



The clinical potential of augmented reality

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Abstract

Augmented reality (AR) is a rapidly emerging technology that superimposes digital objects onto real-world scenes as viewed in real time through a smartphone, tablet, or headset. Whereas AR has been adopted for retail, entertainment, and professional training, it also has potential as a novel, mobile, and efficacious treatment modality for psychological disorders. In particular, extinction-based therapies (e.g., anxiety, substance use disorders) could utilize AR to present stimuli in natural environments, enhancing generalizability beyond the clinic. The limited psychological literature on AR has focused on the treatment of simple phobias. Here, with the goal of bringing this technology to the attention of clinicians and researchers, we describe AR, contrast it with virtual reality, review the theoretical foundation for extinction-based therapies, provide examples for the treatment of substance use disorders, and identify theoretical, practical, and implementation-based research questions.

KEYWORDS

augmented reality, cue exposure, intervention, substance use disorders

1 | INTRODUCTION

The last two decades have brought tremendous advances in the creation of artificial or altered environments via digital technology. *Virtual reality* (VR), which creates a simulated, full digital environment, has been integrated into psychological interventions, including extinction-based treatments for anxiety and substance use disorders. More recently, *augmented reality* (AR) has become available. AR affects the perception of the real-world environment by “augmenting” it with computer-generated digital objects. Here, we discuss the potential of AR as a therapeutic tool, particularly with respect to extinction-based exposure therapies, using substance abuse as the primary example. The goal of this article was to bring AR to the attention of researchers and clinicians as a new tool at their disposal. We begin by placing it in the context of the more familiar VR with respect to extinction-based therapies.

2 | VIRTUAL REALITY

VR combines 3D computer-generated graphics with motion trackers, vibration platforms, and audio in head-mounted displays to create immersive and interactive environments. The ability to create alternative, digital environments has made VR attractive for use in mental health treatments. A recent review of VR technology use within psychiatric disorders (Maples-Keller, Bunnell, Kim, & Rothbaum, 2017) found support for the efficacy of VR interventions—either alone or in conjunction with traditional therapy components—in treating anxiety disorders, schizophrenia, pain management, eating disorders, and addiction. VR interventions most often incorporate cue exposure and social skills training, two components for which interactive, naturalistic virtual environments are well-suited. Advantages of VR cue exposure compared to in vivo cue exposure include better stimulus control and lower risk. For example, treating a snake phobia using VR

does not require the presence of an actual snake, and treating an addictive behavior does not require the actual presence of tempting and potentially illegal or harmful substances. Studies have found that VR exposure compared favorably to in vivo exposure (e.g., Powers & Emmelkamp, 2008). Patient acceptability of VR is high with low refusal (Garcia-Palacios, Botella, Hoffman, & Fabregat, 2007) and treatment dropout rates (Lahiri, Bekele, Dohrmann, Warren, & Sarkar, 2015).

Although existing research using VR suggests its suitability for clinical use, including addiction treatment (e.g., Culbertson, Shulenberger, de la Garza, Newton, & Brody, 2012), VR also has several limitations that reduce its clinical utility: (a) The development of full virtual environments is time-consuming and costly; (b) although constantly improving, the VR scenes are often low in realism, which could impact immersion and limit their effectiveness and generalizability; and (c) because of the limited number of VR scenes, they do not capture the range of contexts that might be needed for the typical substance user. This also limits their generalizability. As discussed in more detail next, AR has the potential to address many of these limitations.

3 | WHAT IS AR?

To be considered AR, a system must: (a) combine real and virtual objects that will appear in a real environment; (b) run in response to the user and connect with the real world in real time; and (c) align real world and virtual objects with one another (Azuma et al., 2001). Thus, whereas VR brings the user into a digitally created world, AR brings a digitally created object into the user's own world as viewed on a smartphone, tablet, or through a headset (see Figure 1 for an example of smoking stimuli presented via AR). As a result, AR addresses certain weaknesses of VR because: (a) only an object rather than an entire environment is digitally created, so AR requires a fraction of the time and cost to develop; (b) objects are much simpler than full environments, so AR objects can be created with a high degree of realism, either through digital artistry, digital photography, or both; and (c) AR objects are superimposed upon the user's natural environment, so an infinite number and range of contexts are possible, with personal relevance to each user.

Rudimentary forms of AR were developed long before the term "augmented reality" was coined in 1990. However, with the exponential increase in computer power in mobile devices, AR hardware and software have been advancing particularly fast over the past decade (Barsom, Graafland, & Schijven, 2016). The first mass awareness of AR occurred with the *Pokémon Go* gaming app, released in 2016, which used smartphones' GPS, gyroscopes, compass, and camera to superimpose primitive (by today's standards) AR "creatures" into the users' natural environment. In the four years since,

Public Health Significance

AR is a rapidly evolving technology that offers novel opportunities for clinical science and practice, with particularly high potential for the treatment of anxiety and substance use disorders. If AR can successfully address context effects that have largely impeded the advancement of traditional cue exposure treatments, a wide range of AR-based clinical interventions could be implemented.

the technology has improved dramatically and has developed more mainstream uses in education, entertainment, architecture, and retail. For example, major furniture retailers are utilizing AR to allow the consumer to place and view digital depictions of their products within the consumer's own home, as viewed on their smartphones. Once a digital AR object has been placed within a user's natural environment, the object closely approximates the perceptual qualities of a real object in that location. That is, the user can approach or view the object from any direction, distance, or angle while maintaining a realistic perspective. The object also maintains its apparent position even when the user turns away and then returns to it. Motion can also be included within an AR object (e.g., an AR cigarette can include smoke actively rising from it). Note that the latest models of smartphones have been designed



FIGURE 1 Example of a digitally created AR smoking image superimposed on a user's desk in real time. This image includes the motion feature of smoking rising from the cigarette tip

to optimize AR applications. Apple's iOS operating system is optimized for AR, and both Apple's ARKit and Google's Tango AR platform allow for the development of AR apps.

4 | CLINICAL USES OF AR

Unlike VR, there has been relatively little clinical use of AR to date. The vast majority of AR application in health care has been in the arena of professional training, particularly surgical training. A recent review of AR technology used in the training of laparoscopic surgery, neurosurgical procedures, and echocardiography found these applications to be reliable and valid methods for training (Barsom et al., 2016). AR is also being used as a navigation tool during surgical procedures. For example, clinicians used Microsoft's HoloLens AR technology to overlay CT scan images showing bones, vascular system, and the target problem onto a patient's leg during a reconstructive surgery (Pratt et al., 2018). In contrast, as recently as 2015, a systematic review identified only 13 published studies of AR within the domain of clinical psychology (Giglioli, Pallavicini, Pedroli, Serino, & Riva, 2015). In these studies, AR was mostly used in the treatment of specific phobias (small animals and heights) in which the goal was anxiety reduction through exposure therapy. AR was successful in each of these studies in reducing anxiety and avoidance behaviors. Although AR could be utilized to present stimuli and information to clients to augment a range of therapeutic strategies, perhaps its greatest potential is to advance extinction-based cue exposure therapies, which have primarily been used to treat disorders conceptualized as originating from or maintained through conditioning processes. These include anxiety disorders and substance use disorders in particular. Given that Giglioli et al. (2015) discussed the theoretical underpinnings of AR for treating anxiety disorders, here our primary focus is on its potential for treating substance use disorders.

5 | CUE EXPOSURE FOR SUBSTANCE USE DISORDERS

Most theories of addiction include a primary role for conditioned cue reactivity. Based on Pavlovian conditioning, during the self-administration of a substance, otherwise neutral stimuli are paired or associated with the unconditioned, pharmacological effects of the drug (e.g., increased heart rate). Over time, the previously neutral conditioned stimuli (CSs) develop the capacity to elicit physiological conditioned responses (CRs) in the absence of drug ingestion (Siegel, 1983; Stewart, de Wit, & Eikelboom, 1984). Data have consistently suggested that environmental CSs (e.g., drug paraphernalia such as ashtrays and beer cans) can cause cue reactivity in

alcoholics, opiate addicts, and smokers (Brandon, Copeland, & Saper, 1995; Rohsenow et al., 1992), and these CRs are subjectively experienced as cravings to use the drug. CRs (craving in particular) appear to contribute to drug-use maintenance and relapse, although the evidence of cue reactivity in the laboratory predicting clinical outcomes has been mixed (Brandon, Vidrine, & Litvin, 2007; Conklin, Parzynski, Salkeld, Perkins, & Fonte, 2012; Perkins, 2012; Shiffman, 2009). The role of conditioned cue reactivity in addictive behaviors has been incorporated into most of the major contemporary influential models of addiction, including psychosocial (e.g., Witkiewitz & Marlatt, 2004), cognitive (Tiffany, 1990), and neurological (Kalivas & Volkow, 2005; Robinson & Berridge, 1993) models. The logical clinical implication of this research is that cue reactivity can be extinguished through repeated presentations of drug-related cues (CSs) in the absence of the unconditioned stimulus (the ingested drug). To the extent that postcessation relapse is initiated by conditioned craving, this treatment—called cue exposure with response prevention, or cue exposure therapy—should have clinical efficacy (Monti & Rohsenow, 1999).

Cue exposure studies for substance use have consisted of presenting drug-related cues to participants for various amounts of time over several trials and/or sessions, and this has been done with a variety of cues including those for alcohol (Collins & Brandon, 2002; Conklin & Tiffany, 2002; Drummond & Glautier, 1994; Mellentin et al., 2019; Monti et al., 1993; Sitharthan, Sitharthan, Hough, & Kavanagh, 1997), smoking (Carpenter et al., 2009; Kamboj et al., 2012; LaRowe, Saladin, Carpenter, & Upadhyaya, 2007; Unrod et al., 2014; Vinci, Copeland, & Carrigan, 2012) and opioids (Childress, McLellan, & O'Brien, 1986; McLellan, Childress, Ehrman, O'Brien, & Pashko, 1986). Cue exposure treatment studies do indeed demonstrate declines in drug cravings or consumption post-treatment (Childress et al., 1986; Drummond & Glautier, 1994; McLellan et al., 1986; Monti et al., 1993; Sitharthan et al., 1997; Unrod et al., 2014). Among those studies that have assessed substance use outcomes post cue exposure, results indicate that substance use and/or relapse risk is lower in the cue exposure group when compared to a control group (Drummond & Glautier, 1994; McLellan et al., 1986; Monti et al., 1993). These findings are consistent with the theoretical underpinnings of cue exposure, such that over time, individuals learn to manage cravings when in the presence of a drug cue, without using the drug. However, long-term clinical outcomes remain modest. A meta-analysis of cue exposure treatments for addictions found that their overall effect size ($d = 0.09$) was small (Conklin & Tiffany, 2002). Learning and addiction theorists have argued that the limited efficacy of cue exposure therapies can be attributed to the minimal attention paid to context effects (Bouton, 2000; Brandon, 2001;

Brandon et al., 1995; Childress et al., 1986; Conklin & Tiffany, 2002; Powell, 1995; Rodriguez, Craske, Mineka, & Hladek, 1999). That is, cue exposure therapy is typically provided via extinction trials that take place in either a laboratory or clinic setting. Based on considerable animal and human research, extinction that occurs in these contexts does not appear to generalize to the user's natural environment (i.e., the renewal effect; Bouton, 2002; Collins & Brandon, 2002).

Researchers have been creative in developing alternative ways to expand the context of cue reactivity, which could then be used to expand the context and generalizability of extinction/cue exposure therapies. For example, attempts to expand the cue reactivity context for smoking have included (a) increasing the realism of the laboratory/clinic context via photos taken by smokers of their natural environment and large-scale projections of environmental scenes (Conklin, Perkins, Robin, McClernon, & Salkeld, 2010); (b) having smokers bring video images of smoking cues into their natural environment (Wray, Godleski, & Tiffany, 2011); and (c) providing smokers with "extinction cues" for them to bring into their natural environment (Collins & Brandon, 2002; Unrod et al., 2014).

Another such approach has been to use VR to create pseudo-natural exposure environments in the laboratory/clinic setting (Pericot-Valverde, Germeroth, & Tiffany, 2015). Although this approach has been effective at provoking cravings and has the advantage of providing multiple, three-dimensional, and interactive environments for cue exposure sessions, it has the limitations mentioned above (a) the VR environments are costly to produce, so only a limited number are available for use; (b) the VR environments are often not graphically realistic; and (c) the VR environments do not represent each individual's actual substance use environments. For this reason, VR-based treatments may be susceptible to the renewal effect found with other extinction-based approaches. Supporting this conclusion, a recent review of VR in the assessment and treatment of addictive disorders (Segawa et al., 2020) found that VR stimuli elicited cue reactivity and could produce short-term extinction, but that clinical efficacy was limited—consistent with cue exposure treatments in general.

The rapid and ongoing development of AR systems presents the opportunity to harness the technical advances of VR, while overcoming many of its limitations. AR requires the development of only specific cues (e.g., cigarettes, beer bottles, drug paraphernalia), rather than the entire substance-using environment. These cues are inserted into the users' actual, naturalistic environments as seen through their tablet or smartphone (e.g., different locations in the home, work, outdoors), as shown in Figure 1. Thus, the development of personalized cue exposure protocols should be less expensive, more flexible, and quicker as compared to VR. Moreover, because exposure trials can be delivered via AR

within substance users' actual use environments, extinction should occur in these environments, attenuating the extinction generalization barrier characterized by the renewal effect. Meanwhile, because the substance cues are digitally rather than physically present, AR retains the safety advantage of VR, which presumably reduces the risk of relapse as compared to in vivo cue exposure in the natural environment.

Although the potential of AR for cue exposure therapies has been recognized (Giglioli et al., 2015; Pallavicini et al., 2016; Riva, Baños, Botella, Mantovani, & Gaggioli, 2016), studies have been mostly limited to small animal phobias—cockroaches, in particular (e.g., Botella et al., 2016). We argue that AR could be useful for improving the efficacy of cue exposure therapies more generally—in particular for substance use disorders—by moving the extinction process into clients' natural environments.

Until additional research can be conducted on the use of AR for cue exposure, some potential limitations should be noted. First, it is possible that some AR cues may be insufficiently realistic to induce cravings or to generalize to actual drug cues. Additionally, there is a risk that the necessary technology (e.g., viewing scenes through a smartphone screen) becomes associated with the extinction context, again limiting the degree to which extinction generalizes to actual drug cues that are directly viewed. This concern might be mitigated with the use of evolving AR headsets that allow for direct viewing of the natural scene with imbedded AR cues. Another potential limitation is that some important, high-risk drug-use contexts may not be well-suited for the presentation of AR stimuli. Such contexts would include areas without an available flat surface (e.g., while walking outdoors) or in social situations where extinction trials would be awkward or embarrassing (e.g., at a party). It is possible that future AR cues could include social elements (e.g., another smoker in the room), but creation of realistic human figures is currently challenging and costly. Finally, AR is usually limited to visual stimuli, whereas actual drug cues often include tactile, auditory, and olfactory stimuli. Inclusion of multiple sensory systems would likely enhance realism and engagement with the cues. Most of these limitations, however, are likely to be attenuated with advances in the rapidly evolving AR technology.

6 | FUTURE DIRECTIONS

There are several potential theoretical, functional, and implementation questions we propose here that could advance AR as a therapeutic technique. Theoretical questions consider the use of AR in the context of the broader classical conditioning and extinction literatures. Functional questions include various elements of the AR treatment that might be modified and tested to determine the most

efficacious combination. Implementation questions consider what will be needed to make AR a feasible and acceptable treatment option, along with how to best incorporate AR into existing treatments.

6.1 | Theoretical questions

- *Will exposure to AR cues elicit subjective, physiological, and behavioral responses sufficiently similar to those elicited by in vivo cues to allow for subsequent extinction?* For AR to have utility as a modality for cue exposure, AR cues need to elicit similar conditioned responses as in vivo cues (e.g., LaRowe et al., 2007).
- *Are AR cues superior to simpler forms of artificial cues, such as photographic images, in eliciting reactivity and extinction in naturalistic contexts?* Given that AR cues add a third dimension with dynamic perspective and that AR cues are fully integrated into the natural context, we would expect AR to elicit greater reactivity and extinction compared to often used, but simpler forms of artificial cues.
- *Will extinction via AR in multiple naturalistic settings be more resistant to the renewal effect, as predicted?* This is the key question that underlies the clinical potential of AR for cue exposure treatments. If this does not occur, the additional cost and complexity of AR compared to conventional extinction paradigms may not be justified.
- *Will conditioning occur to the AR delivery technology itself (smartphone, tablet), impeding the therapeutic utility of AR?* As mentioned earlier, if the modality is a limitation of the treatment, other delivery options may need to be explored as technology continues to advance (e.g., AR delivered via headsets or better yet, contact lenses).

6.2 | Functional questions

- *What is the ideal frequency and duration of AR stimulus presentation to extinguish conditioned responses?* Although the animal conditioning literature has examined various extinction schedules (e.g., Berman & Katzev, 1972; Urcelay, Wheeler, & Miller, 2009), these do not readily generalize to human studies. Therefore, it is unclear which schedule will be ideal to extinguish drug craving. Various frequencies and durations may need to be tested to determine the most efficacious treatment dose.
- *What AR cue characteristics (e.g., size, level of detail, movement, sound, single versus compound stimuli) are necessary or sufficient to optimize cue reactivity and extinction?* Given the novelty of using AR for cue exposure, there is a dearth of literature to guide the development of the stimuli characteristics. Initial open-ended feedback on stimuli characteristics from participants can help inform

cue development, followed by testing to determine impact on drug craving and extinction.

- *What level of personalization (e.g., personal brand of cigarette) is necessary to optimize both extinction and generalization?* Balancing the tailoring of stimuli with generalizability of the treatment could be challenging. One recommendation may be to have a “cue library” that stores different versions of certain products (e.g., different brands of cigarettes or alcohol; white versus red wine) for individuals to tailor the stimuli for their own treatment.
- *How many different cues should be presented?* That is, is there a threshold that must be reached before extinction generalizes to other novel stimuli?
- *Are there key moderators (e.g., sex, age, level of drug dependence, initial cue reactivity) that could inform clinical decisions about client selection or treatment characteristics?* It is likely that certain individuals will benefit more from AR as a delivery option for cue exposure than others. Some variables (e.g., initial cue reactivity) can be hypothesized as theory-based moderators (Conklin & Tiffany, 2002), but other demographic and historical variables should be tested as well.

6.3 | Implementation questions

- *How should AR be presented and packaged to optimize client acceptability, user experience, and adherence?* Although individuals are becoming more aware of AR given its expanded use in day-to-day life (e.g., furniture store apps, social media), therapeutic use will initially be novel and unexpected for clients. The theoretical rationale may also seem esoteric in the context of substance use treatment for many clients. Nevertheless, client engagement and adherence will be critical throughout the extinction process, so clinicians will need to find ways to explain the rationale and motivate continued use to ensure that individuals receive an adequate dose of treatment.
- *Can assessment tools be integrated into the AR experience to track reactivity and extinction?* Integration of ecological momentary assessment would allow real-time data to guide decisions about continuing, terminating, or altering the extinction regimen.
- *Can AR be embedded into other novel intervention modalities, such as serious gaming?* Creative ways are needed to engage clients and maintain their participation in the AR-based extinction trials. By design, extinction tends to become monotonous over time, which can threaten ongoing adherence. Gaming principles have the potential to enhance the entertaining aspects of the treatment protocol and reinforce continued use (Johnson et al., 2016).
- *Can AR be a stand-alone treatment option, or, is efficacy improved when combined with an existing intervention?*

AR might be suitable as an adjuvant to a wide variety of interventions, including traditional in-person counseling, brief phone counseling (e.g., telephone quit lines for smokers), text messaging (SMS) interventions, and/or pharmacotherapy. It could also be incorporated into other mobile apps.

Note that AR has therapeutic potential in addition to extinction-based approaches. For example, in the treatment of substance abuse, AR stimuli could be used to train individuals to execute cognitive and behavioral coping responses when confronted by substance cues. Alternatively, AR stimuli could be incorporated into mindfulness-based (e.g., Bowen et al., 2014) or acceptance and commitment (Bricker, Bush, Zbikowski, Mercer, & Heffner, 2014) therapies to train appropriate responses to drug craving (e.g., acknowledging and staying present with cravings without trying to avoid, escape, or change it). Moreover, AR likely has therapeutic uses beyond the presentation of appetitive cues. For example, AR could be used to superimpose within risky contexts (e.g., mealtime for a weight-control client) either messages (e.g., reasons for managing diet, real-time behavioral advice) or instructive images (e.g., recommended food portions superimposed on the client's plate).

7 | CONCLUSION

AR is a rapidly evolving technology that offers novel opportunities for clinical science and practice. Importantly, there are multiple avenues of research that need to be explored, including how best to incorporate AR into existing treatment modalities. If AR can successfully address context effects that have largely impeded the advancement of traditional cue exposure treatments, a wide range of AR-based clinical interventions could be implemented.

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