Crushing Virtual Cigarettes Reduces Tobacco Addiction and Treatment Discontinuation

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Abstract

Pilot studies revealed promising results regarding crushing virtual cigarettes to reduce tobacco addiction. In this study, 91 regular smokers were randomly assigned to two treatment conditions that differ only by the action performed in the virtual environment: crushing virtual cigarettes or grasping virtual balls. All participants also received minimal psychosocial support from nurses during each of 12 visits to the clinic. An affordable virtual reality system was used (eMagin HMD) with a virtual environment created by modifying a 3D game. Results revealed that crushing virtual cigarettes during 4 weekly sessions led to a statistically significant reduction in nicotine addiction (assessed with the Fagerström test), abstinence rate (confirmed with exhaled carbon monoxide), and drop-out rate from the 12-week psychosocial minimal-support treatment program. Increased retention in the program is discussed as a potential explanation for treatment success, and hypotheses are raised about self-efficacy, motivation, and learning.

Introduction

Tobacco use creates a triple addiction: physical, psychological, and social. Epidemiologic data suggest that more than 45% of smokers in the United States try to quit smoking each year, with limited success.1 The interaction among multiple factors that cause and maintain the addiction makes quitting very complex.2 Although several pharmacological, cognitive-behavioral, and motivational options have been proposed,3–5 more effective and innovative treatments are needed because traditional therapeutic methods listed and evaluated by the Agency for Healthcare Research and Quality3 and the World Health Organization6 still need to be improved.

Virtual reality (VR) is a useful tool in addiction research and treatment. For example, Bornick et al.2 immersed smokers in a virtual environment containing stimuli associated with urges to smoke, such as burning cigarettes, cigarette packs, and people offering cigarettes. They showed that when compared to a virtual environment without smoking cues, such as an empty underwater room, participants reported a statistically significant increase in cravings as measured with self-report. Lee et al.3 compared the response to smoking cues while immersed in VR versus being exposed to still images of the same 3D stimuli. They found that immersion in an interactive and real-time 3D virtual environment significantly increased craving compared to still images. Since the two studies used participants who were not deprived of nicotine prior to the cue-reactivity tests, Bauman and Sayette9 performed a cue-exposure experiment with participants who had been deprived of nicotine for 12 hours. Even if their stimuli were presented on a computer monitor instead of a head-mounted display, they still found a significant increase in urges to smoke. More recently, Carter et al.10 examined the craving experience of young adult smokers while immersed in VR. They found that virtual smoking cues elicit the types of reasons to smoke, including positive outcome expectancies associated with smoking (e.g., things would be better if I smoke right now) and amelioration of negative affective states (e.g., I feel depressed).

Cue-reactivity studies have shown that drug-related stimuli can also elicit strong craving reactions,11 but the efficacy of treatment based exclusively on exposure to drug-related cues appears to be limited.12 Inconsistent evidence for the effectiveness of cue-exposure therapy may be explained by a need to better integrate this form of treatment with recent theoretical findings on learning.12 However, VR may help in providing ecologically valid contexts that would make cue exposure more effective.9 The use of cue-exposure therapy using VR is still in its infancy.13,14 Participants’ level of presence (the impression of being there in the virtual environment) and cybersickness (virtual reality–induced side effects)

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were found to be acceptable, and functional magnetic resonance imaging data show that expected brain areas are recruited during the immersion and treatment. One significant challenge for effective treatments is drop-out, since treatment continuation is a significant predictor of its effectiveness. Based on preliminary data from 16 smokers treated in an open trial in our clinic, the action of crushing cigarettes in VR may have an impact on the behaviors and motivation of smokers undergoing therapy. We proposed that adding crushing virtual cigarettes to a psychosocial treatment program could have a synergistic effect and significantly increase the effectiveness of the psychosocial program.

The objective of this study is to test the advantages of combining cybertherapy (four sessions during which the patient crushes virtual cigarettes) to a psychosocial smoking-cessation treatment program for adults. The participants were assigned randomly to one of two conditions: (a) Balls, where grasping balls (control group) in VR was combined with the psychosocial program; and (b) Cigarettes, where crushing cigarettes (experimental group) in VR was combined with the psychosocial program.

Method

Sample

The sample was recruited from the general population through ads in local medias. After they called the GRAP clinic, participants were contacted by telephone to see whether they met the selection criteria, then seen individually to inform them of the details of their participation in the study. They were also informed about VR and the potential side effects. After completing the consent form, participants were seen individually by a nurse to complete a sociodemographic questionnaire describing their tobacco consumption and to undergo a brief medical examination. They also completed the questionnaires described below and a first exhaled carbon monoxide test. Participants were then told to which of the two experimental groups they had been randomly assigned to. Finally, they tried out a virtual environment (different from the one used in treatment) to familiarize themselves with VR and with how to “walk” in the virtual environment. No target date for stopping was fixed.

The following selection criteria were applied: (a) being between 18 and 65 years old, (b) being in good general health, and (c) regularly consuming 10 cigarettes or more daily during the last year. The following exclusion criteria were also applied and were sufficient for rejection: (a) treatment for a mental health problem during the last year (e.g., major depression, panic disorder, psychosis, bipolar affective disorder, anorexia, bulimia), (b) regular ingestion of a medication affecting the central nervous system, (c) a positive history of alcoholism or severe drug addiction during the last year, (d) a body mass index (BMI) below 15 kg/m² (anorexia) or above 40 kg/m² (obesity class III), (e) one or more periods of abstinence from cigarettes of more than 3 months during the last year, (f) previous attempt to stop smoking in the last 6 months, (g) serious illness during the last 6 months, and (h) use of smoking-cessation products (e.g., gum, patch, bupro- pion, varenclline) during the last 6 months.

The sample at the start of the study consisted of 91 participants, 45 assigned randomly to the Balls condition and 46 to the Cigarettes condition. The average age was 44 years (SD = 11 years), and the participants had been smoking for an average of 27 years (SD = 12 years). Forty-five percent smoked more than 21 cigarettes a day. Fifty-seven percent were women, and 68% were employed. Statistical analyses comparing the two conditions on these sociodemographic parameters did not find any significant difference.

Procedure

Participants came to the clinic once a week for the first 4 weeks, then once every 2 weeks for the second and third months of the study. The psychosocial program and data collection took place in weeks 1, 2, 3, 4, 6, 8, 10, and 12. Each session included 30 minutes with a nurse, who took their vital signs (blood pressure, pulse, weight), collected the smoker’s journal, administered the questionnaires, performed carbon monoxide testing, discussed with the participant any personal conflicts related to smoking cessation, and provided a brief counseling session and support in the application of a French self-help program (English title of the program: On the Road to Quitting: Guide to Becoming a Non-Smoker).

Participants also took part in one VR session per week during the first 4 weeks/visits of the treatment. All were exposed to VR for 30 minutes in each session. In the virtual environment, the participants were asked, depending on which experimental condition they were in, to either find and crush up to 60 virtual cigarettes (active treatment in VR) or grasp up to 60 virtual balls (control placebo condition in VR).

A 6-month follow-up was conducted by phone. Participants were asked to state whether or not they had smoked in the last week, how many cigarettes were smoked, and if they had flashback memories of the virtual environment.

Equipment

The virtual environment was displayed on an eMagin Z800 head-mounted display (with built-in 3-dof motion tracker) using a Pentium IV computer (3.2 GHz, 1 GB of RAM) running on Windows XP and an nVidia 7300GS video card with stereoscopy.

The virtual environment consists of a map created using the game engine Unreal 2™. It represents a fictional medieval castle with several indoor rooms and outdoor areas with varied materials, lights, and sounds. XSI from Softimage™ was used to design the virtual arm and to integrated it with cigarettes and balls in the 3D environment (see Fig. 1). Forward and backward motion in the virtual environment and the action of the virtual arm were controlled with a Logitech wireless gamepad.

Measures: main outcome variables

Fagerström test for nicotine dependence. Nicotine addiction was estimated using the revised version of the Fagerström, which includes six items and provides a global score ranging from 0, no addiction, to 10, high level of addiction. It measures significant signs of nicotine addiction, such as the time before smoking the first cigarette of the day and the frequency of smoking. This instrument was administered before the start of the first week of therapy (start of treatment), at the fourth week of therapy (end of the virtual reality phase), and at the twelfth week (end of the program).
Daily smoker's journal and exhaled carbon monoxide. The abstinence rate was measured on the basis of the smoker's journal (daily self-reported measurement of the number of cigarettes per day) and confirmed by an exhaled carbon monoxide test as measured at the fourth and last sessions of the program. A stringent cutoff score on the carbon monoxide test was set at 6 parts per million to confirm abstinence in the last week reported in the smoker's journal.

Drop out. The drop-out rate was defined as follows: participants who stopped coming to the psychosocial program sessions, no matter the reason evoked by the participant, including moving to another city, having reached his or her own therapeutic objectives, or using a smoking-cessation product listed in the selection criteria. The number of participants who dropped out of the program was measured each week.

Measures: predictors and side effects variables

Two variables were used in multiple regressions analyses: urges to smoke and the feeling of presence. Virtual reality induced side effects were also assessed.

Questionnaire of Smoking Urges—Brief (QSU-Brief)\textsuperscript{23,24}. The QSU-Brief assesses actual urges to smoke in the presence of positive and negative reinforcements. It is built on two factors, the intention to smoke (approach motivation) and the anticipation of relief of negative affect (avoidance motivation), but only the total score is reported here. The short version, in French, has 10 items, rated on a scale of 1, totally disagree, to 7, totally agree, and the score obtained at the first therapy session was used in a statistical regression analysis to control the severity of smoking problems in predicting treatment drop-out.

Presence Questionnaire (PQ)\textsuperscript{25}. The PQ uses a 7-point Likert scale (1, not at all, to 7, completely) to measure dimensions of presence. We used an adapted version for a French sample\textsuperscript{26,27} and its factor structure consists of six factors: realism (extent to which virtual environments look natural), affordance to act (active exploration and control of events), quality of the interface (delay or awkwardness related to the apparatus), ability to examine (observing objects from different angles), self-evaluation of performance (feeling of competence and adaptation with respect to the execution of tasks), and auditory and tactile cues (ability to touch certain objects). Participants completed this instrument at the end of each immersion in VR, and the average of the total presence scores for each VR session was used in a statistical regression analysis to control for presence in predicting treatment outcome.

Simulator Sickness Questionnaire (SSQ)\textsuperscript{28}. The SSQ contains 16 items measuring on a 4-point scale (0, not at all, to 3, severely) the degree of discomfort felt by the individual (nausea, vertigo, tired eyes, etc.). Our adaptation for a French sample\textsuperscript{29} has two dimensions: nausea and oculomotor problems. Participants completed this instrument at the end of each VR immersion to document potential side effects (cybersickness).

Results

In planning the statistical design of this study, it was decided to use the intent-to-treat principle; that is, the results of all the participants were analyzed, whether or not some participants dropped out of treatment. This approach is considered to be more conservative because it tends to decrease the effect of a treatment by carrying forward to the different measurement times the negative scores of patients.

FIG. 1. Screenshot of the virtual arm extending to pick up and crush a virtual cigarette.
who dropped out and is not based exclusively on the people who had the most chance of benefiting from the treatment. For intention-to-treat analyses, the last data obtained from participants who stopped participating in the program, for any reason, was carried forward to all subsequent measurements.

The mean number of virtual stimuli (cigarettes or balls) picked up during each session (between 33 and 46) was not significantly different between the two conditions: group effect, $F(1, 57) = 0.49, \text{ns}$; time-condition interaction, $F(3, 171) = 0.27, \text{ns}$. However, it increased significantly over the course of the treatment: time effect, $F(3, 171) = 88.16, p < 0.001$.

The program’s impact on the Fagerström measure of nicotine addiction (see Table 1) was tested using a repeated measures ANOVA with three measurement times (pretreatment, end of the VR sessions, end of the program). The results revealed significant differences in the time, $F(2, 178) = 33.07, p < 0.001$; condition, $F(1, 89) = 4.69, p < 0.025$; and time/condition interaction, $F(2, 178) = 3.75, p < 0.05$, effects. These analyses showed that the treatment program significantly reduced nicotine addiction and that crushing cigarettes in VR had a significantly better impact than grasping balls. The contrast analysis showed that the impact of the program began to be felt by the fourth week, $F(1, 89) = 33.34, p < 0.001$, and continued until the end, $F(1, 89) = 55.18, p < 0.001$. The contrast analysis showed, however, that the specific advantage of crushing cigarettes instead of grasping balls became significant only between week 4 and the end of the treatment, $F(1, 89) = 6.87, p < 0.01$.

The percentage of abstinence was tested using a chi-square test on the intention-to-treat data. After the fourth week, 2% of participants in the Balls condition and 9% in the Cigarettes condition were abstinent. This difference was not significant: $\chi^2(1) = 1.84, \text{ns}$. On the other hand, the rate of abstinence reached 15% in the twelfth week for participants crushing virtual cigarettes, as opposed to 2% for participants in the placebo virtual condition who were grasping balls. This difference was statistically significant: $\chi^2(1) = 4.79, p < 0.05$.

At the 6-month telephone follow-up, 39% of the participants in the Cigarettes condition stated they had not smoke in the last week, as opposed to 20% in the Balls condition: $\chi^2(1) = 4.05, p < 0.05$. The mean number of cigarettes they recalled smoking in the last week was 8.4 in the Cigarettes condition and 15.5 in the control condition: $t(89) = 3.13, p < 0.01$. Also, 23% of the participants in the experimental condition reported having had flashback memories of crushing cigarettes in the virtual environment, as opposed to 3% in the control condition: $\chi^2(1) = 7.34, p < 0.01$.

The drop-out rate was measured each week (see Fig. 2), and a survival analysis applied to the overall comparison of the two groups’ retention curves showed that the retention profile differed significantly between the two conditions: Gehan’s Wilcoxon test $(1) = 6.96, p < 0.01$. On average, participants in the control condition dropped out of the program after 5.89 weeks $(SD = 4.66)$, and those crushing virtual cigarettes dropped out on average after 8.26 weeks $(SD = 4.17)$, which is significantly later: $t(89) = 2.56, p < 0.025$. Overall, it suggests that participants in the control condition still com-
pleted the four placebo VR immersions and that the impact of crushing virtual cigarettes on retention in the program manifested itself later on during the treatment. However, chi-square tests revealed that significantly more controls had dropped out of treatment at week 4 (22% vs 49%), \( \chi^2(1) = 7.35, p < 0.001 \), and week 12 (50% vs 71%), \( \chi^2(1) = 4.24, p < 0.05 \).

Interestingly, participants who stayed in the psychosocial treatment program until the end had been smoking for a longer period of time than those who dropped out: 29.8 years, \( SD = 11.8 \) vs 24.2 years, \( SD = 12.5 \); \( t(89) = 2.04, p < 0.05 \). To document the relative impact of crushing cigarettes in VR, we performed a logistic multiple regression analysis to predict who would or would not stay in the program until the end (week 12). The data gathered the first week was used for three predictors: the total score on the QSU-brief, the number of years the participants had smoked, and the experimental condition to which participants were assigned to. The regression equation explained a significant percentage of cases that remained in the program: 65%, \( \chi^2(3) = 8.1, p < 0.05 \). The respective contributions of the three predictors were significant only for the variable experimental condition, \( \beta = -0.92 \), Wald \( (1) = 4.08, p < 0.05 \), suggesting that whether or not one crushes cigarettes in VR is more important in predicting retention in the program than severity of smoking urges, \( \beta = -0.001 \), Wald \( (1) = 0.005 \), ns, or duration of the smoking problem, \( \beta = 0.04 \), Wald \( (1) = 3.33 \), ns.

Table 2 shows the scores measuring presence obtained during the four VR immersions. A repeated measures ANOVA did not detect any significant difference between the two conditions: condition effect \( F(1, 55) = 0.01, ns \); interaction \( F(3, 165) = 0.36, ns \). But a significant time effect over the four sessions, \( F(3, 165) = 4.08, p = 0.01 \), showed that presence increased significantly with practice.

A multiple regression analysis was used to examine the role of presence (averaged over the four sessions) on the impact of the intervention program on the Fagerström test (utilizing presence and residualized change scores to measure change on the outcome measure).\(^{33} \) The multiple regression was significant, \( F(2, 90) = 39.78, p < 0.001 \), and showed that presence contributes significantly to changes in scores measuring tobacco addiction, semipartial correlation (sr)\(^2 = -0.18 \), \( p < 0.025 \).

Finally, VR-induced side effects were measured after each therapy session (see Table 3). The repeated measures ANOVA showed that participants crushing cigarettes in VR felt significantly more cybersickness, \( F(1, 57) = 4.10, p < 0.05 \), and that this effect diminished over time, \( F(1, 171) = 2.92, p < 0.05 \), in a similar fashion in both conditions, interaction \( F(3, 171) = 1.90, ns \).

### Table 2. Presence during Immersion in Virtual Reality (N = 91)

<table>
<thead>
<tr>
<th></th>
<th>Grasping virtual balls condition Mean (SD)</th>
<th>Crushing virtual cigarettes condition Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>121.44 (19.59)</td>
<td>119.09 (19.64)</td>
</tr>
<tr>
<td>Week 2</td>
<td>124.00 (21.65)</td>
<td>125.74 (26.81)</td>
</tr>
<tr>
<td>Week 3</td>
<td>125.65 (19.00)</td>
<td>126.71 (20.48)</td>
</tr>
<tr>
<td>Week 4</td>
<td>127.04 (19.24)</td>
<td>128.77 (22.73)</td>
</tr>
</tbody>
</table>

### Table 3. Descriptive Data on Simulator Sickness (N = 91)

<table>
<thead>
<tr>
<th></th>
<th>Grasping virtual balls condition Mean (SD)</th>
<th>Crushing virtual cigarettes condition Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Week 1</td>
<td>39.39 (48.72)</td>
<td>81.93 (70.11)</td>
</tr>
<tr>
<td>Week 2</td>
<td>41.62 (42.45)</td>
<td>58.91 (55.57)</td>
</tr>
<tr>
<td>Week 3</td>
<td>41.77 (44.01)</td>
<td>51.91 (45.53)</td>
</tr>
<tr>
<td>Week 4</td>
<td>28.67 (41.47)</td>
<td>51.24 (62.55)</td>
</tr>
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### Conclusion

This study shows a significant impact of crushing cigarettes in VR on three variables: nicotine addiction, rate of abstinence, and retention of patients in the psychosocial treatment program. Results appear to hold at follow-up, although measurement was performed differently at post-treatment and follow-up. Presence seems to be associated with the beneficial effect of the program, and cybersickness is more frequent among participants in the experimental condition.

The mechanism explaining our findings remains unclear and deserves further study. The first explanation that comes to mind may have less to do with behavior change and more with retention in the counseling and self-help program. Crushing virtual cigarettes may have made patients more willing to come to their regular meetings with the nurse, and continuation of treatment being an important predictor of outcome.\(^{16–19} \) the impact of the cybertherapy may be limited to foster treatment attendance and adherence. Enjoying crushing virtual cigarettes would only be a motivator, and the active ingredients in the treatment would remain those related to counseling and applying self-help strategies. If this is the case, it would still be interesting to test the benefits of adding crushing virtual cigarettes to more powerful smoking-cessation treatment, such as cognitive-behavior therapy or pharmacotherapy (e.g., patches, varenicline, rimonabant) or new approaches.\(^{7,13,19} \)

However the impact of crushing virtual cigarettes is probably more complex than only motivating patients to attend to their appointments. Its impact could hardly be limited to the VR experience alone, since participants who grasped virtual balls were also immersed in the same virtual environment. At least four additional potential explanations can be formulated, and the first two fall under factors associated with beliefs and self-regulation. First, successfully crushing virtual cigarettes may increase perceived self-efficacy to perform behaviors associated with smoking cessation. Bandura has shown repeatedly that people’s confidence in their ability to perform a behavior is a strong predictor of the emission of such behavior.\(^{34} \) The contribution of self-efficacy is also important in the treatment of tobacco addiction.\(^{35–37} \) Perceived self-efficacy to quit smoking might be increased by seeing oneself succeeding in crushing cigarettes and investing efforts in finding more cigarettes to crush.

Another hypothesis related to self-regulation could be a positive impact on motivation to quit smoking. Investing time and effort to crush virtual cigarettes, as well as enjoying their success in crushing cigarettes, might boost people’s motivation to quit smoking. Motivation, and especially
stage of changes, are factors associated with treatment outcome.\textsuperscript{38–40} It may be important to note that perceived self-efficacy and motivation contribute differently to behavior change, although they are both related concepts. Holding strong self-beliefs of capabilities to perform a behavior does not mean that someone will actually engage in behavioral changes. Crushing virtual cigarettes not only may help people believe they can do it but also may give them a stronger drive to keep doing it.

Conditioning models of addictions\textsuperscript{41,42} could offer two additional alternative explanations. One hypothesis could be that the task performed in VR helped our participants practice the automatic response to crush cigarettes through intensive repeated experiences. Seeing smoking cigarettes in a 3D environment is a cue known to elicit urges to smoke.\textsuperscript{43} But crushing cigarettes with a virtual arm is quite different and could be seen as a sensorimotor stimulus or an action-cue exposure. Perceiving oneself in an embodied experience\textsuperscript{44} of repeatedly crushing cigarettes could facilitate the automatization of a new conditioned response. However, since the task performed in VR did not require actual motor behavior of the arm and hand to crush the virtual cigarettes, the advantage of VR over visualization might be that it is more powerful, and the therapist can confirm that the patient is really engaged in crushing the cigarettes.

The second explanation, derived from learning and conditioning models, focuses on the association between positive mood and behaviors associated with smoking cessation. For a person addicted to tobacco, seeing smoking-related stimuli elicits a conditioned response that triggers the desire to smoke and the affective, cognitive, and motor responses associated with smoking. It has been shown that similar mechanisms occur with cue exposure to virtual stimuli.\textsuperscript{7,14,43} Experienced these conditioned responses can be frustrating for someone who wants to quit smoking. Having fun playing a game in which one finds and crushes cigarettes could create a more positive emotional response than frustration to seeing and expecting conditioned stimuli. In this case, what would be conditioned in VR is not a new behavior but a mood that facilitates smoking cessation. Since enjoyment with the game has not been systematically measured, but only observed by the experimenters, this hypothesis is only tentative.

It may be possible that some or all of the five potential explanations interact with each other. Experimental manipulations could also be planned to test which of these hypotheses are most plausible. It would be interesting to measure self-efficacy and motivation in a study comparing the impact of crushing real cigarettes to virtual ones. Experiments addressing the learning and conditioning hypotheses could compare (a) crushing virtual cigarettes depicted with high and low visual realism, (b) performing crushing behavior with and without a virtual arm and hand tracking the physical arm with 6-dof trackers or motion capture systems, or (c) using strong and weak reinforcers to manipulate emotions associated with crushing the virtual stimuli. Assessing perceived self-efficacy, motivation to quit smoking, motivation to come to counseling sessions, and stages of change during an outcome trial would also be important. Even if the exact mechanism involved still eludes us somewhat, one fact remains: crushing cigarettes in a 3D environment with a virtual arm led to decreased nicotine dependence and increased retention of patients in treatment. It is hoped that our study will stir new interest in the field of addiction by opening a new avenue in addition to cue exposure.\textsuperscript{13}

**Disclosure Statement**

Conflict of interests exist. This project was funded internally by the G.R.A.P. Clinic. The software may be released as a commercial product at some point. This clinical trial has been registered under the number NCT00639093.

**References**


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