Preliminary Usability Evaluation of a Virtual Reality (VR) Application for Quitting Nicotine Vaping

Bethany K. Bracken[1], Phillip C. Desrochers[1], Ian McAbee[1], Nicolette M. McGeorge[1], Susan Latiff[1], Bradly T. Stone[1], Dan T. Duggan[1], Corinne Cather[2] and A. Eden Evins[2]
[1]*Charles River Analytics, Inc., Cambridge, MA, U.S.A.*
[2]*Center for Addiction Medicine, Massachusetts General Hospital, Boston, MA, U.S.A.*

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Abstract: Nicotine vaping is a global problem. Limited vaping cessation interventions are available; and current treatments have limited accessibility due to systemic barriers to care (e.g., scarcity of treaters). Digital therapeutics (DTx) can reduce these barriers. We have embedded standard cognitive behavioral therapy (CBT) content into virtual reality (VR) to create a VR-based app focused on vaping cessation: Novel, On-demand VR for Accessible, Practical, and Engaging therapy (NO VAPE). NO VAPE allows users to practice CBT skills gained in traditional therapy through an accessible, immersive, and engaging platform. Our ultimate goal is to conduct a full clinical trial to test whether NO VAPE motivates greater intervention adherence and satisfaction. To prepare, we conducted a usability study with N = 6 young adults who currently vape, aiming to evaluate safety, usability, and overall enjoyment of NO VAPE. We categorized errors into categories in ascending severity from minor usability errors to safety violations. There were no safety violations by any participants providing evidence that the app is low-risk and safe (from a software use perspective, not a substance use perspective). Participant reported high levels of enjoyment, said they would like to use NO VAPE again, and did not experience symptoms of simulator sickness. We also identified multiple software bugs we are now addressing.

1 INTRODUCTION

Vaping is an increasing problem around the world. In 2017-2018, the prevalence of vaping was 2.4% across Europe. The highest prevalences were 7.2% in England, 4.3% in France, and 4.1% in Greece (Gallus et al., 2023). In 2019 in Asia, the highest prevalence was 32.2% in Indonesia (Ko et al., 2024). In 2022, in the US, an estimated 2.5M youths reported vaping. Vaping is increasingly being used to assist in smoking cessation (McNeill et al., 2021); however, vaping—although likely less harmful than smoking (Abafalvi et al., 2019; Levy et al., 2021)—is associated with multiple adverse reactions, such as oral health problems, cardiac disorders, lung injury, respiratory disorders, and gastrointestinal disorders (Hammond, 2019; Irusa et al., 2020; McNeill et al., 2021; Traboulsi et al., 2020). To help individuals attempt to quit or maintain abstinence from vaping, in addition to drug therapy, multiple psychological therapies exist. Cognitive behavioral therapy (CBT), teaches individuals to recognize the events that trigger craving; their mental, physical, and behavioral reactions to the events; and provides training on strategies to resist cues and handle stressful situations without vaping.

Traditional vaping cessation interventions have limited accessibility due to systemic barriers to care, including scarcity of treaters and personal factors (e.g., lack of transportation). There are several potential routes to maximize reach and efficacy of current therapies. Growing evidence suggests that digital and technology-based therapies improve various mental health and substance use disorder outcomes, as a standalone treatment or augmentation strategy for in-person treatment (Graham et al., 2021, 2024). VR technology in particular may allow individuals to practice CBT techniques to cope with symptoms (e.g., cravings) and situations (e.g., stress at work) in an immersive environment that may be more evocative and effective than standard CBT for a wide range of mental health and substance use

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disorders (Gao et al., 2013). VR-delivered substance use disorder treatments have been developed to address multiple substances (e.g., nicotine, alcohol, and marijuana (Loria, 2016)). People who successfully develop relapse-avoidance strategies in VR do translate those strategies to the real world (Bellum, 2014). Presentation of smoking cues in VR (García-Rodríguez et al., 2012) or smoking a virtual cigarette (García-Rodríguez et al., 2013) increases craving and heart rate similar to real-world stimuli (Ferrer-Garcia et al., 2012). The use of VR may also make interventions more engaging (Gao et al., 2013); participants in one study reported enjoying a VR game designed for quitting vaping and said they would recommend it to friends (Weser & Hieftje, 2020), demonstrating its feasibility, satisfaction, and salience. Technological interventions to aid quitting can embed therapeutic content into VR (Lee et al., 2004; Lee et al., 2003), thereby allowing participants to practice resisting cues to use substances in a safe environment (Metcalf et al., 2018).

Even though this research is encouraging, currently, no engaging, immersive intervention exists for vaping cessation therapy, and there are no published controlled clinical trials to our knowledge testing the efficacy of embedding CBT content into VR to increase success at achieving vaping abstinence. To address this need, we built Novel, On-demand VR for Accessible, Practical, and Engaging therapy (NO VAPE). In the next Phase of the project we will conduct a pilot controlled clinical trial of its efficacy for vaping abstinence outcomes. **The project presented here is thus a usability study, NOT an efficacy study or clinical trial.** In preparation for this clinical trial, we conducted a preliminary human factors usability study to assess its ease of use, engagement, and safety, including not inducing simulator sickness (FDA, 2016). The usability study's goals were to:

1 Determine if there are usability issues that could increase risks to users (e.g., walking into a wall) to unacceptable levels, and test whether the NO VAPE system can be used by representative users under simulated conditions without producing patterns of failure that could result in negative impact to the user.
2 Evaluate effectiveness of instructional materials.
3 Determine if the potential for critical errors that would or could result in high-severity outcomes to the user (from a software-use perspective, not a substance use perspective) have been mitigated.
4 Provide recommendations for the device, instructional materials, and labeling that may mitigate the probability of use errors (usability- and safety-related).
5 Assess the navigation of the interface and identify areas for improvement.

2 METHODS

Participants evaluated NO VAPE during one-on-one sessions lasting up to three hours. Participants were paid $25 per hour in gift cards (e.g., Amazon, Visa) to encourage participants not to rush and to take their time in the VR environments. Each participant completed 11 scenarios (a tutorial and all 10 simulated vaping scenarios). First, they completed the tutorial, which provided instruction on how to move around the VR environment and interact with items around them. Then they completed the 10 vaping scenarios in randomized order, including scripted activities and CBT content. The environments included: (1) a bedroom in the morning where they decide whether to take their vape with them when they leave, (2) a kitchen where they get ready for the day, (3) a coffee shop where someone asks them to watch their bag then the person goes into the bathroom and vapes, (4) a classroom where friends ask them to go to lunch (where they will be vaping), (5) a work or school bathroom where someone in the next stall is vaping, (6) a car ride with a friend who is vaping, (7) a stressful day at work in an office environment, (8) a party where people are vaping and they must navigate an awkward conversation, (9) a corner store where they previously bought vapes, and (10) a living room at home alone at night. See Figure 1 for a screenshot of one of the scenarios (the classroom scenario). Participants were encouraged to "think aloud" during their interactions in each environment to express what they were thinking, doing, had questions about, etc.

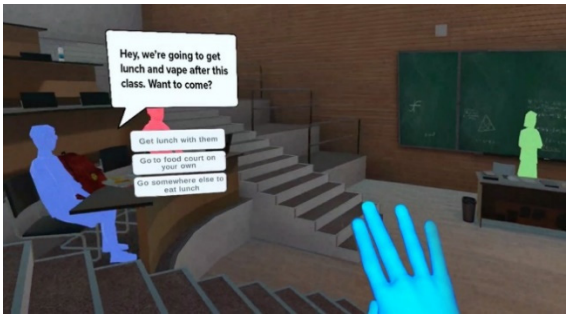

Figure 1: Screenshot from the classroom scenario.

As participants completed tasks within the VR environment, we mirrored the screen in the VR

headset onto a laptop to allow experimenters to view and record (screen capture recording) what the participant was seeing in the VR environment. The video recording allowed review and coding of user interactions and activities in the VR environment (e.g., what task they were struggling to complete and why), and enabled coders to hear participants' comments in context. Two "raters" recorded completion of each task in real time as the participant progressed through tasks in the environment. In the case of a mismatch in ratings between the two experimenters, a third rater reviewed the video of the experimental session and served as the "tie breaker." Task performance was assessed based on task completion success and the number and type of use-based errors.

Table 1: Task Hierarchy for the bathroom scenario (a breakdown of the tasks required to complete the scenario).

Task	Task X	Task X.X	Task X.X.X
1	Read "Reach for Vape"	Respond	
2	Read "Plan"	Respond	
3	Read "Sit Down"	Navigate to Toilet	
4	Read "Check Phone"	Respond	
5	Read "Response"	Respond	
6	Read "Think"	Click Next	
7	Read "How to Reward"	Respond	
7.1		Deep Breathing	Respond
7.2		Meditation	Listen to exercise
7.3		Muscle Relaxation	Respond
8	Read "Check In"	Respond	
9	Read "Deal with Boredom"	Respond	
10	Read "Wash Hands"	Navigate to Sink	
10.1			Place Hands Under Sink

Participants who had previously expressed interest in studies about reducing or quitting vaping were contacted to determine whether they were interested in learning more about this study. Interested individuals were screened by phone for eligibility. Inclusion criteria were: age 18 years or older, reported vaping nicotine daily or near daily in the prior ≥ 3 months, nicotine dependence operationalized by a score of ≥4 (at least mild dependence) on the 10-item E-cigarette Dependence Inventory (ECDI) (Piper et al., 2020; Vogel et al., 2020), self-reported interest in quitting vaping, at least one prior experience with using a VR program, ability to understand study procedures and read and write in English, and vision corrected to within 20/500 bilaterally.

To identify critical tasks, we conducted a Hierarchical Task Analysis (HTA), a task decomposition method that produces a hierarchy of activities users must do within NO VAPE and the associated necessary conditions (i.e., required subtasks to meet goals) (Diaper & Stanton, 2003). HTA establishes conditions when sub-tasks should be carried out to meet goals. See Table 1 for an example Task Hierarchy required to complete the bathroom scenario. We used the result of this HTA to identify errors (e., inability to complete a task).

For each scenario, we categorized errors into the following categories: (1) Slips: occur as the result of minor errors of execution, but the participant was able to recover without help from the experimenter, (2) Lapses: occur when a person could not complete a task without a hint by the experimenter (we let them fail 3 times before providing a hint), (3) Mistakes: occur when participants did not complete the task even with the help of the experimenter (note that these were mostly software errors when we had to restart the software), and (4) Violations: occur when actions deviate from safe procedures, standards, or rules, whether deliberate or erroneous. Importantly, there were not Violations by any participants in any scenario providing evidence that the app is low-risk and safe to use.

Average prevalence of each error was calculated as a percentage of all tasks and averaged across participants. We counted errors for top-level tasks. For example, if there are multiple steps to complete a task, we count the entire procedure as a single task. As a specific example, in the bathroom scenario, to fully complete Task 8, the participant had to complete the top-level task (8) as well as at least one of the second level tasks (8.1, 8.2, or 8.3) (see Table 1).

Participants completed the following questionnaires: Demographics, E-cigarette Dependence Inventory (ECDI)) (Piper et al., 2020; Vogel et al., 2020), Vaping History, Presence (Witmer & Singer, 1998), Simulator Sickness (Lin et al., 2002), Engagement, Enjoyment, Interactivity, and Immersion (E^2I) (Lin et al., 2002), Post Experience (adapted from (Usoh et al., 2000)), Post Evaluation Interview.

3 RESULTS

Participants included 6 adults (3 female; we did not collect race/ethnicity information) aged 20-31

(average age = 24). All reported having some experience with VR (i.e., previously used VR at least five times for five minutes). 50% of participants (3/6) reported also currently smoking tobacco.

Table 2 shows prevalence of each error type in each scenario. For example, of the 8 tasks in the tutorial, participants slipped an average of 10% of the time, ranging from 0 slips to 2 slips per participant across the full tutorial level. Participants committed lapses 8% of the time, ranging from 0-1 lapse per participant. There were no mistakes in the Tutorial.

Table 2: For each scenario, we calculated the percentage of each type of error for each participant, then averaged across participants. We show the number of tasks as a reference as each scenario had differing numbers of major tasks to complete (see Table 1 for an example of a task hierarchy).

Scenario	# Tasks	% Slips (Range)	% Lapses (Range)	% Mistakes (Range)
Tutorial	8	10% (0-2)	8% (0-1)	0%
Bathroom	17	2% (0-1)	0%	0%
Bedroom	22	7% (0-3)	0%	0%
Café	21	2% (0-2)	0%	1% (0-1)
Car	19	5% (0-1)	0%	5% (0-1)
Classroom	21	5% (0-1)	0%	0%
Kitchen	16	6% (0-2)	0%	1% (0-1)
Living Room	32	4% (0-3)	1% (0-1)	2% (0-1)
Party	26	3% (0-2)	0%	1% (0-1)
Store	29	5% (0-2)	3% (0-2)	0%
Work	36	2% (0-2)	0%	1% (0-1)

E-Cigarette Dependence Index scores ranged from 8 to 16 (mean = 11.8) consistent with moderate dependence (Foulds et al., 2015). Daily use varied from 0 to 5-9 times (50-90 mins). All participants reported vaping within 60 minutes of waking when able to vape freely. Half of participants reported awakening at night to vape at least twice a week. All participants reported finding it very hard to quit and finding it hard to keep from vaping in places they are not supposed to. With all participants having strong cravings to vape, all noted that they become more irritable when they are unable to use an electronic cigarette and 4/6 felt nervous, restless or anxious when they could not use an electronic cigarette.

Average age to begin vaping was 20.1 years. Most common reasons for initiation was peer pressure and having family/friends who vape. Participants had vaped 3.5 years on average, between 0.14 and 1 cartridge per day. The Crave brand was used by 4/6 participants. The most common reason for wanting to quit were concerns about future health problems followed by financial reasons. All participants had tried to quit vaping within the past year; half had quit vaping for at least 24 hours with an average cessation period of 27.1 days. Two participants reported having used nicotine gum, 1 participant reported use of bupropion, and 1 participant reported using medication other than bupropion or nicotine and/or herbal treatments.

In the Presence Questionnaire, participants characterized their experience in the virtual environment, rating their experience on a scale of 1-7, from 1 (bounds related to low presence) to 7 (bounds related to high presence), across seven questions (see Figure 2). Participants noted their interactions in the environment felt less natural (see discussion), with a mean of 2.83 (1 – "Completely artificial" to 7 – "Completely natural"). However, they felt somewhat involved in the visual (mean=5.33) and auditory (mean=4.83) aspects of the environment on a scale of 1 being "Not at all" to 7 being "Completely". Experiences in the simulation were consistent with those in the real world (mean = 5.5 (1 – "Not at all" to 7 – "Completely")). Completeness of the ability to visually survey the environment was good (mean=5.33) (1 – "Not at all" to 7 – "Completely"). Participants were somewhat able to successfully identify sounds (mean = 4.67 (1 – "Not at all" to 7 – "Completely")). Participants felt involved in the virtual experience with a mean of 6 (1 – "Not involved" to 7 – "Completely engrossed").

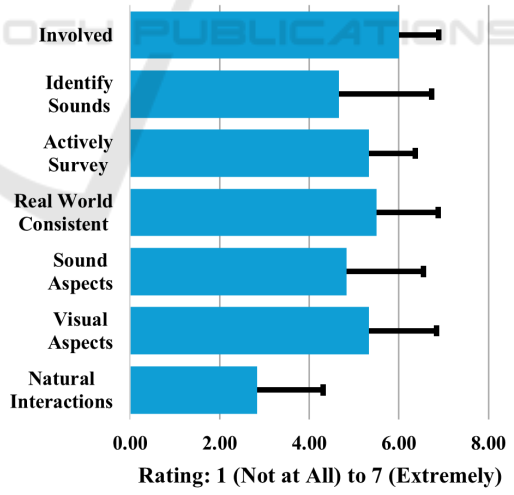

Figure 2: Presence questionnaire results.

For the Simulator Sickness questionnaire, participants were asked to rate on a scale of 1-3 (1- "Not at all" to 3 – "a lot") the degree to which they experienced sixteen conditions: general discomfort, fatigue, headache, eyestrain, difficulty focusing, increased salivation, sweating, nausea, difficulty

concentrating, fullness of head, dizzy (eyes open), dizzy (eyes closed), vertigo, stomach awareness, and burping. The mean across all conditions was 1.15. The only negative symptom that participants experienced from the simulation was increased eyestrain (mean=1.7). Sweating (mean=1.5), headaches (mean=1.33) and difficulty focusing (mean=1.33) were felt but not strongly. See Figure 3.

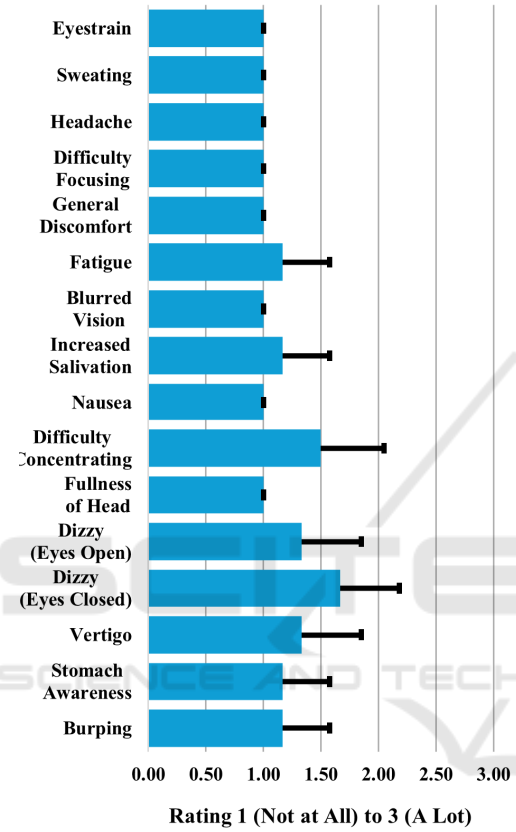

Figure 3: Simulator Sickness questionnaire results.

For the Engagement, enjoyment, interactivity, and immersion questionnaire, participants were asked to respond to 12 questions on a scale of 1-7 (1- "Not at all" to 7 – "A lot"). Most participants were attracted to the visual scenes within the application with a mean of 5.5 and noise outside the simulation was not an issue for most (mean=1.33). Feelings were mixed about the matching of the real world to the virtual environment with participants feeling an average of somewhat "being there" in the virtual environment (mean=4.6). Overall, moving objects within the virtual space was somewhat compelling (mean=4.83) as was moving oneself through the space (mean=4.67). Time tracking varied across participants with two participants losing track of time entirely, and one not at all (mean=4.75). All participants were not unhappy when the simulation was over (mean=1.8). They would likely repeat the experience (mean=5.6) and found it interesting (mean=5.83), however they would not be likely to pay for it. Results are summarized in Figure 4.

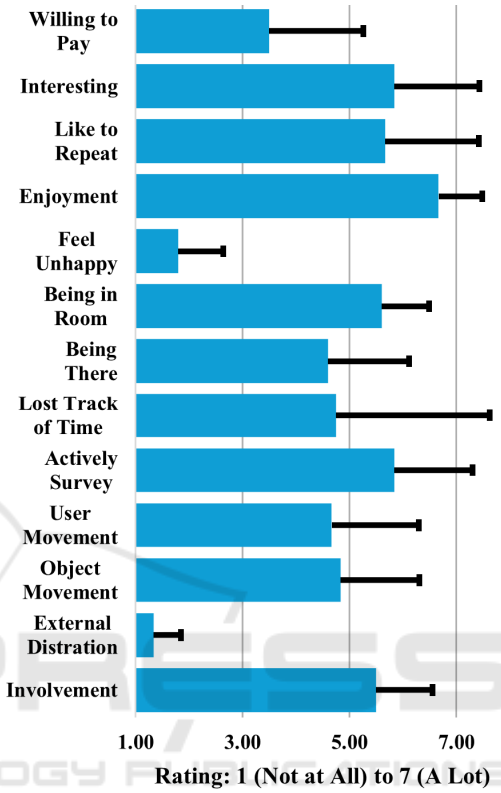

Figure 4: Engagement, enjoyment, interactivity, and immersion questionnaire (E2I) results.

Participants answered a Post Experience Questionnaire to probe for additional factors related to VR presence and physiological effects on a scale of 1 (seemingly artificial) to 7 (like being in the real world) For presence-related questions, participants felt mixed about the simulation accurately representing their normal experiences of being in a place (mean=5). The virtual environment did not feel completely like a "reality" to most (mean=4.17) and their sense of being fully immersed was average. Participants recalled simulated images both as images they saw and places they visited (mean of 4.17 on a scale of 1 - "Simulated images" to 7 - "Somewhere that I visited"). Their sense of being in the simulated environment was slightly greater than being elsewhere with a mean of 5.17 (1 – "Being elsewhere" to 7 – "Being in the simulated environment"). Participant memory of the virtual space was somewhat vivid as it related to places they had visited that day (mean of 4 on a scale of 1 – "Not

at all" to 7 – "Very much so"). Most participants did not pay attention to events in the real world during their time in the simulation (mean=2.33) and most were completely focused on the tasks (mean=6.33). Participants also rated the degree to which they experienced physiological effects during NO VAPE use, on a scale from 1 ("not at all") to 7 ("almost all the time"). None of the participants experienced strong feelings of nausea (mean=1.2), dizziness (mean=1.2) or headaches (mean=1.3). However, there was some degree of mild eye strain noted (mean=2.2).

After the session, we asked open-ended questions to understand the opinions of participants. Participants did note several areas of improvement in the simulation. The meditation room was not well-received by several participants who noted it needed visual and audio improvements ("Immersion breaks for meditation", "More detail in meditation room would be nice."). The placement of text messages in the space were difficult for some users to view, with the text being too close or running into the walls during some scenarios. Some of the interactions proved challenging for participants and they would have liked to become more familiar with the controls before they began the scenarios ("was looking at hands for feedback on what each control did", "teleportation was sometimes hard"). Some of the options were difficult to select and there was confusion about which objects could be interacted with. Inconsistent interaction mechanics pulled some of the participants out of the experience and specific issues with object interaction broke the immersion ("immersion stronger in some parts than others").

However, overall, feedback was positive. Participants felt that scenarios were generally accurate, immersive, relatable and valuable ("Scenario content was accurate", "Felt real/actual situations that happen"). They really enjoyed the interaction-based approach once they got used to the controls and how to navigate the space. They noted that the activities in the scenarios reinforced good habits. The highlighting was a very effective means of guiding users through tasks and when not present, participants faltered. Participants liked the options they were given for where they could place objects ("multiple options to hide the vape was good"). Participants felt that the system would be safe for use at home, and some viewed it as an empowering therapeutic tool for quitting ("more empowered to quit"). They "could see it as a therapeutic tool.", felt "more empowered to quit", and "didn't think of it as therapy until after."

4 CONCLUSIONS

This preliminary study addressed all the initial goals outlined in Section 1. First, we determined that there are no usability issues that could increase risks to users to unacceptable levels (from a software use perspective, not a substance use perspective), and that the NO VAPE System can be used by representative users under simulated conditions without producing patterns of failure that could result in negative impact or injury to the user. Across all of our participants, and in all of our scenarios, there were zero deviations from safe procedures (i.e., Violations).

Second, we evaluated the effectiveness of the instructional materials for teaching users how to interact with the system without frustration. The Tutorial scenario was always the first scenario that participants completed, and the goal of this scenario was to teach participants how to interact with the application (e.g., how to navigate from one place to another, open cupboards or drawers, pick up items and put them into a bag, interact with non-player characters (NPCs), eat and drink, etc.). As expected, participants committed more errors in the tutorial (slips an average of 10% of major tasks and lapses an average of 8% of major tasks) than the later scenarios as they were not yet familiar with how to navigate the software. However, one weakness was that participants had difficulty interacting with the environment (found interactions to be unnatural). This information allowed us to review videos and task completion information to identify where interactions were difficult for participants (e.g., interacting with the phone), allowing us to fix these issues.

Third, we determined that the potential for critical errors that would or could result in high-severity outcomes to the user have been mitigated to the extent reasonable or possible through the design of the device and instructional materials. We previously completed a related VR application focused on smoking cessation (called Constructed Environments for Successfully Sustaining Abstinence Through Immersive and On-Demand Treatment; CESSATION), and conducted a full set of human factors studies on that app. During that work, we discovered that the errors with high severity outcomes were related to using the VR itself. These included potentially walking physically throughout the environment rather than virtual teleporting, resulting in a potential to walk into a wall or other furniture, and "forgetting" that they were in VR and potentially trying to physically sit on a chair that was not present outside of the VR world. That study resulted in the production of a similar Tutorial

environment in CESSATION. We used those lessons when building NO VAPE. The results of the current usability evaluation indicate that we were successful in mitigating any potential high-severity outcomes through this Tutorial material.

Fourth, by analyzing the errors that were made whenever a participant had trouble with or could not complete a task, we were able to collate information about each error, and provide recommendations for VR app refinement, including to improve instructional materials (e.g., participants wanted to receive additional information about the trivia question content), and labeling to mitigate the probability of use errors (usability- and safety-related content). Most of the Mistakes were actually a result of software errors that would not allow the participant to play further through the level. For example in the living room scenario, sometimes the participant accidentally dropped the TV remote onto the couch before they turned on the TV. The remote disappeared and they could not retrieve it again. This prevented them from turning on the TV, preventing them from completing any task further into the scenario. As planned, this usability study has allowed us to fix these identified software errors.

Fifth, we assessed the navigation of the interface and identify areas for improvement. During the study, participants were encouraged to use the "think aloud" method to talk about what they were doing in the environment (the experimenter could also view participant interactions on a mirrored screen). This allowed us to collect subjective comments from participants (e.g., "ooh, I like the nature sounds" and "this room feels really sterile" during the meditation practice in a separate meditation room). We collated all of the participant comments that occurred naturally during the experiment as well as the responses to the post-evaluation interview, and compiled a list of recommendations that will inform refinement of the NO VAPE app prior to conduct of the planned clinical study.

One limitation to this work is the number of participants, and the fact that all participants were over 18 years old, even though we plan to use it with participants 16+. We are now working to enroll additional participants for a target of N=15 who are 18+ and N=15 who are 16-17.

We believe that the results of this preliminary usability evaluation indicate that once we implement the recommended software and scenario content improvements, we will have a safe and user-friendly VR application to use in our clinical study. The only controlled trial to date of an intervention for cessation of vaped nicotine is a parallel, two-group, double-blind, individually randomized clinical trial of "This is Quitting (TIQ)", a free, anonymous texting app, that incorporates messages from people who have attempted to or successfully quit e-cigarettes. This study included 2588 young adults aged 18-24. Participants were significantly more likely to quit vaping when receiving TIQ than without intervention (24.1% versus 18.6%; $p<0.001$) (Graham et al., 2021, 2024). However, text messaging is not immersive, provides no opportunity for ecologically valid practice of resisting cravings, and may not be engaging across continuous use. Therefore, in the next phase of this work, we will conduct a single-blind, parallel group, randomized clinical trial in 90 non-smoking, nicotine-dependent people, age 16+, who want to quit vaping. We hypothesize that those assigned to NO VAPE combined with a 12-session vaping cessation CBT program (experimental group) will have a higher rate of 4-week continuous abstinence at the end of 12 weeks treatment than those assigned to CBT alone (control group). If successful, this will provide clinical evidence of real-world outcomes and efficacy of NO VAPE.

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REFERENCES

Abafalvi, L., Pénzes, M., Urbán, R., Foley, K. L., Kaán, R., Kispélyi, B., & Hermann, P. (2019). Perceived health effects of vaping among Hungarian adult e-cigarette-only and dual users: A cross-sectional internet survey. *BMC Public Health*, *19*(1), 1–10.

Bellum, S. (2014). *Virtual Reality and Drug Abuse Treatment*. NIDA for Teens. https://teens.drugabuse.gov/blog/post/virtual-reality-and-drug-abuse-treatment

Diaper, D., & Stanton, N. (2003). *The handbook of task analysis for human-computer interaction*. https://books.google.com/books?hl=en&lr=&id=EuddOAMeI5sC&oi=fnd&pg=PP1&dq=the+handbook+for+task+analysis&ots=7M0qGFaefd&sig=HGOX2pLKhUVXRFYBGsyZdhwKNWI

Ferrer-Garcia, M., Garcia-Rodriguez, O., Pericot-Valverde, I., Yoon, J. H., Secades-Villa, R., & Gutierrez-

Maldonado, J. (2012). Predictors of smoking craving during virtual reality exposure. *Presence: Teleoperators and Virtual Environments*, *21*(4), 423–434.

Food and Drug Administration. (2016). *Applying Human Factors and Usability Engineering to Medical Devices* [Guidance]. https://www.fda.gov/regulatory-information/search-fda-guidance-documents

Foulds, J., Veldheer, S., Yingst, J., Hrabovsky, S., Wilson, S. J., Nichols, T. T., & Eissenberg, T. (2015). Development of a questionnaire for assessing dependence on electronic cigarettes among a large sample of ex-smoking E-cigarette users. *Nicotine & Tobacco Research*, *17*(2), 186–192.

Gallus, S., Lugo, A., Stival, C., Cerrai, S., Clancy, L., Filippidis, F. T., Gorini, G., Lopez, M. J., López-Nicolás, Á., & Molinaro, S. (2023). Electronic cigarette use in 12 European countries: Results from the TackSHS survey. *Journal of Epidemiology*, *33*(6), 276–284.

Gao, K., Wiederhold, M. D., Kong, L., & Wiederhold, B. K. (2013). *Clinical experiment to assess effectiveness of virtual reality teen smoking cessation program.*

García-Rodríguez, O., Pericot-Valverde, I., Gutiérrez-Maldonado, J., Ferrer-García, M., & Secades-Villa, R. (2012). Validation of smoking-related virtual environments for cue exposure therapy. *Addictive Behaviors*, *37*(6), 703–708.

García-Rodríguez, O., Weidberg, S., Gutiérrez-Maldonado, J., & Secades-Villa, R. (2013). Smoking a virtual cigarette increases craving among smokers. *Addictive Behaviors*, *38*(10), 2551–2554.

Graham, A. L., Amato, M. S., Cha, S., Jacobs, M. A., Bottcher, M. M., & Papandonatos, G. D. (2021). Effectiveness of a Vaping Cessation Text Message Program Among Young Adult e-Cigarette Users: A Randomized Clinical Trial. *JAMA Internal Medicine*, *181*(7), 923–930. https://doi.org/10.1001/jamainternmed.2021.1793

Graham, A. L., Cha, S., Jacobs, M. A., Amato, M. S., Funsten, A. L., Edwards, G., & Papandonatos, G. D. (2024). A vaping cessation text message program for adolescent e-cigarette users: A randomized clinical trial. *Jama*, *332*(9), 713–721.

Hammond, D. (2019). Outbreak of pulmonary diseases linked to vaping. In *Bmj* (Vol. 366). British Medical Journal Publishing Group.

Irusa, K. F., Vence, B., & Donovan, T. (2020). Potential oral health effects of e-cigarettes and vaping: A review and case reports. *Journal of Esthetic and Restorative Dentistry*, *32*(3), 260–264.

Ko, K., Ting Wai Chu, J., & Bullen, C. (2024). A Scoping Review of Vaping Among the Asian Adolescent Population. *Asia Pacific Journal of Public Health*, *36*(8), 664–675. https://doi.org/10.1177/10105395241275226

Lee, J. H., Ku, J., Kim, K., Kim, B., Kim, I. Y., Yang, B.-H., Kim, S. H., Wiederhold, B. K., Wiederhold, M. D., & Park, D.-W. (2003). Experimental application of virtual reality for nicotine craving through cue exposure. *CyberPsychology & Behavior*, *6*(3), 275–280.

Lee, J., Lim, Y., Graham, S. J., Kim, G., Wiederhold, B. K., Wiederhold, M. D., Kim, I. Y., & Kim, S. I. (2004). Nicotine craving and cue exposure therapy by using virtual environments. *CyberPsychology & Behavior*, *7*(6), 705–713.

Levy, D. T., Tam, J., Sanchez-Romero, L. M., Li, Y., Yuan, Z., Jeon, J., & Meza, R. (2021). Public health implications of vaping in the USA: The smoking and vaping simulation model. *Population Health Metrics*, *19*(1), 1–18.

Lin, J.-W., Duh, H. B.-L., Parker, D. E., Abi-Rached, H., & Furness, T. A. (2002). Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment. *Virtual Reality, 2002. Proceedings. IEEE*, 164–171.

Loria, K. (2016). Therapists have created a virtual reality heroin cave in an attempt to help addicts. *Tech Insider*.

McNeill, A., Brose, L., Calder, R., Simonavicius, E., & Robson, D. (2021). Vaping in England: An evidence update including vaping for smoking cessation, February 2021. *Public Health England: London, UK*, 1–247.

Metcalf, M., Rossie, K., Stokes, K., Tallman, C., & Tanner, B. (2018). Virtual Reality Cue Refusal Video Game for Alcohol and Cigarette Recovery Support: Summative Study. *JMIR Serious Games*, *6*(2), e7.

Piper, M. E., Baker, T. B., Benowitz, N. L., Smith, S. S., & Jorenby, D. E. (2020). E-Cigarette dependence measures in dual users: Reliability and relations with dependence criteria and e-cigarette cessation. *Nicotine and Tobacco Research*, *22*(5), 756–763.

Traboulsi, H., Cherian, M., Abou Rjeili, M., Preteroti, M., Bourbeau, J., Smith, B. M., Eidelman, D. H., & Baglole, C. J. (2020). Inhalation toxicology of vaping products and implications for pulmonary health. *International Journal of Molecular Sciences*, *21*(10), 3495.

Usoh, M., Catena, E., Arman, S., & Slater, M. (2000). Using presence questionnaires in reality. *Presence: Teleoperators and Virtual Environments*, *9*(5), 497–503.

Vogel, E. A., Prochaska, J. J., & Rubinstein, M. L. (2020). Measuring e-cigarette addiction among adolescents. *Tobacco Control*, *29*(3), 258–262.

Weser, V. U., & Hieftje, K. D. (2020). Invite Only VR: A Vaping Prevention Game: An Evidence-Based VR Game for Health and Behavior Change. *Special Interest Group on Computer Graphics and Interactive Techniques Conference Talks*, 1–2.

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence*, *7*(3), 225–240.