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CONTINGENT REINFORCEMENT FOR CARBON MONOXIDE REDUCTION: WITHIN-SUBJECT EFFECTS OF PAY AMOUNT

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The relationship between reinforcer amount and daytime smoking reduction in smokers offered money for reduced afternoon breath carbon monoxide (CO) levels was examined. Twenty-three hired regular smokers with average baseline CO levels of about 30 ppm were exposed in random order to five sliding scale payment schedules that changed daily or weekly. Money was available for afternoon CO readings between 0 and 21 ppm with pay amount inversely related to the absolute CO reading obtained. Maximum pay amount for readings below 7 ppm varied among \$0, \$1.50, \$3, \$6, and \$12 per day. Contingent reinforcement promoted CO and daytime cigarette reduction within individuals with the amount of behavior change related to the amount of payment available. Average CO levels decreased from 30 to 15 ppm as a function of pay amount whereas self-reported daytime cigarettes decreased from 12 to 5 per day. Average minutes of cigarette abstinence prior to the afternoon study contact increased from 62 to 319 minutes as a function of pay amount, whereas the percentage of available money earned increased from 22% to 48%. Nontargeted evening cigarette use also decreased during periods of daytime smoking reduction. The orderly effects of this contingent reinforcement intervention on daytime smoking of regular smoker volunteers suggest that this is a sensitive model for continued evaluation of factors that influence smoking reduction and cessation.

DESCRIPTORS: smoking, reinforcement, contingencies, carbon monoxide reduction

Two recent studies by Stitzer and Bigelow (1982, 1983) showed that breath carbon monoxide (CO) readings can be used simultaneously as a target for reinforcement interventions that promote smoking reduction and as a reliable objective measure of recent smoking behavior. Breath CO provides a valid index of recent tobacco smoke exposure that directly reflects plasma carboxyhemoglobin levels (Cohen, Perkens, Ury, & Goldsmith, 1971; Jones, Ellicott, Cadigan, & Gaensler, 1958; Ringold, Goldsmith, Helwig, Finn, & Schuette, 1962; Sjöstrand, 1948) and correlates highly with plasma nicotine levels (Ashton, Stepney, & Thompson, 1981; Russell, Wilson, Patel, Feyerabend, & Cole, 1975). Breath CO levels are correlated with self-reported number of cigarettes smoked per day (Horan, Hackett, & Lindberg, 1978; Jaffe, Kanzler, Friedman, Stunkard, & Verebely, 1981; Rickert & Robinson, 1981; Ringold et al., 1962; Vogt, Selvin, Widdowson, & Hulley, 1977) and reflect within-subject changes in smoke exposure (Henningfield, Stitzer, & Griffiths, 1980; Stitzer & Bigelow, 1982). Nonsmokers generally have breath CO levels below 8 ppm, whereas smokers typically have levels between 15 and 40 ppm, though these may range higher depending on the amount of recent smoke exposure.

In the first study that used breath CO as a measure of recent smoking and a target for contingent reinforcement intervention (Stitzer & Bigelow, 1982), hired regular smokers were offered \$5 per day to reduce their afternoon CO levels by 50% or more from their own baselines. The study showed that smokers could successfully reduce afternoon CO levels to earn payments and that they did so by reducing the number of daytime cigarettes smoked and abstaining for several hours prior to the afternoon CO measurement. A second

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study (Stitzer & Bigelow, 1983) showed that greater monetary reinforcement ($0–10 per day for different groups of smokers) was associated with greater daytime smoking reduction during a 2-week trial. However, smoking returned to baseline levels when reinforcement was withdrawn. By demonstrating that contingent reinforcement procedures can modify ongoing smoking behavior these studies suggested that motivational approaches might be helpful in smoking cessation efforts rather than the skills training approaches that are more commonly used. Further, the functional relationship between smoking behavior and contingent reinforcement pay amount has potential application in the design of optimal smoking cessation interventions.

The study reported here was a replication and extension of the relationship between pay amount and smoking reduction previously observed in groups of smokers using a design in which each smoker was exposed to five different payment schedules. In contrast to previous studies where smokers were offered a single dollar amount for all CO readings that were 50% or less of their own baseline values, pay amounts in this study were inversely related to CO readings under a sliding scale, with maximum amounts ($0 to $12 per day under different schedules) available only for CO readings in the nonsmoker range, in this case below 7 ppm. It was anticipated that smokers might make more substantial reductions under a sliding payment schedule than had previously been observed under fixed amount schedules. First, some smokers might want to take advantage of maximum available payments. Secondly, the sliding scale provided an incentive for partial smoking reduction in individuals who could not or would not achieve a single fixed CO reduction criterion.

METHOD

Smokers. Twenty-three female cigarette smokers volunteered to participate. All were employees of a metropolitan hospital and were recruited through bulletin board advertisements and word of mouth. Average age was 31.6 years with a range from 21 to 61 years. Average prior years of smoking was 15.3 years with a range from 5 to 40 years. Average reported cigarettes smoked per day was 23.7 with a range from 14 to 42 cigarettes per day. Volunteers with CO levels below 18 ppm at initial screening were excluded. Prior to participation, smokers were told that this was not a program to help them quit smoking, but that optional changes in smoking might be encouraged during the study. As compensation, they received free cigarettes during the study (their own brand) and a $50 bonus upon study completion.

Experimental procedures. Two groups of smokers participated sequentially. During the first study week (Monday to Friday), they were told to smoke in their normal fashion; baseline data were collected. On Friday of Week 1, all volunteers were told that they would have the opportunity to earn money during the remainder of the study for providing evidence of smoking reduction as revealed in their afternoon breath CO readings. Payment was based on a sliding scale so that more money was paid for lower CO readings. Specifically, as shown in Table 1, carbon monoxide readings of 6 ppm or lower qualified for the maximum pay amounts, whereas readings between 7 and 21 ppm were grouped into five categories across which the amount of money available was inversely related to the CO reading obtained. Each volunteer was exposed to five different sliding scale payment schedules. As seen in Table 1, these differed on the amount of money that could be earned for given CO readings. Minimum pay for CO readings of 19–21 ppm ranged from $0.00 to $2.00 under the five payment schedules and maximum pay for readings of $\leq$6 ppm ranged from $0.00 to $12.00 per day.

For one group of smokers (n = 12), the payment schedule was changed daily. These volunteers were exposed to each of the five pay schedules 4 times each in a randomized block design and received a notice each time they reported to the study site indicating the pay schedule in effect on the following study day. For another group (n = 11), the payment schedule was changed weekly. These volunteers were exposed to each pay schedule for

5 consecutive days (Monday through Friday), with order of exposure randomized. They received a notice on Friday of each week describing the pay schedule for the following week. Data have been combined for these two groups because results were similar.

Data collection procedures. Volunteers reported Monday through Friday to a convenient location in the hospital between 3:00 and 5:00 p.m. At each study contact, a breath sample was collected following 20 s of breath holding; this was analyzed immediately for carbon monoxide (CO) level using a Mini CO carbon monoxide analyzer (Research Catalyst Corporation Model 1000) calibrated daily to 50 ppm. At each study contact, smokers received a supply of their own brand of cigarettes sufficient to last until the next scheduled study contact and turned in unused cigarettes from the previous day. They also turned in cards on which they had recorded the time of day each cigarette was smoked during the previous 24 hours. A cigarette count was used to corroborate self-report information on number of cigarettes.

Data analysis. Five measures were used in data analysis: (a) carbon monoxide levels obtained at the afternoon study contact (ambient CO levels not subtracted), (b) daytime cigarettes recorded from the time of arising in the morning to the time of the afternoon study contact, (c) evening cigarettes recorded from time of the afternoon study contact until time of arising the next morning, (d) time since the last cigarette, which was time elapsed between collection of the afternoon breath sample and the most recently recorded cigarette, and (e) amount of money earned under each payment condition as a percentage of the maximum available amount.

An average score was obtained for each smoker on each measure during exposure to each payment schedule; these average scores were entered into a repeated measures analysis of variance to evaluate statistical significance of the effects of pay amount on smoking measures. The effect of pay amount was further evaluated by comparing across payment schedules the percentage of smokers whose average CO values met arbitrary cutoff criteria of ≤21 ppm, ≤15 ppm, or ≤9 ppm. Because average baseline CO was about 30 ppm, these cutoffs represent approximately 30%, 50%, and 70% reductions from baseline. Readings below 9 ppm are generally considered nonsmoker values (Hughes, Epstein, Andrasik, Neff, & Thompson 1982; Petitti, Friedman, & Kahn, 1981; Vogt et al., 1977).

Table 1
Sliding Scale Payment Schedules

Carbon monoxide levels (ppm)	Maximum pay amount (dollars)				
	0	1.5	3	6	12
21–19	0.00	0.25	0.50	1.00	2.00
18–16	0.00	0.50	1.00	2.00	4.00
15–13	0.00	0.75	1.50	3.00	6.00
12–10	0.00	1.00	2.00	4.00	8.00
9–7	0.00	1.25	2.50	5.00	10.00
≤6	0.00	1.50	3.00	6.00	12.00

RESULTS

Carbon monoxide levels. The upper left panel of Figure 1 shows average CO values during baseline and during exposure to the five sliding scale payment schedules. Average CO level was 29.6 ppm during the baseline week and 23.6 ppm under the $0 pay schedule. Average carbon monoxide readings decreased as pay amount increased, declining to 15.1 ppm under the richest pay schedule. Analysis of variance revealed a significant effect of pay amount on CO levels, $F(5, 110) = 27.9$, $p < .001$; a post hoc Sheffé test showed that all pay conditions were significantly different from baseline and that $12 was significantly different from the $0, $1.50, and $3 pay conditions.

Daytime cigarettes. As shown in the upper right panel of Figure 1, the average number of reported daytime cigarettes also decreased in an orderly manner as the amount of payment available for CO reduction increased. Volunteers reported smoking an average of about 12 daytime cigarettes during baseline, 9.6 under the $0 payment condition, and 5.3 under the richest payment schedule. Repeated measures analysis of variance

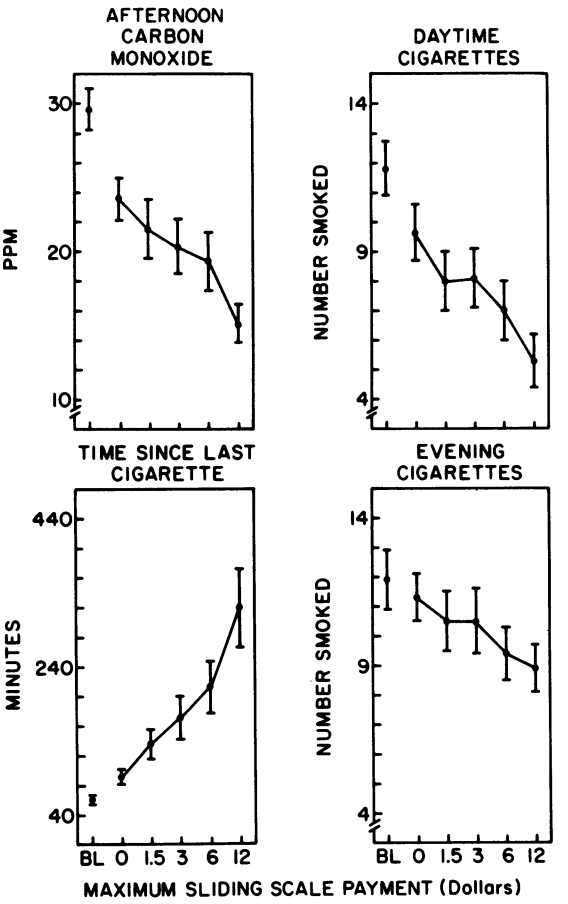

Figure 1. Average smoking measures are shown for preintervention baseline week (BL) and during exposure to five sliding scale payment schedules for afternoon carbon monoxide reduction. Measures are afternoon carbon monoxide level (upper left panel), reported number of daytime cigarettes smoked (upper right panel), reported time elapsed between the afternoon CO measurement and the most recently recorded cigarette (lower left panel), and reported number of evening cigarettes (lower right panel). Each of 23 smokers contributed an average score based on four or five daily exposures to each sliding scale payment schedule. Brackets are ±1 *SEM*.

was significant for the daytime cigarette measure, $F(5, 110) = 20.7$, $p < .001$; a post hoc Sheffé test showed that all pay conditions except \$0 were significantly different from baseline, \$6 was significantly different from \$0, and \$12 was significantly different from the \$0, \$1.50, and \$3 pay conditions.

Time since last cigarette. Under the contingent payment schedules, smokers increased the amount of time they remained cigarette abstinent prior to the afternoon study contact. As shown in the lower left panel of Figure 1, average time since the last cigarette was 62 min during baseline, 92 min during exposure to the \$0 pay schedule, and 319 min during the richest payment schedule. Pay effects on time since the last cigarettes were significant in repeated measures analysis of variance, $F(5, 110) = 14.7$, $p < .001$; a post hoc Sheffé test showed that both the \$6 and \$12 conditions were significantly different from baseline, \$6 was different from \$0, and \$12 was significantly different from the \$0, \$1.50, and \$3 conditions.

Evening cigarettes. As shown in the lower right panel of Figure 1, the number of reported evening cigarettes smoked decreased from about 12 per day during baseline to about 9 per day during the richest payment schedule. Repeated measures analysis of variance revealed a significant effect of pay amount on the evening cigarette measure, $F(5, 110) = 5.8$, $p < .001$); a post hoc Sheffé test showed that the \$6 and \$12 conditions were significantly different from baseline and that \$12 differed significantly from \$0.

Money earned. The percentage of available money earned increased from 22% under the lowest payment schedule (\$1.50 maximum) to 48% under the richest payment schedule (\$12.00 maximum). Percentage of available money earned was analyzed in repeated measures analysis of variance after arcsine transformation, which is the recommended method for normalizing percentage data prior to statistical analysis (Cohen & Cohen, 1975). Effects of pay amount were significant, $F(3, 66) = 11.5$, $p < .001$) but only the \$12 condition was significantly different from the \$1.50 pay condition in a post hoc Sheffé test.

Individual analysis. Table 2 shows that the percentage of smokers with average CO readings below three specified criteria levels increased as a function of pay amount. Virtually all the smokers (96%) had average CO values of 21 ppm or lower under the richest payment schedule, whereas only 35% had average CO values this low under the \$0 schedule; 9% had average CO values of 21

ppm or lower during baseline evaluation. About half (48%) had average CO values of 15 ppm or lower under the richest payment schedule, whereas only 4% had average CO readings this low under the $0 pay schedule. Similarly, one-quarter (26%) had average CO values of 9 ppm or lower under the richest payment schedule; none had average readings this low under the $0 pay schedule.

Table 2
Percentage of Smokers with Low Average Carbon Monoxide Levels

Average carbon monoxide level	Sliding scale payment schedule Maximum pay amount (dollars)					
	BL	0	1.5	3	6	12
≤21	9	35	48	52	52	96
≤15	0	4	26	26	35	48
≤9	0	0	13	13	17	26

DISCUSSION

This study showed that contingent reinforcement for reduced afternoon carbon monoxide levels promoted daytime smoking reduction and that the magnitude of change in measures of smoking was related in an orderly way to the amount of payment offered for CO reduction. Results of this study, which used a within-subject design, are similar to those obtained in a previous between-group investigation (Stitzer & Bigelow, 1983). These studies both show that the smoking behavior of individuals is responsive to changing environmental contingencies and specifically to the amount of monetary payment offered for afternoon CO reduction. The smoking reductions seen as pay amount increased are consistent with previous observations both from animal studies (Griffiths, Bradford, & Brady, 1979; Neuringer, 1967; Schwartz, 1969) and from human studies (Fisher, 1979; McLeod & Griffiths, 1983; Paxton, 1981) that larger valued reinforcers are generally more efficacious in promoting and maintaining behavior change than are smaller valued reinforcers. Nearly identical results were obtained in this study under two procedural modifications in which pay scales changed either daily or weekly. This lends additional generality to the results and suggests that smokers are equally capable of modulating their daytime smoking behavior on either a long-term (weekly) or short-term (daily) basis.

Carbon monoxide levels under the $0 pay scale were 20% lower than those observed during baseline. This reduction is consistent with observations from a previous study (Stitzer & Bigelow, 1983) and can be attributed to instructional, feedback, and demand characteristics of the contingent reinforcement procedure. The magnitude of this instruction effect must be interpreted cautiously, however, because baseline smoking was always determined during the first study week. It is likely, for example, that differences between baseline and $0 pay CO levels would be smaller if the baseline condition had been included within the random order experimental sequence. The fact that CO levels decreased from baseline under the $0 pay condition without either a significant reduction in daytime cigarettes or a significant increase in time since the last cigarette suggests that smokers were changing their puffing or inhalation patterns or both to alter smoke exposure during contingent payment interventions as well as altering the number and timing of daytime cigarettes used.

We originally anticipated that the sliding payment scale would promote greater overall reduction in CO levels and smoking than had been observed in previous studies. In fact, however, results obtained under the richest payment schedule ($12 per day) were strikingly similar to results obtained previously when smokers were offered $10 per day for any CO readings which were 50% or less of their own baseline levels (Stitzer & Bigelow, 1983). In both cases, average afternoon CO readings decreased to about 50% of preintervention values while smokers typically smoked about five cigarettes in the morning and then abstained for about 5 hours prior to the afternoon study contact. Perhaps smokers self-selected these maximum levels and patterns of daytime smoking reduction because they still felt relatively comfortable but anticipated experiencing withdrawal symptoms if they

reduced further. Additional studies are needed to delineate procedures and conditions, that promote greater magnitudes of smoking reduction and to examine the symptomatic effects of such reductions.

Smokers did not compensate for reduced daytime smoking by increasing the number of cigarettes smoked in the evening. On the contrary, there was a significant reduction in evening cigarette use during the time that daytime smoking was decreased. Although it is possible that smokers took more puffs or inhaled more deeply from the cigarettes they did use in the evening, the lack of compensatory increases in nontargeted substance use, in this case number of evening cigarettes, is consistent with previous observations from smoking reduction studies (Stitzer & Bigelow, 1982, 1983) and with the lack of symptom substitution observed in treatment evaluation studies where contingent reinforcement procedures have been used to promote specific reductions in drug or alcohol use (Liebson, Tommasello, & Bigelow, 1978; Stitzer, Bigelow, Liebson, & Hawthorne, 1982).

Repayment of security deposits contingent on nonsmoking has been used to promote abstinence among smokers enrolled in cessation treatment programs (Elliott & Tighe, 1968; Paxton, 1980; Spring, Sipich, Trimble, & Goeckner, 1978; Winett, 1973), but there has been little research on the effects of different repayment schedules or on isolating the effects of reinforcement from those of instructions and feedback. Results of our study suggest that contingent reinforcement interventions have specific effects on smoking behavior beyond instructions and feedback and that the potency of these interventions is related to the magnitude of reinforcement offered. This latter conclusion is consistent with results of a study by Paxton (1981) who found that more smokers were abstinent at several time points during an 8-week smoking cessation program when they had been required to pay a larger compared to a smaller security deposit. However, results from our study cannot be applied directly to the clinical situation because the study used hired chronic smokers rather than smokers committed to quitting and focused on daytime smoking reduction rather than abstinence. Additional studies will be needed to evaluate the relationship between daytime smoking reduction and the more clinically significant outcome of smoking cessation. However, the orderly effects of contingent reinforcement interventions on daytime smoking of regular smoker volunteers suggests that this is a sensitive model for continued evaluation of factors that influence smoking reduction and cessation. Further, the efficacy of reinforcement interventions demonstrated in this and previous studies suggests that smoking cessation efforts might be profitably directed toward providing smokers with the motivation to quit rather than providing them with the skills that might be required to quit smoking. The ability of smokers to respond appropriately to such motivational interventions indicates that the requisite skills are already present.

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