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The Use of Virtual Reality in the Production of Cue-Specific Craving for Cigarettes: A Meta-Analysis

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Abstract

Introduction: The cue-reactivity procedure has demonstrated that smokers respond with increases in subjective craving in the presence of smoking-related cues. Virtual reality is an emerging mode of cue presentation for cue-reactivity research. Despite the successful implementation of virtual reality during the last decade, no systematic review has investigated the magnitude of effects across studies.

Methods: This research systematically reviewed findings from studies using virtual reality in cigarette craving assessment. Eligible studies assessed subjective craving for cigarettes in smokers exposed to smoking-related and neutral environments. Cohen's *d* was used to assess differences in craving between smoking-related and nonsmoking-related virtual environments. A random effects approach was used to combine effect sizes.

Results: A total of 18 studies involving 541 smokers was included in the final analyses. Environments with smoking-related cues produced significant increases in craving relative to environments without smoking-related cues. The mean overall effect size (Cohen's *d*) was 1.041 (*SE* = 0.12, 95% CI = 0.81 to 1.28, $Z = 8.68$, $P < .001$).

Conclusions: The meta-analysis suggested that presentations of smoking cues through virtual reality can produce strong increases in craving among cigarette smokers. This strong cue-reactivity effect, which was comparable in magnitude to the craving effect sizes found with more conventional modes of cue presentation, supports the use of virtual reality for the generation of robust cue-specific craving in cue-reactivity research.

Introduction

Drug craving is defined as a strong urge or desire to use substances and is generally viewed as a central feature of addiction.[1,2] Craving has been associated with the maintenance of drug use behavior[3–5] and has been described as a barrier for individuals trying to quit.[6]

Considerable research shows that individuals with substance-use disorders have increased craving after exposure to drug-related cues, a phenomenon known as cue-reactivity.[7,8] Drug-related cues can be classified as proximal, contextual, and complex based on the temporal and physical relationship of the cue to drug consumption.[9–11] Proximal cues are specific objects that usually accompany substance consumption, such as packs of cigarettes or syringes. Contextual cues are settings or physical situations where drugs are used, such as a party or a bar. Complex cues refer to a combination of contextual and proximal cues, such as situations involving social interactions where people are smoking or offered cigarettes, dancing, having coffee, and drinking alcoholic beverages.

Traditionally, cue-reactivity studies have used a variety of modes of cue presentations including imagery scripts (eg, drug users imagine drug-use scenarios), photographs (eg, pictures of cigarettes), videos (eg, videos depicting the purchase of the substance), or drug paraphernalia (eg, pack of cigarettes).[12–15] A previous meta-analysis found that these methods elicit robust cue-reactivity effects compared with neutral cues,[16] but those approaches have limitations. While imagery scripts depend on the participant's ability to imagine the situation, the use of photographs, videos, or paraphernalia provide the experimenter more control of the cue presentation during the experimental situation. Paraphernalia presentations offer a multisensory experience (ie, viewing, touching, and smelling cues) similar to that found in the real environment, but do not present contextual and complex cues associated with drug use. Though pictures and videos present more complex and dynamic features of drug-use stimuli, participants are passive observers of the situation.

Another mode of cue presentation that has received increasing attention in the literature is the use of virtual reality. Virtual reality uses computer-based technology to generate three-dimensional environments that allow people to move through their surroundings and interact with the created environment. Virtual reality has been utilized for the assessment and treatment of several psychological conditions including social anxiety disorder,[17] posttraumatic stress disorder,[18] specific phobias,[19] schizophrenia,[20] eating disorders[21], and addictive behaviors.[22] In substance-use disorders, virtual reality has been used mainly to assess craving and reactivity to drug-related cues including nicotine,[9,23–25] alcohol,[26–28] cocaine,[29] methamphetamine,[30] opioids,[31] and cannabis.[32] In addiction research, virtual reality may have some advantages over traditional techniques of exposure.[23,33] For example, virtual reality allows the individual to navigate and interact in a natural-looking environment, producing experiences arguably similar to those evoked in the real world. Also, virtual environments can reproduce certain situations, such as social interactions, with high ecological validity. Such situations are difficult to stage through more conventional, static modes of stimulus presentation.

A recent review qualitatively summarized results from 28 studies published between 2003 and 2014 that used virtual reality for both assessing cue-reactivity and exploring the efficacy of cue-exposure therapy for various substance-use disorders.[34] Of the 15 studies that explored the capability of virtual reality to produce cigarette craving, all showed that virtual reality increased craving for cigarettes. The review also distinguished between studies that allowed or did not allow social interactions with avatars during the virtual exposure. After comparing virtual environments with or without social interactions, the authors concluded that the presence of smoking-related cues in the virtual environment was sufficient to produce increases in craving. A major limitation of narrative reviews is that they provide subjective, nonquantitative overviews of the literature. The narrative approach is also less efficient for synthesizing a wide range of information. Finally, narrative reviews do not generate estimates of the average effect size of cue-reactivity produced through virtual reality procedures.[35] In this meta-analysis, we complemented the information from the Hone-Blanchet, Wensing, and Fecteau review[34] by focusing only on cigarette craving. Moreover, we integrated the quantitative findings from previous studies and estimated the overall effect of the manipulation of smoking cues through virtual reality on craving.

Various studies have shown that virtual environments embedded with smoking-related cues are able to produce increases in craving compared with virtual environments containing neutral cues.[9,23,24] There are, however, some methodological issues confronting these studies that make it difficult to draw general conclusions about the impact of cues delivered through virtual reality. First, most studies have small samples with corresponding low statistical power,[36,37] which may reduce the chance of detecting a true effect.[4,38] Second, virtual reality studies have been conducted with a wide variety of cue-reactivity procedures and samples. For example, while some studies included deprived smokers,[23,39,40] other studies asked participants to smoke a cigarette *ad libitum*.[41,42] These studies also differ in the order of cue presentation (eg, randomized, counterbalanced, fixed).[43,44]

Although some researchers have suggested that virtual reality would be better than traditional modes of exposure in eliciting craving,[31,45] few studies have specifically compared virtual reality and other modes of cue presentation. To our knowledge, only two studies have examined reactivity to cigarette cues presented though virtual reality and with photographs.[45,46] Those studies did not, however, provide direct comparisons of cue-specific craving effects generated across these modes of presentation, so the question of the impact of virtual reality presentations relative to more conventional cue presentations has not been addressed. Meta-analyses can generate effect size estimates for cue-specific craving produced through virtual reality. The magnitude of these effects can be compared with average effect sizes identified through previous meta-analyses of studies using conventional modes of stimulus presentation.

In light of the number of studies using virtual reality for cue-reactivity in cigarette smokers, this article sought to provide a systematic review of published literature about this technology for the assessment of cigarette craving. The secondary goal was to compare the present results with those obtained with an earlier meta-analysis on cue-reactivity studies[16] in an effort to determine whether virtual reality manipulations produce cue-specific craving comparable or superior to conventional modes of cue presentation.

Methods

Meta-Analysis Sample

A search of three databases (PsycInfo, PsycArticles, and Medline) via Ebscohost was conducted using the following keywords and Boolean operators: "craving" or "urge" or "desire" in combination with "cigarette" or "smoke" or "smoking" or "tobacco" and "virtual reality" or "virtual environments." Abstracts and titles of possible articles were reviewed, and those that assessed nicotine cue-reactivity through virtual reality were selected for further investigation. Selected studies were inspected and were included for this meta-analysis if they met the following criteria: (1) the sample was comprised of cigarette smokers; (2) self-reported craving was assessed; (3) the study included both smoking-related and neutral environments; (4) the study was published in a peer-review journal; and (6) statistics to compute an effect size were reported. The criteria for exclusion were: (1) case studies and (2) survey data or prospective studies. Studies published through December 2014 were included.

Data from two published studies with nontreatment seeking smokers[44,47] that followed the same procedure were combined. Although the original papers did not provide the statistics necessary to compute effect sizes, those values were reported by Bordnick, Yoon, Kaganoff, Carter[9] for these combined studies.

Study Coding and Extraction

The studies that met eligibility criteria were coded independently by two authors. There was 90% agreement on the data extracted (Cohen's κ = 0.90). Discrepancies between raters were resolved through discussion with the third author. The following study features were extracted: authors, year of publication, sample size, gender, age, treatment seekers, average of cigarettes smoked per day, nicotine dependence (via *DSM-IV*-TR diagnosis, Fagerström Test for Nicotine Dependence and Nicotine Dependence Questionnaire), expired carbon monoxide breath, time elapsed since the last tobacco use, and qualitative/quantitative data from analyses.

Quantitative Data Analysis

Effect sizes and meta-analytical statistics were calculated using Comprehensive Meta-Analysis version 2.0.[35] Cohen's *d*[48] was used in order to assess the difference in craving between smoking-related virtual environments and nonsmoking-related virtual environments. Cohen's *d* may be interpreted as reflecting a small (*d* = 0.20), medium (*d* = 0.50), or large effect (*d* = 0.80).

In the majority of studies, effect sizes were computed using *F*, *P*, *t*, and χ^2; if any of these statistics were not available, means and standard deviations were used. When correlations were not presented in within-subject design groups, we assumed a conservative correlation (0.7) as recommended by Rosenthal.[49]

Cochran's (Q) and I^2 were used to investigate the heterogeneity between studies. The Q statistic, which examines the alternative hypothesis that studies included evaluated different effects, is calculated by summing the standard deviations of each study's estimate from the overall meta-analytic estimate, and weighting the contribution of each study in the same way as in the meta-analysis.[50] The Q statistic follows a chi-square distribution with *k* – 1 degrees of freedom (*k* = number of studies). Because this method has poor power to detect true heterogeneity among studies when the meta-analysis uses a small number of studies, we also used the I^2 index.[51] The I^2 represents the percentage of the total variability in a group of effect sizes due to true heterogeneity (between-studies variability); I^2 was interpreted using Higgins, Thompson, Deeks, Altman[52] cutoffs for low (25%), moderate (50%), and high (75%) heterogeneity.

Data were analyzed using a random effects approach, which assumes that variability in effect sizes was likely produced by the diversity of sample types, outcome measures, and experimental manipulations among studies.

Publication bias involves the tendency of prioritizing for publication studies with a particular outcome, usually those with statistically significant results.[53] To assess publication bias in this meta-analysis, the following techniques were used: visual examination of the funnel plot, Duval and Tweedie's trim and fill approach, Egger's regression asymmetry test, Begg and Mazumdar adjusted-rank correlation test, and classic fail-safe numbers.[54–56] The funnel plot is a scattergram that plots individual studies' effect sizes against the standard error of the effect size. In the presence of bias, the graph resembles an asymmetrical inverted funnel. The trim and fill method inputs values estimated to be missing from the analysis due to publication bias and reestimates the effect size. Egger's statistical test explores whether the intercept deviates significantly from zero in a regression of the standardized effect estimates against precision. The Begg and Mazumbar test examines the association between the effect estimates and their variances. Egger's and Begg and Mazumbar's tests are analogues of the funnel plot approach and provide significance tests of the presence of publication bias. The classic fail-safe number method estimates the number of missing studies that would need to be added in the meta-analyses to change the results from significant to nonsignificant. Based on Rosenthal's method, a fail-safe number higher than (5 × the number of studies included in the meta-analytic database + 10) is typically considered free of publication bias.[49,57] We also computed a fail-safe number using Comprehensive Meta-Analysis version 2.0,[35] which recently has become more common practice.[58]

Results

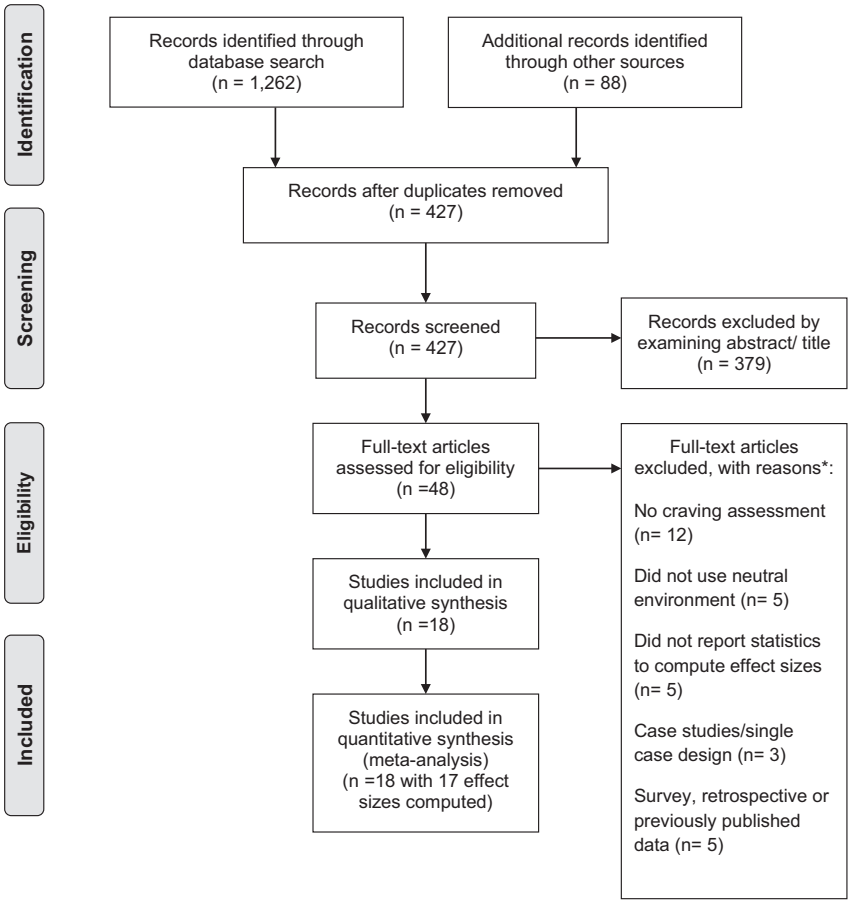
Figure 1 shows the flow diagram of study selection based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[59] The initial database search resulted in 48 potentially eligible studies that were then selected for deeper inspection. For several reasons, 30 studies were excluded from the meta-analysis. The reasons for not being included were as follows: the studies did not include craving assessments (*n* = 12), did not use a neutral environment (*n* = 5), did not report statistics to compute effect sizes (*n* = 5), were case studies (*n* = 3), or were retrospective surveys or previously published data (*n* = 5). Of the omitted studies that included craving assessment, several reported that virtual reality induced craving,[45,60,61] a result consistent with the findings of the present meta-analysis. Study characteristics included in the meta-analysis are summarized in Table 1. The sample used for the meta-analysis consisted of 18 studies (*n* = 541).

The primary meta-analysis showed that smokers experienced significant increases in craving when exposed to environments with smoking-related cues compared with environments without smoking-related cues. The mean overall effect size was Cohen's *d* = 1.041 (*SE* = 0.12, 95% CI = 0.81 to 1.28, *Z* = 8.68, *P* < .001). Effect size estimates indicated a large effect size (Figure 2).

The test for heterogeneity was nonsignificant *Q*(16) = 25.92, *P* = .051, suggesting no evidence of heterogeneity. This result, however, needs to be interpreted carefully due to the *Q* statistic having low power in a meta-analysis that included a small number of studies.[52] The I^2 index was 38.28%, suggesting low to moderate heterogeneity across studies. The funnel plot was asymmetrical (Figure 3). Using the Trim and Fill method, seven studies would be needed to fall on the left of the mean effect size to make the plot symmetric. The *P* values for the Egger test and Begg and Mazumbar test were both *P* < .001 which raises the possibility of publication bias. These results suggest that the research that appears in the published literature may be unrepresentative of the completed studies. The fail-safe number was 100 using the Rosenthal approach, and 571 (*P* < .001, *Z* = 11.52) with the Comprehensive Meta-Analysis software. These values indicated the minimum number of null studies that would have to be included to convert the *P* value to a nonsignificant value (>.05).[64] The greater the fail-safe numbers, the more stable the result. Both values were larger than the number of studies in this meta-analysis (ie, 18) suggesting that the results were reliable.

Discussion

This meta-analysis on 18 studies meeting the criteria for inclusion found that virtual reality for cue-reactivity can increase craving in cigarette smokers. This result was consistent with a previous meta-analysis of cue-reactivity research using more traditional methods of exposure (ie, photographs, video, auditory, in vivo, and imaginary presentation of cues), which also found that smokers increased



*Some studies were excluded for more than one reason

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram of study selection.

craving levels when they were exposed to smoking-related cues relative to neutral cues.[16]

The cue-specific craving effects associated with virtual reality manipulations were large and comparable in magnitude to the effect sizes found with more conventional modes of cue presentation as reported in the meta-analysis by Carter and Tiffany.[16] Indeed the average effect size obtained in the current analysis (d = 1.041) was only slightly less than the effect size reported by Carter and Tiffany for studies with cigarette smokers exposed to cues with conventional modes of presentation (d = 1.18). Only two studies have directly compared virtual reality with a more conventional mode of cue presentation (ie, photographs).[45,46] One study reported that virtual reality produced stronger craving effects[45] and the other found that more attention, visual balance, and coordinating movement was observed during the exposure to smoking-related cues using virtual reality.[46] Lee and colleagues' research used baseline measures of craving as the comparison condition for estimating cue-specific craving.[45] This pre-post approach generates measures of cue-specific craving confounded with the passage of time, making it difficult to isolate the cue-specific effect of the manipulation.

The present meta-analysis, in conjunction with the results reported by Carter and Tiffany,[16] suggests that virtual reality may generate cue-specific craving effects that are comparable, but not superior, to conventional modes of stimulus presentation. These findings, however, need to be interpreted with caution as no controlled study has evaluated the effect of virtual reality relative to the effect of traditional methods of cue presentation. Only more research that specifically compares the effects of modes of presentation within the same study can resolve this issue. Even though both virtual reality and traditional methods of cue exposure can elicit strong cue-induced craving, virtual reality provides realistic environments for cue exposure that would be impossible to create with conventional cue presentation procedures. Other major aspects closely related to the virtual reality experience were not evaluated in this meta-analysis including immersion (ie, the extent to which the exposure is extensive, surrounding, inclusive and vivid) and presence (ie, the sense of being in the virtual reality).[65] Notably, only two studies included in the meta-analysis directly assessed these features of the virtual reality procedure.[43,63]

In the overall analysis, there was moderate evidence for heterogeneity across studies. This heterogeneity could be due to differences among samples in sociodemographic characteristics (gender, age), smoking-related characteristics (level of dependence, cigarettes smoked per day), smoking status of participants (deprived, satiated), or the order of cue presentation (randomized, counterbalanced, fixed). Unfortunately, the small number of studies available for the meta-analysis precludes systematic investigations of the source(s) of the variability of the effect sizes.

There were some notable methodological shortcomings in several of the studies included in the meta-analysis. First, some studies

Table 1. Summary of the Studies Included in the Primary Meta-Analysis

Study	*N*	Gender (% women)	Treatment-seeking smokers (Y/N)	Age (M ± *SD*)	CPD (M ± *SD*)	Dependence (M ± *SD*)	CO (ppm) (M ± *SD*)	Last tobacco use	Type of craving measure	Craving instrument
Acker and MacKillop[41]	47	39	N	28.0 ± 10.8	14.9 ± 7.2	FTND 4.1 ± 2.2	17.3 ± 10.5	*Ad libitum* smoking before the experiment	Multi-item	Ad-hoc scale
[a]Baumann and Sayette[23]	22	50	—	37.7 ± 12.3	20 ± 8	FTND 4.4 ± 3.0	5.3 ± 3.4	Deprived minimum 12 hours	Single item	VAS
[b]Bordnick et al.[44,47]	23	61	N	32.7 ± 12.6	25.4 ± 7.0	—	—	*Ad libitum* smoking before the experiment	Single item	VAS
Bordnick et al.[9]	82	48	Y	45.5 ± 9.3	23.8 ± 7.3	*DSM-IV*-TR diagnosis	—	—	Single item	VAS
Carter et al.[62]	22	—	N	20.8 ± 1.4	20.8 ± 5.2	—	—	*Ad libitum* smoking before the experiment	Multi-item	4 QSU items
Choi et al.[36]	10	10	—	26.2 ± 5.1	14.2 ± 6.0	FTND 5.7 ± 1.2	12.5 ± 2.1	—	Single item	VAS
Culbertson et al.[37]	15	13.33	Y	42.2 ± 15.5	19.8 ± 3.9	—	17.9 ± 12.5	—	Multi-item	UTS
Gamito et al.[43]	21	—	—	21.6 ± 4.2	12	FTND 4	—	—	Multi-item	QSU-Brief
García-Rodríguez et al.[24]	46	47.77	N	25.5 ± 9.9	15.6 ± 5.3	—	—	*Ad libitum* smoking before the experiment	Single item	VAS
García-Rodríguez et al.[25]	45	57.8	N	25.7 ± 8.9	15.2	FTND 3.4 ± 2.1	9.8 ± 4.9	—	Single item	VAS
Kaganoff et al.[33]	46	47.8	Y	46.9 ± 9.2	25.5 ± 7.8	*DSM-IV*-TR diagnosis	—	—	Single item	VAS
Muñoz et al.[39]	32	100	—	22.9 ± 3.3	14.8 ± 5.0	FTND 2.4 ± 1.6	—	Mean time since the last cigarette 3.3 hours ± 2.8	Single item	Pictographic Assessment of Desire
Paris et al.[63]	24	37.5	—	33.1	18.6	—	26.2	*Ad libitum* smoking before the experiment	Single item	VAS
[c]Thompson-Lake et al.[42]	36	38	N	—	18.3 ± 8.6	FTND 6.0 ± 2.4	16.6 ± 6.6	*Ad libitum* smoking before the experiment	Single item	VAS
Traylor et al.[10]	20	40	N	20.9 ± 1.4	13.4 ± 4.5	*DSM-IV*-TR diagnosis and NDQ 8.0 ± 2.2	—	*Ad libitum* smoking before the experiment	Single item	VAS
Traylor et al.[11]	21	38.09	N	38.6 ± 9.8	15.6 ± 5.7	NDQ 9.5 ± 1.9	—	*Ad libitum* smoking before the experiment	Single item	VAS
Yoon et al.[40]	29	17.24	Y	47.8 ± 1.5	18.5 ± 2.2	FTND 5.7 ± 1.9	25.5 ± 3.3	Deprived since 5 PM the day before the experiment	Multi-item	UTS

CO = carbon monoxide; CPD = cigarettes per day; *DSM-IV*-TR diagnosis = structured clinical interview for the *DSM-IV*-TR; FTND = Fagerström Test for Nicotine Dependence; NDQ = Nicotine Dependence Questionnaire; ppm = parts per million; QSU = Questionnaire on Smoking Urges; Symbol punctuation — = information not reported in the study; UTS = urge to smoke; VAS = visual analogue scale).

[a]Baumann and Sayette.[23] This study recruited 22 participants, but 20 completed the experiment.

[b]Bordnick et al.[44,47] Two studies following the same procedure were combined.

[c]Thompson-Lake et al.[42] Data analysis was for 35 of 36 participants.

First author (year)	Cohen's *d*	Standard error	Variance	Lower limit	Upper limit	*Z*-value	*p*-value
			Statistics for each study				
Acker & MacKillop (2013)	1.540	0.381	0.145	0.794	2.285	3.092	0.002
Baumann & Sayette (2006)	0.579	0.187	0.035	0.212	0.945	2.826	0.005
Bordnick et al. (2004, 2005)	0.671	0.237	0.056	0.206	1.136	2.612	0.009
Bordnick et al. (2013)	1.439	0.551	0.304	0.359	2.519	2.947	0.003
Carter et al. (2008)	0.701	0.238	0.057	0.235	1.168	2.265	0.024
Choi et al. (2011)	3.312	1.462	2.138	0.446	6.177	2.309	0.021
Culbertson et al. (2012)	1.788	0.774	0.600	0.270	3.306	2.134	0.033
Gamito et al. (2014)	0.620	0.290	0.084	0.051	1.189	3.765	0.000
García-Rodríguez et al. (2012)	1.403	0.373	0.139	0.673	2.133	1.714	0.087
García-Rodríguez et al. (2013)	0.613	0.358	0.128	-0.008	1.314	3.600	0.000
Kaganoff et al. (2011)	1.314	0.365	0.133	0.598	2.029	3.954	0.000
Muñoz et al. (2013)	2.163	0.547	0.299	1.091	3.236	3.215	0.000
Paris et al. (2011)	1.969	0.612	0.375	0.768	3.168	2.668	0.001
Thompson-Lake et al. (2014)	1.070	0.401	0.161	0.284	1.856	1.888	0.008
Traylor et al. (2008)	1.030	0.546	0.298	-0.039	2.100	2.004	0.059
Traylor et al. (2011)	1.072	0.535	0.286	0.024	2.120	2.473	0.045
Yoon et l.(2013)	1.109	0.449	0.201	0.230	1.988	8.683	0.013
Overall estimate	1.041	0.120	0.014	0.806	1.276	8.683	0.000

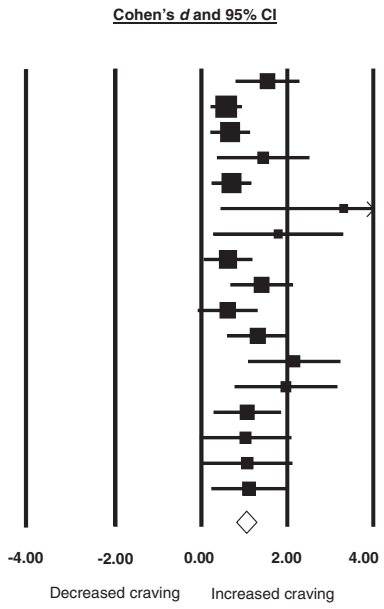


Figure 2. Forest plot of studies included in the meta-analysis. Effect sizes (Cohen's *d*), standard errors, variances, 95% confidence intervals (CI), *Z* scores and *P* values for the meta-analysis. The area of each square is proportional to the study's weight in the meta-analysis.

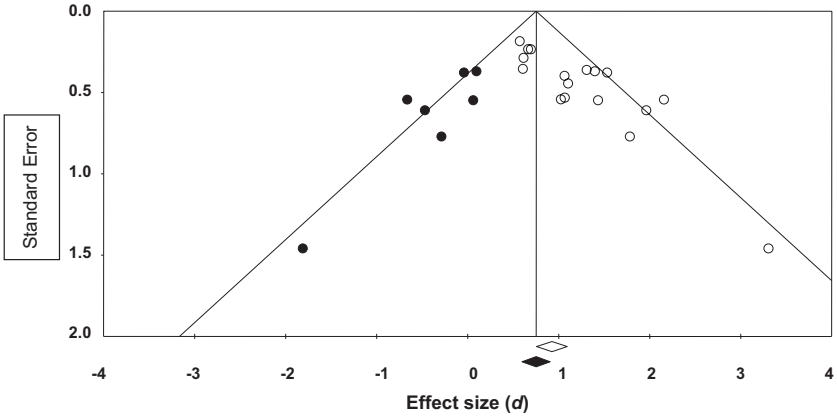


Figure 3. Funnel plot evaluating publication bias using Cohen's *d*. The open circles indicate the studies included in the meta-analysis and the filled circles estimate the missing studies that are necessary to create an equal distribution of expected effects. In this case, the method suggests that seven studies are missing. The bottom diamonds show the observed effects size (open) and the adjusted effect size (filled) after publication bias adjustment.

did not provide objective measures of nicotine dependence or level of cigarette consumption (eg, questionnaires or expired carbon monoxide).[24,33,44,47,62] In the absence of such information, the level of cigarette smoking across participants cannot be fully characterized, and assertions about potential generalizability across studies are more difficult. Second, despite the importance of latency since the last cigarette was smoked in cue-reactivity procedures, a number of studies did not report that information.[33,36,43] Third, some investigations did not clarify whether participants were treatment-seeking or nontreatment-seeking smokers.[39,43,63] This last point is critical, as some research indicates that the treatment-seeking status of participants may affect the magnitude of cue-reactivity.[9]

It is important to note that most of the studies (12/18) used a single item, visual analog scale (VAS) for craving assessment (Table 1). Alternatively, five studies assessed the experience of cigarette craving through multi-item questionnaires, including the Urge to Smoke Questionnaire (UTS),[66] the Questionnaire on Smoking Urges or the short version of the Questionnaire on Smoking Urges (Questionnaire on Smoking Urges-Brief),[67,68] and an ad-hoc questionnaire designed in a previous study to assess craving.[69] Finally, one study used a single item from a nonverbal pictographic scale to assess the strength of craving.[39] Single-item questionnaires are limited in that they assume that the item wording chosen to reflect craving is interpreted by all participants in the same way. Multiple items with different craving descriptors circumvent this problem. Moreover, single items may limit the reliability of the assessment.[70] Both of these factors, which affect the sensitivity of the assessment, would serve to reduce the magnitude of the effects obtained with manipulations of smoking-specific cues. This issue is not limited to virtual reality literature, as some of these problems appear in the conventional cue-reactivity literature.

The present meta-analysis had several potential limitations, all of which are derived from inadequacies in the literature and in the studies available for analyses. First, we uncovered evidence consistent

with publication bias. This is a common limitation of meta-analyses; unpublished studies may be more likely to have nonsignificant results. Another source of bias might be related to the large number of studies omitted because of shortcomings detected in the procedures. The current meta-analysis was also limited by the relatively small number of studies, which restricts the statistical power to compute more detailed analyses (eg, moderator tests). With the increasing number of relevant studies using virtual reality that are likely to be published over the next few years, future meta-analyses should explore the possible moderating influence of individual characteristics (eg, treatment-seeking) on cue-specific craving. The third limitation comes from the heterogeneity observed in the procedures used across studies. Researchers are encouraged to move towards methodologically comprehensive procedures for assessing cue-reactivity via virtual reality including larger sample sizes, consistent use of neutral cue control conditions, and adequate sequence of presentation of the smoking and neutral cues. Finally, this meta-analysis was restricted to studies of cigarette craving. The results of this meta-analysis must be interpreted with caution if other drugs of abuse are of interest.

Future Research With Virtual Reality

The primary conclusion from this meta-analysis is that virtual reality is an effective method for generating cue-specific craving with overall effects sizes comparable to those achieved through traditional methods of cue presentation. This finding supports the use of virtual reality as a highly adaptable method for studying cue-specific craving and as an alternative to traditional modes of cue presentation. Considering the consistency of cue-reactivity effects associated with virtual reality across the large number of studies published to date, there is no need for more research primarily investigating whether virtual reality can produce cue-specific craving in smokers. Future research on virtual reality and cue-reactivity should target more advanced questions related to the dynamics of cue-reactivity and the role of cue-specific craving in addiction motivation.

Most studies using virtual reality exposed smokers to smoking-related cues and then assessed self-reported craving at single or fixed time points. Such assessment procedures are unlikely to reveal much about the dynamic psychological mechanisms that regulate craving.[71] Virtual reality offers the opportunity to explore implicit measures related to craving processes in changing, subject-controlled, real-life scenarios while minimizing possible interferences that may occur in the real word. Smokers are free to move around and interact with the virtual environments using an avatar, which allows for the assessment of craving in relation to participants' movements and behaviors over a wide range of contexts and actions. For example, a few studies using virtual reality have explored eye movements as an implicit measure of craving, finding that smokers' attention is sensitized to smoking-related cues.[39,43,72] Other measures arguably related to craving (eg, approach toward smoking-related cues in the virtual environment) can be assessed using virtual reality in controlled laboratory studies, which can aid our understanding of the relationship between cigarette craving and drug seeking and self-administration.

A second area for further research is to explore possible moderators of the relationship between craving and smoking behavior. For example, negative affect has been systematically associated with craving and smoking behavior.[73,74] Previous laboratory studies have demonstrated that negative affect manipulations can increase both smoking-related craving and cigarette use (ie, measured by latency to smoke and number of puffs) in smokers.[75,76] Nevertheless, because of inherent limitations of the cues used, the extent to which those results can be generalized to naturalistic settings is unclear.[75,77] Those studies mainly employed psychosocial stress tasks, including public speaking, photographs, and the Trier Social Stress Test, which maximize control over confounding variables but may compromise generalization to the real-world. Virtual reality can generate negative affect manipulations in controlled environments while maintaining some degree of external validity.[78] Future research should employ virtual reality to investigate negative affect as a moderator of relationships between craving and drug use.

Summary

The current meta-analysis demonstrated that virtual reality procedures can produce robust increases in cigarette craving among smokers exposed to smoking-related virtual environments, and that cue-specific craving is similar in magnitude to the craving effects produced by traditional methods of exposure. Future research should focus on determining the association between craving and moderator variables and how craving can affect drug-seeking behavior.

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Declaration of Interests

None declared.

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