



Brief Report

Testing Augmented Reality for Eliciting Cue-Provoked Urges to Smoke: Toward Moving Cue-Exposure Into the Real World

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Abstract

Background: Cue exposure for extinguishing conditioned urges to smoking cues has been promising in the laboratory, but difficult to implement in natural environments. The recent availability of augmented reality (AR) via smartphone provides an opportunity to overcome this limitation. Testing the ability of AR to elicit cue-provoked urges to smoke (ie, cue reactivity [CR]) is the first step to systemically testing the efficacy of AR for cue exposure therapy.

Objectives: To test CR to smoking-related AR cues compared to neutral AR cues, and compared to in vivo cues.

Methods: A 2 × 2 within-subject design comparing cue content (smoking vs. neutral) and presentation modality (AR vs. in vivo) on urge response. Seventeen smokers viewed six smoking-related and six neutral cues via AR smartphone app and also six smoking and six neutral in vivo cues. Participants rated their urge to smoke and reality/co-existence of the cue.

Results: Average urge to smoke was higher following smoking-related AR images (Median = 7.50) than neutral images (Median = 3.33) ($Z = -3.44$; $p = .001$; $d = 1.37$). Similarly, average urge ratings for in vivo smoking-related cues (Median = 8.12) were higher than for neutral cues (Median = 2.12) ($Z = -3.44$; $p = .001$; $d = 1.64$). Also, greater CR was observed for in vivo cues than for AR cues ($Z = -2.67$, $p = .008$; $d = .36$). AR cues were generally perceived as being realistic and well-integrated.

Conclusions: CR was demonstrated with very large effect sizes in response to AR smoking cues, although slightly smaller than with in vivo smoking cues. This satisfies the first criterion for the potential use of AR for exposure therapy.

Implications: This study introduces AR as a novel modality for presenting smoking-related stimuli to provoke cue reactivity, and ultimately to conduct extinction-based therapy. AR cues presented via a smartphone have the advantage over other modes of cue presentation (pictures, virtual reality, in vivo, etc.) of being easily transportable, affordable, and realistic, and they can be inserted in a smokers' natural

environment rather than being limited to laboratory and clinic settings. These AR features may overcome the generalizability barriers of other methods, thus increasing clinical utility for cue exposure therapies.

Introduction

Conditioned cue reactivity (CR) has long been a component of addiction theory, with implications for treating substance dependence, including tobacco smoking. In short, Pavlovian conditioning of cues associated with the unconditioned effects of smoking (nicotine) results in previously neutral stimuli (eg, ashtrays) eliciting conditioned responses to the cues, often perceived subjectively as craving or urges. In this manner, the mere sight of smoking-related items eventually elicits urges, which may contribute to both the maintenance of smoking and postcessation relapse.¹ Attempts to extinguish the urge through repeated exposures without nicotine (cue exposure therapy) have been mixed.²⁻⁵ In general, studies find that cue exposure leads to short-term urge reduction,^{6,7} but little or no long term reduction in urges or substance use.⁷ That is, extinction does not appear to generalize well beyond the clinic or lab.⁸ The lack of attention to context effects that exist in the smoker's real world⁹ may contribute to poor generalizability.

CR is a necessary but not sufficient requirement for extinction in cue exposure treatments. CR to smoking stimuli has been demonstrated reliably in the lab,^{1,10,11} but such an environment is very different from the usual places individuals smoke, limiting clinical efficacy. Attempts to enrich the context for CR include projections of smoker's home environments onto laboratory walls,¹² video images of cues from home,¹³ portable extinction cues,⁶ and virtual reality.¹⁴ Although many of these studies found support for initial CR, there remains little evidence of treatment efficacy. The emergence of augmented reality (AR) technology addresses many of the context limitations of current cue-exposure treatments, as we described in an earlier publication.¹⁵ AR superimposes—usually via a smartphone or tablet—virtual, digital 360° objects into the user's real-world environment, wherever that may be. Early examples of widely used AR technology include Pokémon Go, Snapchat filters, and first down lines in televised football games. More recently, online vendors have added AR options for shoppers to view furnishings in their own homes. The generated object (eg, couch) viewed through the smartphone screen maintains its position and relative size in the room as the user views the object from various perspectives. The object appears to exist in the user's world, albeit viewed through their smartphone screen. Motion can also be a feature of AR images (eg, smoke from a lit cigarette). Thus, AR allows for CR to be elicited in the smoker's natural environment with the potential for more robust extinction. Furthermore, AR is affordable and accessible given the widespread use of smartphones.

To our knowledge, there have been no studies examining the CR potential of AR cues for smoking or other substance use. This study's primary aim was to test CR, in a controlled laboratory setting, using AR smoking cues when compared to AR neutral cues, with in vivo cues as the gold standard. Our primary hypothesis was that AR smoking-related cues would produce a greater urge to smoke than AR neutral cues, approaching CR elicited by in vivo cues.

Methods

Study Design

The study used a 2 (cue content: smoking-related or neutral) × 2 (presentation modality: AR or in vivo) within-subject design. Six smoking-related and six neutral cues were presented via the AR

smartphone app and also in vivo. Participants completed 24 trials of cue presentation (12 AR, 12 in vivo) with each including 6 smoking-related and 6 neutral cues (ie, 6 AR smoking, 6 AR neutral; 6 in vivo smoking, 6 in vivo neutral). Cues were blocked by presentation modality (AR vs in vivo) and cue order within blocks were randomly assigned across six random order sequences that mixed smoking and neutral cues. Each cue was presented for 15 seconds. The primary dependent variable was the self-reported urge rating following each cue presentation.

Participants

Participants were recruited in February and March of 2020. Inclusion criteria were: (1) ≥18 years of age, (2) currently smoking ≥3 cigarettes per day for the past year, (3) a breath carbon monoxide (CO) level ≥5 ppm to verify smoking status, (4) motivated to quit smoking in the future (Yes/No), (5) a valid home address in the local area, (6) a functioning telephone number, and (7) the ability to speak, read, and write in English. Exclusion criteria were regular use of other tobacco products, pregnancy and/or lactation, or a household member already enrolled in the study. Inclusion criteria reflected the characteristics of smokers who would likely use the app in smoking cessation efforts. Participants were recruited through referrals from previous studies within our laboratory and assessed by phone for eligibility.

This sample was part of a larger, ongoing within-subject study with two sub-studies occurring as separate sessions. The first comprised the current CR test. The second is an ongoing randomized between-subject test of extinction of urge to smoke following repeated cue exposure. The overall study was powered for the extinction test (target $N = 128$). However, the study was suspended due to COVID-19 restrictions in March 2020 after 17 participants completed the first session. To minimize contact-based risks to participants, and given the already robust effects observed, we ended the CR portion of the study, yielding the final sample size of 17.

Procedures

Cues

The development of the AR cues are described elsewhere¹⁶ and are consistent with cues within the field.^{7,12,13} Six smoking cues (cigarette, pack of cigarettes, pack and lighter, pack and ashtray, cigarette and lighter, and lit cigarette in an ashtray with the smoke motion) and six neutral cues (pen, notebook, pencil and eraser, a pencil with notepad, sticky notes and pen, and soda bottle with the motion of effervescence and condensation) were developed for comparison. Neutral cues were similar to smoking cues in complexity, features, and size. In vivo cues mirrored the AR cues (eg, pack of cigarettes, lighter).

In-Person Session

Eligible participants attended a lab session where they provided consent and a breath CO sample. Participants completed a survey of demographics, smoking behavior, nicotine dependence, intention to quit smoking, and familiarity with AR.

AR cues were presented via the app on an Apple 10xr iPhone.¹⁶ Participants were instructed to aim the phone screen at the tabletop

of a small café table, empty except for a tissue box. In vivo cues were on a separate table underneath sequentially numbered opaque boxes. For both the AR and the in vivo blocks, participants were instructed via written, timed directions on the app when to uncover the object (in vivo) or press “start” to view the image (AR) and when to move to the next task or cue. Participants completed a smoking urge rating and three reality/co-existence ratings (AR only) via the app after each cue and engaged in a neutral activity (word search puzzle) for one minute between each cue to reduce carryover effects.

The session lasted approximately 1.5 hours and participants were compensated \$40. All procedures were approved by Advarra Institutional Review Board and the protocol was registered in clinicaltrials.gov (NCT04101422).

Measures

Baseline Variables

Self-report items assessed demographic variables, cigarettes per day in the past month, and intention to quit smoking within 30 days and six months (Yes/No). Tobacco dependence was measured by the six-item Fagerström Test for Nicotine Dependence scale (FTND).¹⁷ Participants’ familiarity with AR was assessed: “Have you ever used any kind of augmented reality app before? (eg, AR feature in Pokemon Go, Ikea or other furniture app, Snapchat filters, google Sky Map, etc.)”; “How frequently do you use augmented reality apps?” Additional items assessed smoking behaviors, confidence in quitting smoking, tobacco dependence, withdrawal effects, and affect, but are not included in this report.

Ratings of Cues

Urge to smoke was rated on a 1–10 Likert scale (“No urge” to “Strongest urge”). Three items assessed how real and present the AR images seemed¹⁸ using similar Likert scales: *reality*, “How real did the object seem to you?”; *environment co-existence*, “How well did the object appear to be part of the scene?”; and *user co-existence*, “How much did you feel the object was right there in front of you?” (“Not at all” to “Very Real/Very well/Very much”).

Statistical Analysis

Due to the small sample size and non-normality of variables, median urge, realism, and both co-existence scores of smoking versus neutral cues were compared using the Wilcoxon signed-rank test after calculating each participant’s mean rating across smoking and neutral cues. CR was assessed separately for AR and for in vivo cues. The within-subject design allowed for computing CR difference scores (CR_{diff}) by subtracting the neutral from the smoking mean. Mann-Whitney U tests were conducted to examine order effects of cue presentation modality. Cohen’s *d* was calculated to describe effect sizes.

Results

Sample Characteristics

Forty-four individuals were screened and 35 met eligibility criteria. Seventeen participants consented and completed the session before the CR sub-study was halted due to COVID-19. Participants’ characteristics are summarized in Table 1. Most participants were female, white, non-Hispanic, and had a modest annual household income. All participants were daily smokers. Participants smoked an average of 15 cigarettes per day, were moderately nicotine dependent, and were typically motivated to quit smoking within the next six months.

Table 1. Summary Statistics for Participant Characteristics

Variable	Mean (SD) or percent (n)
Demographics	
Age	50.41 (11.25)
Female	70.6% (12)
Latinx	5.9% (1)
Income <\$30,000	58.8% (10)
Education ≤High School	41.2% (7)
Race	
White	52.9% (9)
Black	47.1% (8)
Smoking characteristics	
Cigarettes per day	15.06 (5.7)
FTND total (1–10)	6.17 (2.07)
Seriously plans to quit smoking within 30 days	47.1% (8)
Seriously plans to quit smoking within six months	82.4% (14)
Augmented reality (AR) use	
Ever used	35.35% (6)
Frequency of AR use of those who had ever used AR	
7 days/week	5.9% (1)
1–5 days/Month	5.9% (1)
Less than once/month	11.8% (2)
Don’t know	11.8% (2)

Ratings of Cues

Figure 1 shows the median ratings of urge to smoke across the smoking-related and neutral images for AR and in vivo cues and reality/co-existence for AR cues. As hypothesized, participants reported higher average ratings of smoking urge in response to the AR smoking stimuli compared to AR neutral stimuli, $Z = -3.44$, $p = .001$, with a very large effect size (Cohen $d = 1.37$). In vivo cues also demonstrated significant CR, ($Z = -3.44$, $p = .001$), with a very large effect (Cohen $d = 1.64$). The difference between the CR_{diff} for AR (Median = 3.00) and in vivo (Median = 4.50) was also significant with a small effect size ($Z = -2.67$, $p = .008$, $d = .36$). Participants reported higher ratings of reality/co-existence for the smoking versus neutral AR cues (realism: $Z = -3.18$, $p = .001$; environmental co-existence: $Z = -2.90$, $p = .004$; user co-existence: $Z = -3.30$, $p = .001$).

There was a significant effect of presentation modality order upon the average cue rating such that the nine participants who viewed the AR block of cues first had higher average urge ratings for neutral in vivo cues (Mean = 4.42, SD = 2.95) than the eight participants who saw in vivo cues first (Mean = 2.10, SD = .85, $p = .04$). Urge ratings following smoking cues and AR neutral cues did not show order effects.

Discussion

Principal Results

As hypothesized, we found significant CR in response to both AR and in vivo cues. The CR effect size of the AR cues was consistent with the existing literature on cue reactivity using in vivo items,¹⁹ photos,¹³ and virtual reality cues.¹⁴ Although the potential for AR for cue exposure therapies in addiction has been recognized,¹⁵ this study’s demonstration of CR is an important first step to testing AR as a cue exposure treatment component for smoking cessation. Despite the somewhat smaller CR effect size in this study

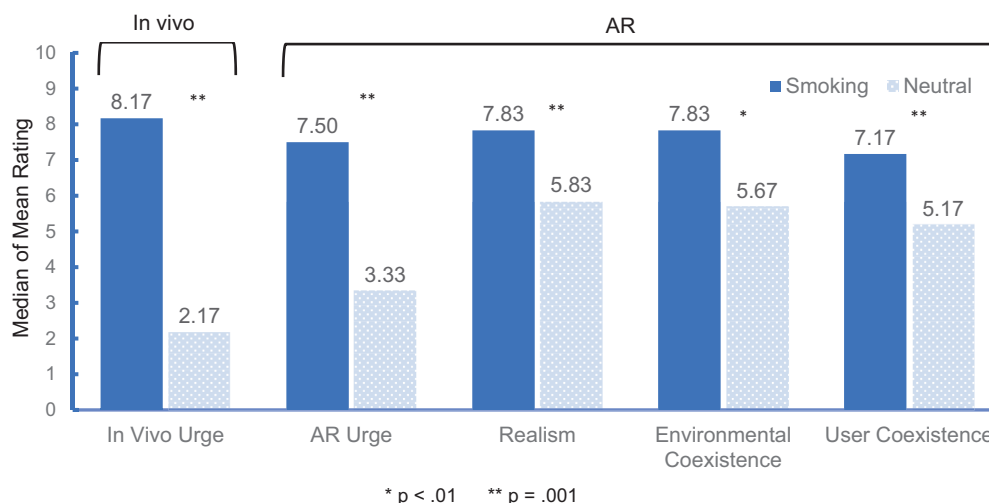


Figure 1. Sample median of each participant's mean ratings of smoking urge as well as reality/co-existence of augmented reality (AR) images.

for AR compared to in vivo cues, CR to AR cues were nevertheless impressively robust enough to be detected in a small sample. As AR technology continues to advance, the images likely will more closely approximate in vivo objects. Moreover, AR cues are transportable to almost any location where smokers may need to extinguish cue-provoked urges. Unlike in vivo cues, AR cues cannot actually be consumed, reducing the risk of relapse during exposure trials, although it may also reduce the impact of drug availability upon CR.²⁰

Smoking AR cues were perceived as more realistic and better integrated into the environment than neutral cues, perhaps reflecting the greater saliency of these cues to smokers. A small order effect of presentation modality was found, such that CR to in vivo neutral cues was slightly higher in participants who saw the AR block of cues before in vivo cues. It is possible that the novelty of AR images led to more durable CR, producing carry-over effects. If replicated, it would be worthy of greater attention, given both its effect upon the interpretation of CR research and the possible implications for cue exposure treatments.

Limitations include the small sample, which may limit generalizability to the broader population of smokers, particularly given that males were under-represented. Additionally, we utilized a narrow range of smoking-related cues. Although this study's cues represent some of the most common smoking paraphernalia, expanding the cues to include more distal associations (eg, coffee, alcohol) or idiosyncratic cues (eg, specific cigarette brands) might enhance future clinical efficiency. Current AR technology is limited to visual cues, and quality is affected by environmental factors such as available surfaces and lighting. Advances in AR hardware and software will likely address some of these limitations. Additionally, viewing AR images directly via AR glasses rather than on screens is likely to enhance the perceived reality and co-existence of the experience. Finally, this initial controlled, laboratory-based study did not exploit the advantage of AR for generating images in smokers' natural environments. Future studies will test this portability.

Conclusions

This is the first demonstration of CR to smoking stimuli using AR-generated cues. The success of AR for eliciting urges to smoke

addresses one of the boundary conditions for future testing of AR in cue exposure therapy. The next step toward the development of an AR cue-exposure adjuvant to smoking cessation are to test the extinction of urge in a controlled experimental design, followed by testing in smokers' natural environments. The emergence of readily available AR technology introduces novel strategies for eliciting and extinguishing conditioned urges to smoking and other substance stimuli. AR may overcome generalizability barriers of other methods, thus increasing clinical utility for cue exposure therapies.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at <https://academic.oup.com/ntr>.

Funding

The research reported in this publication was supported by an award from the National Institute on Drug Abuse (R34DA047598) and by the Participant Research, Interventions, and Measurement Core at the H. Lee Moffitt Cancer Center & Research Institute, a comprehensive cancer center designated by the National Cancer Institute and funded in part by Moffitt's Cancer Center Support Grant (P30-CA076292).

Declaration of Interests

TB has received research support from Pfizer, Inc. and is on the advisory board for Hava Health, Inc.

References

1. Niaura RS, Rohsenow DJ, Binkoff JA, Monti PM, Pedraza M, Abrams DB. Relevance of cue reactivity to understanding alcohol and smoking relapse. *J Abnorm Psychol.* 1988;97(2):133–152.
2. Shiffman S. Responses to smoking cues are relevant to smoking and relapse. *Addiction.* 2009;104(10):1617–1618.
3. Brandon TH, Vidrine JI, Litvin EB. Relapse and relapse prevention. *Annu Rev Clin Psychol.* 2007;3:257–284.

4. Conklin CA, Parzynski CS, Salkeld RP, Perkins KA, Fonte CA. Cue reactivity as a predictor of successful abstinence initiation among adult smokers. *Exp Clin Psychopharmacol*. 2012;20(6):473–478.
5. Perkins KA. Subjective reactivity to smoking cues as a predictor of quitting success. *Nicotine Tob Res*. 2012;14(4):383–387.
6. Unrod M, Drobos DJ, Stasiewicz PR, et al. Decline in cue-provoked craving during cue exposure therapy for smoking cessation. *Nicotine Tob Res*. 2014;16(3):306–315.
7. Conklin CA, Tiffany ST. Applying extinction research and theory to cue-exposure addiction treatments. *Addiction*. 2002;97(2):155–167.
8. Collins BN, Brandon TH. Effects of extinction context and retrieval cues on alcohol cue reactivity among nonalcoholic drinkers. *J Consult Clin Psychol*. 2002;70(2):390–397.
9. Bouton ME. A learning theory perspective on lapse, relapse, and the maintenance of behavior change. *Health Psychol*. 2000;19(1s):57–63.
10. Carter BL, Tiffany ST. Meta-analysis of cue-reactivity in addiction research. *Addiction*. 1999;94(3):327–340.
11. Shiffman S, Dunbar M, Kirchner T, et al. Smoker reactivity to cues: effects on craving and on smoking behavior. *J Abnorm Psychol*. 2013;122(1):264–280.
12. Conklin CA, Perkins KA, Robin N, McClernon FJ, Salkeld RP. Bringing the real world into the laboratory: personal smoking and nonsmoking environments. *Drug Alcohol Depend*. 2010;111(1–2):58–63.
13. Wray JM, Godleski SA, Tiffany ST. Cue-reactivity in the natural environment of cigarette smokers: the impact of photographic and *in vivo* smoking stimuli. *Psychol Addict Behav*. 2011;25(4):733–737.
14. Pericot-Valverde I, Germeroth LJ, Tiffany ST. The use of virtual reality in the production of cue-specific craving for cigarettes: a meta-analysis. *Nicotine Tob Res*. 2016;18(5):538–546.
15. Vinci C, Brandon KO, Kleinjan M, Brandon TH. The clinical potential of augmented reality. *Clin Psychol (New York)*. 2020;27(3):e12357.
16. Vinci C, Brandon KO, Kleinjan M, et al. Augmented reality for smoking cessation: development and usability study. *JMIR Mhealth Uhealth*. 2020. doi:10.2196/21643
17. Heatherton TF, Kozlowski LT, Frecker RC, Fagerström KO. The fagerström test for nicotine dependence: a revision of the Fagerström Tolerance Questionnaire. *Br J Addict*. 1991;86(9):1119–1127.
18. Baus O, Bouchard S. Moving from virtual reality exposure-based therapy to augmented reality exposure-based therapy: a review. *Front Hum Neurosci*. 2014;8:112.
19. Brandon TH, Copeland AL, Saper ZL. Programmed therapeutic messages as a smoking treatment adjunct: reducing the impact of negative affect. *Health Psychol*. 1995;14(1):41–47.
20. Sayette MA. Augmented reality in addiction: promises and challenges. *Clin Psychol (New York)*. 2020;27(3):e12366.