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Augmented Reality for Extinction of Cue-Provoked Urges to Smoke: Proof of Concept

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Objective: Cue-exposure therapy (CET) aims to extinguish conditioned cue reactivity (CR) to aid in smoking cessation. A key disadvantage of extant CET is its limited ability to generalize extinction to the real world. Our team developed a set of augmented reality smoking-related and neutral cues that can appear in real-time in smokers' natural environments as viewed through a smartphone screen. Prior to deployment as a clinical tool, the present study tested the ability of AR smoking cues to extinguish CR in a controlled laboratory study with an AR smartphone application developed for this project. We hypothesized that daily smokers who completed a single session of cue exposure with AR smoking cues (extinction condition) would demonstrate lower cue-provoked urge to smoke at posttest compared to those who viewed AR neutral cues (control condition). ***Method:*** Daily smokers (N = 129, 46.5% female, M_{age} = 47.6, $M_{\text{cigarettes/day}}$ = 19.1) in acute abstinence were randomized to either the extinction or control condition comprising 28 AR trials. ***Results:*** As hypothesized, we found a Time × Condition interaction indicating that posttest urge ratings were lower in the extinction condition than in the control condition (p = .034). A secondary hypothesis that participants in the extinction condition would show a longer latency to smoke when provided a cigarette was not supported. ***Conclusions:*** These laboratory findings provide evidence supporting the potential clinical efficacy of AR cues for cue-exposure trials, setting the stage for testing in smokers' naturalistic environments.

Public Health Significance Statement

This study found that a single cue-exposure session with augmented reality (AR) cigarette cues produced evidence of extinction of urge to smoke among daily smokers. Findings support the potential clinical efficacy of AR for cue exposure.

Keywords: cue-exposure therapy, smoking, urge, augmented reality, extinction

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A part of the current findings was presented in a symposium at the annual meeting of the Society for Research on Nicotine Tobacco 2022, Baltimore, MD, United States. Two main findings were presented: (a) the evidence of extinction of cue-provoked urge following an exposure to the augmented reality smoking cues in the extinction condition versus the control condition and (b) the nonsignificant condition difference in the smoking latency following the experimental session.

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Cigarette smoking remains the leading cause of preventable disease, disability, and mortality. Thus, the development of effective smoking cessation treatment remains crucial. Cue-exposure therapy (CET) is a treatment approach for smoking cessation that targets conditioned cue reactivity (CR; Monti & Rohsenow, 1999). CR, a core motivational process in nicotine dependence (Betts et al., 2021), is developed through Pavlovian conditioning. Self-reported cue-provoked urge, a strong index of CR (Betts et al., 2021), predicts relapse following a cessation attempt (Conklin et al., 2012). Thus, CET for smoking aims to extinguish cue-provoked urge by the repeated presentation of conditioned stimuli (i.e., smoking-related cues) without the presence of unconditioned stimuli (i.e., nicotine), which in turn, should change smoking behavior.

CET is efficacious for short-term urge reduction in various substance using populations (e.g., Pericot-Valverde et al., 2019). However, long-term efficacy of CET has shown small effect sizes (Conklin & Tiffany, 2002), likely due to the limited generalization of extinction learning to novel contexts—that is, the renewal effect (Bouton, 2000; Collins & Brandon, 2002). Therefore, it is thought to be critical that extinction trials occur in multiple contexts, preferably in an individual's natural smoking environment (Conklin & Tiffany, 2002). However, repeated and systematic exposure to an addictive substance outside of the controlled setting of a clinic or laboratory presents logistical and ethical challenges. For example, it would be impractical for a therapist to be in every environmental situation in which an individual typically smokes to conduct CET. Further, without a therapist, challenges arise around systematically exposing an individual to certain cue types and environments, as well as the potential harm and risk of exposure to the substance itself for someone attempting to quit.

Previous research has taken several approaches to expand the extinction context and generalizability of CET, including (a) increasing the realism of the laboratory/clinic context via large-scale projections of photos taken by smokers of their natural environments (Conklin et al., 2019); (b) having smokers bring pictorial smoking cues into their natural environment (Wray et al., 2011); (c) providing smokers with "extinction cues" to bring into their natural environments (Collins & Brandon, 2002; Unrod et al., 2014); and (d) exposing smokers to virtual reality (VR) smoking cues and environments (Pericot-Valverde et al., 2019).

More recently, augmented reality (AR), a rapidly advancing technology, has been identified as having the potential to facilitate extinction in individuals' unique smoking environments, potentially enhancing CET efficacy (Vinci, Brandon, Kleinjan, & Brandon, 2020). AR enables the placement of a digitally created object, either still or moving, in the user's natural environment through a smartphone or tablet screen. The ability for the AR objects to coexist within a smoker's natural environment in real time through a mobile device screen might facilitate CET by increasing the range and authenticity of extinction contexts, as compared to other treatment modalities such as VR or clinic-based presentation of in vivo cues (Vinci, Brandon, Kleinjan, & Brandon, 2020). Whereas VR attempts to insert the user fully into an artificial, computer-generated environment, AR inserts digital objects into the user's actual environment in real time. In particular, unique advantages of AR versus VR for CET include relatively lower costs to develop the AR objects compared to VR scenes, and the preservation of the user's natural context during extinction. Further, given that smartphone use is ubiquitous (e.g., 76% of U.S. low-income populations own a smartphone, Pew Research Center, 2021), CET delivered via AR has the potential to increase therapeutic accessibility and affordability. Although its clinical utility has been explored (e.g., phobias, De Witte et al., 2020; Zimmer et al., 2021), AR has not yet been applied to substance use treatment.

We developed smoking-related proximal AR objects (i.e., smoking paraphernalia such as a cigarette and ashtray) and neutral AR objects (e.g., pen, notebook) to test the efficacy of AR cues for CET in a laboratory setting. Earlier studies demonstrated that AR smoking cues are perceived as integrated into the environment and elicit urge to smoke, with CR approximating that of in vivo cues (K. O. Brandon et al., 2021; Vinci, Brandon, Kleinjan, Hernandez, et al. 2020). As a next step, the current proof of concept study for AR aimed to test the ability of AR cues to extinguish CR, as measured by self-reported urge in the laboratory. Daily smokers in acute abstinence and randomized to either an extinction (smoking-related cues) or control (neutral cues) condition completed a single session of multiple exposures via a smartphone application. The primary hypothesis was that participants in the extinction condition, as compared to those in the control condition, would demonstrate lower CR at the end of the experimental session. A secondary hypothesis was that participants in the extinction condition would show greater latency to smoke when provided with a cigarette immediately after the experimental session, as a behavioral index of smoking motivation. In addition, exploratory analyses evaluated three a priori moderators: biological sex, heaviness of smoking index (HSI), and Wisconsin Inventory of Smoking Dependence Motives (WISDM)-cue exposure.

Method

Participants

Daily smokers ($N = 143$) consented to participate between February 2020 and March 2020 and then between September 2020 and April 2021. Participants were recruited via local Craigslist ads (46%), other studies in our research laboratory (35%), word-of-mouth (16%), ResearchMatch from the NIH participant matching service (2%) and flyers that were distributed throughout the community (1%). Inclusion criteria were (a) $\geq$ 18 years of age, (b) currently smoking $\geq$ 3 cigarettes per day (CPD) for the past year, (c) breath carbon monoxide (CO) level $\geq$ 5 ppm, (d) motivated to quit smoking (via a single question reflecting the "preparation" stage of the transtheoretical model, Prochaska et al., 1992), (e) valid home address and phone number, and (f) able to speak, read, and write English. Exclusion criteria were regular use of other tobacco products (>30% of the time), a household member already enrolled in the study, and pregnancy or lactation.

Transparency and Openness

We report how we determined our sample size, all data exclusions, all manipulations, and all measures relevant to the stated hypotheses. We followed Journal Article Reporting Standards (Appelbaum et al., 2018). Data and study materials will be available upon reasonable request. The project was registered in https://clinicaltrials.gov/ (NCT04101422). This study addressed the "Laboratory Validation of AR Stimuli Session 2: Extinction" aim, using an independent sample (please see COVID-19 Procedures section). None of these data have been previously published.

Procedure

Prior to arrival, participants were asked to abstain from all nicotine products for 3 hr and bring a pack of their own cigarettes. Participants were told that CO would be collected to confirm their 3-hr abstinence, a procedure that aids in improving accuracy of self-reported smoking behavior (e.g., Adams et al., 2008). The 3 hr of abstinence was expected to elicit sufficient increases in urge to smoke with less burden than longer abstinence periods (Hendricks et al., 2006). Participants were randomized to either the extinction or control condition stratified by sex and CPD (< 11 or ≥ 11). The randomization block size was eight given an a priori target sample size of 64 per condition and the four stratification cells. Our random allocation sequence was generated by the statistician, and study staff enrolled and assigned participants to each condition; staff and participants were not blinded to condition. Upon arrival, participants completed the informed consent, verified smoking status via CO level, and completed baseline questionnaires. Participants viewed their respective AR cues and completed the latency to smoke task. The session was video-recorded to code latency to smoke and lasted 1.5–2.5 hr. Participants were compensated $60. All procedures were approved by the institutional review board (Protocol Number 20007).

COVID-19 Procedures

Recruitment was paused between March 2020 and August 2020 due to the COVID-19 pandemic. Fourteen participants completed the extinction session prior to this time. These participants had also completed an initial CR session approximately 1 week before the extinction session. This initial session had been designed to address the separate question of CR to AR cues (K. O. Brandon et al., 2021). After resuming the study in September 2020, the format of the on-site visits was modified from face-to-face sessions to virtual sessions via Zoom in adjacent rooms to reduce the spread of COVID-19. Also, to reduce study contact, the initial CR session was dropped. In other words, there was no change in the extinction session procedures with the exception of minimizing face-to-face contact. That is, after escorting the participant to their study room, the experimenter stayed in an adjacent room during the entire study session, obtaining consent and providing initial instructions over Zoom per institutionally approved COVID-19 protocols. Participants used the AR app independently both pre-and post-COVID-19 procedures. Thus, the critical elements of session procedures were equivalent before and after COVID-19 adjustments.

Augmented Reality Trials

AR cues were presented via a smartphone application (app) developed for this study, presented on an Apple 10xr iPhone provided by the study staff. Study staff assisted with a practice session that preceded the experimental session (in-person pre-COVID-19 pandemic; via Zoom during pandemic). In the practice session, participants were instructed to move the phone around until a blue placement circle appeared on the lab table for the AR cue to appear (Figure 1). Once the placement circle was positioned, participants tapped it, which triggered the AR practice cue (a rubber duck) to appear at the location of the placement circle. Participants

Figure 1
Screenshots of the Blue Placement Circle and Example of Smoking Cue

Note. Screenshots of the digitally created blue placement circle to locate AR cues and an example smoking cue superimposed on laboratory table in real-time. This cue has the motion feature of smoke rising from the cigarette tip. AR = augmented reality. See the online article for the color version of this figure.

then pressed the "Start" button to begin the practice session. Participants were able to practice as many times as they wanted. Once the practice session ended, the experimental session began with the blue placement circle appearing on the screen for the placement of experimental AR cues. The placement of the cues for the experimental session followed the same procedures as the practice session described above. Strategies to enhance immersion with AR cues included instructing participants to approach the AR object from different angles and distances so as to experience the full 3-D AR capability. Two motion AR cues were also presented (i.e., a lit cigarette emitting rising smoke, a soda bottle with movement of effervescence and condensation). A tissue box was also on the lab table as a reference point for the AR cues.

The goal of this proof of concept study was to test whether exposure to AR smoking cues would produce evidence of extinction in a controlled setting prior to advancing to naturalistic and intervention studies. Thus, we used a single extinction session, comprising multiple consecutive trials of fixed duration. Moreover, we limited the AR extinction cues to proximal smoking-related stimuli rather than more complex or distal cues (e.g., human figures, affective cues, or other precursors of smoking, such as coffee or alcohol) because these proximal cues produce the most reliable urge responses (Conklin et al., 2008) and are more generalizable than other personalized conditioned stimuli. The experimental AR cues consisted of six AR smoking cues (i.e., smoking paraphernalia: cigarette, pack of cigarettes, pack and lighter, pack and ashtray, cigarette and lighter, and lit cigarette in an ashtray with smoke motion) and six AR neutral cues (i.e., pen, notebook, pencil and eraser, pencil with notepad, sticky notes and pen, and soda bottle with motion of effervescence and condensation, K. O. Brandon et al., 2021). Each cue was presented for 60 s. In both conditions, a pretest AR neutral cue (i.e., pencil) was presented in the first trial to establish a baseline urge, and then a pretest AR smoking cue (i.e., cigarette) was presented in the second trial to assess pretest CR. For trials 3–26, participants in the extinction condition viewed smoking cues, whereas those in the control condition viewed neutral cues. Each set of cues (6 smoking or neutral cues) was presented four times (i.e., four blocks of six cues) in four quasi-random orders. Finally, participants in both conditions saw the posttest AR cigarette cue in trial 27, and the posttest AR pencil cue in trial 28 (Figure 2). This sequence allowed for the series of smoking cues to be uninterrupted by neutral cues for the extinction group, thought to maximize the detection of an extinction signal within the single session. The pretest and posttest cues permitted evaluation of between-group differences in change in urge to smoke.

Measures

Demographic, Tobacco Use, and AR Familiarity

Demographics included age, ethnicity, race, biological sex, sexual orientation, marital status, education, and income. Tobacco use and behavior were assessed via items on smoking history. Nicotine dependence was assessed by the HSI (Heatherton et al., 1991), a strong predictor of short-term relapse (Yong et al., 2014), and the Fagerström test for cigarette dependence (Fagerström, 2012). We assessed smoking motives (WISDM; Smith et al., 2010), nicotine withdrawal symptoms (Wisconsin Smoking Withdrawal Scale [WSWS]; Welsch et al., 1999), familiarity with AR (two items on ever use of AR [yes/no]), and frequency of AR use.

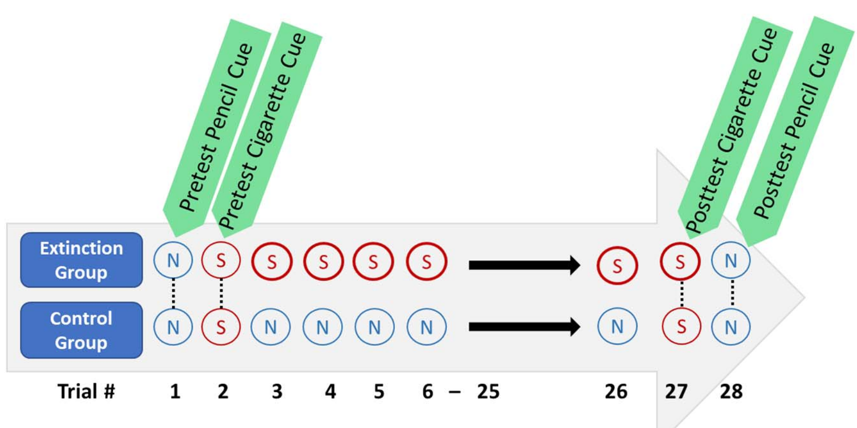
Urge Rating

A single-item assessed urge to smoke, an index of CR, on a 10-point Likert scale (1 = *absolutely no urge to smoke*, 10 = *strongest urge to smoke*), which has been found to be reliable and valid (Kozlowski et al., 1996) and used in other similar studies (T. H. Brandon et al., 2011; Vinci et al., 2012). Participants indicated their urge level by moving a bar on visual-analog scale within the AR app.

Latency to Smoke

Latency to smoke, a behavioral measure of smoking motivation, was coded in seconds by two independent researchers (Ditre &

Figure 2
Experimental Session Flow



Note. N = neutral cue; S = smoking cue; dotted lines indicate paired cues. See the online article for the color version of this figure.

Brandon, 2008) from the timestamps of the video-recorded sessions (intercoder reliability by intraclass correlation = .95). Participants were instructed to place the cigarette, ashtray, and lighter on the table and to take at least one puff after the experimenter left the session. On this measure, two participants were excluded due to data loss.

Data Analysis

The sample was powered to detect a medium effect size (Cohen's $d \geq .50$) of differences in posttest urge ratings between the extinction and control groups. All analyses were completed using SAS Version 9.4 (SAS Institute, Cary, NC, United States) with $\alpha = .05$ for all tests. Group differences in characteristics were evaluated using χ^2 or t test. We tested the hypothesis that posttest urge ratings would be smaller in the extinction condition using a mixed model with Type 3 tests of fixed effects with urge rating as the dependent measure. The predictors were cue type (cigarette vs. pencil), time (pretest vs. posttest), and condition (control vs. extinction). A significant Time × Condition interaction would support the primary hypothesis. Latency to smoke was evaluated using a generalized linear regression model with condition as the primary predictor. Preliminary analyses that identified strong, consistent predictors of urge ratings or latency to smoke would be added as covariates to the primary models. Potential covariates were the demographic and smoking measures listed in Table 1. Preliminary analyses found WISDM total and WSWS craving to be consistent, unique predictors of urge to smoke and smoking latency. These two variables were entered as covariates. Finally, additional models explored three a priori, moderators of extinction (biological sex, HSI, and WISDM-cue exposure) by adding the moderator and its interaction with condition to each model. Sex was tested as a moderator because of research indicating sex differences in smoking motivations (e.g., Perkins, 2008). The HSI was included because of evidence that CR varies by levels of nicotine dependence (Donny et al., 2008; Dunbar et al., 2014), which could affect the efficacy of extinction. And the WISDM Cue Exposure Scale was included as a self-report measure of reactivity to smoking cues, which could also affect extinction processes. Because the moderators were exploratory and the study was not powered specifically for moderation analyses, we did not specify a priori moderation hypotheses.

Results

Baseline Sample Characteristics

The original sample size of 143 was reduced to 129 for analyses after excluding 14 participants who were deemed ineligible due to having CO level < 5 ppm ($n = 9$), withdrawing ($n = 1$), or clearly not attending to the stimuli (e.g., falling asleep during the exposure; $n = 4$). See Figure 3, for the CONSORT diagram. No adverse events occurred during the study period. Key demographic and smoking-related variables, experience with AR, and urge ratings are presented in Table 1. Almost half of participants had used AR previously, with those in the control condition reporting more experience ($\chi^2 = 8.53$, $p = .014$). WISDM total and WSWS craving were found to be significant positive predictors of urge ratings (rs > 0.18, ps < .041) and negative predictors of latency to smoke (rs < −0.24, ps < .006). Although neither of these variables differed by group, the strength of the associations with the outcome variables prompted all analyses to be conducted both with and without these covariates.

Primary Outcome: Urge Ratings

Table 2 and Figure 4 show the pre- and post-test urge ratings, and Table 3 shows the results of the mixed models. Confirming CR, we found a main effect for cue type, with greater urge to smoke in response to smoking cues (cigarette) versus neutral cues (pencil; Cohen's $d = 0.76$). We also found a main effect for time, with higher urge ratings at posttest ($d = 0.22$), most likely reflecting increasing nicotine withdrawal during the course of the session. We found the hypothesized Time × Condition interaction, representing greater posttest urge ratings in the control condition compared to the extinction condition. No two or three-way interactions with cue type were significant, indicating that the smoking and neutral cues were similarly affected by both time and condition. Inclusion of covariates did not alter statistical significance of these findings.

Follow-up analyses on the Time × Condition interaction revealed no differences in pretest urge ratings by condition, $F(1, 127) = 0.04$, $p = .85$, Cohen's $d = -0.06$. In contrast, posttest urge ratings were marginally lower for the extinction condition than for the control condition, $F(1, 127) = 2.92$, $p = .090$, $d = 0.51$, and significantly lower, $F(1, 125) = 5.08$, $p = .026$, with covariates in the model. Follow-up analyses within condition revealed that urge ratings increased over time in the control group, $F(1, 64) = 14.68$, $p < .001$, $d = 0.50$, but not within the extinction group, $F(1, 63) = 0.18$, $p = .68$, $d = -0.02$. Including covariates did not change the statistical significance of these two findings.

Exploratory moderation analyses revealed a marginal HSI × condition interaction on posttest urge ratings, $F(1, 125) = 3.33$, $p = .070$, which reached significance when covariates were included, $F(1, 123) = 5.08$, $p = .026$. Follow-up analyses (without covariates) indicated that participants with HSI scores under 3 ($n = 42$) did not differ on posttest urge ratings between control ($M = 4.0$, $SD = 3.0$) and extinction ($M = 4.1$, $SD = 2.6$), $F(1, 40) = 0.04$, $p = .85$, $d = -0.06$. However, among those with higher HSI scores ($n = 87$), control participants reported higher posttest urge ratings ($M = 6.5$, $SD = 3.0$) than extinction participants ($M = 5.0$, $SD = 2.7$), $F(1, 85) = 7.26$, $p = .009$, $d = 0.55$. Models with covariates did not result in any changes in statistical significance of the follow-up comparisons. The other two prospective moderators (sex and WISDM-cue exposure) were not significant (Fs < 1.08, ps > .30).

Secondary Outcome: Smoking Latency

The groups did not differ in latency to smoke, $F(1, 125) = 1.57$, $p = .21$, $d = 0.22$ (Table 2). None of the three prospective moderators were significant (ps > .38), and the inclusion of covariates did not alter the pattern of results.

Discussion

We tested whether participants who viewed AR smoking cues of smoking paraphernalia (extinction condition) over several trials would demonstrate lower posttest urges and longer latency to smoke, compared with those who viewed AR neutral cues (control condition). The main finding of the current proof of concept study was that regardless of AR cue type, participants in the extinction

Table 1
Sample Characteristics and Descriptive Statistics of Baseline Variables (N = 129)

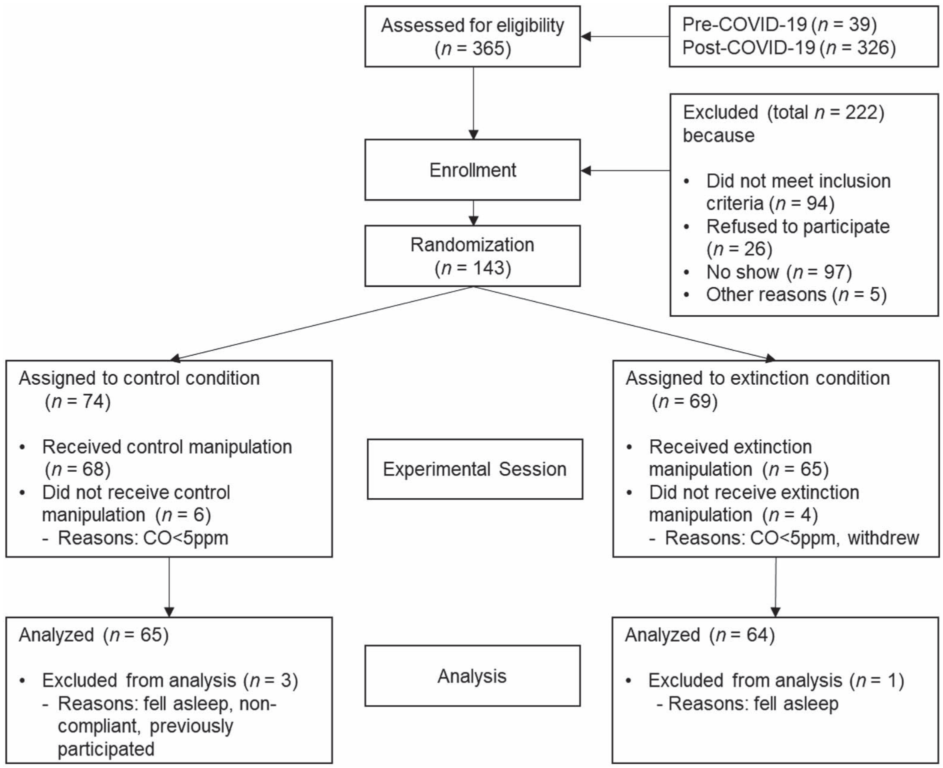
Variable	Total (n = 129)	Control (n = 65)	Extinction (n = 64)
Age (*M*, *SD*)	47.6 (13.4)	47.7 (13.7)	47.5 (13.3)
Biological sex: female (*n*, %)	60 (46.5%)	31 (47.7%)	29 (45.3%)
Sexual orientation (*n*, %)			
Lesbian, gay, or bisexual	17 (13.2%)	9 (13.8%)	8 (12.6%)
Straight	110 (85.3%)	55 (84.6%)	55 (86.0%)
Other	2 (1.6%)	1 (1.5%)	1 (1.6%)
Hispanic/Latinx (*n*, %)	10 (7.8%)	4 (6.2%)	6 (9.4%)
Race (*n*, %)			
White	81 (62.8%)	40 (61.5%)	41 (64.1%)
Black/African American	45 (34.9%)	24 (36.9%)	21 (32.8%)
Native Hawaiian or Other Pacific Islander	2 (1.6%)	0 (0.0%)	2 (3.1%)
More than one race	1 (0.8%)	1 (1.5%)	0 (0.0%)
Marital status (*n*, %)			
Single	67 (51.9%)	33 (50.8%)	34 (53.1%)
Married or partnered	33 (25.6%)	18 (27.7%)	15 (23.4%)
Separated, divorced, or widowed	29 (22.5%)	14 (21.5%)	15 (23.4%)
Education (*n*, %)			
Less than high school	15 (11.6%)	6 (9.2%)	9 (14.1%)
High school diploma or GED	35 (27.2%)	16 (24.6%)	19 (29.7%)
Some college or technical school	57 (44.2%)	33 (50.8%)	24 (37.5%)
Undergraduate degree and beyond	22 (17.1%)	10 (15.4%)	12 (18.8%)
Annual household income: <$30,000 (*n*, %)	66 (51.2%)	33 (50.8%)	33 (51.6%)
Cigarettes per day (*M*, *SD*)	19.1 (19.3)	17.6 (19.6)	20.6 (19.0)
FTND (*M*, *SD*)	4.7 (2.0)	4.5 (1.7)	4.8 (2.3)
HSI (*M*, *SD*)	3.1 (1.4)	2.9 (1.3)	3.2 (1.5)
Plan to quit smoking within 30 days (*n*, %)	59 (45.7%)	31 (47.7%)	28 (43.8%)
Plan to quit smoking within 6 months (*n*, %)	117 (90.7%)	62 (95.4%)	55 (85.9%)
WISDM-total (*M*, *SD*)			
Total	43.6 (10.8)	43.1 (10.6)	44.0 (11.1)
Cue exposure Subscale	4.6 (1.3)	4.6 (1.2)	4.7 (1.4)
WSWS-craving (*M*, *SD*)	18.1 (7.3)	17.1 (7.6)	19.1 (6.9)
Previous experience with AR			
Ever used (*n*, %)			
No	60 (46.5%)	31 (47.7%)	29 (45.3%)
Yes	58 (45.0%)	33 (50.8%)*	25 (39.1%)*
Don't know	11 (8.5%)	1 (1.5%)	10 (15.6%)
Frequency of AR use among ever users (*n*, %)			
Daily	5 (3.9%)	3 (4.6%)	2 (3.1%)
1–6 days/week	13 (10.1%)	9 (13.9%)	4 (6.3%)
1–5 days/month	14 (10.9%)	6 (9.2%)	8 (12.5%)
<1 day/month or do not know	97 (75.2%)	47 (72.3%)	50 (78.1%)

Note. *SD* = standard deviation; GED = Graduate Equivalency Degree; FTND = Fagerström Test for Nicotine Dependence; HSI = heaviness of smoking index; WISDM = Wisconsin Index of Smoking Dependence Motives; WSWS = Wisconsin Smoking Withdrawal Scale; AR = augmented reality.
* Significant group difference at $p < .05$.

condition did not show the increase in urge by the end of the session that was found among control participants. No differences emerged by condition on smoking latency.

Although the difference in urge to smoke at posttest is consistent with extinction, interpretation of the results would have been cleaner if the extinction condition had shown a decrease in smoking urge following the cue-exposure trials. The apparent flat response in the extinction condition may reflect two countervailing forces in play. First, with the passage of time since participants last smoked, nicotine withdrawal and the associated urge to smoke likely increased (Hendricks et al., 2006), as evidenced in the control condition. Simultaneously, in the extinction condition, the extinction trials appeared to reduce cue-provoked urge to smoke. Thus, in that condition, the sum of both of these forces would negate the withdrawal-based urge increase seen in the control condition and yield the apparent stable effect on self-reported urge. This explanation is also consistent with the finding suggesting that posttest urge ratings were moderated by nicotine dependence level, with higher nicotine dependence associated with greater evidence of extinction. Given that more dependent smokers appear to have greater CR and experience higher withdrawal-based urge (Donny et al., 2008), it follows that they would also be more responsive to extinction trials. Future studies should examine whether individuals with different degrees of nicotine dependence might benefit from different doses of CET (e.g., number of sessions). Additionally, longer extinction sessions and multiple postcessation sessions (as would be used when AR is applied as an intervention) should attenuate the effect of nicotine withdrawal upon urge changes, thus isolating the expected extinction-driven decline in urges. Finally, it should be noted that because the present study used a brief 3-hr abstinence period, few participants reported the high end of urge ratings. We would expect to find higher urge ratings if the

Figure 3
CONSORT Diagram



app were used with a clinical sample of individuals in the early days of actively quitting smoking. Higher initial ratings would also provide a larger target for extinction processes.

Across both assessment points, we found the expected difference in urge response to smoking versus neutral AR cues, replicating our previous research with these cues (K. O. Brandon et al., 2021). In theory, we might expect that the extinction trials would reduce this difference, yet the lack of interaction effects with cue type indicates that the trials had similar effects upon reactivity to both types of cues. The most parsimonious explanation is that the possible extinction effect observed in the extinction condition in response to the smoking cue at posttest carried over to the neutral cue that immediately followed. Carryover effects between drug and nondrug cues have been identified across multiple response domains (Wilson et al., 2007). The increase in posttest urge in the control condition might also reflect, in part, carryover from the preceding smoking cue. Future research should include a longer intercue interval or an intervening distraction task to neutralize the effect of the smoking cue.

Contrary to our secondary hypothesis, we found no difference in smoking latency between conditions. Although a behavioral index of smoking motivation would have strengthened the self-report finding, this hypothesis was secondary because smoking latency is a less robust index of CR compared to urge rating (Shiffman et al., 2013). It is also worth noting that our participants were in acute withdrawal with no intention to remain quit following the experimental session, which might have affected the smoking latency results.

Limitations include the restricted range of smoking-related cues, mainly smoking paraphernalia. Including distal cues commonly associated with smoking (e.g., coffee) might enhance the clinical efficacy of AR for CET. As AR technology advances, adding more complex cues, such as other smokers, could be helpful. However, one of the advantages of AR is that it preserves other cues already in the user's smoking context, so it may not be necessary to create extensive AR cue libraries. It is also possible that some of our neutral images (e.g., soda bottle) might have elicited cue-provoked urges in some participants due to their association with smoking, functioning as distal cues. Second, given this was a lab-based, proof of concept study for AR, the smoking context was quite different from the natural settings in which smoking typically occurs. Third, we provided only a single session of cue exposure to test the potential

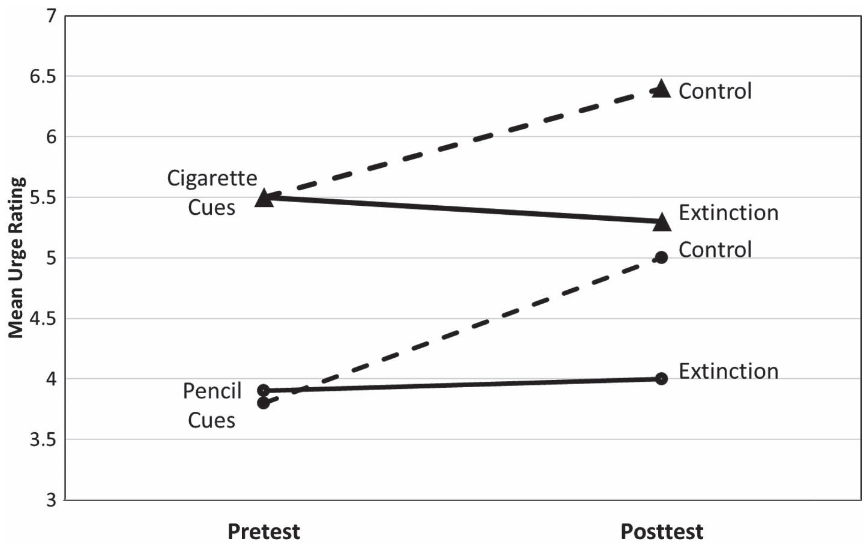
Table 2
Descriptive Statistics of Outcome Variables

Variable	Control ($n = 65$)	Extinction ($n = 64$)
Urge ratings (M, SD)		
Cigarette—pretest	5.5 (3.2)	5.5 (2.9)
Cigarette—posttest	6.4 (3.3)	5.3 (2.9)
Pencil—pretest	3.8 (3.0)	3.9 (2.5)
Pencil—posttest	5.0 (3.4)	4.0 (3.0)
Latency to smoke (M, SD in seconds)[a]	6.2 (3.1)	5.6 (2.2)

Note. SD = standard deviation.
[a] $N = 127$ for latency to smoke as two participants could not complete the task.

Figure 4

Mean Urge Ratings Pre vs Post-Test for the Extinction vs Control Conditions



Note. Mean urge rating at pre-test and post-test in extinction condition (solid line) and control condition (dashed line) in response to cigarette cues (upper set with triangle) and pencil cues (lower set with circle).

of extinction to AR cues. Although this was not representative of clinical CET, the fact that we observed an extinction signal after a single session suggests that stronger effects are likely with full CET utilizing multiple sessions over a longer duration.

Given both the novelty and limitations of the present study, additional research is warranted. First, it will be important to verify that the extinction of urges elicited by AR cues generalizes to in vivo cues—both in the laboratory and in participants' natural environments. There are also numerous theoretical (e.g., Will extinction via AR across various naturalistic settings be resistant to the renewal effect?), functional (e.g., For extinction of conditioned responses, what is the ideal frequency and duration of stimuli presentation?), and implementation questions (e.g., To optimize user acceptability, experience, and adherence, what is the best way to present and package AR for smoking cessation?) that need to be addressed (see Vinci, Brandon, Kleinjan, & Brandon, 2020). Ultimately, the efficacy of AR-based CET upon clinical outcomes such as smoking cessation must be tested.

Table 3

Primary Analysis Results (Without Covariates)

Predictor	*F*-ratio	*df*	*p*
Cue type (cigarette vs. pencil)	**83.20**	**1, 127**	**<.001**
Time (pretest vs. posttest)	**7.80**	**1, 127**	**.006**
Condition (extinction vs. control)	0.04	1, 127	.852
Cue type × time	3.59	1, 127	.061
Cue type × condition	0.05	1, 127	.823
Time × Condition	**4.62**	**1, 127**	**.034**
Cue type × Time × Condition	0.07	1, 127	.794

Note. Bolded indicates significant results at $p < .05$.

The present study was the first, to our knowledge, to demonstrate the potential clinical utility of AR cues for CET for treating smoking or other substance use. Results suggest that reactivity to AR smoking cues can potentially be extinguished through multiple exposures in the laboratory. CET via AR has potential as an adjuvant that could enhance outcomes from a range of interventions for smoking and other substance use, including traditional cessation counseling, telephone quitlines, digital interventions, and pharmacotherapy.

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