Original investigation

Web-Based Contingency Management for Adolescent Tobacco Smokers: A Clinical Trial

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Abstract

Introduction: Adolescence is a critical time when the majority of tobacco users initiate smoking. Contingency management for adolescent smoking cessation has shown promise in previous studies, but efficacy following removal of contingencies is not well understood. This study examined a remote form of contingency management among non-treatment-seeking adolescent smokers.

Methods: Participants ($N = 127$) submitted breath carbon monoxide (CO) three times daily throughout a 42-day program. For this randomized trial, participants in the active condition ($n = 63$) were reinforced for providing CO measurements on schedule and below a set criterion, whereas those in the control condition ($n = 64$) were reinforced for providing CO measurements on schedule. Self-reported smoking and urinary cotinine levels were collected at several timepoints.

Results: Active condition showed greater within-group reductions in CO levels relative to control condition, but not at 3- or 6-month follow-up. Active condition reported significantly less smoking during treatment compared to control condition, but not at follow-up. There were no significant differences for urinary cotinine. Overall treatment adherence was low, with only 37% and 51% of possible CO samples being submitted among active and control, respectively. Poor treatment adherence may explain the disparity between CO and cotinine results, and poor follow-up treatment efficacy.

Conclusions: This study replicates feasibility of a remote form of contingency management for adolescent smoking. CO results suggest active condition reduced smoking within group, but treatment adherence and posttreatment efficacy was poor. Future research should focus on increasing adherence for this type of program among adolescent smokers.

Implications: This study demonstrates feasibility of a remote form of contingency management therapy for smoking cessation among adolescents, while providing posttreatment efficacy data. Within-group efficacy of this form of treatment is suggested, but treatment adherence and follow-up efficacy were poor. This study underscores the need for further development of contingency management therapy for adolescent smoking cessation, which emphasizes better treatment adherence and posttreatment efficacy.

Introduction

Tobacco use continues to be a significant public health problem for adolescents. In 2014, 22.1% of middle- and high-school students reported having ever used a tobacco cigarette and 6.4% reported use of a tobacco cigarette in the last 30 days.¹ Among high-school students specifically, 9.3% reported past month use of tobacco cigarettes in 2015, representing approximately 1.4 million individuals in the United States.² Particularly concerning is the fact that 75% of adult tobacco smokers report initiating tobacco use during adolescence (ie, 11–17 years of age).³ As such, cessation interventions for adolescent smokers could potentially reduce tobacco use during adolescence and eventually most adults.

There are several nonpharmacological treatment approaches that have been investigated for adolescent tobacco smoking cessation. Examples include the Not On Tobacco program,⁴ psychosocial treatments (such as motivational enhancement or cognitive behavioral therapies),⁵ and contingency management (CM) therapy.⁶ Although brief nonpharmacological tobacco cessation interventions have shown some efficacy, treatments involving more frequent interactions over longer periods of time are likely more effective. For example, Anderson et al.⁷ point out there is a dose-dependent relationship between the quantity of counseling sessions for smoking cessation and their efficacy. However, interventions requiring frequent visits to a clinic can be impractical to implement because of the heavy burden they place on participants and clinicians. A possible solution to this challenge is to use computer-mediated treatments that can be delivered remotely to the individual's home. In support of this method, a review of randomized controlled trials on multiple types of computer-delivered treatments for tobacco cessation concluded that computer-delivered treatments (both online and offline) can be effective for tobacco cessation.⁸

Previous research has demonstrated efficacy of CM therapy for cessation of tobacco use.⁹ Using operant-conditioning principles, CM offers a mutually exclusive alternative reinforcer (eg, money) to compete with the reinforcing effects of the target behavior (eg, smoking). A CM approach can be effective for adolescent smokers. Roll⁶ demonstrated that adolescent tobacco smokers receiving monetary rewards for meeting tobacco abstinence criteria reduced their use significantly more than a control group. Krishnan-Sarin et al.¹⁰ demonstrated that CM combined with a cognitive behavioral therapy was significantly more effective than cognitive behavioral therapy alone at promoting tobacco abstinence among adolescent tobacco smokers. As with other tobacco cessation therapies, one potential drawback to CM is the requirement for frequent sessions, particularly because CM requires regular verification of tobacco abstinence and delivery of contingent rewards. To address this issue, Reynolds et al.¹¹ demonstrated that a computer-delivered version of CM¹² is effective for tobacco cessation among adolescents living in rural areas with limited health care accessibility.

Although the aforementioned studies have demonstrated efficacy of CM for smoking cessation among adolescents during the treatment, it is unclear what efficacy CM has after treatment is complete. To address this concern, this study recruited 183 adolescent smokers from urban and rural areas of Ohio, Kentucky, and West Virginia for a clinical trial of remotely delivered CM for tobacco cessation. Tobacco use was measured using daily carbon monoxide (CO) readings, with the addition of urinary cotinine and self-reported tobacco use at several points throughout the study. Participants smoking behaviors were also monitored 3 and 6 months following the end of treatment. As such, this study represents the most comprehensive

evaluation of a remotely delivered CM program for tobacco cessation with adolescent smokers to date.

Methods

Participants

Sample size was calculated based on efficacy of previous research using CM among an adolescent population,⁶ indicating a minimum of 90 total participants (45 in active or control conditions) would be required to achieve 80% power with a 5% Type I error probability. To ensure adequate power was achieved, a target of 125 completers was established. Participants initially consisted of 183 adolescents who were not currently pursuing tobacco cessation treatment. Of these initial 183, 56 dropped out of the study ($n = 16$ dropped out before randomization, $n = 24$ from active treatment [AT], and $n = 16$ from control treatment [CT]). A total of 127 participants (49.6% female) completed the study. Inclusion criteria consisted of afternoon breath CO level of at least 9 ppm (Micro III; Bedfont Instruments, United Kingdom) or a urinary quantitative cotinine value at least 100 ng/mL (homogenous enzyme immunoassay at J2 Laboratories in Tucson, AZ). Potential participants were initially interviewed by telephone, and those who met the inclusion criteria were invited in for a pretreatment laboratory session.

Overall Procedures

Pretreatment laboratory sessions (see later for further description) were conducted in a clinical facility or mobile laboratory (described in detail later). Prior to beginning the pretreatment laboratory session, an institutional review board-approved consent form was reviewed and signed by participants' parents or guardians, and assent forms were reviewed and signed by adolescent participants, unless they were 18 years or older. Participants were randomized to the AT or CT condition at the end of the baseline phase. Participants were told about the contingent reward schedules and their relationship to CO levels at pretreatment sessions, and told which condition they were in following randomization. A Web-based monitoring system called Mōtiv8, which has previously shown good feasibility for adolescent smoking cessation,^{12,13} was used to verify breath CO measurements. Participants could use their home computers and Internet services to complete the CM program, or they were loaned a laptop (Dell Latitude 2110 with Intel Atom processor) with Verizon Wireless access to the Internet. All participants were loaned a Web camera (Logitech, Newark, CA) and a breath CO monitor (piCO Smokerlyzer; Bedfont Inc, Medford, NJ) for the duration of their participation in the CM program. Research staff familiarized and practiced the CO sampling and Web site usage procedures with participants prior to study initiation.

During the CM program phases, three breath samples were required per day—each separated by at least 5 hours but not more than 8 hours. CO samples were video-recorded and securely uploaded to the Mōtiv8 server. Participants were instructed to use the Web camera to show the following: (1) the CO monitor set to zero, (2) themselves taking a deep breath and holding it for 15 seconds (indicated by a timer shown on the CO monitor), (3) fully exhaling into the mouthpiece, and (4) the final CO reading on the monitor. Following CO measurement, participants entered their CO reading into the Mōtiv8 site. All videos and CO values were reviewed by study personnel on a daily basis for completeness and accuracy. Video samples not meeting the above criteria were considered invalid and vouchers were not awarded. Participants were also notified that

attempts to falsify a sample are easily detected and would lead to early dismissal from the study. To detect falsified samples, Microsoft Windows' date and time stamps were used to determine if video clips were altered or taken at different times. To prevent tampering, computers were administratively locked so participants could not alter the time and date. Lastly, the CO monitor emitted an audible hiss when air passed through the mouthpiece, which was detectable by the videos and used to verify that the participant was exhaling through the monitor. Participants in both conditions were allowed two "freebies" to count for late or missed breath samples, but not invalid samples or samples not meeting CO criterion. Only one freebie could be used during the abstinence phase, but the other could be used during any other program phase.

Throughout the study participants were given access to a Web site featuring a graph of their CO results, cumulative and current voucher earnings, and a link to a Web page that listed Internet vendors (eg, <http://amazon.com>, <http://bestbuy.com>) where vouchers could be redeemed. The Web site also provided a list of links to smoking cessation Web sites and other health-related information. To purchase items, participants notified research staff when they wished to purchase and, if they had enough vouchers, research staff ordered and delivered the item(s). Participants could not buy firearms, weapons, drugs, or alcohol.

CM Phases

AT Condition

Program phases and contingencies for the AT condition are based on previous research using several different populations.¹²⁻¹⁴ The program consisted of five distinct phases described in chronological order:

Baseline Phase. During baseline phase (7 days), participants were required to provide three timely breath samples per day, with no criteria for CO level. The purpose of the baseline phase was to familiarize participants with the protocol and submission of CO breath samples and to determine average baseline CO level. For providing all three samples each day, participants received \$6 per day, but

received nothing for days with missing or late samples. Total possible earnings during this phase was \$42.

Shaping Phase. Shaping phase (4 days) was designed as a transition between regular cigarette use and abstinence. During this phase, participants received reinforcements for gradual decreases in CO level. Before this phase began, average CO level for each participant over the preceding 6 days was calculated and the rate of CO reduction required over the 12 breath samples of the shaping phase to reach 4 ppm by the last sample was determined. If CO levels needed to be reduced by more than 3 ppm per day (ie, by more than 1 ppm per sample), the larger reductions were scheduled for the earlier samples of that day. Just prior to starting the shaping phase, each participant received a full schedule of specific "goal-CO" values by E-mail and phone for each of the 12 breath samples of this phase. Participants received \$3 for each breath sample at or below their goal-CO value for that sample, equaling a potential of \$36 for this phase.

Abstinence Phase. To receive vouchers during the abstinence phase (21 days), all three breath samples per day were required to be at most 4 ppm. This phase involved an ascending pay schedule with a reset component. The participant received \$3 for their first criterion breath sample, and an additional \$0.25 for each consecutive criterion sample. A \$5 bonus was awarded for every five consecutive criterion samples. If a participant provided a noncriterion sample (ie, samples >4 ppm or late samples), they were not rewarded for that sample, and the next criterion sample was reset to the original payment amount (\$3). The ascending pay schedule then resumed as before from \$3, but after three consecutive criterion samples the payment amount was returned to the highest established value before the reset occurred. With the ascending pay schedule and bonuses for consecutive criterion samples, participants could potentially earn \$737.25 for this phase.

Thinning Phase. During thinning phase (5 days), participants tapered off incentives for abstinence. During this phase, participants received \$6 per day for providing three breath samples with a CO level at most 4 ppm, for a possible total of \$30 for this phase.

Figure 1. Model estimates of breath carbon monoxide levels. Return to B = return-to-baseline phase. All values are least-mean squares estimates derived.

Figure 2. Model estimates of self-report smoking behaviors. Return to B = return-to-baseline phase. FU = follow-up. All values are least mean.

Return-to-Baseline Phase. Return-to-baseline phase (5 days) was identical to the baseline phase. Participants received \$6 per day for providing three timely samples each day, with no specified criterion CO level. This phase was included to evaluate program effects immediately following removal of CO-dependent contingencies. Participants could earn \$30 for this phase.

CT Condition

The five phases of the CT condition were identical to the phases of the AT condition, and the payment schedules (including bonuses) and timing of samples were the same. However, there was no set criterion for CO level during any program phase. Participants earned vouchers for providing valid and timely breath samples at any CO level. Therefore, in terms of the reset parameter during the abstinence phase, control participants only encountered a reset for late or missed samples.

Assessments

Pretreatment Assessments. Within the 2 weeks prior to beginning the CM program, participants completed an approximately 2.5-hour laboratory session in a research office or mobile behavioral research laboratory (see Reynolds et al.¹¹ for further description). Research staff were blind to treatment condition for the pretreatment session, as randomization had not yet occurred. During pretreatment, participants completed the following self-report measures: (1) demographic questionnaire specifically designed for this study, (2) assessment of IQ,¹⁵ (3) Timeline Followback (TLFB) procedure for daily smoking frequency over the preceding 2 weeks,¹⁶ (4) Stage of Change Ladder¹⁷ to measure changes in the transtheoretical model of quitting smoking, and (4) Modified Fagerström Test for Nicotine Dependence.¹⁸ Participants also submitted breath and urine samples to verify smoking status, provided information about any smokeless tobacco use over the previous 14 days, and completed laboratory behavioral measures of impulsivity (see Harris et al.⁴ for a full description of these measures); however, impulsivity results are not reported here. Depending on behavioral-task performance, participants were compensated between \$40 and \$50 for this appointment.

During-Treatment Assessments.

Data were collected at four different timepoints: the day before starting the CM program and at the approximate midpoints of the baseline (days 3–4 during baseline), abstinence (days 10–12 during abstinence), and return-to-baseline (days 2–3 of return-to-baseline) phases. Data collected included urine samples for cotinine analyses, TLFB, Stage of Change Ladder, and the Modified Fagerström Test for Nicotine Dependence. Participants were compensated \$10 for each during-treatment assessment for a total of \$40.

Posttreatment and Follow-up Assessments. Posttreatment assessments occurred within 2 weeks of a participant finishing the CM program. This session included the same measures and compensation (\$40–\$50) as the pretreatment assessment appointment. In addition, at 3 and 6 months following treatment urinary cotinine, breath CO, and TLFB were assessed. Participants earned \$10 per follow-up assessment, for a total of \$20.

Data Analysis

Demographics across conditions were compared using chi-square tests, Fisher's exact test, and *t* tests, as appropriate. Because multiple breath

CO levels were collected as part of the CM program during each program phase, the mean CO level for each participant within each phase was calculated and used as one of the primary outcome measures of smoking behavior. Average CO levels were calculated regardless the percentage of possible CO samples submitted during each phase, but CO adherence (ie, percentage of possible samples submitted) during each phase was used to account for the varying number of CO measurements that went into each average. Mean CO level at baseline, shaping, abstinence, thinning, and return to baseline phases were modeled with a mixed model while adjusting for adherence (ie, percentage of program breath samples submitted) during each phase, participant sex, and study condition (AT vs. CT). Main effects were further explored using post hoc contrasts for between-groups and within-group changes in CO levels from baseline to each treatment phase.

In addition to program CO levels, smoking behavior was tracked using cotinine and TLFB. Cotinine and TLFB were measured once prior to randomization and then at approximate midpoint of the baseline, abstinence and return to baseline phases, and then at 3 and 6 months after the CM program had been completed. Mixed models were used to examine cotinine and TLFB. Change in cotinine or TLFB compared to pre-randomization values were the dependent variables in these models. The same independent variables as used for the program CO models were used (ie, CO adherence during each phase [overall adherence was used for follow-up visits], sex, and study condition). All participants were included in TLFB and cotinine models, regardless of whether some of their values were missing during certain timepoints.

Because each program phase was temporal, an autoregressive correlation structure was used to model intraclass correlations. All reported pairwise *p* values were adjusted using the Holm–Sidak method for between- and within-condition comparisons independently. All statistical analyses were performed using SAS 9.4. Alpha was set at .05 for all statistical tests.

Results

Demographic and clinical variables, and associated statistics, are reported in Table 1. No demographic variables were significantly different between the conditions.

Carbon Monoxide

The mean overall treatment adherence (ie, percentage of CO samples submitted throughout the treatment) was 37% in AT and 51% in CT, which is significantly different ($p = .004$). The mixed model for CO indicated significant effects of treatment phase [$F(4,394) = 8.34$, $p < .001$], treatment condition [$F(1,124) = 3.92$, $p = .05$], and treatment phase by treatment condition [$F(4,394) = 3.73$, $p = .005$]. Post hoc analyses indicate that during the thinning phase (see Figure 1), participants in the CT condition had a significantly higher mean CO levels (9.9 ppm) compared to participants in AT (6.9 ppm) ($p = .03$). Differences between treatment conditions during the abstinence phase approached statistical significance, with a *p* value of .08. Within-group comparisons revealed that reduction of CO from baseline to return-to-baseline phase was not significant for CT (1.4 ppm, $p = .13$), but was for AT, with a reduction of 5.0 ppm ($p < .001$). The reduction for AT was also a significantly larger reduction compared to CT ($p < .001$).

Timeline Followback

For the TLFB, the mixed model indicated significant effects of treatment phase [$F(5,569) = 4.22$, $p < .001$], treatment condition [$F(1,123) = 3.35$, $p = .07$], and treatment phase by condition [$F(5,569) = 5.20$, $p < .001$].

Table 1. Demographic and Clinical Variables

	Active (<i>n</i> = 63)	Control (<i>n</i> = 64)	All (<i>N</i> = 127)
Age (years), <i>M</i> [<i>SD</i>]	17.0 [1.4]	16.9 [1.4]	16.9 [1.4]
Sex (% female)	31 (49.2)	32 (50.0)	63 (49.6)
Race (<i>n</i> ; black/white/other)	7/50/6	8/48/7	15/98/13
KBIT 2 (IQ Standard Score), <i>M</i> [<i>SD</i>]	87.8 [11.7]	87.2 [10.7]	87.5 [11.2]
Cigarettes (number per day), <i>M</i> [<i>SD</i>] ^a	13.9 [11.1]	11.4 [6.4]	12.6 [9.1]
Nicotine dependence, <i>M</i> [<i>SD</i>]	5.2 [1.8]	5.2 [1.7]	5.2 [1.8]
Baseline carbon monoxide (ppm), <i>M</i> [<i>SD</i>]	9.6 [6.5]	10.5 [7.8]	10.1 [7.2]
Baseline cotinine (ng/mL), <i>M</i> [<i>SD</i>]	1268.0 [967.2]	1097.6 [785.0]	1182.8 [881.3]
At least one parent smokes (% reporting yes)	57 (90.5)	55 (85.9)	112 (88.2)
How many friends smoke, <i>M</i> [<i>SD</i>] ^b	4.0 [0.8]	3.7 [0.8]	3.8 [0.8]
Closest/best friend smokes (% reporting yes)	58 (92.1)	56 (87.5)	114 (89.8)
Contemplation Ladder: State-of-Change score	6.6 [1.6]	6.8 [1.8]	6.7 [1.7]
Marijuana, <i>M</i> [<i>SD</i>] ^c	2.4 [1.9]	2.3 [1.7]	2.4 [1.8]
Alcohol, <i>M</i> [<i>SD</i>] ^c	1.7 [1.1]	1.8 [1.0]	1.7 [1.0]
Smokeless tobacco, <i>M</i> [<i>SD</i>] ^d	1.3 [1.8]	1.3 [2.0]	1.3 [1.9]

^aCigarettes per day were calculated using a Timeline Followback calendar (TLFB) to determine cigarettes smoked each day during the past 14 days.

^bFriends who smoke was assessed using the following question: "How many of your friends smoke cigarettes/black & milds?": 1 = none, 2 = some, 3 = half, 4 = most, 5 = all.

^cDrug use was assessed with the following question: "Thinking about the past six months, how often have you used the following substances?": 0 = *never tried*, 1 = *tried it*, 2 = *1–2 times/month*, 3 = *once a week*, 4 = *times/week*, 5 = *5 or more times a week*.

^dSmokeless tobacco use was assessed with the following question: "Do you use any form of smokeless tobacco?"

Table 2. Raw Values for Smoking Outcome Measures

	Active	Control
Carbon monoxide, mean ± <i>SD</i> (percentage collected)		
Baseline	11.0 ± 6.0 (76.2)	9.9 ± 5.0 (76.2)
Shaping	7.8 ± 5.7 (58.3)	8.9 ± 4.7 (62.5)
Abstinence	7.8 ± 6.3 (22.2)	9.7 ± 5.1 (47.6)
Thinning	6.3 ± 6.3 (6.7)	9.6 ± 5.5 (26.7)
Return-to-baseline	6.8 ± 4.8 (6.7)	8.7 ± 5.1 (20.0)
Timeline Followback, ^a mean ± <i>SD</i> (percentage collected)		
Pretreatment assessment,	–40.6 ± 545.7 (92.1)	45.3 ± 517.9 (90.6)
Baseline	–83.3 ± 521.7 (85.7)	105.6 ± 699.2 (87.5)
Abstinence	–32.3 ± 467.43 (88.9)	51.9 ± 713.8 (81.3)
Return-to-baseline	–82.4 ± 579.1 (93.7)	–12.9 ± 598.7 (82.8)
3-mo follow-up	–133.7 ± 733.7 (95.2)	–12.3 ± 615.7 (79.7)
6-mo follow-up	98.8 ± 639.5 (88.9)	–128.0 ± 667.7 (76.6)
Urinary cotinine, ^a mean ± <i>SD</i> (percentage collected)		
Pretreatment assessment	–1.3 ± 2.7 (96.8)	–0.8 ± 2.4 (98.4)
Baseline	–4.8 ± 7.8 (88.9)	–1.6 ± 3.9 (95.3)
Abstinence	–5.4 ± 9.6 (90.5)	–1.6 ± 4.3 (90.6)
Return-to-baseline	–3.7 ± 6.5 (95.2)	2.7 ± 4.7 (92.2)
3-mo follow-up	–2.8 ± 6.5 (96.8)	–3.1 ± 4.9 (89.1)
6-mo follow-up	–3.3 ± 6.5 (93.7)	3.6 ± 5.2 (84.4)

Carbon monoxide values during these timepoints represent median values ± standard deviation (*SD*) for all days during this period, whereas Timeline Followback and urinary cotinine values represent single measurements taken during this period.

^aTimeline Followback and urinary cotinine measurements reflect changes from baseline values for each participant.

Post hoc analyses indicated significant differences between AT and CT in reductions of TLFB scores during abstinence and return-to-baseline phases: CT was 2.90 higher than AT during the abstinence phase ($p = .02$) and 3.89 higher at return-to-baseline phase ($p < .001$). By 1 month, however, posttreatment differences in TLFB scores between the AT and CT conditions were no longer significant (see Figure 2).

Urinary Cotinine

Mixed models did not indicate a significant effect of treatment condition, treatment phase, or treatment phase by treatment condition on cotinine levels (see Table 2 for raw values).

Discussion

This study examined remotely delivered CM designed for smoking cessation using a sample of 127 adolescent smokers (63 AT and 64 CT). These data partially replicate results from a previous CM study of adolescent smokers living in rural Appalachia.¹¹ However, the current study included a longer follow-up period (ie, 3 and 6 months compared to only 1.5 months in Reynolds et al.¹¹) and a larger more diverse sample of adolescent smokers. Participants in the AT condition had lower CO levels within treatment during the thinning phase relative to CT, and participants in the AT condition reported smoking less during the abstinence and return-to-baseline phases compared to those in the CT condition. In contrast, there were no urinary cotinine differences between AT and CT groups during treatment or at 3- and 6-month follow-up. One major issue with these data, however, is the significant decrease in adherence (ie, submission of CO samples) among AT and CT.

Similar to previous work,¹¹ CO levels were reduced among participants in AT relative to CT; however, CO reductions were more pronounced in the earlier work with significant differences between AT and CT during shaping, abstinence, thinning, and return-to-baseline phases. Reductions in cotinine levels were similarly less pronounced in the current study, with no significant reductions in cotinine levels among AT relative to baseline or CT, whereas in Reynolds et al.¹¹ significant reductions in cotinine from baseline were noted among participants in AT condition at return to baseline and 6 weeks posttreatment. Reductions in self-reported smoking in the current study were comparable to Reynolds et al.¹¹ with significantly lower self-reported smoking among AT, relative to CT, during the abstinence and thinning phases of treatment. Although the treatment used in this study is similar to that in Reynolds et al.,¹¹

this study examined a larger sample of more regionally diverse adolescent smokers compared to only those living in rural Appalachia.¹¹ These results may indicate that this broader population is less sensitive to CM effects.

Compared to adolescent CM programs delivered in clinical settings, the efficacy of this study is mixed. For example, Roll⁶ observed significant decreases in CO levels throughout all timepoints within a 4-week treatment period and at 1-month follow-up. Compared to the current study, Roll⁶ required participants express desire to quit smoking, which likely elevated treatment efficacy. Roll⁶ also assessed CO once daily, and used no other biological smoking verification (eg, cotinine), which makes it difficult to directly compare efficacy to the current study. In another study, Gray et al.¹⁹ examined combined treatment for adolescent smoking cessation using CM and bupropion sustained-release. Although they observed moderate efficacy in the bupropion and CM group, the CM only group showed relatively low abstinence rates (10%) and efficacy no greater than the control group. Further, only 17% in the CM group completed all treatment visits. Thus, the current study had relatively higher adherence rates perhaps due to the greater convenience of the remote form of treatment and a more frequent reinforcement schedule.

Results from this study underscore the importance of increasing treatment adherence for future CM studies. One challenge in developing CM therapies is determining reward values that are large enough to be effective, yet not impractically high. Adherence rates from this study suggest that reward rates could be increased further to promote increased sample submissions. If, however, participants are selectively omitting samples at times when they have recently smoked, it may be helpful to partially incentivize submissions that do not meet CO criteria, but only fully reward criterion meeting samples. Although this study was designed to be more convenient for participants by allowing them to submit CO samples from home, the requirement to be at home three times daily may have negatively affected adherence. One way to address this issue could be to use mobile phones for video recording, which would allow participants to submit samples from any location.

Although CO levels were reduced among AT relative to CT during treatment, this effect did not persist at 3- and 6-month follow-up. One possible reason treatment effects did not persist is that participants were not treatment seeking and therefore were not motivated to quit once abstinence-promoting rewards were no longer available. Yet, another similar study using a Web-based CM treatment for adult smokers with desire to quit smoking found no significant differences between active and CT groups at 3- and 6-month follow-up,²⁰ suggesting that desire to reduce or quit smoking may not necessarily improve posttreatment outcomes. As such, the current study further underscores the need for techniques to extend CM effects posttreatment.

It should be noted that there are several pitfalls to this study that likely reduced study efficacy and the ability to detect intervention effects. Although reductions in CO and self-reported smoking were noted during treatment, and previous research has demonstrated high concordance rates between cotinine and CO measurements,²¹ there were no significant reductions in urinary cotinine for participants in the AT condition. One possible explanation for this disparity is difference in time of measurement. As CO levels were measured three times daily throughout treatment and cotinine levels were only assessed once during certain treatment phases, some disparity between these measurements is to be expected. Another potential explanation is that participants may have omitted CO samples throughout treatment if

they had been smoking. As only 37% of the possible CO samples were submitted for AT during treatment (compared to 83% of cotinine samples collected during the same time frame), CO may have not detected some brief periods of smoking that were captured by the more complete cotinine dataset. Yet, each participant's percentage of CO samples submitted was used as a covariate for cotinine analyses to attempt to compensate for this possibility, and differences in the percentage of CO samples submitted did not account for the cotinine results. Another possibility is that participants smoked at times immediately following CO collection times (eg, after the last CO measurement on a particular day). As CO has a relatively short half-life compared to cotinine, CO measurements may not have detected this smoking behavior whereas cotinine measurements did. Lastly, participants could have used electronic cigarettes during the study, which would not likely elevate CO levels but could cause increases in urinary cotinine levels. Although this is possible, there was no observed evidence during the study that participants were using electronic cigarettes.

In conclusion, this study represents a rigorous examination of a remotely delivered CM therapy for adolescent tobacco smoking. Reduced CO levels during treatment suggest there was some efficacy in reducing smoking while contingent rewards were in place. However, this effect did not persist posttreatment, and future efforts should be devoted to developing ways to extend CM treatment effects to follow-up. Further, urinary cotinine and breath CO measurements were not concordant in terms of treatment outcomes, and more research examining potential causes for this discrepancy is warranted. Future research should also explore methodologies to increase adherence rates. In sum, this type of remote CM treatment is a feasible treatment for adolescent tobacco smoking in the short term, but further work should aim to improve program efficacy during and following treatment.

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Declaration of Interests

None declared.

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