Brief training in regulation of craving reduces cigarette smoking

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Abstract

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 likelihood of relapse. Although this suggests that the regulation of craving is an important mechanism underlying smoking cessation, it is unclear whether targeted interventions that train smokers to regulate craving can directly impact real-world smoking behaviors. 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. Participants were first randomly assigned 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. Participants' smoking was subsequently assessed via daily diaries for 3-6 days, and via self-report up to 1-month follow-up. Across both studies, ROC-T conditions were associated with significant reductions in average cigarettes smoked per day, with effects persisting through follow-up. 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.

Keywords: Craving, regulation, smoking, computer-delivered training

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 1,200 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 US 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 US 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 US 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 smoking has been linked 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 previously has been linked 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 – known as *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 & Kober, in revision). Indeed, this type of craving may be especially important when considering treatment programs (Ferguson & Shiffman, 2009).

Importantly, 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, use of such strategies has been linked to reduced smoking in studies using ecological momentary assessment (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, et al., 2010a). In turn, recruitment of these prefrontal regions was associated with reduced activity in the ventral striatum and vmPFC (Kober et al., 2010b)—regions typically linked to reward computation and the subjective experience of craving (e.g., see Diekhof, Kaps, Falkai, & Gruber, 2012 for a meta-analysis). This CBT-based ROC task has also been administered 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, such antecedent-focused strategies are hypothesized to be 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 it is 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 above strategies 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 described above. In the other ROC-T condition, participants were trained 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 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.

Two primary hypotheses were tested in both studies, building on previous studies of the efficacy of cognitive strategies in attenuating craving (e.g., Kober et al., 2010a; 2010b; 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.

Study 1

Method

Participants. Participants were recruited 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). Participants were excluded if they reported any current or past psychiatric and/or non-nicotine substance use disorders. Lastly, 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, they were enrolled 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 was excluded (due to rolling their own cigarettes).¹ The final sample used for all subsequent analysis consisted of 33 smokers (17 Female; $M_{\text{age}} = 27.8$, $SD_{\text{age}} = 7.28$). Of these participants, 50% identified as being 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; as far as ethnicity, 78.8% identified as non-Hispanic, and 21.2% identified as Hispanic. Participants were randomly assigned to the study's conditions as follows: Reappraisal-based ROC-T (N=11), Distraction-

¹Although 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).

based ROC-T (N=11), and Control (no training; N=11). For all in-lab sessions, participants were instructed to abstain from caffeine, food, and cigarettes for at least two hours.

Procedure. Study 1 had six major stages (see Figure 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.

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 present 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 minutes 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?”

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 were re-tested 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 et al., 2010a; 2010b). 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, participants were instructed to just 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).

Post-intervention 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 post-intervention 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 post-intervention measurements of smoking urges and cigarette attitudes (assessed via questionnaires), and as well as other behavioral tasks and individual difference questionnaires (not reported). Lastly, 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). For

each follow-up interview, participants were asked “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%.

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 $\geq .08$ (see Table 1), and differences in participants' education level are reported in the Supplementary Analyses. To assess whether there were overall changes in cigarettes smoked per day (CPD) throughout the study's measurement periods, and whether there were time-by-group interactions, 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. There was a significant main effect of time on CPD ($F_{(3, 78)} = 2.88$, $\eta^2_{\text{partial}} = .10$, $p = .042$), which was qualified by a significant group-by-time interaction ($F_{(6, 78)} = 2.37$, $\eta^2_{\text{partial}} = .15$, $p = .037$). The nature of this interaction was clarified in a significant linear contrast for the interaction ($F_{(2, 26)} = 3.41$, $\eta^2_{\text{partial}} = .21$, $p = .048$). 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 Figure 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 22-49% across the post-intervention assessment and one- and two-week follow-ups, and the Distraction ROC-T group reported reductions of 26-36%.

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.

Method

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 ($\eta^2_{\text{partial}} = .15$) 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 (time was indicated as the within-subjects factor with 5 levels and group/training status was indicated as the between-subjects factor with 3 levels). The required total sample size ranged from 40-70, but we wanted to be able to detect smaller effects, so we aimed to have approximately 20-25 participants per condition.

Participants. For Study 2, screening and inclusion criteria 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 were then randomly assigned 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 figure S1 for CONSORT diagram). Among these participants ($M_{\text{age}} = 37.35$, $SD_{\text{age}} = 9.39$), there were 28 Females, 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; as far as ethnicity, 72.9% identified as non-Hispanic, and 27.1% identified as Hispanic. These participants were randomly assigned 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 two hours.

Procedure. Study 2 followed Study 1's procedure closely. However, in order 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 there were fewer tasks administered during lab sessions. Further, to assess whether the effects of ROC-T were robust and longer lasting (compared to Study 1), the post-intervention daily diary sampling period was extended to seven days, and there was 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 Figure 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 baselines 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 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. 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, responses rates for the daily dairies and follow-up assessments
 2 were high, ranging from 72% to 100% across all assessment periods, with the lowest response
 3 rates (i.e., 72% and 83%) taking place at the longer-term follow ups.

4 **Results**

5 As in Study 1, there were no group differences in age, gender, Ladder scores, FTCD
 6 scores, or pre-study mean CPD (all p 's $\geq .39$; see Table 2), and differences in participants'
 7 education level are again reported in the Supplementary Analyses. To test for whether effects
 8 from Study 1 replicated in Study 2, we subjected the data to a mixed 3-by-5 repeated-measures
 9 ANOVA with group (Control, Reappraisal-based ROC-T, Distraction ROC-T) as the between-
 10 subjects factor and time (Pre-intervention, Post-intervention, and 1-week, 2-week, and 1-month
 11 follow-up) as the within-subjects factor. Sphericity in the variance-covariance structure was
 12 violated (Mauchly's $W = 0.42$, $p = .001$), so we used the Greenhouse-Geisser correction with
 13 adjusted degrees of freedom. There was a significant main effect of time on CPD ($F_{(2.62, 91.70)} =$
 14 15.14 , $\eta^2_{\text{partial}} = .30$, $p < .001$), which was qualified by a significant group-by-time interaction
 15 ($F_{(5.24, 91.70)} = 4.46$, $\eta^2_{\text{partial}} = .20$, $p = .001$). The nature of this interaction was clarified in a
 16 significant linear contrast for the interaction term ($F_{(2, 35)} = 7.26$, $\eta^2_{\text{partial}} = .29$, $p = .002$), and a
 17 significant linear trend overall ($F_{(1, 35)} = 23.20$, $\eta^2_{\text{partial}} = .40$, $p < .001$). In this case, there were
 18 sustained reductions in CPD in both Reappraisal-based and Distraction ROC-T groups, while
 19 CPD in the Control group was relatively flat throughout (see Figure 4 for a visual depiction of
 20 these effects). Lastly, in terms of percentage reductions in cigarettes smoked per day, the
 21 Reappraisal-based ROC-T group reported reductions ranging between 29-39% across the post-
 22 intervention and follow-up assessments, and the Distraction ROC-T group reported reductions of
 23 30-47%.

Discussion

The primary goal of the present 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 real-world smoking (compared to control groups), and this persisted for 2 weeks (Study 1) and 1 month (Study 2) post-intervention. Importantly, this pattern of results was obtained 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), 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, Gendler, & Gross, 2016; Gross, 2002). Nevertheless, despite the similar reduction in smoking across reappraisal- and distraction-based ROC-T, it is also likely that the two strategies 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 present results are consistent with previous work demonstrating that smokers can successfully regulate their cravings using a CBT-based ROC strategy (Kober et al., 2010a) and the neural mechanisms supporting such regulation (see Kober et al., 2010b). 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

1 results, such as Chen and colleagues (2018) who showed that domain-specific, food-cue
2 inhibitory training (versus domain-general training) was effective in reducing the strength of
3 daily food cravings in dieters (Chen, Kelley, Lopez, & Heatherton, 2018).

4 The present findings also highlight the promise of applying CBT-based ROC strategies as
5 a brief, targeted, computerized, mechanism-focused intervention to reduce smoking. This is
6 consistent with prior clinical work on coping skills, which are often a key component of CBT
7 and involve strategies that help patients better understand their cravings and avoid particular
8 triggers that elicit such craving for the desired substance. Coping skills training has been shown
9 to predict long-term abstinence for marijuana dependence (Litt, Kadden, Kabela-Cormier, &
10 Petry, 2008), and coping skill acquisition and development, as part of CBT, has been associated
11 with reduced drinking and increased abstinence among those with alcohol abuse or dependence
12 (Litt, Kadden, Cooney, & Kabela, 2003). In another study of individuals seeking treatment for
13 substance use disorders, quality of coping responses during CBT mediated treatment success to
14 predict greater abstinence up to three-months post-treatment (Kiluk, Nich, Babuscio, & Carroll,
15 2010). This suggests that a particularly effective component of coping strategies administered in
16 CBT may be the regulation of cue-induced craving, so clinicians may want to consider explicitly
17 incorporating personalized ROC strategies (as operationalized here) into daily or weekly CBT
18 homework to promote reduction of craving and abstinence over time.

19 As an intervention, ROC-T has the distinct advantage of being theory-based and
20 mechanism-focused, specifically around craving and the regulation of craving, both core
21 processes long thought to be central to addictions in general and cigarette smoking in particular.
22 Indeed, a theory-driven focus on core mechanisms can facilitate development, testing, and
23 refinement of interventions, leading to better efficacy, effectiveness, and efficiency (e.g., Naqvi

1 & Morgenstern, 2015; Onken, Carroll, Shoham, Cuthbert, & Riddle, 2014). Indeed, a focus on
2 mechanisms can facilitate precision-based delivery of interventions for substance use (including
3 smoking) in the real-world, via monitoring of changes in the targeted mechanism at
4 symptomatic, cognitive, and neural levels (including changes that may occur before symptom
5 change). It can also ultimately facilitate matching of interventions to specific subpopulations
6 (Onken et al., 2014; Witkiewitz, Roos, Mann, & Kranzler, 2019). Further, ROC-T has the
7 distinct advantage of being fully computerized, and thus easy to implement, test, and
8 disseminate, including as a web-based intervention. This is important as technology-based
9 interventions have the potential to greatly expand the reach of evidence-based treatments (e.g.,
10 Price et al., 2014; Schueller & Torous, 2020) and have been shown to be viable, effective, and
11 cost-effective for a wide range of disorders, including SUDs (e.g., Carroll & Kiluk, 2017;
12 Marsch, Carroll, & Kiluk, 2014).

13 Despite the promise of the present findings and their implications for smoking cessation
14 treatment, there are some limitations that are worth mentioning. First, although daily diary
15 measures are a valid and often preferred method to capture daily substance use behaviors *in vivo*
16 (Roos et al., 2020), our main outcome measure (cigarettes smoked per day) was nonetheless
17 estimated from self-report. Future studies can and should incorporate additional validation of
18 smoking (e.g., via carbon monoxide or urine cotinine measures)—which is now our practice as
19 well (Kober, Brewer, Height, & Sinha, 2017). Second, despite consistent effects observed across
20 the two studies, sample sizes (especially in Study 1) were low, so the design used in the present
21 work should be applied to new, larger samples and the effects should be tested and replicated in
22 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, those 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, it is possible that ROC strategies may only be effective for those smokers who are intrinsically/autonomously motivated to change their behavior in the first place. Future studies will need to 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, it is not clear whether ROC-T leads to sustained and lasting smoking reduction or abstinence on its own. If not, perhaps this kind of training can be paired with other treatments to ensure long-term reductions in smoking and eventual quitting. Lastly, 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 will also need to test for generalizability across a wider 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-

1 T, as this would give individuals additional strategies that they could flexibly deploy across real
2 world contexts that elicit craving.

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

Tables & Figures

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)	4.82 (1.78)	11.64 (7.60)

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)

Figure 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.

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

Figure 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.

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

Supplementary Materials

Supplementary Analyses

Frequencies and chi-square tests for participants' education level (Study 1)

Level		Count	Proportion
HS	Observed	1	0.0370
	Expected	9.00	0.333
Postbac/grad	Observed	10	0.3704
	Expected	9.00	0.333
Some college/in progress	Observed	16	0.5926
	Expected	9.00	0.333

χ^2 Goodness of Fit

χ^2	df	p
12.7	2	0.002

Counts by group

Group	HS	Postbac/grad	Some college/in progress	Total
Control	1	0	9	10
Health	0	5	5	10
Neutral	0	5	2	7
Total	1	10	16	27

χ^2 Tests

	Value	df	p
χ^2	10.9	4	0.027
N	27		

Frequencies and chi-square tests for participants' education level (Study 2)

Level		Count	Proportion
HS	Observed	6	0.143
	Expected	14.0	0.333
Postbac/grad	Observed	19	0.452
	Expected	14.0	0.333
Some college/in progress	Observed	17	0.405
	Expected	14.0	0.333

χ^2 Goodness of Fit

χ^2	df	p
7.00	2	0.030

Counts by group

Group	HS	Postbac/grad	Some college/in progress	Total
Control	2	6	8	16
Health	1	7	4	12
Neutral	3	6	5	14
Total	6	19	17	42

χ^2 Tests

	Value	df	p
χ^2	2.11	4	0.716
N	42		

Tests for differences in cigarettes smoked per day (at screening) and motivation to reduce and quit between participants who completed and did not complete the study (Study 2)

For Study 2, screening information for participants who did not finish the study was incomplete, but for a subgroup for whom we did have complete screening data ($N=16$), we conducted three independent samples t-tests to test for potential differences in cigarettes smoked per day (at time of screening), motivation to reduce, and motivation to quit. Given the unequal sample sizes ($N=16$ and $N=60$), we tested whether the assumption of homogeneity of variance was violated in these cases, but it was not for any of the tests, all p 's $\geq .252$. The t-tests revealed that there was no significant difference in cigarettes smoked per day, $t(74) = 0.48$, $p = .64$, motivation to reduce smoking, $t(74) = 0.42$, $p = .67$, or motivation to quit smoking, $t(74) = 0.67$, $p = .51$.

Results and discussion from mixed ANOVAs with craving instances as the outcome measure

For Study 1 and Study 2, we ran mixed ANOVAs with craving instances as the outcome measure. For both studies, there was a significant main effect of time, p 's $\leq .007$, and no significant group-by-time interaction, p 's $\geq .112$. However, as an exploratory analysis to assess within-group changes in craving, we carried post-hoc pairwise comparisons with Tukey's correction for multiple tests. We found that for the Distraction ROC-T group, there was a significant decrease in craving for the post-intervention, compared to the pre-intervention period; this was true for Study 1, $t(27) = 3.45$, $p_{\text{tukey}} = .02$, and for Study 2, $t(56) = 3.50$, $p_{\text{tukey}} = .01$.

Although this result came out of an exploratory analysis, it provides preliminary evidence that Distraction ROC-T may more directly target craving as to whether it is experienced or not in the first place, a plausible mechanism given that it is a regulatory strategy that intervenes earlier in the impulse-generation process, as per the process model of emotion regulation (Duckworth et

1 al., 2016). This pattern was not observed in the Reappraisal ROC-T group(s), which is not
2 surprising since our measure of craving frequency was relatively coarse and did not get at the
3 nature or intensity of the experienced craving, which presumably would be affected by
4 reappraisal.

Supplemental Figure S1. CONSORT diagram for Study 2.

Essay read by participants assigned to the Reappraisal-based ROC-T group

Every year, about 438,000 people in the United States die of smoking related illnesses.

That is more than AIDS, suicide, alcohol, car accidents, homicide, and illegal drugs combined.

Cigarette smoking is responsible for almost 1 in 5 deaths in the United States.

In 1982, the Surgeon General's Report stated, "Smoking is the major single cause of cancer mortality in the United States." This statement remains true in 2008. Cigarette smoking is a behavior that people choose to do, making it the most preventable cause of premature death.

There are numerous illnesses caused by cigarette smoking. The most prevalent and serious among them are: cardiovascular disease, cancer, and chronic obstructive pulmonary disease (COPD).

Cardiovascular Disease:

Cardiovascular disease is the leading cause of death due to smoking. It occurs when cholesterol and other fats are deposited in the arteries, making them rigid, narrowed, or completely blocked. This process happens naturally over time, but is accelerated and exacerbated by cigarette smoking. In smokers, the narrowing and hardening of the arteries starts earlier, and blood clots are two to four times more likely to occur. Imagine the constant chest pains, the drastically impaired quality of life, and worst of all, the high risk of heart attack and stroke.

Blood clots can travel to different places in the body, blocking the blood vessels, and cutting off blood supply. Coronary thrombosis occurs when a blood clot blocks the arteries that supply the heart, which can lead to a heart attack. During a heart attack, a person experiences sharp pains in the chest that last for several minutes, and are often described as an unbearable pressure or squeezing. Other signs of a heart attack include shortness of breath, nausea, cold

sweats, and light-headedness. Smoking causes about 33% of all heart attacks.

Cerebral thrombosis occurs when the blood vessels that supply the brain become blocked. This can lead to stroke and paralysis. Strokes are characterized by sudden numbness or blindness, an inability to speak or understand, and a loss of balance and coordination. Coronary and cerebral thromboses are the most common causes of sudden death.

Cancer:

Smokers are more likely than non-smokers to get cancer. Some cancers, such as lung cancer, throat cancer, and mouth cancer are common among smokers but hardly ever occur in non-smokers. Other types of cancers that are common among smokers are bladder cancer, esophageal cancer, cervical cancer, and cancers of the kidneys and pancreas. Though there have been many advances in cancer treatment, cancers related with smoking remain some of the most deadly and hard to treat. Imagine the intense pain of treatment, the staggering medical bills, and the depression of dealing with a potentially unbeatable disease.

Smoking accounts for more than 90% of lung cancer cases. Often the cancer has already metastasized and spread beyond the lungs to places like the liver, the brain, and bones before the person notices symptoms and seeks medical attention.

When the most common type of lung cancer spread to other chest areas, the five-year survival rate is 5-15%. Once it reaches areas outside of the chest, the five-year survival rate is less than 2%. The second most common type of lung cancer holds a 0-2% five-year survival rate when it spreads to other areas of the lung.

Chronic Obstructive Pulmonary Disease (COPD):

COPD is a term that refers to a group of illnesses that cause breathing difficulties and block airflow. Between 85 percent and 90 percent of all COPD cases are caused by cigarette

1 smoking and it is the 4th leading cause of death in the U.S.
2 One illness is emphysema, which is caused by damage to the alveoli of the lungs. This damage
3 inhibits the oxygenation of the body's blood supply and causes a permanent state of
4 breathlessness. Chronic bronchitis is another illness of COPD and is characterized by heavy
5 mucus production and incessant coughing, the irritation from which causes a person to frequently
6 cough up blood. The symptoms of COPD make it virtually impossible to lead a normal life.
7 Imagine the persistent shortness of breathing, the wheezing and coughing, and constant
8 weakness.

9 People with this disease are unable to supply their bodies with the oxygen it needs,
10 causing constant fatigue, and an inability to complete even mildly physical tasks. Severe
11 breathing problems can lead to hospitalization, and eventual death from progressive
12 breathlessness.

13 **Other Health Risks:**

14 There are several other long-term health effects of cigarette smoking. Smokers are twice
15 as likely to get macular degeneration, resulting in blindness, and have an increased risk of
16 cataracts. Additionally, smokers get sick more frequently; on average they take 25% more sick
17 days than non-smokers.

18 Couples who smoke are more likely to have fertility problems. Women who smoke are
19 more likely to get cervical cancer, which, upon surgical removal, can leave a woman unable to
20 have children. Men who smoke have a 50% increased risk of erectile dysfunction (ED). This is
21 because smoking damages the blood vessels leading to the penis, resulting in a decreased blood
22 flow and increased impotence.

Essay read by participants assigned to the Distraction ROC-T group

In 1609, Native Americans first introduced European settlers to the tobacco plant.

However, Native Americans were using tobacco recreationally for centuries before introducing it to European settlers. Tobacco was used for currency, religious ceremonies, personal prayer, gift-giving, and leisurely smoking.

Later in 1620, John Rolfe exported 40,000 pounds of tobacco for sale in England.

Throughout the 17th and 18th centuries, tobacco remained the leading cash crop in Virginia and the Carolinas. Last year, about 360 million cigarettes were sold in the United States.

There are numerous types of tobacco that have been developed since then for use in cigarette production. The most popular kinds are: Brightleaf tobacco, white burley, and shade tobacco.

Brightleaf Tobacco:

Brightleaf tobacco was the leading type of tobacco grown for smoking. It became popular in the 19th century, when farmers discovered that it grows robustly when planted in sandy, thin, starved soil, where other crops will not grow. It was first processed using charcoal for heat-curing, but farmers quickly developed new techniques to accelerate the curing process. In areas that were formerly undeveloped, the growth of Brightleaf tobacco led to property values multiplying by 25 to 30 times their initial worth. You can imagine what a boon this was for farmers who had previously been unable to grow crops in areas of poor soil.

Brightleaf tobacco's popularity grew after the end of the Civil War. It had been a favorite of Confederate soldiers, who brought Brightleaf tobacco with them to the front lines, where they traded it with Union soldiers. At the end of the war, soldiers returned home and maintained their preference for this kind of tobacco, which led to a national market for the

1 formerly local crop. During the antebellum period, Brightleaf became the number one type of
2 tobacco grown in the United States.

3 To this day, Brightleaf tobacco (which is also known as Virginia tobacco) remains a very
4 popular crop among tobacco farmers. In fact, almost all Canadian cigarettes are made from 100%
5 pure Brightleaf tobacco. The Brightleaf capital of the United States is Pitt County, North
6 Carolina.

7 **White Burley:**

8 White Burley tobacco was developed from a subtype of Red Burley tobacco, when a
9 farmer noticed that some of the Red Burley plant leaves were paler in color and finer in texture.
10 He began cultivating only the lighter plants, which gave rise to White Burley tobacco. News of
11 this mild tobacco spread quickly across Ohio and the developing Midwest. It was first cultivated
12 and sold in Cincinnati but the demand for it grew, and it quickly began to sell for a premium. It
13 became the main tobacco used for chewing tobacco, American blend pipe tobacco, and
14 American-style cigarettes. Since White Burley has a much milder flavor than Brightleaf, you
15 can imagine why it would become more popular for use in cigarettes.

16 Although White Burley was first developed from Red Burley, the latter is no longer
17 farmed for commercial use. Therefore, people generally refer to the first type as just “Burley,”
18 dropping the color description from its name. 70% of Burley tobacco that is cultivated today in
19 the United States comes from Kentucky. Another 20% is grown on farms in Tennessee, with
20 smaller amounts produced in Indiana, North Carolina, Missouri, and Ohio.

21 **Shade Tobacco:**

22 Shade tobacco refers to the variety of the plant that was grown by Native Americans in
23 the Connecticut River valley, and is still farmed there today. It was originally smoked by Native

Americans and shared with settlers in the area. However it was outlawed in 1650 by the Puritans, who called it “the evil weed.”

Cigar smoking increased in the 19th century, and Shade tobacco began to be used as the outer wrapper of cigars. However, each tobacco plant yields only 18 leaves useful as cigar wrappers, and each leaf requires a great deal of individual manual attention during harvesting. It is no longer used for cigarette production. You can imagine how difficult and tedious producing cigars from Shade tobacco must be.

In 1921, Shade tobacco production in Connecticut peaked, at 31,000 acres under cultivation. The rise of cigarette smoking and the decline of cigar smoking have caused a corresponding decline in the demand for Shade tobacco, reaching a minimum in 1992 of only 2,000 acres under cultivation.

Other Types of Tobacco:

There are several other kinds of tobacco that are grown around the world, and used for different purposes. Perique tobacco is predominantly grown in Louisiana, and is characterized by a strong, spicy taste. Small amounts of it are usually mixed in to pipe-blends.

Dokha is an Iranian tobacco that is often mixed with leaves, bark, and herbs for aromatic smoking in a water-pipe. Other varieties of tobacco are used to make snuff, which is insufflated through the nose, chewing tobacco, which is kept in the mouth for extended periods of time.

1 ***Implementation Intentions and Instructions (Reappraisal-based ROC-T group)***

You indicated that you were motivated to reduce or quit smoking. We therefore want you to make a plan to reduce or quit smoking during the next few days.

I will _____

HOW:

One obstacle to reducing or quitting smoking is craving for cigarettes. Now, we want you to try a behavior that will help you overcome this obstacle: When you feel the desire to smoke, focus on the information you read in the essay today. Recall and think vividly of as many details as possible. For example, you can think about suffering from cardiovascular disease, cerebral thrombosis, lung or throat cancers, chronic obstructive pulmonary disease (COPD), and other long term effects of cigarette smoking.

Before we go on, please tell us, in your own words, the goal you plan to follow. Simply fill in the missing parts:

<p>I will _____ !</p> <p>And when _____, then _____</p> <p>_____ !</p>

WHERE and WHEN: We want you to formulate your plans to use the strategy in as much detail as possible, by identifying obstacles to your goal. Please pay particular attention to the situations in which you will implement these plans. To do so, generate the 10 situations that you think will tempt you to smoke over the next few days and might be obstacles to your goal as you stated above.

2

3 ...

For each situation, please plan to use the strategy we proposed.

Example: When I am watching TV at night, I will remember the information I read in the essay today (specify what information you will bring to mind).

4

1. When.....

1 ***Implementation Intentions and Instructions (Distraction ROC-T group)***

You indicated that you were motivated to reduce or quit smoking. We therefore want you to make a plan to reduce or quit smoking during the next few days.

I will _____

HOW:

One obstacle to reducing or quitting smoking is craving for cigarettes. Now, we want you to try a behavior that will help you overcome this obstacle: When you feel the desire to smoke, focus on the information you read in the essay today. Recall and think vividly of as many details as possible. For example, you can think about the history of the brightleaf tobacco, white burley tobacco, shade tobacco, or other types of tobacco and their uses.

Before we go on, please tell us, in your own words, the goal you plan to follow. Simply fill in the missing parts:

<p>I will _____ !</p> <p>And when _____, then _____</p> <p>_____ !</p>

WHERE and WHEN: We want you to formulate your plans to use the strategy in as much detail as possible, by identifying obstacles to your goal. Please pay particular attention to the situations in which you will implement these plans. To do so, generate the 10 situations that you think will tempt you to smoke over the next few days and might be obstacles to your goal as you stated above.

2

3

For each situation, please plan to use the strategy we proposed.

Example: When I am watching TV at night, I will remember the information I read in the essay today (specify what information you will bring to mind).

4

1. When.....

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