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Brief training in regulation of craving reduces cigarette smoking

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ABSTRACT

Introduction: Craving is an important contributing factor in cigarette smoking and has been added as a diagnostic criterion for addiction in the DSM-5. Cognitive-behavioral therapy and other treatments that incorporate craving regulation strategies reduce smoking and the likelihood of relapse. Although this finding suggests that the regulation of craving is an important mechanism underlying smoking cessation, whether targeted interventions that train smokers to regulate craving can directly impact real-world smoking behaviors is unclear.

Method: Across two pilot studies ($N = 33$; $N = 60$), we tested whether a brief, computer-delivered training session in the cognitive regulation of craving altered subsequent smoking behaviors in daily life. The study first randomly assigned participants to either a no training (control) group, or one of two Regulation of Craving Training (ROC-T) conditions. Next, all participants came into the lab and those assigned to ROC-T conditions were trained to implement a cognitive strategy to regulate their craving, by either focusing on the negative consequences of smoking, or by distracting themselves. Then, these participants underwent ROC-T during which they practiced using the strategy to regulate their craving during cue exposure. The study subsequently assessed participants' smoking via daily diaries for 3–6 days, and via self-report up to 1-month follow-up.

Results: Across both studies, ROC-T conditions were associated with significant reductions in average cigarettes smoked per day, with effects persisting through follow-up.

Conclusion: These results confirm that the regulation of craving is an important mechanism of smoking cessation, and can be targeted via easily administered training procedures, such as ROC-T.

1. Introduction

Cigarette smoking remains the most prevalent cause of preventable morbidity and mortality in the world, including in the United States (Centers for Disease Control and Prevention (CDC), 2008). On average, smoking kills 1200 Americans every day, accounting for 480,000 deaths per year (National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health, 2014), far exceeding deaths from AIDS, murders, suicide, car crashes, alcohol, and all illicit drugs—combined (Mokdad, Marks, Stroup, & Gerberding, 2004). As far as morbidity, recent estimates indicate that approximately 14 million U. S. adults had smoking-related medical conditions (Rostron, Chang, & Pechacek, 2014). Moreover, smoking is associated with significant economic costs—including medical expenses and lost worker productivity—exceeding $289 billion in the United States alone (National Center for Chronic Disease Prevention and Health Promotion (US) Office on Smoking and Health, 2014). Finally, despite a marked declines in smoking rates over the past four decades (i.e., 42.4% of U.S. adults in 1965 to only 15.5% in 2016; Jamal et al., 2018), the coronavirus pandemic has halted this trend (North American Quitline Consortium, 2021; Rigotti et al., 2021) and research has linked smoking to increased severity of COVID-19 (Patanavanich & Glantz, 2020; Purkayastha et al., 2020).

Importantly, smoking cessation rates remain low (Babb, Malarcher, Schauer, Asman, & Jamal, 2017; Dutra et al., 2008), despite many smokers recognizing the harms of smoking and wanting to quit. Indeed, recent figures indicate that although 68% of smokers express the desire to quit every year, and 55.4% make an effort to quit, only 7.4% are successful (Babb et al., 2017). Why is quitting still an unattainable goal for so many smokers?

One important contributor to smoking is craving. Craving is defined in the DSM-5 as "a strong desire," and previous research has linked

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craving to smoking and relapse following quit attempts (Allen, Bade, Hatsukami, & Center, 2008; Cooney et al., 2007; Doherty, Kinnunen, Militello, & Garvey, 1995; Gass, Motschman, & Tiffany, 2014; Shadel et al., 2011; Shiffman et al., 1997). Further, craving that arises following exposure to smoking cues—*cue-induced craving*—has also been reliably linked to smoking and relapse in particular studies (e.g., Carpenter et al., 2009; Conklin et al., 2015; Waters et al., 2004) and across multiple studies in terms of robust meta-analytic effects (Vafaie and Kober, in revision). Indeed, this type of craving may be especially important when considering treatment programs (Ferguson & Shiffman, 2009).

Many models of addiction posit that the inability to exert control over cue-induced craving underlies compulsive smoking and other drug-seeking behaviors (Everitt & Robbins, 2005; Goldstein & Volkow, 2011; Koob & Le Moal, 2001). As such, cue-induced craving, and especially its *regulation*, might serve as an important target of smoking cessation interventions to improve outcomes. Indeed, a key feature of cognitive-behavioral therapies (CBT) for smoking cessation (and addiction more broadly) is to train individuals to change their natural or prepotent responses (e.g., craving) to appetitive and/or affective stimuli by using cognitive reappraisal strategies (e.g., considering their negative consequences). Further, studies using ecological momentary assessment have shown use of such strategies to be linked to reduced smoking (O'Connell, Hosein, Schwartz, & Leibowitz, 2007).

We and others have tested whether such strategies effectively reduce craving in controlled laboratory settings. For example, in a CBT-based regulation of craving (ROC) task, cigarette-smoking participants were instructed to focus on the negative consequences of smoking while being exposed to smoking cues, and reported a significant reduction in craving (Kober, Kross, Mischel, Hart, & Ochsner, 2010). Subsequent studies have replicated this result by demonstrating that cigarette smokers can successfully implement this strategy via the ROC task (Kober, Kross, et al., 2010; Luijten, van Meel, & Franken, 2011), and that regulation success depends on the extent to which smokers recruit brain regions that were previously associated with regulation of negative emotions (i.e., dorsolateral and ventrolateral prefrontal cortex; Buhle et al., 2014; Kober, Kross, et al., 2010). In turn, recruitment of these prefrontal regions was associated with reduced activity in the ventral striatum and vmPFC (Kober et al., 2010)—regions typically linked to reward computation and the subjective experience of craving (e.g., see Diekhof, Kaps, Falkai, & Gruber, 2012 for a meta-analysis). Researchers have also administered this CBT-based ROC task to methamphetamine users, who successfully diminished their craving when employing the regulation strategy described above (Lopez, Onyemekwu, Hart, Ochsner, & Kober, 2015). Similar findings have since been reported with other stimulant users, alcohol-dependent individuals, and with food (Giuliani, Calcott, & Berkman, 2013; Giuliani, Mann, Tomiyama, & Berkman, 2014; Naqvi et al., 2015; Suzuki et al., 2020; Volkow et al., 2010).

Another class of regulation strategies involves attentional deployment, which consists of directing attention away from one's craving so it is not as intensely experienced and thereby reduces the likelihood of someone indulging their craving. Indeed, research has hypothesized that such antecedent-focused strategies are effective because they intervene early before a craving is fully expressed (Duckworth, Gendler, & Gross, 2016), with some studies showing that smokers will naturally use or favor attentional deployment (specifically distraction) over other strategies (Hartwell et al., 2011). And although less frequently used in addiction treatment, distraction is also part of CBT (Beck, 2011).

To build on these lines of work, we developed Regulation of Craving Training (ROC-T)—a training procedure based on the ROC task, in which participants practiced using the strategies we discussed to regulate their craving over and over in the presence of cigarette cues. Here we tested whether this brief, computerized training procedure is effective in reducing not only craving, but also cigarette smoking in daily life. Specifically, we conducted two pilot studies: we recruited daily smokers who were motivated to reduce or quit smoking and randomly assigned them to one of three groups: two experimental groups that received ROC-T and a control group that did not receive an intervention. Both ROC-T conditions were CBT-based, with participants in one condition trained to engage in cognitive reappraisal by focusing on the negative consequences of smoking when experiencing craving, as we have described. The other ROC-T condition trained participants to cognitively distract themselves by bringing to mind something completely different when they feel craving. We included both strategies to test whether they would be equally or differentially effective. Across both studies, participants completed ROC-T via a computer in the lab, and we measured their post–intervention craving and smoking behaviors with daily diary surveys, an ecologically valid and increasingly common way to assess longitudinal changes in substance use behaviors (Roos, Kober, Trull, MacLean, & Mun, 2020), as well as follow-up telephone interviews.

Both studies tested two primary hypotheses, building on previous studies of the efficacy of cognitive strategies in attenuating craving (e.g., Kober, Kross, et al., 2010; Kober, Mende-Siedlecki, et al., 2010; Lopez et al., 2015; Naqvi et al., 2015). We predicted that (1) participants in the Reappraisal-based ROC-T and Distraction ROC-T groups would reduce their smoking relative to participants in the control group; and (2) training in Reappraisal-based ROC would be more effective than training in Distraction ROC. Accordingly, we specified a priori contrasts that reflect these hypotheses in all relevant statistical tests.

2. Study 1

2.1. Method

2.1.1. Participants

The study recruited participants from the New York City area via flyers and postings on Craigslist.org. To be eligible, participants had to be 18–50 years old, smoke every day of the week, at least three cigarettes per day, and report being at least moderately motivated to quit or reduce their smoking (i.e., > 4 on a 1–7 Likert scale). The study excluded participants if they reported any current or past psychiatric and/or non-nicotine substance use disorders. Last, to ensure compliance with the daily diary portion of the study, participants had to have reliable Internet access at home. If participants fulfilled all eligibility criteria, the team enrolled them in the study. After being screened by phone and deemed eligible, all participants gave informed consent in accordance with the Institutional Review Board of Columbia University (under approved protocol AAAC1363). Forty-six current cigarette smokers consented to participate in the study and were randomized to one of the three experimental conditions. Of these participants, six were no-shows for the first session and were not later reachable by email or phone, three did not complete the baseline surveys, two did not complete the post-study surveys, one did not come to the last study appointment, and one was found to be ineligible at a later time and the study excluded them (due to rolling their own cigarettes).[1] The final sample used for all subsequent analysis consisted of 33 smokers (17 Female; $M_{age} = 27.8$, $SD_{age} = 7.28$). Of these participants, 50% identified as White; 21.9% as Black or African American; 9.4% as Asian, Asian American, or Pacific Islander; and 18.8% as Other/mixed race/unspecified; 78.8% identified as non-Hispanic, and 21.2% identified as Hispanic. The study randomly assigned participants to the study's conditions as follows: Reappraisal-based ROC-T ($N = 11$), Distraction-based ROC-T ($N = 11$), and Control (no training; $N = 11$). For all in-lab sessions, the study staff instructed participants to abstain from caffeine, food, and cigarettes for at least two hours.

[1] Although we provide information regarding retention and allocation for Study 1, we did not have all the information needed to generate a CONSORT diagram. However, we have included most items listed on the "*CONSORT checklist when reporting a pilot or feasibility trial.*" For Study 2, we provide a CONSORT diagram (see Supplementary figure S1).

2.1.2. Procedure

Study 1 had six major stages (see Fig. 1 for schematic of study design): (1) an initial session in the lab to acquire baseline cognitive and personality measurements (Day 1), not reported here except the Ladder and Fagerström Test for Cigarette Dependence (FTCD; Fagerström, 2011; Heatherton, Kozlowski, Frecker, & Fagerström, 1991); (2) a pre-intervention period in which participants completed daily diaries to assess smoking (cigarettes per day; Days 1–3); (3) a lab session that included surveys for all groups and ROC-T for the experimental groups (Day 4); (4) a post-intervention sampling period of daily smoking behavior via daily diaries (Days 4–7); (5) a final lab session with personality and cognitive task measures (Day 8); and (6) One- and two-week follow-up assessments of smoking behavior, administered by phone.

2.1.2.1. Pre-intervention period. For the initial lab session (Day 1), participants completed the FTCD as well as a battery of cognitive tasks and individual difference questionnaires (which are not relevant to the current hypotheses, and may be reported elsewhere). For the following three days (Days 1–3), to establish a baseline, participants completed online daily diaries within 30 min of going to bed and were asked the following questions: "How many times did you crave cigarettes today?"; "How many cigarettes did you smoke today?"; "Did you buy a new pack?"; and "Did you encounter situations that may have triggered craving?"

2.1.2.2. ROC-T lab session. Next, on Day 4 all participants came back to the lab and completed laboratory and questionnaire measures (not reported here). At this point, the lab session ended for participants in the control condition, but participants in the intervention conditions continued on to the training stage of the session.

For training, participants first read either an essay detailing the negative consequences associated with smoking (Reappraisal-based ROC-T) or an essay about the history of tobacco in the United States (Distraction-based ROC-T; see Supplementary Materials). Participants then performed a memory recall task to ensure they adequately remembered 10 facts from the essays (e.g., "over 400,000 people die each year from smoking related illnesses" or "70% of Burley tobacco comes from Kentucky"). If they did not have a 100% score on the recall task, they were given additional attempts to respond (after re-reading the essay), and the study re-tested them until they achieved a 100% score.

Next, participants read a statement in which they were reminded of their goal to reduce and/or quit smoking for the following week and were instructed to formulate a specific plan consistent with their goal (e.g., "I will smoke X fewer cigarettes a day for the next week"). Once they indicated their plan, they were given a strategy by which they could implement their plan by first generating 10 situations or cues that was likely to induce craving to smoke on a daily basis (e.g., "When I have my morning cup of coffee"). Based on these self-generated situations or cues, participants generated "if-then" implementation intentions (adapted from Gollwitzer, 1999) and were instructed to focus on recalling the essay material (see Supplementary Material). For example, a participant might generate the statement, "If I experience craving when having my morning cup of coffee, I will think about (1) the negative consequences of smoking (if in Reappraisal-based ROC-T condition); or (2) historical facts about tobacco (if in Distraction-based ROC-T condition)." After specifying these implementation intentions, and stating they understood the overall strategy, participants completed a training block of trials in which they imagined the craving-inducing situations they previously identified and practiced implementing the strategy. Next, to train them to use the strategy in moments of craving, we administered ROC-T, which we adapted from our prior work (Kober, Kross, et al., 2010; Kober, Mende-Siedlecki, et al., 2010). On each trial during the task, the word "LOOK" or "STRATEGY" would appear on the screen, followed by an appetitive smoking cue (e.g., a lit cigarette in an ashtray), then a rating scale that ranged from 1 (*not at all*) to 5 (*very much*) for participants to indicate their cue-induced craving on that trial. On "LOOK" trials, the study instructed participants to respond naturally to the subsequent smoking. On "STRATEGY" trials, participants were prompted to implement the strategy (i.e., either "think about the negative consequences of smoking" or "think about historical facts about tobacco") when the smoking cue was on the screen. In total, ROC-T included 50 trials, with 25 "LOOK" trials and 25 "STRATEGY" trials (instruction-cue pairings randomized for each participant).

2.1.2.3. Postintervention and follow-up periods. On the night of the in-lab intervention session (Day 4), participants completed a daily diary in which they were asked to report the time of the first cigarette they smoked after leaving the lab, and how many cigarettes they craved and smoked across several blocks of time between leaving the lab and when they started the daily diary. Next, for the postintervention sampling period (Days 4–7), participants responded to online daily diaries each night before going to bed. All questions were the same as the pre-intervention diaries, with the only difference being that the Reappraisal-based and Distraction ROC-T groups answered questions about how successful they were in implementing the strategy.

On Day 8, all participants returned to the lab for postintervention measurements of smoking urges and cigarette attitudes (assessed via questionnaires), as well as other behavioral tasks and individual difference questionnaires (not reported). Last, follow-up assessments of daily smoking, conducted via phone interview, occurred 1 week and 2 weeks following the final (Day 8) lab session for all groups (ROC-T groups and control group). Each follow-up interview asked participants, "How many cigarettes are you smoking, on average, each day?" Overall, responses rates for the daily dairies and follow-up assessments were high, ranging from 88% to 100%.

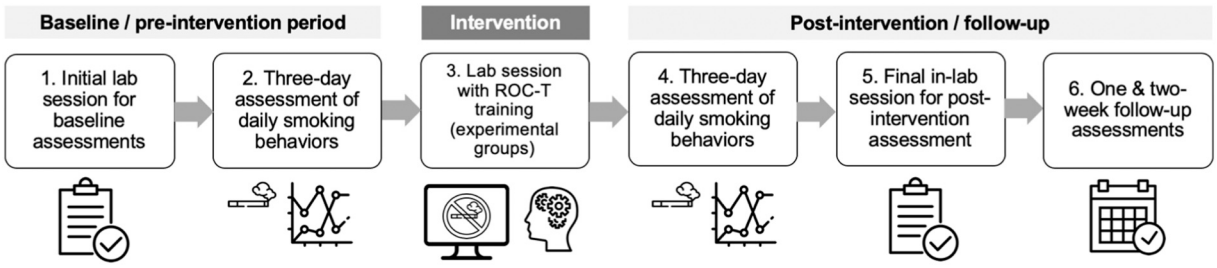

Fig. 1. Schematic of study design for Study 1, which consisted of the following components and assessment periods: (1) an initial session in the lab to acquire baseline cognitive and personality measurements (Day 1); (2) a pre-intervention period in which participants completed daily diaries to assess smoking (cigarettes per day; Days 1–3); (3) a lab session that included surveys for all groups and ROC-T for the experimental groups (Day 4); (4) a post-intervention sampling period of daily smoking behavior via daily diaries (Days 4–7); (5) a final lab session with personality and cognitive task measures (Day 8); and (6) One and two-week follow-up assessments of smoking behavior, administered by phone.

2.2. Results

We observed no group-level baseline differences in age, gender, Ladder scores, FTCD scores, or pre-study cigarettes smoked per day, all p's ≥ 0.08 (see Table 1), and differences in participants' education level are reported in the Supplementary Analyses. To assess whether overall changes in cigarettes smoked per day (CPD) occurred throughout the study's measurement periods, and whether time-by-group interactions occurred, we ran a mixed, 3-by-4 repeated-measures ANOVA, with group (Control, Reappraisal-based ROC-T, and Distraction ROC-T) as a between-subjects factor, and time (Pre-intervention, Post-Intervention, 1-week follow-up, 2-week follow-up) as the within-subjects factor. A significant main effect occurred of time on CPD ($F_{(3, 78)} = 2.88$, $\eta^2_{partial} = 0.10$, $p = .042$), which was qualified by a significant group-by-time interaction ($F_{(6, 78)} = 2.37$, $\eta^2_{partial} = 0.15$, $p = .037$). The nature of this interaction was clarified in a significant linear contrast for the interaction ($F_{(2, 26)} = 3.41$, $\eta^2_{partial} = 0.21$, $p = .048$). Specifically, the Reappraisal-based ROC-T group showed sustained reduction in CPD over time, while the Distraction ROC-T group had an initial reduction, and the Control group showed little to no change in CPD over the study timeline (see Fig. 2). In terms of percentage reductions in cigarettes smoked per day (compared to participants' pre-intervention levels), the Reappraisal-based ROC-T group reported reductions ranging between 22% and 49% across the postintervention assessment and one- and two-week follow-ups, and the Distraction ROC-T group reported reductions of 26–36%.

3. Study 2

The motivation for Study 2 was to replicate the findings from Study 1 in a larger sample of smokers and to test whether ROC training would be effective for relatively heavier smokers.

3.1. Method

3.1.1. A priori power analysis

To guide sample size planning and stopping rules for Study 2, we used the effect size of the interaction term in Study 1 ($\eta^2_{partial} = 0.15$) and conducted power analyses with G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), assuming 90% power and a range of small-to-medium effect sizes for a repeated measures ANOVA with a within-between interaction effect (the study indicated time as the within-subjects factor with 5 levels and indicated group/training status as the between-subjects factor with 3 levels). The required total sample size ranged from 40 to 70, but we wanted to be able to detect smaller effects, so we aimed to have approximately 20–25 participants per condition.

3.1.2. Participants

Screening and inclusion criteria in Study 2 were identical to those for Study 1 (see above), except that respondents had to report smoking at least eight cigarettes a day, seven days a week to be eligible to participate. This was done to determine if the training would also benefit relatively heavier smokers. So, we recruited a new, independent sample of ninety-five eligible participants from the New York City area via flyers and online Craigslist postings. All participants completed an online consent form and the study then randomly assigned them to one of the three conditions (Reappraisal- or Distraction-based ROC-T, or Control/No Training). Of these, eighty-one began study assessments (i.e., initial daily diaries) and of these, 60 participants (28 female) continued with the rest of the study through its completion, leaving a final N of 60 for all reported analyses (see Supplementary fig. S1 for CONSORT diagram). Among these participants ($M_{age} = 37.35$, $SD_{age} = 9.39$), 28 identified as female, and 44.1% identified as being White; 25.4% as Black or African American; 10.2% as Asian, Asian American, or Pacific Islander; 1.7% as Native American; and 18.8% as Other/mixed race/unspecified; and 72.9% identified as non-Hispanic and 27.1% identified as Hispanic. The study randomly assigned these participants to the study conditions as follows: Reappraisal-based ROC-T ($N = 21$), Distraction-based ROC-T ($N = 18$), and Control (no training; N = 21). For all in-lab sessions, participants were instructed to abstain from caffeine, food, and cigarettes for at least 2 h.

Table 1
Demographics for the Study 1 Sample ($N = 33$).

Group (N)	Mean age (SD)	Male	Female	Mean Ladder (SD)	Mean FTCD (SD)	Pre-study CPD (SD)
Control (11)	27.82 (8.42)	6	5	6.27 (1.68)	4.09 (1.92)	11.68 (6.44)
Reappraisal-based ROC-T (11)	24.64 (5.85)	6	5	8.00 (1.48)	5.09 (1.81)	9.59 (4.75)
Distraction ROC-T (11)	31.09 (6.44)	4	7	7.09 (2.02)	4.8 2 (1.78)	11.64 (7.60)

3.1.3. Procedure

Study 2 followed Study 1's procedure closely. However, to streamline the study design and increase compliance over the study's timeline, we enacted the following changes: participants in Study 2 did not come in for an initial lab session and lab sessions administered fewer tasks. Further, to assess whether the effects of ROC-T were robust and longer lasting (compared to Study 1), the study team extended the post-intervention daily diary sampling period to seven days, and added an additional follow-up timepoint at one month. Participants were also randomly assigned to group at the outset of the study (after consent), so only the experimental (Reappraisal-based and Distraction ROC) groups came in to the lab to complete the lab session. Accordingly, Study 2 had five stages (see Fig. 3 for schematic): (1) An initial, pre-intervention period in which participants completed daily diaries to assess smoking (as in Study 1; Days 1–3); (2) An in-lab session in which we assessed baseline levels of nicotine dependence (indexed by the FTCD), administered ROC-T for both active groups, as well as other individual difference measures (not described here; Day 4); (3) A postintervention sampling period of smoking behavior via daily diaries for one week (Days 4–10); (4) A final in-lab session in which we re-administered some measures (not described here; Day 11); and (5) Follow-up phone surveys, administered at 1-week, 2-week, and 1-month post-intervention, in which participants reported their levels of daily smoking. All other procedural details, survey questions, and task protocols of these five stages were identical to those in Study 1 (see above). As in Study 1, response rates for the daily dairies and follow-up assessments were high, ranging from 72% to 100% across all assessment periods, with the lowest response rates (i.e., 72% and 83%) taking place at the longer-term follow-ups.

3.2. Results

As in Study 1, no group differences occurred in age, gender, Ladder scores, FTCD scores, or pre-study mean CPD (all p's ≥ 0.39; see Table 2), and differences in participants' education level are again reported in the Supplementary Analyses. To test for whether effects from Study 1 replicated in Study 2, we subjected the data to a mixed 3-by-5 repeated-measures ANOVA with group (Control, Reappraisal-based ROC-T, Distraction ROC-T) as the between-subjects factor and time (Pre-intervention, Post-intervention, and 1-week, 2-week, and 1-month follow-up) as the within-subjects factor. Sphericity in the variance-covariance structure was violated (Mauchly's $W = 0.42$, $p = .001$), so we used the Greenhouse-Geisser correction with adjusted degrees of freedom. A significant main effect occurred of time on CPD ($F_{(2.62, 91.70)} = 15.14$, $\eta^2_{partial} = 0.30$, $p < .001$), which was qualified by a significant group-by-time interaction ($F_{(5.24, 91.70)} = 4.46$, $\eta^2_{partial} = 0.20$, $p = .001$). The

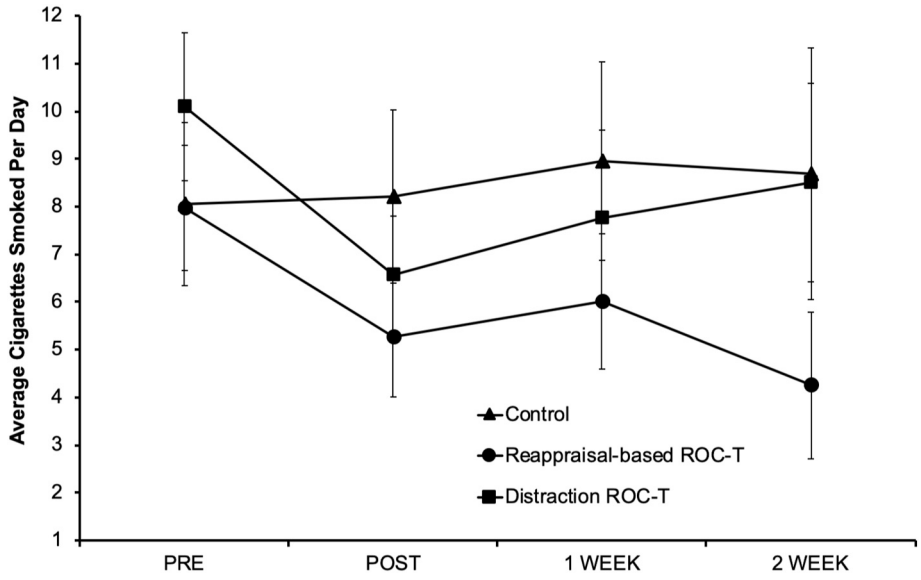

Fig. 2. Average cigarettes smoked per day by group (indicated by line type), across Study 1's assessment periods (error bars indicate ± SEM).

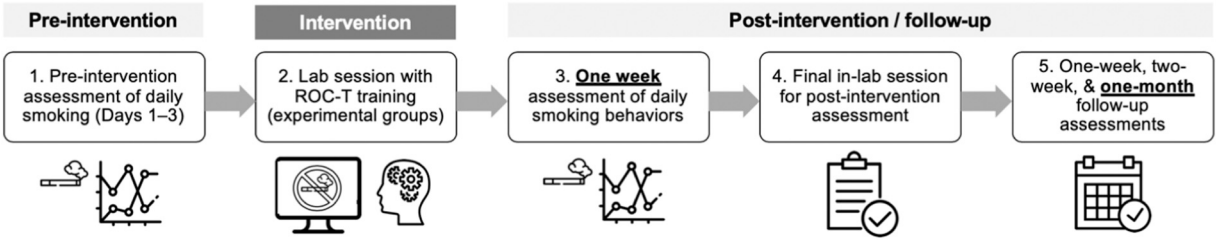

Fig. 3. Schematic of study design for Study 2, which consisted of the following components and assessment periods: (1) An initial, pre-intervention period in which participants completed daily diaries to assess smoking (as in Study 1; Days 1–3); (2) An in-lab session in which we administered ROC-T for both active groups, as well as other measures (not described here; Day 4); (3) A post-intervention sampling period of smoking behavior via daily diaries for one week (Days 4–10); (4) A final in-lab session in which we re-administered some measures (not described here; Day 11); and (5) Follow-up phone surveys, administered at 1-week, 2-week, and 1-month post-intervention, in which participants reported their levels of daily smoking.

Table 2
Demographics for the Study 2 Sample (N = 60).

Group (N)	Mean age (SD)	Male	Female	Mean Ladder (SD)	Mean FTCD (SD)	Pre-study CPD (SD)
Control (21)	38.00 (10.52)	10	11	7.42 (2.76)	5.34 (2.38)	18.17 (7.77)
Reappraisal-based ROC-T (21)	35.14 (9.25)	13	8	8.00 (1.84)	4.90 (2.55)	15.91 (8.05)
Distraction ROC-T (18)	39.17 (8.07)	9	9	8.00 (2.20)	5.08 (1.75)	18.53 (7.68)

nature of this interaction was clarified in a significant linear contrast for the interaction term ($F_{(2,\ 35)} = 7.26$, $\eta^2_{partial} = 0.29$, $p = .002$), and a significant linear trend overall ($F_{(1,\ 35)} = 23.20$, $\eta^2_{partial} = 0.40$, $p < .001$). In this case, sustained reductions occurred in CPD in both Reappraisal-based and Distraction ROC-T groups, while CPD in the Control group was relatively flat throughout (see Fig. 4 for a visual depiction of these effects). Last, in terms of percentage reductions in cigarettes smoked per day, the Reappraisal-based ROC-T group reported reductions ranging between 29% and 39% across the postintervention and follow-up assessments, and the Distraction ROC-T group reported reductions of 30% to 47%.

4. Discussion

The primary goal of the current studies was to assess whether ROC-T—brief training in CBT-based cognitive strategies targeting regulation of craving—would effectively reduce cigarette smoking in daily life. Specifically, we hypothesized that participants in the experimental ROC-T groups (Reappraisal-based ROC-T and Distraction ROC-T groups) would experience significantly lower craving and smoke less than participants in the control group, and that training in Reappraisal-based ROC-T (vs. Distraction ROC-T) would be most efficacious. Across both studies, and in support of our first hypothesis, smokers who underwent ROC-T—either Reappraisal-based or Distraction-based—successfully reduced their smoking (compared to control groups), and this persisted for 2 weeks (Study 1) and 1 month (Study 2) postintervention. Importantly, the study obtained this pattern of results across two independent samples that consisted of relatively lighter (Study 1) and heavier (Study 2) smokers, respectively. These results suggest that a brief, single-session training that targets the regulation of craving using CBT-based principles is effective for smoking reduction, at least in the short term.

Interestingly, we did not find support for our second primary hypothesis, that Reappraisal-based ROC-T would be more effective in reducing smoking than Distraction ROC-T. The finding that *both* ROC strategies equivalently reduced craving suggests they may share some common mechanism, such as controlling the deployment of attention. For the Reappraisal-based ROC-T group, this meant directing attention toward the negative consequences of the craved item (i.e., cigarette),

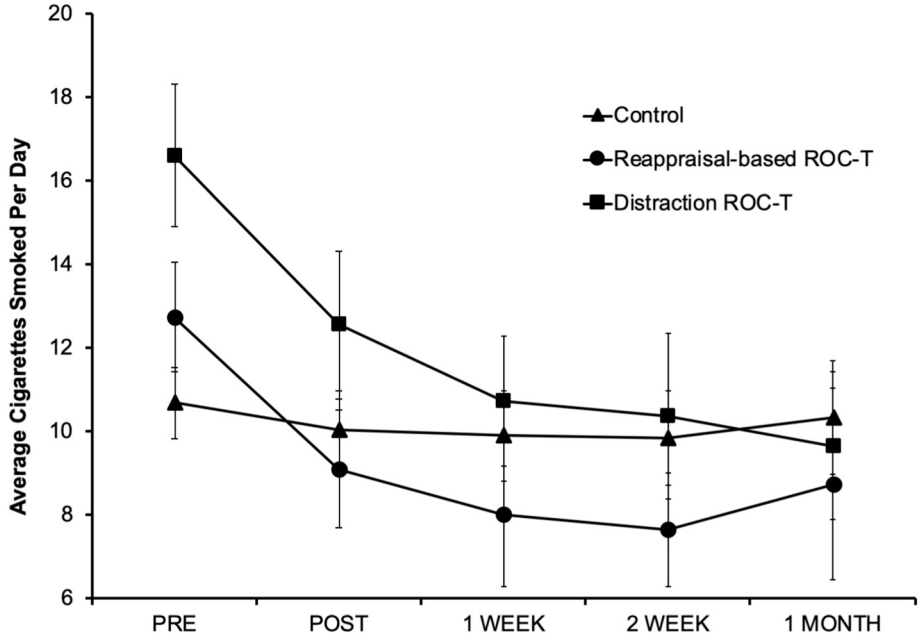

Fig. 4. Average cigarettes smoked per day by group (indicated by line type), across Study 2's assessment periods (error bars indicate ± SEM).

and for the Distraction ROC-T group, this meant directing attention toward unrelated, neutral content (i.e., the history of tobacco) tangential to the act of smoking. In either case, participants could redirect their attention and therefore avoid experiencing the full intensity of craving they would otherwise experience. This interpretation is consistent with process models of emotion and craving regulation, which posit that antecedent-focused strategies, such as attentional (re)deployment, are particularly effective because they can be implemented relatively early on in the emotion/craving generation process (Duckworth et al., 2016; Gross, 2002). Nevertheless, despite the similar reduction in smoking across reappraisal- and distraction-based ROC-T, the two strategies likely have some distinct mechanisms as well. For example, reappraisal-based ROC-T may alter the subjective valuation of smoking (Berkman, Hutcherson, Livingston, Kahn, & Inzlicht, 2017; Sun & Kober, 2020).

Overall, these findings suggest that successful implementation of ROC strategies can mitigate the known effects of cue exposure (e.g., Kober, Turza, & Hart, 2009) and cue-induced craving (e.g., Ferguson & Shiffman, 2009) on smoking and relapse. The current results are consistent with previous work demonstrating that smokers can successfully regulate their cravings using a CBT-based ROC strategy (Kober, Kross, et al., 2010) and the neural mechanisms supporting such regulation (see Kober, Mende-Siedlecki, et al., 2010). More recently, we followed up on the current study (which was yet unpublished) and showed that ROC-T in the eating domain promotes healthier food choices and reduces caloric consumption (Boswell, Sun, Suzuki, & Kober, 2018). Individual differences in implementation success of a ROC strategy also have been linked to healthier eating patterns in daily life, as measured by ecological momentary assessment (Reader, Lopez, & Denny, 2018).

Importantly, ROC-T in the present studies and other cited work is domain-specific, as it targets cue-induced craving in a particular domain (e.g., smoking, eating), and therefore avoids the issues associated with domain-general training, such as limited transfer effects (e.g., Beauchamp, Kahn, & Berkman, 2016). Others have taken a similar approach with positive results, such as Chen, Kelley, Lopez, and Heatherton (2018) who showed that domain-specific, food-cue inhibitory training (versus domain-general training) was effective in reducing the strength of daily food cravings in dieters (Chen et al., 2018).

The current findings also highlight the promise of applying CBT-based ROC strategies as a brief, targeted, computerized, mechanism-focused intervention to reduce smoking. This is consistent with prior clinical work on coping skills, which are often a key component of CBT and involve strategies that help patients to better understand their cravings and avoid particular triggers that elicit such craving for the desired substance. Coping skills training has been shown to predict long-term abstinence for marijuana dependence (Litt, Kadden, Kabela-Cormier, & Petry, 2008), and coping skill acquisition and development, as part of CBT, has been associated with reduced drinking and increased abstinence among those with alcohol abuse or dependence (Litt, Kadden, Cooney, & Kabela, 2003). In another study of individuals seeking treatment for substance use disorders, quality of coping responses during CBT mediated treatment success to predict greater abstinence up to three months post-treatment (Kiluk, Nich, Babuscio, & Carroll, 2010). This suggests that a particularly effective component of coping strategies administered in CBT may be the regulation of cue-induced craving, so clinicians may want to consider explicitly incorporating personalized ROC strategies (as operationalized here) into daily or weekly CBT homework to promote reduction of craving and abstinence over time.

As an intervention, ROC-T has the distinct advantage of being theory-based and mechanism-focused, specifically around craving and the regulation of craving, both core processes long thought to be central to addictions in general and cigarette smoking in particular. Indeed, a theory-driven focus on core mechanisms can facilitate development, testing, and refinement of interventions, leading to better efficacy, effectiveness, and efficiency (e.g., Naqvi & Morgenstern, 2015; Onken, Carroll, Shoham, Cuthbert, & Riddle, 2014). A focus on mechanisms can facilitate precision-based delivery of interventions for substance use (including smoking) in the real-world, via monitoring changes in the targeted mechanism at symptomatic, cognitive, and neural levels (including changes that may occur before symptom change). Such a focus can also ultimately facilitate matching interventions to specific subpopulations (Onken et al., 2014; Witkiewitz, Roos, Mann, & Kranzler, 2019). Further, ROC-T has the distinct advantage of being fully computerized, and thus easy to implement, test, and disseminate, including as a web-based intervention. This is important as technology-based interventions have the potential to greatly expand the reach of evidence-based treatments (e.g., Price et al., 2014; Schueller & Torous, 2020) and have been shown to be viable, effective, and cost-effective for a wide range of disorders, including SUDs (e.g., Carroll & Kiluk, 2017;

Marsch, Carroll, & Kiluk, 2014).

Despite the promise of the current findings and their implications for smoking cessation treatment, some limitations are worth mentioning. First, although daily diary measures are a valid and often preferred method to capture daily substance use behaviors in vivo (Roos et al., 2020), our main outcome measure (cigarettes smoked per day) was nonetheless estimated from self-report. Future studies can and should incorporate additional validation of smoking (e.g., via carbon monoxide or urine cotinine measures)—which is now our practice as well (Kober, Brewer, Height, & Sinha, 2017). Second, despite consistent effects observed across the two studies, sample sizes (especially in Study 1) were low, so the design used in the current work should be applied to new, larger samples. Researchers should test and replicate the effects in those samples, in randomized-controlled clinical trials.

Another limiting factor, as far as the generalizability of the results, is that we only recruited from a subset of the smoking population. That is, smokers who were already somewhat motivated to reduce or quit smoking. Previous work has highlighted the benefits of autonomous motivation (i.e., personally valuing and "owning" behavior change goals), versus controlled motivation (i.e., goal pursuit due to externally imposed demands), for various self-regulatory behaviors, including healthy eating (Pelletier, Dion, & Slovinec-D'Angelo, 2004), diabetes management (Senécal, Nouwen, & White, 2000), and even smoking cessation (Williams, Gagné, Ryan, & Deci, 2002). Therefore, ROC strategies may only be effective for smokers who are intrinsically/autonomously motivated to change their behavior in the first place. Future studies should examine this possibility by specifically comparing effects of ROC-T on smoking cessation outcomes as a function of autonomous (versus controlled) motivation. Moreover, since we did not assess participants' long-term abstinence outcomes, whether ROC-T leads to sustained and lasting smoking reduction or abstinence on its own is unclear. If not, perhaps this kind of training can be paired with other treatments to ensure long-term reductions in smoking and eventual quitting. Last, the education level of participants was relatively high, as most were college-educated or had some postgraduate training (see tables in Supplementary Materials), so future studies should also test for generalizability across a wide range of education levels. We also recommend that future intervention studies specifically test for moderation effects, as the efficacy of ROC-T generally—or reappraisal or distraction strategies in particular—may vary based on gender, nicotine dependence, baseline craving, and other factors. Future work should also assess the potential benefits of joint training in both reappraisal-based ROC-T and distraction-based ROC-T, as this would give individuals additional strategies that they could flexibly deploy across contexts that elicit craving.

To conclude, we have demonstrated that a brief, 45-min training session in regulation of craving can impact real-world smoking levels. Our findings also demonstrate ecological validity of laboratory-based cognitive strategy training, as applied to regulating smoking behaviors in the wild and across idiosyncratic cues and contexts across participants. And despite the caveats described above, we believe that an approach like the one this study used can help scientists and clinicians alike to develop relatively easy-to-administer smoking cessation protocols to help cigarette smokers achieve their goals to reduce smoking or quit altogether.

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CRediT authorship contribution statement

K·O and H·K designed the study; R.L. and H·K. conducted analyses. The manuscript was written by R.L. and H.K, and edited by KO. The final manuscript was approved by all authors. The authors report no conflicts of interest.

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Appendix A. Supplementary data

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