine levels at baseline and on the final day of the study were compared using a paired-samples t-test. To determine if reinforcer magnitude and reinforcer delay influenced the subjective experience of desire to smoke and withdrawal symptoms, repeated-measures ANOVA was used to analyze VAS results across groups. The possible influence of demographic and baseline smoking measures significantly influencing the outcome measures was investigated with ANCOVA.
RESULTS

Demographic and smoking history variables across all participants are summarized in Table 2. Analysis of descriptive and smoking history variables by group is summarized in Table 3.

Table 2. Descriptive and Baseline Data

<table>
<thead>
<tr>
<th></th>
<th>M</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cigarettes per Day</td>
<td>19.4</td>
<td>5.6</td>
</tr>
<tr>
<td>Years Smoked</td>
<td>14.4</td>
<td>10.0</td>
</tr>
<tr>
<td>Baseline CO</td>
<td>18.8</td>
<td>9.2</td>
</tr>
<tr>
<td>Fagerstrom</td>
<td>5.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Percent Friends</td>
<td>76.1%</td>
<td>--</td>
</tr>
<tr>
<td>Marital Status (Single)</td>
<td>67%</td>
<td>--</td>
</tr>
<tr>
<td>Age</td>
<td>30.1</td>
<td>9.8</td>
</tr>
<tr>
<td>Education</td>
<td>12.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Gender (Male)</td>
<td>73.8%</td>
<td>--</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
</tr>
<tr>
<td>White/Caucasian</td>
<td>87.4%</td>
<td>--</td>
</tr>
<tr>
<td>Black/African</td>
<td>1%</td>
<td>--</td>
</tr>
<tr>
<td>American</td>
<td>6.8%</td>
<td>--</td>
</tr>
<tr>
<td>Native American</td>
<td>4.9%</td>
<td>--</td>
</tr>
<tr>
<td>Other/Multi-Racial</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Summary of descriptive and smoking history variables by group

<table>
<thead>
<tr>
<th></th>
<th>LMD (n=26)</th>
<th>LMND (n=25)</th>
<th>HMD (n=26)</th>
<th>HMND (n=26)</th>
<th>Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cigarettes per Day</td>
<td>19.7 5.8</td>
<td>20.8 5.1</td>
<td>18.9 4.9</td>
<td>18.3 6.4</td>
<td>F(3, 99) =1.687, p=.175</td>
</tr>
<tr>
<td>Years Smoked</td>
<td>11.2 8.5</td>
<td>17.3 12.1</td>
<td>15.3 10.2</td>
<td>14.0 8.4</td>
<td>F(3, 99) =.052, p =.984</td>
</tr>
<tr>
<td>Baseline CO</td>
<td>18.8 8.7</td>
<td>18.3 7.9</td>
<td>18.6 6.3</td>
<td>19.3 12.9</td>
<td>F(3, 99) =.933, p =.428</td>
</tr>
<tr>
<td>Fagerstrom</td>
<td>5.4 1.9</td>
<td>6.1 2.1</td>
<td>5.2 1.7</td>
<td>4.8 2.3</td>
<td>F(3, 99) =2.00, p =.119</td>
</tr>
<tr>
<td>Friends who smoke (%)</td>
<td>73.4 --</td>
<td>80.0 --</td>
<td>70.0 --</td>
<td>81.7 --</td>
<td>X² (54, N = 103) = 61.542, p =.224</td>
</tr>
<tr>
<td>Marital Status (%)</td>
<td>73.1 --</td>
<td>48.0 --</td>
<td>73.1 --</td>
<td>67.0 --</td>
<td>X² (12, N = 103) = 9.697, p =.643</td>
</tr>
<tr>
<td>Race</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X² (9, N = 103) = 8.782, p =.458</td>
</tr>
<tr>
<td>White/Caucasian</td>
<td>100 --</td>
<td>80.0 --</td>
<td>84.6 --</td>
<td>87.4 --</td>
<td>X² (9, N = 103) = 8.782, p =.458</td>
</tr>
<tr>
<td>Black/African</td>
<td>0 --</td>
<td>4.0 --</td>
<td>0 --</td>
<td>1.0 --</td>
<td>X² (3, N = 103) = 7.918, p =.05</td>
</tr>
<tr>
<td>Native Am.</td>
<td>0 --</td>
<td>0 --</td>
<td>7.7 --</td>
<td>6.8 --</td>
<td></td>
</tr>
<tr>
<td>Other/Multi-Racial</td>
<td>0 --</td>
<td>4.0 --</td>
<td>7.7 --</td>
<td>4.9 --</td>
<td></td>
</tr>
</tbody>
</table>
Randomization into treatment groups resulted in no difference among groups on descriptive and smoking history variables, with the exception of gender. Chi^2 analysis of participant gender by group revealed a significant result, \( \chi^2 (9, N = 103) = 7.92, p = .05 \). This difference is not expected to influence the outcome measures of smoking abstinence as previous research has shown that gender is not a predictor of smoking cessation (Freund, D’Agostino, Belanger, Kannel, & Stokes, 1992; McGrady & Pederson, 2002).

The results of the 15 CO tests conducted over the five days of the study are displayed in Figure 1, showing the CO test results for each participant by group. The results of CO testing may be interpreted using multiple clinically relevant definitions of abstinence. These include the number of trials abstinent, the longest duration of abstinence, the time to first negative trial, and the time to first positive trial. Table 4 summarizes the ANOVA results for the outcome variables as a function of Magnitude and Delay. The analysis of each measure of abstinence resulted in a significant main effect of reinforcer magnitude and a significant interaction of reinforcer magnitude and reinforcer delay, and no significant main effect of reinforcer delay.
Figure 1. The results of CO testing for each individual, categorized by group. Each row represents the test results for an individual participant, identified by their participant ID number. The columns on each panel represent the 15 tests that participants engaged in (3 tests per day x 5 days). A blue square indicates a CO sample ≤ 6ppm. An orange square indicates a CO sample > 6ppm. A gray square indicates that no CO sample was provided.
### Table 4. Analysis of variance for outcome variables as a function of Magnitude and Delay

<table>
<thead>
<tr>
<th></th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Eta²</th>
<th>Observed Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Number of Abstinent Trials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td>1240.41</td>
<td>40.25</td>
<td>&lt; .01</td>
<td>.29</td>
<td>1.00</td>
</tr>
<tr>
<td>Delay</td>
<td>1</td>
<td>35.47</td>
<td>1.15</td>
<td>.29</td>
<td>.01</td>
<td>.19</td>
</tr>
<tr>
<td>Magnitude*Delay</td>
<td>1</td>
<td>189.16</td>
<td>6.14</td>
<td>.02</td>
<td>.06</td>
<td>.69</td>
</tr>
<tr>
<td>Error</td>
<td>99</td>
<td>.49</td>
<td></td>
<td>.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Longest Duration of Abstinence</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td>1107.02</td>
<td>38.05</td>
<td>&lt; .01</td>
<td>.28</td>
<td>1.00</td>
</tr>
<tr>
<td>Delay</td>
<td>1</td>
<td>37.79</td>
<td>1.30</td>
<td>.257</td>
<td>.01</td>
<td>.20</td>
</tr>
<tr>
<td>Magnitude*Delay</td>
<td>1</td>
<td>113.11</td>
<td>3.88</td>
<td>.05</td>
<td>.04</td>
<td>.50</td>
</tr>
<tr>
<td>Error</td>
<td>99</td>
<td>29.10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Time to First Negative</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td>.00</td>
<td>.001</td>
<td>.97</td>
<td>.00</td>
<td>.05</td>
</tr>
<tr>
<td>Delay</td>
<td>1</td>
<td>.20</td>
<td>.63</td>
<td>.43</td>
<td>.02</td>
<td>.12</td>
</tr>
<tr>
<td>Magnitude*Delay</td>
<td>0</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>.00</td>
<td>--</td>
</tr>
<tr>
<td>Error</td>
<td>40</td>
<td>.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Time to First Positive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td>46.02</td>
<td>8.18</td>
<td>.005</td>
<td>.10</td>
<td>.81</td>
</tr>
<tr>
<td>Delay</td>
<td>1</td>
<td>20.37</td>
<td>3.62</td>
<td>.061</td>
<td>.05</td>
<td>.47</td>
</tr>
<tr>
<td>Magnitude*Delay</td>
<td>1</td>
<td>45.48</td>
<td>8.08</td>
<td>.006</td>
<td>.10</td>
<td>.80</td>
</tr>
<tr>
<td>Error</td>
<td>75</td>
<td>5.63</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Attendance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td>1446.24</td>
<td>45.16</td>
<td>&lt; .01</td>
<td>.31</td>
<td>1.00</td>
</tr>
<tr>
<td>Delay</td>
<td>1</td>
<td>20.36</td>
<td>.64</td>
<td>.43</td>
<td>.01</td>
<td>.12</td>
</tr>
<tr>
<td>Magnitude*Delay</td>
<td>1</td>
<td>175.46</td>
<td>5.48</td>
<td>.019</td>
<td>.05</td>
<td>.64</td>
</tr>
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<td>Error</td>
<td>99</td>
<td>32.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Money Earned</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnitude</td>
<td>1</td>
<td>302964.23</td>
<td>69.17</td>
<td>&lt; .01</td>
<td>.41</td>
<td>1.00</td>
</tr>
<tr>
<td>Delay</td>
<td>1</td>
<td>16282.26</td>
<td>3.72</td>
<td>.06</td>
<td>.04</td>
<td>.48</td>
</tr>
<tr>
<td>Magnitude*Delay</td>
<td>1</td>
<td>19829.44</td>
<td>4.53</td>
<td>.04</td>
<td>.04</td>
<td>.56</td>
</tr>
<tr>
<td>Error</td>
<td>99</td>
<td>4380.31</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Group data showing means, standard deviations, and n for the independent variables as a function of group for each outcome variable are displayed in Table 5. The group percentages of dichotomous outcome variables, those that achieved complete abstinence, those that achieved a 24 hr period of abstinence, and those that relapsed after achieving a 24 hr period of abstinence, are summarized in Table 6 as a function of group.
Table 5: Means and Standard Deviations for abstinence and treatment outcome variables as a function of group

<table>
<thead>
<tr>
<th>Measure of Abstinence</th>
<th>LMD</th>
<th>LMND</th>
<th>HMD</th>
<th>HMND</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>Number of Trials Abstinent</td>
<td>26</td>
<td>2.58</td>
<td>4.81</td>
<td>25</td>
<td>1.04</td>
</tr>
<tr>
<td>Longest Duration</td>
<td>26</td>
<td>1.88</td>
<td>3.76</td>
<td>25</td>
<td>1.00</td>
</tr>
<tr>
<td>Time to First Positive</td>
<td>7</td>
<td>1.14</td>
<td>.38</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Attendance</td>
<td>26</td>
<td>2.96</td>
<td>5.49</td>
<td>25</td>
<td>1.24</td>
</tr>
<tr>
<td>Money Earned</td>
<td>26</td>
<td>6.88</td>
<td>15.85</td>
<td>25</td>
<td>4.28</td>
</tr>
</tbody>
</table>

Table 6: Summary of dichotomous outcome variables as a function of group.

<table>
<thead>
<tr>
<th>Measure of Abstinence</th>
<th>LMD</th>
<th>LMND</th>
<th>HMD</th>
<th>HMND</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>Complete Abstinence</td>
<td>1</td>
<td>3.8</td>
<td>1</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>24 hr Period</td>
<td>7</td>
<td>26.9</td>
<td>2</td>
<td>8</td>
<td>13</td>
</tr>
<tr>
<td>24 hr Abstinence w/ relapse</td>
<td>6</td>
<td>85.7</td>
<td>1</td>
<td>50</td>
<td>3</td>
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</table>
Across groups comparisons of the number of trials that met criteria for being abstinent showed in post-hoc analysis that those participants in the high magnitude groups had more abstinent trials than those in the low magnitude groups (F = (3, 99) 14.40, p < .01). The effect of delay to reinforcement did not reach significance, but there was a trend for reinforcer delay to be associated with a higher number of trials abstinent in the low magnitude conditions and to be associated with a lower number of trials abstinent at the high magnitude level (see Figure 2).

![Figure 2. Mean number of abstinent trials as a function of magnitude and delay. The HMD group significantly differed from the LMD and LMND groups, and the HMND group significantly differed from the LMD and LMND groups. * = p ≤ .01.](image-url)
Similar results were seen in the analysis of the longest duration of abstinence by group (see Figure 3). High magnitude of reinforcement was associated with longer duration of abstinence than low magnitude of reinforcement, \( F = (1, 99) \) 38.05, \( p < .01 \). Also, while not significant, delayed reinforcement was associated with longer duration of abstinence in the low magnitude condition, but associated with shorter duration of abstinence in the high magnitude condition.

![Figure 3. Mean longest duration of abstinence. The HMD group significantly differed from the LMD and LMND groups, and the HMND group significantly differed from the LMD and LMND groups. * = p ≤ .01.](image)

For those participants that submitted at least one negative sample an analysis was conducted across groups comparing the number of trials that passed before the first negative sample was submitted. Inspection of cell counts revealed that the LMND group had only two of
25 participants that had tested negative at least one time. As a result, this group was not included in the analysis. When the remaining groups were compared there was no difference between groups in number of trials before a test indicated smoking abstinence.

A similar analysis was conducted for those that submitted at least one positive sample or missed an appointment, comparing across groups the number of trials until the first positive sample was submitted or an appointment was missed. The HMND group \((n=13, M=4.15, SD=5.48)\) took significantly longer on average to have a positive test when compared to the HMD \((n=17, M=1.53, SD=1.07)\), LMND \((n=24, M=1.00, SD=0)\), and LMD \((n=25, M=1.52, SD=1.36)\) groups (see Figure 4).

![Number of trials to first positive test](image)

*Figure 4. Number of trial to first positive test. * indicates significant difference with all other groups.*

The strictest definition of abstinence is complete abstinence over the 5-day span (i.e., none of the 15 biological samples provided over the course of the experiment testing positive for smoking). To analyze the effect of magnitude and delay on complete abstinence, data were coded with a dichotomous dummy variable to indicate if the participant had submitted 15 CO
samples that met the criteria of smoking abstinence (No=0, Yes=1). Chi\(^2\) analysis indicated a similar pattern of results to the analysis of the previously discussed abstinence outcome measures: number of trials abstinent, longest duration of abstinence. Namely, there was a significant overall effect, \(\chi^2 (1, N = 103) = 25.38, p < .01\), and a main effect of magnitude, \(\chi^2 (1, N = 103) = 24.11, p < .01\), but no significant main effect of delay. The interaction of reinforcer magnitude and reinforcer delay could not be analyzed using the Chi\(^2\) statistic. Also consistent with previous analysis of abstinence outcomes, pair-wise post-hoc Chi\(^2\) comparisons indicate that a greater proportion of participants in the high magnitude groups achieved complete abstinence than the proportion of participants in the low magnitude groups (see Figure 5).

* 

Figure 5. Analysis of the percentage of participants that provided 15 negative samples by group. The HMD group significantly differed from the LMD and LMND groups, and the HMND group significantly differed from the LMD and LMND groups. * = \(p \leq .05\).
A final analysis of smoking abstinence conducted was that of comparing across groups the proportion of participants that achieved a 24 hr period of abstinence (three consecutive trials). This clinically relevant outcome measure showed a significant overall effect of reinforcer magnitude and reinforcer delay, $\chi^2 (3, N = 103) = 34.24, p < .01$, but no main effect of reinforcer magnitude or reinforcer delay. Post-hoc pair-wise Chi$^2$ comparisons indicating the HMND group had a greater proportion of participants that achieved a 24 hr period of abstinence than the low magnitude groups and that the HMD group had a greater proportion of participants achieve a 24 hr period of abstinence compared to the LMND group (see figure 6).

![Figure 6. Mean number of participants by group that achieved at least 24 hr of abstinence. The HMD group significantly differed from the LMND group, and the HMND group significantly differed from the LMD and LMND groups. * = p ≤ .05.](image-url)
The analysis of the proportion of those in each group that achieved a 24 hr period of abstinence and then resumed smoking revealed an overall effect of reinforcer magnitude and delay, $\chi^2 (1, N = 43) = 4.01, p = .05$, and a significant main effect of reinforcer magnitude, $\chi^2 (1, N = 43), p = .02$, with a trend toward a greater proportion of those in the low magnitude groups relapsing after achieving a 24 hr period of abstinence when compared with the proportion of those in the high magnitude groups (see Figure 7). However, post-hoc pair-wise Chi$^2$ analyses indicated no significant differences between groups.

Figure 7. Percent of participants by group that achieved at least 24 hr of abstinence, and then relapsed.

Differences between groups in terms of the number of sessions attended (regardless of test result) were analyzed. There was a statistically significant difference between groups on the number sessions attended, $F = (3, 99) 17.03, p < .01$, with those in the high magnitude conditions attending more sessions than those in the low magnitude conditions, $F = (1, 99) 45.16, p < .01$. The effect of reinforcer delay was not significant, but there was a trend of delay to reinforcement being associated with more sessions attended in the low magnitude condition and fewer sessions attended in the high magnitude condition ($F = (1, 99) 5.48, p = .02$) (see Figure 8).
Figure 8. Mean number of sessions attended by group, regardless of test outcome. The HMD group significantly differed from the LMD and LMND groups, and the HMND group significantly differed from the LMD and LMND groups. * = p ≤ .05.

Between group comparisons of mean amount of money earned demonstrated a significant overall effect, F (3,99) = 25.82, p < .01, a main effect of reinforcer magnitude, F (1,99) = 69.17, p < .01, and a significant interaction of reinforcer magnitude and delay, F (1,99) = 4.53, p = .04. The HMND (M= $140.52, SD= $85.61) and HMD (M = $87.62, SD = $97.65) groups differed from each other and from the LMND (M = $4.28, SD = $15.51) and LMD (M = $6.88, SD = $15.85) groups (see Figure 9).
Figure 9, Mean amount of money earned by group. * indicates significant difference from all other groups.

Cotinine levels at baseline and on the last test of the study were compared across groups using a paired-samples t-test. Baseline cotinine \( (M=169.09 \text{ ng/ml}, \ SD=55.41) \) and time 2 cotinine \( (M=51.33\text{ng/ml}, \ SD=52.44) \) levels were significantly different \( (t(33)=9.33, \ p<.01) \) with cotinine levels lower at time 2 than at baseline levels.

VAS scores of current desire to smoke and current withdrawal symptoms were analyzed using repeated measures ANOVA. Because only a single participant in each of the LMND and LMD groups completed all 15 trials, these groups were excluded from these analyses. No significant difference was found between the HMD and HMND groups for either current desire to smoke \( (F(1, 25) = 1.44, \ p = .24) \) or current withdrawal symptoms \( (F(1, 25) = 1.95, \ p = .18) \).

The number of self-reported cigarettes smoked during the experiment did not differ when between groups comparisons were made using ANOVA.

The influence of demographic and smoking baseline measures on all outcome variables was investigated using ANCOVA. Only baseline CO was a significant covariate on outcome variables. Table 7 summarizes the results of analysis of each outcome variable (total number of
trials abstinent, longest duration of abstinence, time to first negative, time to first positive, and attendance). Despite accounting for a significant portion of the variance, controlling for baseline CO level did not change the influence of reinforcer magnitude and reinforcer delay on outcome measures. To understand the effect of baseline CO on treatment outcomes, mean number of trials abstinent by groups was selected as a representative outcome measure for further analysis.

A baseline CO level of 10 – 18ppm indicates moderate smoking, while a CO level greater than 18 indicates heavy smoking. Participants were classified as either moderate or heavy smokers and compared within groups on the mean number of trials abstinent using a t-test. Only in the HMND group did moderate smokers have more trials abstinent than heavy smokers, t=(24) 2.11, p = .002 (see Figure 10). A comparison of moderate and heavy smokers collapsed across groups on mean number of trials abstinent was not significant (see Figure 11).
Table 7. Analysis of Covariance for Outcome Variables as a Function of Reinforcer Magnitude and Delay, Using CO Baseline as a Covariate

<table>
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<tr>
<th>Outcome Variable</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
<th>Eta²</th>
<th>Observed Power</th>
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<td>.08</td>
<td>.82</td>
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<td>.01</td>
<td>.20</td>
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<td>.75</td>
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<td><strong>Longest Duration of Abstinence</strong></td>
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<td>6.62</td>
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<td>.063</td>
<td>.722</td>
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<td><strong>Attendance</strong></td>
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<td>252.63</td>
<td>8.49</td>
<td>.004</td>
<td>.08</td>
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<td>29.78</td>
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</table>
Figure 10. Within group differences of mean number of trials abstinent as a function of Baseline CO level. * indicates a significant within group difference. Black bars represent participants with a baseline CO level ≤ 18ppm. Gray bars represent participants that had a baseline CO level > 18ppm.

Figure 11. Mean number of trials abstinent as a function of Baseline CO level.
DISCUSSION

The results of the present study demonstrate that high magnitude alternative reinforcement results in higher rates of abstinence compared to low magnitude alternative reinforcement. A magnitude of reinforcement approximately 50% greater than that typically used in CM analog studies, compared with a magnitude of reinforcement approximately 50% less than that typically used (Roll & Higgins, 2000; Roll et al., 1996; Roll et al., 1998; Roll & Howard, 2008), was associated with more test sessions attended, more frequent abstinence from cigarette smoking, and longer durations of abstinence from cigarette smoking. These findings are in accord with Roll, Reilly, & Johanson (2000), which found that higher magnitude of alternative reinforcement and immediate delivery of the reinforcer resulted in fewer choices for drug. However, in that study participants were choosing between drug and alternative reinforcement in a laboratory setting. The present results systematically replicate those prior findings and extend them by demonstrating the effect of high magnitude of alternative reinforcement when the participants’ opportunity to choose drug is unconstrained and occurs in their natural environment.

Moreover, the current study found that a high magnitude of contingent alternative reinforcement that was available immediately resulted in a longer period of time before a participant relapsed (tested positive for smoking) than a high magnitude of alternative reinforcement that was available after a delay. This finding implies that even at high magnitude of reinforcement a delay to reinforcement is associated with a decrease in the ability of the reinforcer to maintain abstinence. Given that maintenance of abstinence is a hallmark of successful addiction treatment this finding is both theoretically and clinically relevant, suggesting that minimizing delay to high magnitude reinforcement promotes continuous abstinence.
The results of the current study regarding high magnitude reinforcers are in accord with the findings of an extensive body of previous research involving high magnitude reinforcers. These include studies with animals (Nader & Woolverton, 1991), humans (Higgins et al., 1994), and CM treatment programs (Businelle et al., 2009; Dallery et al., 2001; Garcia-Rodriguez et al., 2009; Petry et al., 2004; Stitzer & Bigelow, 1983).

Unlike Roll, Reilly, & Johanson (2000) the results of the current study showed a significant interaction of reinforcer delay and reinforcer magnitude, and did not find a significant main effect of delay for each outcome variable. The interaction was caused by the effect of delay being associated with worse outcomes in the high magnitude conditions, but better outcomes in the low magnitude conditions. Based on the findings of Roll, Reilly, & Johanson (2000) it was predicted that there would be no effect of delay in the high magnitude condition, and that delay would be associated with a decrease in target behavior in the low magnitude condition. The lack of an effect of delay in the low magnitude condition was unexpected and is possibly related to the very low rate of behavior in the low magnitude groups (i.e., that the magnitude of reinforcement was not sufficient to maintain behavior). The interaction of reinforcer magnitude and reinforcer delay is possibly due to the behavior of those in the delay group being influenced by the total amount they would receive (a lump sum of $70), and the behavior of those in the no-delay condition being influenced by the amount they would receive for their first negative trial ($0.50). Further study and replication will be useful for interpreting this result.

The lack of a significant difference between the LMD and LMND groups for any outcome measure was unexpected. As previously discussed, the detrimental effect of delay to reinforcement on a target behavior has support in the literature (Kirby et al., 1998; Lussier, Heil,
Mongeon, Badger, & Higgins, 2006b). As stated above, the likely reason that an effect of delay to reinforcement was not detected is the very low response rates in the low magnitude condition. Future studies using a magnitude of reinforcement that is able to maintain behavior in the low magnitude condition will help to resolve this issue.

The results of the comparison of cotinine levels at baseline and at the final trial of the study confirm the findings from measured CO levels. Namely, that cotinine levels across groups at the end of the study were lower than at the beginning of the study. This finding verifies that the participants did not supplement or replace their nicotine use during the study with a form of nicotine that would not be detected by the CO meter (e.g., a nicotine patch or smokeless tobacco).

The analysis of covariance conducted for each outcome measure with demographic and baseline smoking status variables as covariates was conducted to test for the effect these variables might have on the dependent measures. Baseline CO level was the only significant covariate with treatment outcome measures. To our knowledge this is the first time that in cigarette smokers the level of use at baseline has been shown to be a predictor of treatment outcome. This finding is in accordance with the literature. For example, data from studies involving treatments of drug abuse have found that treatment outcome is significantly predicted by drug use status at treatment intake (Stitzer, Peirce, et al., 2007; Stitzer, Petry, et al., 2007). These findings imply that, in treatment, those that use at a higher rate may require additional or different interventions (such as higher magnitude of reinforcement or an adjusted schedule of reinforcement) in order to produce outcomes similar to those that have an initial lower rate of use. While baseline CO level in the current study did not account for enough of the variance to
change the significance of any outcome variable, higher CO levels were significantly associated with poorer outcomes across all outcome variables.

This study used an analog model of drug abuse treatment to investigate the influence of specific elements of reinforcement used to decrease drug use in CM based treatments. The results of this study have implications for CM based treatment of drug addiction. The findings that a high magnitude of reinforcement results in better treatment outcomes than a low magnitude of reinforcement, and that while both high magnitude groups demonstrated considerable abstinence, immediate reinforcement resulted in a statistically longer amount of time before relapse occurred, demonstrate the importance of using high magnitude reinforcement with minimal delay in CM paradigms.

The low level of reinforcement used in this study is a clear limitation of the study. As mentioned above, the level of reinforcement used in the low magnitude condition was selected because it was 50% of the amount typically used in similar studies conducted previously (Roll & Higgins, 2000; Roll et al., 1996; Roll et al., 1998; Roll & Howard, 2008). This magnitude of reinforcement was apparently too low to maintain behavior. As a result, many meaningful comparisons of the effect of delay could not be made between the delay conditions of low magnitude and high magnitude conditions. A future study should include a magnitude of reinforcement greater than the low magnitude used here to allow comparison with the high magnitude of reinforcement groups.

The results of the current study indicate that a high magnitude of alternative reinforcement results in better treatment outcomes than a low magnitude of alternative reinforcement. A future study that includes a low magnitude of reinforcement that is greater than that used in the current study and able to maintain behavior would likely clarify some of the
findings of the current study (namely the interaction of reinforcer magnitude and delay, and the lack of a significant effect of reinforcer delay).

CM has a solid foundation in empirical research regarding the influence of environmental variables on behavior. The current study adds to this literature by investigating the influence of magnitude and delay to a reinforcer offered as an alternative to drug in a CM analog study. Specifically, the current study adds to the literature demonstrating that high magnitude reinforcers maintain abstinence better than low magnitude reinforcers. Furthermore, these data are the first to demonstrate than delayed reinforcement in a CM analog study decreases the efficacy of the reinforcer, resulting in relapse to drug use.
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