“Go up in smoke”: Feasibility and initial acceptance of a virtual environment to measure tobacco craving in vulnerable individuals

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***Abstract*—Tobacco smoking is substantially more prevalent in vulnerable groups, such as people with intellectual disability, psychiatric disorders, or low socioeconomic status. Though smoking cessation programs for the general population are available, accessible and inclusive approaches are lacking. An encouraging new approach toward more practice-oriented and tailorable smoking cessation is virtual reality. Research indicates that virtual environments (VEs) with tobacco-related cues can elicit cue-reactivity (e.g. craving and physiological responses) and provide various new options to integrate treatment approaches. Yet, the potential to elicit cue-reactivity and the practicability of cue-reactivity measures have not been studied in vulnerable groups. This explorative study aggregated the data of twenty-three vulnerable individuals, who present themselves in three clinical settings, to validate the VEs, assess the practicability of several cue-reactivity measures (i.e. self-report questionnaires, psychophysiological data), and investigate the initial acceptance toward a prototype VE with tobacco-related cues. The results confirm the potential of the VE to elicit tobacco craving compared to baseline scores and craving in a neutral VE, as measured using one-dimensional (VAS) and multi-dimensional scales (QSU-Brief). Furthermore, the participants reported a good initial acceptance toward the VE as a potential treatment for smoking cessation. However, measuring psychophysiological responses in the clinical setting proved to be unfeasible in this research. Future studies should investigate the versatile possibilities of VEs to assess and treat vulnerable groups with tobacco dependence.**

Keywords—virtual reality, virtual environment, smoking, cue-reactivity, craving

I. Introduction

Tobacco smoking remains the leading preventable cause of death [1]; The World Health Organization (WHO) reports that yearly over 8 million deaths can be attributed to tobacco use. Though smoking rates have declined over the past decades, still 1.1 billion people worldwide smoke. However, smoking rates in vulnerable groups, such as people with an intellectual disability, psychiatric illness, or lower socioeconomic status, are substantially higher than in the general population [2-5]. This high prevalence is partially explained by low health literacy, high levels of stress, the absence of social and professional support, as well as lack of access to suitable quitting resources [6, 7]. While evidence-based smoking cessation programs (e.g., individual counseling and nicotine replacement therapy) have low long-term success rates in the general population, in vulnerable populations their effectiveness is even lower [7, 8]. Research indicates that psychosocial influences, such as higher dependence, lower motivation, lower health literacy, lack of self-efficacy, differences in cognition and perception, and lower adherence to treatment, are factors that decrease treatment success in vulnerable groups [4]. Furthermore, these groups might have difficulties to understand oral and written treatment instructions [9, 10]. An interesting new approach to circumvent such factors may be the use of virtual reality (VR) technology [11]. Through computer-generated virtual environments (VEs), patients can be confronted with tobacco-related cues (e.g., package of cigarettes, ashtray, lighter) and situations that trigger cue-reactivity (i.e., cravings and physiological responses) in a realistic manner [12]. In contrast, traditional approaches, such as image, video, or *in-vivo* exposure, often lack controllability and ecological validity [12]. VR applications could support vulnerable groups in the process of smoking cessation, for example through an accessible and practice-oriented relapse prevention training, tailored interventions, and simpler psychological treatment with a focus on “doing” instead of talking [11, 12]. Yet, the usability of VR in smoking cessation and the feasibility to elicit cue-reactivity through tobacco-related VEs have not been investigated in this target group. In this paper, we report the findings from an iterative development approach with vulnerable individuals (i.e., people with mild to borderline intellectual disability, low socioeconomic status, or psychiatric illness) to validate the VE, evaluate the practicability of cue-reactivity measures, and assess the initial acceptance of the VR prototype within the natural treatment setting of three clinics. Section 2 introduces background information about the prevalence of tobacco use in vulnerable groups, VR applications for vulnerable groups, and VR for smoking cessation. Section 3 outlines the conducted research method. Section 4 presents the findings, and Section 5 discusses the results. Section 6 provides a summary of the results and considerations for future work.

II. Background

A. Tobacco use in vulnerable groups

Research indicates a greater susceptibility to tobacco use disorder in vulnerable groups, such as people with intellectual disability, psychiatric illness, or lower socioeconomic status. Regarding the first group, an epidemiological study by VanDerNagel et al. (2017) revealed that 61.6% of the

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individuals with mild to borderline intellectual disability (IQ = 50-85) report to be current tobacco users [3]. In contrast, 15-20% of the general population in developed countries are smokers [13, 14]. This difference is also visible in people with psychiatric illnesses, with average smoking rates of 36-40% [15, 16]. However, when considering severe mental illnesses, prevalence rates are even higher with 62% in people with schizophrenia and 37% with bipolar disorder [17]. Generally, individuals with lower socioeconomic status and health literacy are vulnerable to tobacco use, given that more than 30% of the people below the poverty level smoke [4, 18]. Conclusively, these vulnerable groups are disproportionally affected by the problems of tobacco use. The lack of treatment approaches taking into account the needs and limitations of these target groups, adds to the risks for this group, and the need for more tailored approaches [19].

B. *Virtual reality for vulnerable groups*

The application of VR as a supportive tool has been investigated in various vulnerable groups, such as individuals with autism, intellectual disability, and psychiatric disorders [11, 20]. VR systems have been shown to improve learning processes related to social skills, health care, daily life situations, school activities, motor coordination, spatial skills training, and logical reasoning [20, 21]. Thus, these systems could improve health outcomes, foster independent living, and decrease the digital divide through a reasonable hands-on training. In people with a psychiatric disorder, therapeutic VR studies have been applied in treating individuals with anxiety disorders, depression, psychosis, eating-, and substance use disorders [11]. The outcomes are homogenous and highlight the potential of VR to increase the understanding of disorders and simplify psychological treatments. Furthermore, the application of VR is reported to be well-tolerated and safe in these target groups [11, 22]. Therefore, VR applications can be beneficial in multiple areas for vulnerable individuals, potentially leading to more inclusiveness, engagement, as well as better health and learning outcomes.

C. *Virtual reality in the treatment of tobacco dependence*

Several VR studies have shown the potential to elicit and measure smoking-related cue-reactivity in VEs [12]. Cue-reactivity refers to a physiological and subjective reaction to a previously conditioned stimulus, such as smoking-related cues [23]. It typically entails self-reported craving and psychophysiological responses, in particular changes in heart rate (HR), skin conductance (SC), and temperature (TP). Despite the lack of a uniform definition, craving can be described as a "pathological appetite" to use a certain substance, which is "… thought to reflect a drug acquisitive state motivating drug use" [24, p. 2]. VEs have been studied to provide an ecologically valid and safe manner to assess cue-reactivity in deprived (abstaining from smoking) and non-deprived smokers [25, 26]. The investigated environments embedded proximal (e.g., a pack of cigarettes), contextual (e.g., a convenience store) and complex cues (e.g., smokers at a party) and report homogenous results in the possibility to elicit craving [27]. In contrast, psychophysiological responses in cue-reactivity environments were studied less frequently and exclusively in the laboratory setting, yielding heterogeneous outcomes [12]. However, various approaches have been conducted to utilize VEs for therapeutical purposes, for example through VR exposure therapy (VR-ET) and VR cognitive behavioral therapy (VR-CBT). Through VR-ET, patients are systematically confronted with tobacco-related stimuli to minimize or remove the conditioned psychological response by conducting systematic desensitization [28-33]. In contrast, VR-CBT approaches comprise cognitive restructuring and the learning of practical coping mechanisms that help to overcome psychological responses related to tobacco use [34-36]. Notably, no paper focused on participants with comorbidities, specifically vulnerable subgroups, nor designed VEs tailored to the Dutch ambience. Altogether, VR could be an accessible and engaging tool in the treatment of tobacco dependence through tailored, hands-on experiences that improve educational outcomes and increase treatment success. Yet, the feasibility to elicit and measure cue-reactivity, as well as the acceptance of VR technology for smoking cessation, have not been explored in vulnerable groups.

III. METHODS

The study data have been obtained in an iterative development approach. Three iterations were conducted to refine the VE (Fig. 1) and assess the feasibility of cue-reactivity measurements in the vulnerable sample. In this study, we report on the exploration of craving levels of the participants, the suitability of conducted measurements, and initial technology acceptance. This preparatory work is part of a project aiming to teach smoking cessation skills in VEs through playful learning experiences.

Fig. 1. The VEs in our prototype: (A) vendor with smoking goods, (B) at-home environment, (C) bus stop with smoking agents, (D) adjustable visual analogue scale (VAS) in the screen space of the participant, displaying (in Dutch) the question "how much craving do you have now?".

A. *Participants*

In total, n = 23 smokers were recruited through convenience sampling by local therapists from an addiction clinic for people with mild to borderline intellectual disability (n = 9), pulmonary clinic (n = 9), and psychiatric clinic (n = 5). The inclusion criterium was a moderate to very severe nicotine dependence. Exclusion criteria included having a history of migraine, epilepsy, motion-sickness, being currently enrolled in a smoking cessation program, use of nicotine replacement therapy, being unable to wear the head-mounted display (HMD) or to follow verbal instructions, as well as inability to give informed consent.

B. *Measures*

1) Self-report measures: Nicotine dependence was assessed with the Dutch version of the Fagerström Test for Nicotine Dependence (FTND) [37]. The FTND is a 6-item questionnaire assessing nicotine dependence severity with scores ranging from 0 to 10. Scores of 0-2 indicate light dependence, 3-5 moderate dependence, 6-7 severe dependence, and 8-10 very severe dependence.

Nicotine craving was assessed with the Dutch version of the Questionnaire of Smoking Urges Brief (QSU-Brief) and with a Visual Analogue Scale (VAS) [38]. The QSU-Brief is a 10-item questionnaire assessing the urge to smoke. Scores on each item ranged from 1 (“Strongly disagree”) to 7 (“Strongly agree”). The total score is obtained by calculating the mean of the ten items. The VAS is a single-item scale ranging from 0-10, where 0 is interpreted as “no craving” and 10 as “severe craving”.

The acceptance and use of technology were assessed using the Flemish version of the Unified Theory of Acceptance and Use of Technology (UTAUT) [39, 40]. This 20-item questionnaire assesses six subscales (performance expectancy, effort expectancy, social influence, facilitating conditions, anxiety, data security, and knowledge). Scores on each item ranged from 1 (“Strongly disagree”) to 5 (“Strongly agree”).

A semi-structured interview with six open questions was conducted after finishing the general procedure to discuss (1) the participant’s first impression, (2) craving inducing stimuli, (3) craving decreasing stimuli, (4) the expectancy toward the prototype for smoking cessation, (5) intention to use, and (6) points for improvement.

2) Behavioral observations: The cognitive processes while engaging with the cue-reactivity environment were assessed via the think-aloud protocol (thinking aloud during task execution). Furthermore, a researcher kept a written log of the participant’s behavior, including the actions and verbal remarks registered.

3) Psychophysiological measures: The heart rate (HR), temperature (TP), and skin conductance (SC) were measured independently by the Empatica E4 (4Hz) wristband and Shimmer GSR+ (128Hz) wearable sensor. The Shimmer’s electrodes were attached to the participant’s index and middle finger. Also, eye tracking measures were conducted via the HMD’s build-in system from Tobii (120Hz) with a previous 5-point calibration of the system.

C. Hardware & Environment

We used an HTC VIVE Pro Eye head-mounted display (HMD) with built-in eye tracking, 1440 x 1600 pixels per eye (2880 x 1600 combined), a 90 Hz refresh rate, and 110-degree field of view, base stations, controllers, and a compatible computer (Intel Core i7- CPU, 16.0 GB RAM, NVIDIA GeForce GTX 1080ti).

The open-world environment was developed in Unity (v.2019.2.3f1) using the SteamVR SDK and was adapted from previous studies by our department [41]. The participants were able to use teleport locomotion and an approximately 2x2m room-scale area for natural movements. The cue-reactivity VE consisted of three main areas: A crossroad with a bus stop, an at-home environment with a garden, and a restaurant with a terrace and smoking goods vendor (Fig. 1). All areas comprised interactable tobacco cues, such as cigarettes, cigarette packages, lighter, ashtrays as well as smoking and cigarette-offering agents. The neutral tutorial environment comprised a plane with three cubes and a bowling alley to teach basic interaction capabilities (grabbing objects, teleport locomotion). The VAS slider was built into the screen-space of the user and was manually enabled and disabled by the researchers.

D. Procedure

The research was carried out in a quiet room in the three clinics to provide an ecologically valid surrounding to the normal treatment setting. All participants were welcomed by the two researchers upon arrival and thoroughly informed about the procedure. Following informed consent, the audio and screen recording was started. The experimental procedure consisted of four phases: (1) preparation, (2) tutorial, (3) initial exploration, and (4) guided exploration. During the preparation, baseline characteristics were assessed with the FTND, QSU-Brief, and demographics were documented. Then, the wristband and sensors for psychophysiological measures were attached and a small baseline period of two minutes was conducted. After completion, the participants underwent a 10-min tutorial session in a neutral VE to become familiar with the HMD, learn the controls, and calibrate the eye-tracking system. At the end of the tutorial, participants filled in a VAS to rate their tobacco cravings. The participants removed the HMD and were verbally asked the QSU-Brief again before entering a cue-reactivity environment. Upon completion, participants were asked to wear the HMD again to start with the tasks in the cue-reactivity environment together with the think-aloud protocol. In the light of possible cognitive limitations in the target group, participants were regularly encouraged to continue with the protocol. The initial exploration in the cue-reactivity VE comprised a look-around for approximately three minutes without the assistance of the two researchers. In contrast, the guided exploration encompasses the instructed visit of five specific situations: bus stop, restaurant terrace, a vendor with smoking goods, at-home environment with garden, and a man sitting on a bench smoking. During both exploration phases, participants were asked to fill in the VAS every two minutes using the in-game VAS-slider. Furthermore, participants removed the HMD after each exploration phase, and the QSU-Brief was verbally assessed by the researchers. Lastly, the UTAUT questionnaire and semi-structured interview were conducted verbally with the participant. The local therapists were close-by to provide help if needed but were not involved in the data collection. The participants received a small non-monetary gift (≈ 10€) as a sign of gratitude.

E. Iterative optimization of the VE and procedures

The VEs and procedures were refined throughout three iterations based on the qualitative input (i.e. think-aloud protocol, semi-structured interview) of the participants as well as observations by the researchers. In the first iteration, cues like shag, rolling paper, hand-rolled cigarettes, food, and the related smell, were lacking. Also, adding more agents was suggested, though some perceived them as uncanny. For the second evaluation, the aforementioned cues and agents with friendly facial expressions were added. Moreover, participants were given a real package of cigarettes, shag, rolling paper, and lighter in their hands when virtually sitting on a bench, next to a smoking agent, to provide a haptic and olfactory experience. In the second iteration, mostly personalization aspects, such as cigarette vs. shag, coffee vs. tea, specific brands, inside vs. outside, and social vs. non-social smoking, were reported. For the third iteration therefore, a cue-reactivity assessment (showing different smoking cues and neutral objects) was created to tailor three aspects of in-game experience: (1) smoking shag or cigarettes, (2) closed settings or outside smoker, (3) social smoker or preferably alone. Due to the limited explorative behavior of the participants in the previous iterations, this was conducted as part of the initial exploration phase and analyzed accordingly.

F. *Statistical analysis*

The data of the three iterations were aggregated into one dataset to perform the statistical analysis. We calculated the participant's mean VAS score for each part of the research (tutorial, initial exploration, and guided exploration). Since the assumption of normality of data was not satisfied (Shapiro-Wilk test *p*-value ≦ 0.05), non-parametric tests were applied. We used the Friedman test to compare the level of craving over time based on the QSU-Brief and VAS scores. Post-hoc Wilcoxon singed-rank tests were used to investigate differences between measurements. Spearman correlations were conducted to explore the relationship between self-reported craving responses on the QSU-Brief and VAS mean score as well as the results of the FTND, age, and cigarette consumption per day. Furthermore, a descriptive analysis of the UTAUT was performed. We did not perform any analysis based on the psychophysiological data due to an unexpected amount of bias in the data collection process (see results). The statistical analyses were conducted using RStudio (v. 1.3.1093) with a significant threshold of .05. Multiple testing correction was applied using the Bonferroni method.

IV. Results

Table 1 describes the sample's sociodemographic and clinical characteristics. The participants had a mean age of 44.39 (±13.21) years. The nicotine dependence based on the FTND was moderate (*n* = 2), severe (*n* = 11), and very severe (*n* = 10), respectively. Participants smoked on average 23.7 (±13.36) cigarettes per day. Only two participants had previous experience with VR.

TABLE I. Sociodemographic and Clinical Characteristics

Samples	Female	Male	Age	Cig. per day	FTND*
	n (%)	*n (%)*	*M (SD)*	*M (SD)*	*M (SD)*
Iteration 1	2 (25)	6 (75)	47.12 (±11.83)	30.75 (±16.5)	7.12 (±1.25)
Iteration 2	3 (50)	3 (50)	34.67 (±12.37)	18.33 (±4.08)	6.67 (±1.51)
Iteration 3	5 (55.56)	4 (44.44)	48.44 (±12.86)	21 (±12.76)	7.33 (±0.87)
Full sample	10 (43.48)	13 (56.52)	44.39 (±13.21)	23.70 (±13.36)	7.09 (±1.16)

* Fagerström Test for Nicotine Dependence.

TABLE II. Differences in Craving on QSU-Brief (*N* = 23) and VAS (*N* = 22) at T1, T2, T3.

Scale	Mean (SD)	Median	IQR	Cronbach's alpha
Baseline (T0)				
QSU-Brief	2.06 (0.99)	1.9	1.05	0.8
Tutorial (T1)				
QSU-Brief	2.6 (1.28)	2.2	1.6	0.87
VAS	2.2 (2.45)	1	5	-
Initial exploration (T2)				
QSU-Brief	3.66 (1.62)	3.6	2.75	0.91
VAS	3.98 (2.67)	4.66	4.5	-
Guided exploration (T3)				
QSU-Brief	4.68 (1.79)	4.6	2.45	0.93
VAS	6.06 (3.25)	7.16	4.96	-

A. *Self-reported craving*

Table 2 describes the data obtained from the QSU-Brief and VAS across the different measures at baseline (T0), tutorial (T1), initial exploration (T2), and guided exploration (T3).

The results indicate a significant increase of craving over time according to the QSU-Brief (χ^2 (3) = 56.26, *p* = <0.0001, *n* = 23), with significant increases between all measurement points (Fig. 2), except among baseline (T0) and tutorial (T1). Similarly, the VAS (χ^2 (2) = 38.32, *p* = <0.0001, *n* = 22) shows a significant increase over time (Fig. 3), with significant increases between all measurement points.

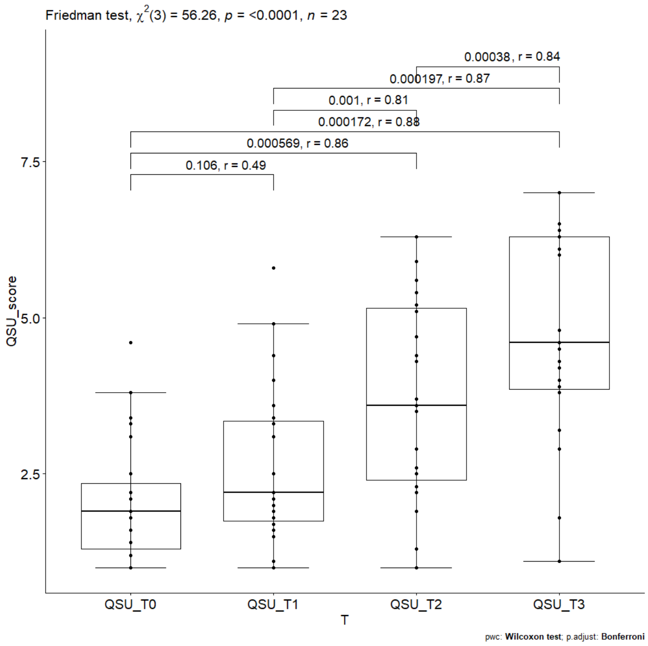

Fig. 2. Friedman-test and pairwise comparison based on the QSU-Brief.

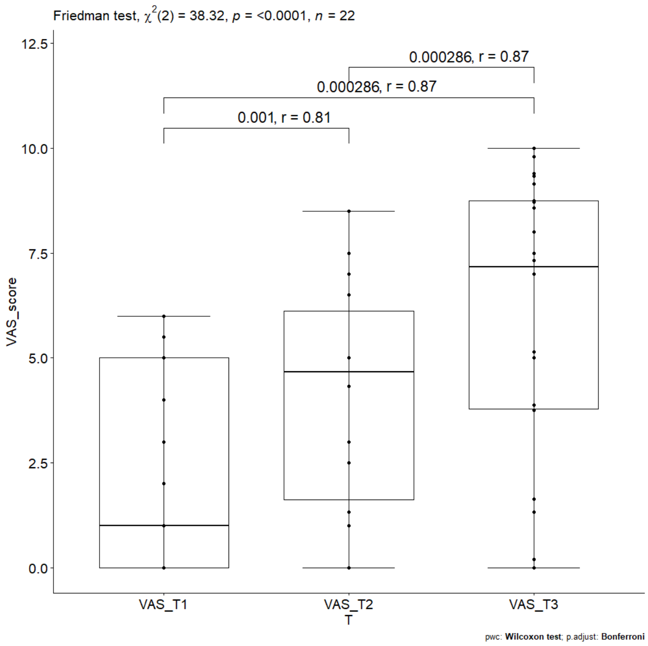

Fig. 3. Friedman-test and pairwise comparison based on the VAS score.

The correlation between the mean QSU-Brief scores and VAS indicates a very strong relationship ($r_s = 0.92$, $p < 0.001$). A moderate negative relationship between age and the mean scores reported in the QSU-Brief (r_s = -0.466, p = 0.025) and VAS (r_s = -0.532, p = 0.011) was found. No significant correlations were found regarding the QSU-Brief and VAS scores with respect to the number of cigarettes smoked per day and the FTND.

Finally, the technology acceptance model (UTAUT) rated by the participants revealed the following subscale outcomes (*M, SD*): Positively rated were the performance expectancy (3.77 ±1.3), effort expectancy (4.25 ±0.7), social influence (4.11 ±0.82), facilitating conditions (3.86 ±1.02), anxiety (1.36 ±0.56), and data security (4.85 ±0.44). In contrast, participants report a lack of knowledge (2.22 ±1.06) toward the technology and its application.

B. *Data of the psychophysiological measurements*

The psychophysiological measurements proved to be unfeasible in our study design due to several reasons. First, the eye-tracking calibration was not manageable for our target group. The calibration attempts in the first iteration took on average five minutes and were successful in only two out of eight subjects. The participants had issues understanding the English instructions presented in the HMD and missed help from the two researchers, which was troublesome, given the asymmetric nature of VR. We observed and documented the frustration of the participants and decided to exclude eye-tracking from iteration two onwards. Secondly, the HR, SC, and TP data measured with the Empatica E4 and Shimmer GSR+ unit were biased through the motion of the participant (motion artifacts) as well as uncontrollable environmental variables in the clinical setting, such as the rising room temperature throughout the experimental procedure. Fig. 4 illustrates an example case in which the acceleration (motion) of the participant highly influenced the obtained data. Due to the interactive design of our research, cue-reactivity-related changes and peaks in the collected data could not be reliably distinguished from motion artifacts.

V. Discussion

The present study aimed to validate the tobacco-related cue-reactivity environment, the feasibility of measurements, and initial acceptance of technology in specifically vulnerable individuals, i.e. people with mild to borderline intellectual disability, low health literacy, or psychiatric comorbidity. The results reveal that our VE can elicit significantly higher craving levels compared to baseline and post-tutorial scores. The verbally obtained QSU-Brief measures show good to excellent internal consistency and a very strong positive relationship with the VAS scores by the participants. The general acceptance of VR technology as a potential smoking cessation program was rated positively, given that performance expectancy, effort expectancy, social influence, facilitating conditions, and data security were rated high. Nevertheless, participants report missing knowledge regarding the system and its applications as a possible obstacle to independently use the technology. However, the applied psychophysiological measures were unfeasible in our study, either due to complex calibration procedures (eye-tracking), or uncontrollable variables within the clinical setting (room temperature and user's motion). Thus, no analysis based on the psychophysiological data was performed to obviate biased and invalid conclusions.

To our knowledge, this is the first exploration of VR as a potential modality for addiction medicine in explicitly vulnerable groups and therefore extends the current applicability. Our findings, obtained in the natural treatment setting, are in line with previous research and confirm the feasibility of tobacco-related VEs to elicit craving in non-deprived smokers [42, 43]. The findings are consistent with previous research that found higher craving scores in tobacco-related environments [42-46]. Despite an expected relationship, the effect of the VE on craving was not significantly correlated with the participant's dependence severity or consumption of cigarettes per day, which can be supported by other cue-reactivity studies [46, 47]. However, the moderate negative correlation of age and craving scores might show barriers toward using VR technology with increasing age. Since the VR systems operation is similar to nowadays entertainment systems in terms of controls and computer graphics, younger generations might be more familiar with the technology. Furthermore, the high cognitive workload to operate the device could be a potential antagonist toward cue-reactivity.

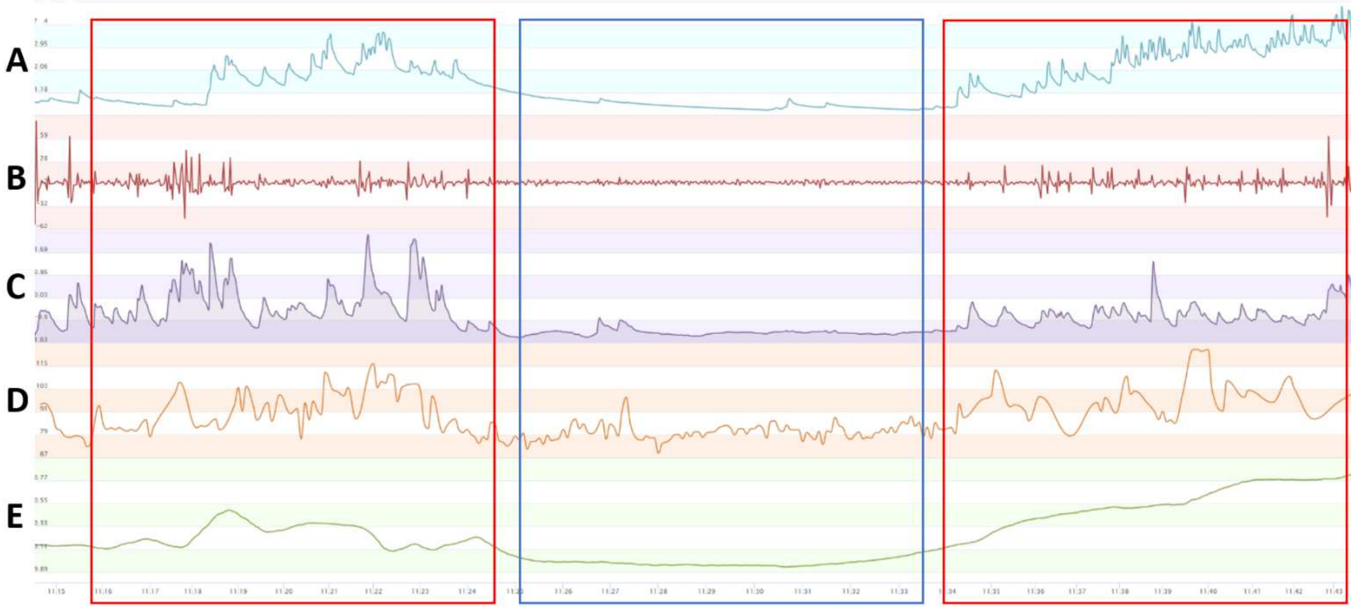

Fig. 4. Psychophysiological data obtained from a single participant in iteration three (Empatica E4). Section (C) shows the acceleration (motion) of the participant. Accordingly, (A) describes the skin conductance (SC), (D) the heart rate (HR), and (E) the temperature (TP). The outlines show periods of high motion (red) vs. low motion (blue).

In contrast to other studies, the present VE was built with an open-world mechanic, enabling participants to realistically interact with their surroundings without a linear storyline. Previous studies reported ecological validity as an important factor [42, 46]. Nevertheless, the guided exploration to specific scenes resulted in greater craving scores than the initial exploration, either by the participant alone or related to the established cue-reactivity assessment in iteration three. This possibly reflects the target group's need for specific tasks in the VE to encounter more complex interactions and therefore challenges the initial exploration. In addition, the use of this initial exploration to subsequently tailor the VE's content and interactions, based on the user's needs, is noteworthy [48].

Focusing on the applied measurements, previous studies utilized predominantly the one-dimensional VAS (in-game and conventionally) to examine the participant's craving, thoughts about smoking, and attentional responses [43, 46, 49, 50]. Furthermore, it has been utilized as a previous assessment instrument to tailor exposure mechanisms in alcohol studies [48]. Nevertheless, multi-dimensional scales could provide deeper insights into the user's cravings and might therefore be of potential interest in future research [12, 23, 25]. Besides, laboratory studies with controlled exposure protocols, and fewer interaction mechanics, successfully applied psychophysiological measurements within tobacco-related VEs [25, 26, 43, 51]. Their findings are contradictory, showing either increases or decreases in HR, SC, and TP. Noteworthy, research concerning methamphetamine-related VEs showed the potential to train classifiers through machine-learning techniques to distinguish healthy from dependent subjects, using psychophysiological data [52, 53]. This approach could lead to new diagnostic modalities, based on automatically-collected data, without the need for standard clinical interviews that rely on oral or written instructions.

Generally, the participants reported a good acceptance toward VR as a treatment modality for smoking cessation. On the contrary, they revealed little knowledge regarding the technology and its application as a therapeutic tool. This might reflect the developmental stage of the present systems and possibly shows the need for technological assistance as well as therapist-delivered interventions during the early stages of technology diffusion. Moreover, the participants experienced the HTC VIVE Pro Eye system, which comprises the installation of infrared base stations and the operation of a high-performance computer. The recent dissemination of inside-out tracking and stand-alone systems, such as the Oculus Quest or HP Reverb G2, allows an unobtrusive and consumer-friendly usage in treatment facilities and home environments. However, the technology acceptance and intention to use are heavily understudied in the available literature and should be an urgent subject to future research. Furthermore, privacy concerns should be addressed, given the current shift toward data collecting hardware and the potential unawareness thereof, especially in vulnerable populations.

There are several limitations in this research that should be considered. First, we failed to obtain valid psychophysiological data due to our research design. Especially the environmental and motion factors in interactive VR research should be considered seriously when aiming to examine a causal relationship between cue presentation and psychophysiological response. Secondly, the QSU-Brief was assessed verbally by a trained psychologist. This approach could lead to an increased social-desirability bias while a paper-based assessment might increase complexness. Therefore, utilizing the one-dimensional VAS in this population could be more suitable than multi-dimensional scales. Thirdly, due to the lack of a control group, this research cannot control for confounding variables, such as the impact of the emerging nicotine deprivation throughout the research. Fourthly, we obtained data from three subgroups with relatively small sample sizes. Though the nature of this research was exploratory, this needs to be considered carefully when interpreting the results. Lastly, due to the iterative development approach, elements in the VE changed between the iterations, as described in the method section. This could have affected the measured craving and technology acceptance.

VI. Conclusion and Future Work

In this study, we demonstrated the (1) possibility to elicit tobacco craving through the VE, (2) feasibility of craving measures by one-dimensional (VAS), and multi-dimensional (QSU-Brief) scales, in vulnerable smokers. Moreover, our participants reported a good (3) technology acceptance toward the VR prototype. We showed that craving increased significantly in tobacco-related VEs compared to baseline and the neutral environment. Given the high prevalence of tobacco consumption in these groups and the lack of accessible and suitable treatment approaches, our research indicates promising results toward new modalities through VR applications.

Future research should evaluate the applicability of VEs as a therapeutic tool in these vulnerable groups separately, including a greater sample size and control group. The investigated measures of craving can be utilized to tailor the environment or assess the impact of treatment approaches, such as the described VR-ET and VR-CBT. Furthermore, psychophysiological measures should be investigated through robust study designs with controlled environmental variables, smart interaction design to avoid, for instance, concurrent measuring and motion in interaction or selecting more feasible measures at the right time of interaction, and subsequent application of data science techniques (cleaning, filtering). Lastly, the application of machine learning algorithms to diagnose or predict treatment needs and outcomes hints toward a deeper understanding of addictive disorders and personalized medicine.

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