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Research Article

Virtual Smoke Signals: How VR Reveals the Unexpected Effects of Antitobacco Advertising

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Objectives: Health promotion campaigns suffer from a lack of systematic evaluation and do not always impact the target population as intended. Our research adopted immersive virtual reality (iVR) to systematically evaluate preventive antitobacco messages in a controlled setting while mimicking a naturalistic and ecological environment. We investigated the effect of incidental exposure to preventive antitobacco billboard posters on attitudes and cravings toward tobacco and poster recognition.
Methods: Participants were undergraduate students ($n = 157$), mostly female (85%). They were immersed in a virtual environment incidentally exposing them to preventive posters or in an environment without any preventive posters. Their gaze was eye-tracked during the entire procedure.
Results: Results indicate that incidental exposure to preventive antitobacco posters, relative to no posters, led to more favorable attitudes toward tobacco. Incidental exposure to posters did not impact their explicit memorization. No significant effect was found on craving.
Conclusions: We advise health campaign designers to consistently evaluate campaigns before launching them as incidental antitobacco messages may inadvertently soften attitudes toward smoking.

Keywords: attitudes; health promotion campaigns; immersive virtual reality; incidental exposure; prevention posters; smoking; tobacco

1. Introduction

Tobacco use is a leading cause of death worldwide, claiming approximately 8 million lives annually [1] and contributing to serious health problems such as cancer and cardiovascular and respiratory diseases [2]. As a result, public health institutions have targeted smoking through various preventive measures [3], including billboard posters, which are a widely used medium due to their wide reach [4]. Nevertheless, assessing their ecological effectiveness is methodologically challenging and often compromises the validity of findings [5, 6]. Our study is aimed at systematically evaluating the impact of antitobacco billboard posters on attitudes, cravings, and recall by using immersive virtual reality (iVR) to simulate the typical viewing environment.

2. Challenges in Evaluating Prevention Campaigns

Prevention campaigns are difficult to evaluate due to the diversity of content and delivery channels [3], with a lack of standardized best practice [5, 6]. Campaigns often rely on theoretical frameworks for design and direct population evaluation [7], but effectiveness assessments can be arbitrary, with meta-analyses calling for more objective criteria [3, 5, 6, 8]. Field assessments of posters are problematic. Estimating exposure frequency and content processing—reflective or reflexive—is challenging [7, 9, 10]. Daily life immersion, with its myriad stimuli, complicates memorization and postexposure assessment of attitudes [11, 12]. Laboratory settings may fall short in simulating the complexity of real life, which could inadvertently increase the appeal of tobacco [11–13].

Incidental exposure to billboard posters, which is commonly studied in brand marketing [14–17], occurs without direct processing. It can increase brand recall and positive attitudes, which parallel the potential unintended effects of antitobacco messaging and can potentially trigger counterproductive cues to smoke [11, 12, 18].

3. Message Framing in Prevention Campaigns

Tobacco use is a leading global health crisis, responsible for approximately 8 million deaths annually [1] and triggering serious diseases [2]. To combat this, public health has deployed interventions such as billboard posters [4], despite challenges in assessing their real-world impact [5, 6]. This study uses iVR to examine the impact of antitobacco billboards on attitudes, cravings, and recall in a naturalistic setting. Evaluating prevention campaigns is complex due to the diversity of content and dissemination methods [3] and the lack of evaluation standards [5, 6]. Theoretical frameworks are needed to guide the design and evaluation of campaigns [7]. However, many campaigns are deemed effective based on subjective rather than objective measures, as noted in literature reviews that question their persuasiveness [3, 5, 6, 8].

Field evaluations of poster effects are fraught with difficulties, from measuring the frequency of exposure to determining whether content is processed consciously or unconsciously [9, 10]. Daily environments are full of distractions that affect how prevention messages are processed, potentially leading to unintentional promotion of smoking [11, 12].

Incidental exposure to billboards, a topic that has been explored in marketing research [14–17], suggests that unattended stimuli can still influence recall and attitudes. In the context of tobacco prevention, unintentional exposure may activate smoking-related concepts without fully conveying the intended message [11, 12], which could unintentionally stimulate smoking desire [18].

Our study also examines how the framing of health messages influences their perception. Although meta-analyses show mixed effects of framing on attitudes [19], this study seeks to understand its role under incidental exposure conditions, an area that has not been fully explored in the current literature. The use of iVR allows us to replicate real-world settings while maintaining experimental control and assess how presence and immersion affect the processing of campaign messages [20–23], making it an ideal tool for campaign evaluation.

4. The Present Study

Our main aim was to evaluate the effectiveness of poster-based tobacco prevention campaigns in an ecological setting using iVR technology. We compared the effects of exposure to antitobacco posters embedded in a virtual environment (VE) that mimics a real-world setting on attitudes, recall, and cravings for tobacco compared to a VE without posters. Variables associated with the use of iVR (i.e., presence, immersion, and cybersickness) were examined as covariates.

4.1. Present Study. We hypothesized that when exposed to tobacco prevention posters in iVR, (H1) attitudes toward tobacco would be negatively impacted and (H2) memorization scores would be higher in comparison to no exposure. Further, we expected that (H3) being exposed to antismoking posters would elicit cravings for tobacco, which were also included as predictors of attitudes and memorization. This study was part of a doctoral thesis [24] and preregistered at https://osf.io/ck2px.

5. Method

5.1. Participants. An a priori power analysis [25] was conducted assuming a medium effect size ($f^2 = 0.15$) for a multiple linear regression (fixed model, R^2 increase with three key predictors: condition, two eye-tracking measures, and their interaction), which recommended a minimum N of 108 to ensure 90% power for our design. Due to technical problems with the eye-tracking technology ($n = 40$ unexploitable data), more participants (25.5%) were recruited.

Participants were 157 undergraduate psychology students (*mean age* = 19.2, *SD* = 3.23, and 85% women) at the Université Paris Nanterre. The majority were nonsmokers (82.4%), followed by regular smokers (7.8%), occasional smokers (6.5%), and former smokers (3.3%). Within smokers, 72.7% were nondependent to tobacco, 13.6% moderately, and 13.6% lightly, as measured with the Fagerstrom Test for Nicotine Dependence (FTND; [26]). Half of the participants declared they had used a VR device in the past (52.3%), and 7.5% declared having felt sick due to the use of VR when they used it.[1] Eighty were assigned to the control condition, and 77 to the experimental condition. No baseline differences were observed between the two groups concerning age, gender, and FTND scores (all $p's > 0.05$).

Participants were recruited through Université Paris Nanterre online participant pool for psychology studies. Participants were screened for eligibility by assessing if they had any perceptive problems (e.g., vision trouble), were prone to cybersickness, or had any disorder for which the use of iVR technology is not recommended (e.g., epilepsy). The study was approved by the Ethics Review Board of Université Paris Nanterre.

6. Measures and Materials

6.1. iVR Device and VE. The experiments took place in a Sensiks VR pod, in which participants can sit and wear an Oculus Rift 2 and use two handheld controllers to move around the VE. The VE depicted a Parisian suburb where billboards standing on the sidewalk or wall-mounted panels were displayed. Posters were randomly[2] selected from a pool and randomly displayed in the experimental condition with an equal amount of negative, positive, and neutrally framed posters. All billboards were blank in the control condition.

6.2. Eligibility Screening Questionnaire. The eligibility screening included questions regarding participants' physical ability to participate and three questions on smoking status: (1) Did the participant used to be a smoker or is currently a smoker? (2) If so, is s/he a regular or occasional smoker? And (3) for how long s/he smoked or used to smoke? For smoking participants, the FTND [26] was further used to assess the severity of nicotine dependence. Response options range from 0 to 3 depending on the item, with a total score used to define four levels of dependence severity: nondependent (0–2), low dependent (3–4), mildly dependent (5–6), and highly dependent (≥ 7).

6.3. Presence. Presence was assessed using the French version of the iGroup Presence Questionnaire (IPQ; [27]), a short, reliable, and widely used questionnaire [28]. The IPQ contains 14 questions rated on a scale from −3 (*completely disagree*) to +3 (*completely agree*), such as "To what extent did the virtual world seem real to you?"

6.4. Immersion. Immersion was assessed by questioning participants about VR device features [22], complementing aspects not mentioned by the IPQ: "I was able to move into the virtual environment without thinking about how to use hand-held controllers" and "I needed to or should have adjusted the helmet during the procedure" on a 1 (*completely disagree*) to 7 (*completely agree*) Likert scale. Immersion was assessed as a manipulation check, aiming at evaluating the validity of our iVR setup.

6.5. Attitudes Toward Tobacco. Participants indicated on a 7-point differential semantic scale their attitudes based on the following adjective pairs: risky/safe, not enjoyable/enjoyable, dislike/like, and bad/good [29]. Ratings were averaged across all pairs, with the higher the score, the more favorable the attitudes toward tobacco.

6.6. Cravings for Tobacco. The French version of the 12-item Tobacco Cravings Questionnaire (TCQ, [30]) was used. Items (e.g., "I would do almost anything for a cigarette now") were rated on a Likert scale from 1 (*strongly disagree*) to 7 (*strongly agree*).

6.7. Explicit Recollection of Prevention Messages. A list of 30 billboard posters[3] was presented to participants, asking whether they saw them during their walk in the VE. This list included 10 posters randomly selected from those presented in the VE and 20 distractors (i.e., posters that were not displayed in the VE). Recognition was correct when the participant indicated viewing posters that were presented in the VE and incorrect when indicating viewing posters that were not presented, or the other way around. Scores for correct recognition ranged from 1 to 10 and for incorrect recognition from 1 to 30. A total score was computed through the difference between correct minus incorrect recognition subscores, with the higher the score, the more individuals correctly recognized the posters (hence, a better memorization).

6.8. Eye-Tracking Measures. In the VE, participants' gaze was constantly monitored with the eye-tracking technology in the HMD. Two scores were derived: exposure duration, indicating the total amount of time (in milliseconds) posters were in the field of view of the participant, independently of whether their gaze was directed at them (i.e., posters could also be in the peripheral view), and directed gaze, indicating to what extent participants directed their gaze toward posters (i.e., more sustained attention). The latter was computed automatically by the eye-tracking system for each participant and poster. Directed gaze was progressively computed and added up every 0.2 s by calculating the percentage of the screen area a billboard took up and transforming it to a score from 0 to 20, which was added up to the current score (e.g., if a billboard occupied 10% of the screen, it was transformed to a score of 2, which was added up to the current total directed gaze). Consequently, the more participants had a poster in their field of view, the more it took up visual space and the higher the directed gaze score. For each participant, an average was made across all posters seen in the VE. For exposure duration, scores for each poster were instead summed up.

6.9. Cybersickness. Cybersickness was assessed using the 9-item Virtual Reality Sickness Questionnaire (VRSQ, [31]) to ensure the VE would not cause any cybersickness and discomfort. The scale assesses to what extent participants felt symptoms such as general discomfort, blurred vision, and dizziness when using the iVR on a 4-point scale (none, slight, moderate, or severe).

Internal consistency was satisfactory for every scale employed: attitudes toward tobacco, $\alpha = 0.87$; Tobacco Craving Questionnaire-12, $\alpha = 0.93$; IPQ, $\alpha = 0.91$; VRSQ, $\alpha = 0.81$; and two-item immersion index, Spearman–Brown $\rho = 0.74$. These values exceed conventional thresholds ($\alpha \geq 0.70$), confirming the reliability of the instruments in the present sample.

6.10. Procedure. Participants were recruited through the Université Paris Nanterre online experiment platform. Participants first had to fill out the eligibility screening questionnaire. The sign-up required participants to complete an informed consent procedure where the experiment was described as a study aiming at studying space perception and movement within a VE. This cover story was used to limit demand bias from the participants (see [32]), ensuring they were exposed incidentally to antitobacco posters during their walk in the VE. At the end of the study, participants were debriefed and informed that the study was in fact about the exposure, perception, and memorization of antitobacco prevention posters.

The experiment took place in the iVR pod lab, and participants were randomly assigned to receive either the VE with posters (experimental condition) or the VE without any tobacco prevention message (control condition). Participants started with a short tutorial in the iVR pod on how to use the device and the handheld controllers to enter the iVR environment. Participants were then immersed in the VE. The experimenter first checked that the participant was using the controller correctly and guided them through the VE. Four short instructions were given for a duration of approximately 5 min of exposure: walk to the bus stop, reach the end of the main street, look for a red-haired person (i.e., virtual agent), and walk from right to left along the street. Participants were encouraged to move at their own pace. After completing the instructions, participants could spend some more time in the VE if they wished. After the iVR exposure, they completed the postintervention measures, starting with the presence, immersion, and cybersickness questionnaires, followed by the tobacco attitudes, cravings, and message recognition measures.

7. Data Analysis

We conducted three hierarchical linear regression models, one for each outcome (i.e., attitudes, cravings, and recognition scores), with condition and the two eye-tracking scores, and their interactions, as main predictors. Age, gender, presence, immersion, cybersickness, and FTND scores were entered as baseline covariates in all models. The analysis for the recognition score was conducted only in the experimental group, since in the control condition, the recognition task was easier (i.e., no posters were present in the VE hence nothing to memorize) than for the experimental condition. We conducted a one-sample t-test for the recognition score in the experimental condition to ensure participants did not complete the task randomly. Finally, exposure duration scores were centered using a Z-score[4] to reduce multicollinearity, which was not necessary for directed gaze as it was already a transformed score (whereas exposure duration was a sum of raw data).

8. Results

8.1. Manipulation Check. Participants felt on average moderately present in the VE ($M = 0.35$, $SD = 0.85$). Immersion was higher than the midscale point ($M = 4.85$, $SD = 1.37$), especially concerning the HMD ($M = 6.12$, $SD = 1.68$), but the use of the controllers was considered less intuitive despite the use of a tutorial prior to the experiment ($M = 3.24$, $SD = 1.93$). Participants did not report cybersickness ($M = 1.23$, $SD = 0.29$). No group difference emerged on any of these variables (all p's > 0.05). One-sample t-test indicated that the recognition scores in the experimental group were significantly different from random responses ($t(76) = -28.2$, $p < 0.001$).

8.2. Hypothesis Testing. Table 1 displays the results for all outcomes, and Table 2 displays all descriptive statistics for each condition. The inclusion of the key predictors did not improve the models except for attitudes, where they explained an additional 5% of the outcome variance ($p = 0.065$). In fact, the interaction effect between condition and exposure duration positively impacted tobacco attitudes ($\beta = 0.38$, $p = 0.02$). In the experimental condition, a longer exposure to posters in the field of view was associated with more positive attitudes toward tobacco, as compared to the control condition. Cravings were also a positive predictor of attitudes ($\beta = 0.71$, $p < 0.001$), while cybersickness negatively impacted recognition scores ($\beta = -3.38$, $p = 0.045$).[5] Below is a summary of all the results according to each hypothesis.

8.2.1. Hypothesis 1: Attitudes. In the hierarchical regression (Table 1, Model 2), condition had no significant main effect on attitudes ($\beta = 0.17$, 95% CI [−0.19, 0.53], $t = 0.96$, and $p = 0.34$). However, there was a significant condition × exposure duration interaction ($\beta = 0.38$, 95% CI [0.08, 0.68], $t = 2.49$, and $p = 0.02$). Hence, H1 was not supported overall, but longer exposure to the experimental posters was associated with more positive attitudes.

8.2.2. Hypothesis 2: Recognition. In the regression predicting recognition (Table 1, Model 2), cybersickness was a significant predictor ($\beta = -3.38$, 95% CI [−6.69, −0.07], $t = -2.06$, and $p = 0.045$), while condition per se was not included by design. H2 was not supported: Recognition performance did not differ between conditions once cybersickness and other covariates were accounted for.

8.2.3. Hypothesis 3: Craving. In the craving regression (Table 1, Model 2), condition showed no effect ($\beta = 0.03$, 95% CI [−0.33, 0.40], $t = 0.19$, and $p = 0.85$), whereas nicotine dependence (FTND) remained the strongest predictor ($\beta = 0.63$, $p < 0.001$). H3 was not supported: Craving levels were statistically indistinguishable across experimental and control groups.

9. Discussion

We showed that being in an environment where tobacco prevention posters are displayed is not in itself sufficient to influence attitudes, but that individuals need to have them in their field of view (i.e., without specifically looking at them) for long enough for attitudes to change. However, this resulted in more positive attitudes toward tobacco, in line with previous studies where incidental exposure to "no smoking" signs led to increased appreciation of tobacco [11, 12]. Given the presence of multiple posters in the VE, repeated exposure to tobacco cues may have enhanced attitudes toward tobacco through a mere exposure effect [33]. These results should be treated with caution, as the duration of VE exposure was short (about 5 min) and in one session, and attitudes were measured immediately afterwards. Therefore, we cannot conclude on the lasting effects of repeated exposure to prevention posters on attitudes. Secondly, exposure to prevention posters does not necessarily mean that they are memorized. Neither eye-tracking measure predicted poster recognition, even when participants were still exposed to posters in their field of view at some point (i.e., neither eye-tracking score was close to zero for any participant). Therefore, we can assume that individuals may have been aware of the presence of posters in their environment but paid little attention to them, which is why eye-tracking scores did not predict better memorization [15, 34]. However, the lack of comparison with the control group limits any conclusion. More appropriate conditions are needed, including nonpreventive billboard posters (e.g., advertisements), which are commonly found in real life. Contrary to the hypothesis, tobacco craving was not associated with

TABLE 1: Linear regression models.

Predictor variables	β	*CI 95%*	t	p
Outcome: Attitudes				
Presence	0.07	[−0.11, 0.24]	0.74	0.46
Immersion	−0.05	[−0.17, 0.07]	−0.87	0.39
Cybersickness	−0.18	[−0.72, 0.36]	−0.67	0.51
Cravings	**0.74**	**[0.54, 0.94]**	**7.40**	**< 0.001**
Age	**0.06**	**[0.00, 0.13]**	**2.09**	**0.04**
Gender	0.23	[−0.19, 0.66]	1.08	0.28
FTND	0.17	[−0.09, 0.44]	1.29	0.20
Model 1: $R^2 = 0.51, AIC = 262, BIC = 286, F(7, 103) = 15.1, p < 0.001$				
Presence	0.04	[−0.13, 0.22]	0.51	0.61
Immersion	−0.06	[−0.18, 0.05]	−1.07	0.29
Cybersickness	−0.24	[−0.79, 0.30]	−0.90	0.37
Cravings	**0.71**	[0.51, 0.91]	**7.21**	**< 0.001**
Age	0.05	[−0.01, 0.11]	1.64	0.11
Gender	0.28	[−0.14, 0.70]	1.31	0.20
FTND	0.15	[−0.11, 0.41]	1.16	0.25
Condition (Exp vs. control)	0.17	[−0.19, 0.53]	0.96	0.34
Exposure duration	−0.14	[−0.38, 0.10]	−1.19	0.24
Directed gaze	−0.01	[−0.03, 0.01]	−0.84	0.40
Condition ∗ exposure duration	**0.38**	[0.08, 0.68]	**2.49**	**0.02**
Condition∗directed gaze	0.01	[−0.03, 0.04]	0.30	0.77
Model 2: $R^2 = 0.56, AIC = 260, BIC = 298, F(12, 98) = 10.2, p < 0.001$				
$\Delta R^2 = 0.05, F(5, 98) = 2.16, p = 0.065$				
Outcome: Recognition score				
Presence	−0.25	[−1.15, 0.61]	−0.59	0.56
Immersion	0.12	[−0.53, 0.77]	0.38	0.71
Cybersickness	−2.70	[−5.73, 0.31]	−1.81	0.08
Age	< 0.01	[−0.25, 0.26]	0.05	0.96
Gender	−2.14	[−4.47, 0.18]	−1.86	0.07
FTND	0.43	[0.76, 1.62]	0.74	0.47
Model 1: $R^2 = 0.18, AIC = 242, BIC = 257, F(6, 44) = 1.59, p = 0.17$				
Presence	−0.36	[−1.26, 0.53]	−0.82	0.42
Immersion	0.06	[−0.60, 0.73]	0.19	0.85
Cybersickness	**−3.38**	**[−6.69, −0.07]**	**−2.06**	**0.045**
Age	−0.05	[−0.33, 0.23]	−0.34	0.73
Gender	−2.07	[−4.42, 0.29]	−1.77	0.08
FTND	0.41	[−0.80, 1.62]	0.69	0.50
Exposure duration	0.25	[−0.51, 1.01]	0.66	0.51
Directed gaze	0.03	[−0.06, 0.12]	0.73	0.47
Model 2: $R^2 = 0.20, AIC = 244, BIC = 263, F(8, 42) = 1.32, p = 0.26$				
$\Delta R^2 = 0.02, F(2, 42) = 0.59, p = 0.56$				
Outcome: Cravings				
Presence	−0.01	[−0.18, 0.16]	−0.11	0.91
Immersion	0.03	[−0.08, 0.14]	0.50	0.62
Cybersickness	0.24	[−0.29, 0.77]	0.90	0.37
Age	−0.05	[−0.11, 0.01]	−1.76	0.08
Gender	0.20	[−0.21, 0.62]	0.98	0.33

TABLE 1: Continued.

Predictor variables	*β*	*CI 95%*	*t*	*p*
FTND	**0.66**	**[0.43, 0.88]**	**5.79**	**< 0.001**
Model 1: $R^2 = 0.27, AIC = 256, BIC = 278, F(6, 104) = 6.43, p < 0.001$				
Presence	−0.02	[−0.19, 0.16]	−0.17	0.87
Immersion	0.03	[−0.09, 0.14]	0.44	0.66
Cybersickness	0.18	[−0.38, 0.73]	0.63	0.53
Age	−0.05	[−0.12, 0.01]	−1.72	0.09
Gender	0.20	[−0.2, 0.62]	0.91	0.37
FTND	**0.63**	**[0.40, 0.87]**	**5.44**	**< 0.001**
Condition (Exp vs. control)	0.03	[−0.33, 0.40]	0.19	0.85
Exposure duration	0.05	[−0.19, 0.30]	0.43	0.66
Directed gaze	−0.01	[−0.03, 0.02]	−0.67	0.51
Condition∗exposure duration	0.06	[−0.25, 0.37]	0.41	0.68
Condition∗directed gaze	< 0.01	[−0.03, 0.04]	0.18	0.86
Model 2: $R^2 = 0.29, AIC = 264, BIC = 299, F(11, 99) = 3.58, p < 0.001$				
$\Delta R^2 = 0.02, F(5, 99) = 0.40, p = 0.86$				

Note: Exposure duration = total time in milliseconds the posters were in the field of view; directed gaze = averaged running sum of the percentage of area billboards took up of the screen. All the variables in bold fonts are significants variables ($p < 0.05$) in their respective model.
Abbreviation: FTND, Fagerstrom Test for Nicotine Dependence.

TABLE 2: Descriptive comparison of conditions.

Outcome	Condition	M	SD	Median
Attitude score	Control	1.74	0.97	1.25
	Experimental	1.93	1.27	1.00
Craving (TCQ total)	Control	1.66	0.90	1.42
	Experimental	1.77	1.00	1.42
Recognition (correct–incorrect)	Control	−0.89	1.48	0.00
	Experimental	−8.42	2.62	−8.00

Note: Mean (M), standard deviation (SD), and median for each outcome by condition.

exposure to prevention posters. This suggests that (brief and momentary) exposure to antitobacco posters does not induce craving for tobacco. However, it is not known whether participants smoked prior to the experiment (i.e., satiation), which may play a role in reducing craving. Finally, while presence or immersion did not affect attitudes, desire, or memorization, cybersickness led to poorer recognition scores. The more individuals experienced cybersickness symptoms (e.g., dizziness and eye fatigue), the less likely they were to correctly memorize and recognize posters, as this can lead to cognitive overload and fatigue [15].

The main aim of our research was to assess the effect of incidental exposure to tobacco prevention posters on attitudes and cravings for tobacco and recognition of the posters in an environmental setting using iVR. We tested the difference in these outcomes between exposure to prevention posters and no posters in the environment. We found that the experimental condition alone was not enough to influence attitudes toward tobacco, either participants had to have the posters in their field of view for a long enough time. In the first case, the incidental presence of antitobacco prevention posters in the field of view for a sufficient amount of time led to more favorable attitudes toward tobacco, in line with previous findings (e.g., [11, 12, 16, 17]). The fact that the mere incidental presence of posters in the field of view affects attitudes seems to suggest that incidental exposure may be associated with processing prevention posters in a more automated and passive manner [9, 10]. This is likely to activate the concept of smoking in memory. Through repeated mere exposure [33], individuals exposed to antitobacco posters may show favorable attitudes toward tobacco.

We also tested whether incidental exposure to prevention posters was associated with recognition and whether poster framing affected this. We did not find an effect of the main predictors on recall, suggesting that incidental exposure to prevention posters is not a sufficient condition to leave a significant impression in memory. This is in line with the literature, which shows that incidental exposure or low-involvement treatment of a stimulus can leave a trace in implicit memory, but not in explicit memory (i.e., recognition, [35]). However, the lack of an appropriate active control condition, in which posters without antismoking content were displayed, limits the validity of these conclusions.

Presence, immersion, and cybersickness were assessed to evaluate the effect of the iVR setup. Our protocol elicited moderate presence and immersion, and both variables did not affect the results. However, higher cybersickness was associated with poorer memorization scores. Cybersickness refers to side effects following iVR use [31], such as dizziness, eye fatigue, and potential difficulty concentrating. It is not surprising that the more cybersickness symptoms reported, the more individuals had difficulty recognizing the posters, as their perception of the environment may have been impaired. We therefore recommend a systematic assessment of cybersickness when using iVR.

10. Limitations

This study has some limitations, the first being that we only assessed explicit attitudes and memorization, although some studies recommend measuring both implicit and explicit [35]. Similarly, we did not assess smoking behavior or intentions to smoke, quit, or reduce smoking. Although these measures are used as outcomes in health prevention studies (e.g., [5]), they were not relevant to our research because our protocol used too short an exposure to the VE to have an impact on behavior or intentions. Although not measured in this study, future research could explore whether repeated long-term exposure to prevention posters affects smoking behavior and intentions [7, 36]. Therefore, our studies only allowed us to estimate the short-term effects of exposure to antismoking posters, and the sustained, medium-, and long-term effects of repeated exposure should also be investigated.

The posters were taken from existing tobacco prevention campaigns in our urban environment (i.e., posters used in previous tobacco prevention campaigns). Nevertheless, the use of existing prevention posters supports the ecological validity of our design, as real-world content was used and presented under virtually similar conditions. Similarly, the posters in all conditions displayed only antitobacco prevention messages and no other unrelated content (e.g., advertisements and events), as is usually the case in real life. Therefore, although our VE already reached a good level of realism never before achieved in the evaluation of health promotion campaigns, more work is needed to increase realism to an even higher level, thereby improving both the internal and external validity of our findings. In addition, the lack of an active control group exposed to nonprevention posters limits our ability to isolate the specific effects of antitobacco messages. Future studies should include such a condition to disentangle these effects.

As the sample consisted mainly of young, female, nonsmokers, these findings may not be generalizable to other populations, especially smokers or those with higher nicotine dependence. Future studies should aim to include more diverse samples to better understand these effects. It would be interesting to include more smoking-dependent participants, as nicotine dependence can lead to differences in message processing [13]. We may also gain more insight into the role of cravings [37], as the present study is not informative about the effect of prevention on smoking cravings.

We emphasize that our findings are limited to the short-term effects observed immediately following a brief exposure session. Despite longer VR sessions increasing the risk of cybersickness, which can compromise data quality and participant comfort, future studies should assess the sustainability of these effects over time and after repeated exposure. This will help determine the long-term effectiveness of such campaigns in altering smoking-related attitudes and behaviors. In this study, we intentionally kept the exposure duration short to balance ecological validity and experimental feasibility.

11. Conclusions

By simulating a realistic urban environment, iVR allowed us to systematically evaluate how antitobacco messages are processed under naturalistic conditions, a notable advance over traditional laboratory studies. Thus, the consistent use of negatively framed messages appears to be a better strategy to ensure a negative impact on attitudes toward tobacco. Mixed message framing has been associated with more positive attitudes toward tobacco when exposed incidentally, which may be counterproductive, especially with repeated exposure over time [7]. Replication is needed to confirm these findings, and evaluation of prevention campaigns would need to focus on the size and location of posters to see if and how these affect attention to the posters and, in turn, their memorization.

Finally, our study demonstrates how iVR can be a useful and ideal tool to systematically evaluate the design of population-based health prevention campaigns. iVR provides a highly ecological and realistic setting to assess how individuals process and may be influenced by health-related content embedded in their daily environment in a more standardized way, enabling the design of more impactful and effective health promotion campaigns.

Data Availability Statement

The data that support the findings of this study are openly available in https://osf.io/ck2pxathttps://osf.io/ck2px, reference number https://doi.org/10.17605/OSF.IO/CK2PX.

Conflicts of Interest

The authors declare no conflicts of interest.

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Endnotes

[1]We ran the same analysis, excluding participants who reported feeling sick when using iVR in the past. Nothing changed in terms of the significance of the results: Results that were significant remained significant; results that were not also remained nonsignificant.

[2]In both conditions, 15 billboard locations were available. In the experimental condition, 10 of the 15 available billboard locations were randomly picked to display prevention posters. Among the list of 30 possible posters, 10 were randomly picked to be displayed randomly across the 10 selected billboards. The five remaining billboards were filled with the blank picture shown in the control condition. The randomization of posters and billboard locations in which posters were displayed was done within participants.

[3]Posters were based on existing tobacco prevention posters. An original pool of 45 posters was presented to 388 participants in a previous online survey aimed at evaluating perceived persuasiveness and relevance of the posters. Additionally, participants had to indicate whether the posters were considered preventive (i.e., negatively framed), informative (i.e., neutrally framed), or promoting tobacco cessation (i.e., positively framed). Descriptive analyses were conducted to rank and select the final list of 30 posters (10 for each of the mentioned categories) to be used.

[4]We used a Z-score on exposure duration to reduce multicollinearity, which was not necessary for directed gaze as it was already a transformed score (whereas exposure duration was a sum of raw data).

[5]When removing participants who reported feeling sick in the past when using iVR, the score becomes $B = -2.37$ and $p = 0.02$.

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