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Measuring the Influence of Alcohol Consumption on Presence in Virtual Reality

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ABSTRACT

We examine the influence of alcohol consumption on presence in Virtual Reality (VR) with both subjective and objective data. To measure the level of presence in VR we propose a method using four self-developed indicators, two subjective (*Flow*, *Subjective Behaviour*) and two objective ones (*Objective Behaviour*, *Performance*). To assess the validity of our method, we conducted a user study ($n = 20$). Although results show no significant correlations, we reveal two potential research gaps regarding the general threshold for measurable effects of alcohol consumption in VR and eventual gender differences. Besides the two research gaps, we show three further approaches for future work.

Keywords

Virtual Reality, Presence, Alcohol Consumption, Human-Computer-Interaction, Games

1 INTRODUCTION

Virtual Reality (VR) has reached the mass market, with an ongoing growth in the number of users. In 2023, 14 million Head Mounted Displays (HMD) were sold, leading to estimated 22 million units in active use [Ess23]. Around half of the world's population consumes alcohol as estimated by Hoek et al. [Hoe+22]. Therefore, questions related to the use of VR under the influence of alcohol are increasingly relevant.

To date, there has been little research on this topic [Dur+18]. While previous research e.g. investigated effects on cybersickness [IWB17], questions about presence remain unanswered. To help close this research gap, our paper contributes in two ways:

(i) A method to measure the level of presence in VR in form of four self-developed indicators: two subjective (*Flow*, *Subjective Behaviour*) and two objective (*Objective Behaviour*, *Performance*).
(ii) A user study ($n = 20$) revealing two potential research gaps regarding the general threshold value for measurable effects of alcohol consumption in VR and possible gender differences.

In Chapter 2 we review related work. Our proposed method is presented in Chapter 3. While Chapter 4 describes the conducted user study, we show the results in Chapter 5. After critically reflecting on the results in Chapter 6, we conclude and outline potential future work in Chapter 7.

2 RELATED WORK

Our examination of alcohol's influence on presence in VR comprises three areas of research. In this section we look at literature on: the concept of presence in VR (Section 2.1), ways to measure presence in VR (Section 2.2), and previous research on alcohol and VR (Section 2.3).

2.1 Presence and Immersion

Presence and *Immersion* are two key concepts in VR research, closely linked together and often mistakenly used synonymously even among VR experts [Gen+21a; Sla03]. To better understand and clearly distinguish between them, we are taking a closer look at both.

2.1.1 *Presence*

With VR technologies developing into consumer-level products in the early 1990s, research looked for approaches "to define VR in terms of the human experience rather than the technological hardware" [Ste92]. Subsequently, the concept of *(Virtual) Presence* emerged as a dependent measure of the individual experience in VR. This human experience-focused view, sparked an ongoing debate about the definition of *Presence* in VR [Bar16].

We follow the definition of Slater [Sla09], one of the most commonly cited definitions of *Presence*, as a "feeling of being there", being in a place or virtual environment (VE) even though one is physically in a different place [Min80; Hee92; WS98].

The term can be further distinguished in *Plausibility Illusion* and *Place Illusion*. *Plausibility Illusion* describes how credible events, that happen in the VE, are for the user. *Place Illusion* describes the deception of being in a place created by the *Immersion* of the senses [Sla09].

Factors influencing *Presence* in VE can be separated in interoceptional and exteroceptional. Interoceptional factors relate to the presented content, e.g. participants perceive a greater *Presence* if they feel emotionally affected. An exteroceptional factor is, for example, the degree of *Immersion* [Mar+20]. Slater [Sla09] considers *Immersion* as an influencing factor on *Presence*, describing it as a "human reaction to immersion".

To shed more light on the link between *Presence* and *Immersion* and to differentiate between the two terms, we will subsequently have a closer look at the concept of *Immersion*.

2.1.2 Immersion

Regarding *Immersion* we follow Slater and Wilbur's [SW97] definition "as a quality of the system's technology, an objective measure of the extent to which the system presents a vivid VE while shutting out physical reality".

Definitions are united by understanding the term as a sensory perception triggered by technical elements. Yet it is difficult to provide a standardized definition [BA20] since the literature offers a number of variations [KB18; Nas+00; WS98].

Selzer and Castro [SC23] list variables influencing *Immersion* and categorize them according to different sensorial perceptions.

We found the following visual variables: field of view [Kim+14; WT13], screen resolution [Kim+14; Ahn+14], stereopsis [Kim+14; Ahn+14], response time or latency [KLP20], brightness, contrast, saturation and sharpness [MG96], the level of detail of 3D models [Vol+20], the lighting of the VE [SSC10] and the use of dynamic shadows [SSC10].

Audio-related variables include the use of sound versus no sound [Zel92; PWD13], ambient sound [Bim11], 3D spatial sound [AJC14; Ber+17], the use of headphones versus speakers [Ber+17] and echo or reverberation [Bim11].

Variables related to the tactile system and tracking of the user include sensory bandwidth [Sno98], level of body tracking [Gor+11], degrees of freedom [Bim11], affordance of controls [Wil13], response time or latency of tracking [ABW93], locomotion [Sel18], temperature and wind [AJC14; SC23].

2.1.3 Drawing the Line between Presence and Immersion

To better distinguish *Presence* and *Immersion*, we refer to an abstract comparison from the field of colour science.

Objectively, a colour can be described by its corresponding wavelength distribution. The perception and emotional reaction to a colour by different individuals can in turn have a wide range of results. Thus, *Immersion* can refer to the wavelength distribution, while *Presence* corresponds to colour perception [Sla+09].

2.2 Measuring Presence in VR

Methods to measure *Presence* in VR can be divided in subjective and objective ones. For subjective methods, questionnaires are currently the predominant form [Sch21]. Schwind et al. [Sch+19] identified 15 different questionnaires. Objective methods are e.g. physiological measurements, behavioral observations and performance measurements [Laa+15].

Regarding physiological measurements the most common are heart rate, heart rate variability and skin conductance [Sch21; Sla+22]. Other approaches include, e.g. eye tracking [Sch21], electrodermal activity [Mee+05], muscular responses measured via electromyography [AS11; Kiv+11], functional magnetic resonance imaging [Hof+03] or the integration of electroencephalography [Bau+06; JP16; KN12; KKN12; Cle+14; Pet+20], although the acquisition and interpretation of these data pose a number of challenges [Gen+21b].

Behavioral observations are much-discussed in research and considered experimental, sometimes seen as the most creative method [Sch21]. Sheridan [She92] introduced the idea early on with his approach to evaluate social behaviour in relation to naturalness. Previous results indicate that *Presence* correlates with behaviour in a highly immersive VE and behaviour depends heavily on the specific circumstances under which data points are measured [BA20].

For performance it has been postulated that greater *Presence* enhances task performance. Nevertheless, there is a long debate about the correlation between performance and *Presence* [Wel99]. While some studies show positive correlations, reports of insignificant or even negative correlations exist as well [BA20]. Nash et al. [Nas+00] proposed several measures for performance measurement linked to *Presence*.

Although a variety of methods exists the use of either subjective or objective is insufficient [Sla+22]. Potential disadvantages of questionnaires include memory impairment for extensive questionnaires after an experience [SC23; IWB17] or a potential disturbed feeling of presence in case of short questions during an experience (e.g. 1-item questionnaire) [Sch21]. A purely objective method in turn is difficult due to the subjective nature of *Presence* [Nas+00; BA20]. Hence, literature recommends to combine subjective and objective measures [SBW18; Sla+22].

In their literature review Skarbez et al. [SBW18] recommend considering at least two different methods. Slater et al. [Sla+22] describe the triangulation of using several approaches, e.g. the combination of subjective reports and objective measures, as ideal.

After defining important terms and examining current approaches to measure *Presence* in VR, we take a closer look at research on alcohol and VR next.

2.3 Alcohol and Virtual Reality

A person's alcohol level is measured as blood alcohol concentration (BAC) in alcohol per mille (‰). This value indicates how many millilitres of pure alcohol are contained in one litre of blood.

Alcohol has a direct influence on the human sensory system [IWB17]. Alongside the amount of alcohol consumed its influence depends on a number of factors such as age, gender, genetics, body weight, type of drink, drinking experience, health status and drug use [IWB17; Roe+94; HKW00; Mum+99]. First impairments occur from 0.2 ‰, e.g. in form of slight concentration and problems to focus, reaction delays and deterioration in movement coordination. With increasing BAC restrictions intensify and expand, e.g. on vision. More than 3 ‰ can lead to death [IWB17; BFV20; Gai+18].

Literature on alcohol and VR can be divided into two major research directions. First, the use of VR in alcohol studies. Second, the use of alcohol in VR studies.

While we were able to identify a variety of studies and approaches for the first research direction (e.g. cue exposure therapy [Ghi+19], driving simulators [BFV20], medical training [Gil+23] or educational applications [Lyk+20]), only one study could be assigned to the second research direction, where we also attribute our work to.

As a study targeting the use of alcohol in VR, Iskenderova et al. [IWB17] investigated how alcohol consumption affects cybersickness in VR by conducting a user study ($n = 31$). Cybersickness is one of the main adverse effects of VE and characterised by symptoms like nausea, eye pain, sweating, disorientation, fatigue, headaches and vomiting [BC03]. The study revealed that a BAC of around 0.07 ‰ significantly reduces symptoms of cybersickness. The results are remarkable, as e.g. Blasiis et al. [BFV20] or Gaibler et al. [Gai+18] indicate first noticeable effects above a BAC of 0.2 ‰.

As alcohol has direct effects on human sensory perception [IWB17], we assume correlations between BAC and *Presence* in VR. Although various approaches to measure *Presence* in VR exist, none seems adequate. We therefore propose a method to measure *Presence* in VR in the next section.

3 METHOD

Our proposed method to measure *Presence* in VR consists of four self-developed indicators: two subjective (*Flow*, *Subjective Behaviour*) and two objective ones (*Objective Behaviour*, *Performance*).

The term *Flow* is based on the flow theory of Csikszentmihalyi [Csi90] and describes a positive mental state where people lose their sense of time when they are completely involved in an activity. We consider this state of involvement as an indication for presence in VR. To measure the level of this flow-like state, and therefore presence, we subtract the subjectively perceived time from the actually measured time under the assumption that the difference determines a potential flow-like state. A higher deviation therefore means a higher level of presence.

Both *Subjective Behaviour* and *Objective Behaviour* are based on previous approaches to derive presence from behavioral observations [BA20]. While the literature categorises behaviour as an objective measurement, our method adds a subjective perspective.

For *Subjective Behaviour* we assume presence is correlated with the perceived ability to better position and interact in the VE. For *Objective Behaviour* we assume presence is correlated with the usage frequency of input devices (e.g. controller) for locomotion. If a person uses such devices less frequently, as a result moving more naturally in the VE, we conclude the "feeling of being there", respectively the level of presence, to be higher.

Performance is based on the assumption that better task performance in VE correlates with a higher level of presence in VR [BA20].

To measure subjective data we suggest using short questionnaires presented directly after an experience. For objective data we suggest manually measuring from direct observations or using tracking data from modern HMDs.

In the next chapter we apply and assess the validity of our method in the context of a conducted user study.

4 USER STUDY

In this chapter we describe details regarding the conducted user study for the evaluation of our method to measure *Presence* in VR. We explain the study design, give an overview of the system used as well as the task to be performed. Furthermore we characterise the participants and detail our application of the method plus the general study procedure.

4.1 Study Design

The user study employs a quantitative research design. We chose a between-group experimental design, measuring and comparing the collected variables in two groups. A non-alcoholised group (control group) and an alcoholised group (alcohol group).

4.2 System Overview

The user study was conducted in a laboratory room at our university, which provides an empty area of $3,30m \times 1,80m$. We used a Meta Quest 3 as HMD. As a standalone device it is wireless with an integrated processor, battery-operated, and offers inside-out tracking, which enables the localisation and demarcation of the VE within the real environment as well as game boundaries in a so-called *guardian*. This HMD has a resolution of 2064×2208 pixels per eye, a refresh rate of up to 120 Hz and a field of view of 110° horizontally and 96° vertically. The contained lenses can be adjusted to the pupillary distance of the user.

The HMD is supplied with two (right and left) *Touch Plus Controllers* as input devices. Each controller contains four buttons, a thumb stick, a thumb rest, and a two-stage trigger.

Streaming the visual content from the HMD to a browser is possible enabling us to observe users from outside as well as inside the VR application. The observer setup consists of a workstation with two screens, a mouse and a keyboard.

As the audiovisual stimulus we presented the commercially available VR game *Walkabout Mini-Golf*, which simulates playing mini-golf from a first-person perspective in various VEs with minimalist comic graphics. The user is able to look around the VE by using the head tracking capabilities of the HMD. Locomotion is possible by using the controller in different ways: teleportation by pull and release of the two-stage trigger, snapturning by turning the thumb rest left or right, or real walking within the previously defined guardian. Depending on whether the user is right-handed or left-handed, the golf club is controlled using the right or left controller.

We chose this application since Mini Golf requires no complicated explanation, offers measurable interaction and spatial aspects and, as one of the most popular games in the Oculus Store, promises a certain motivation and enjoyment to participate in the user study.

4.3 Task

The task consisted of two games. First, participants had to hit 10 golf balls at targets on a virtual driving range. The number of points for hitting one of these targets varied, depending on distance, size and whether the targets were static or moving. Collecting as many points as possible was the goal.

Second, after selecting the level *Blossom Tree*, participants had to play three classic mini-golf courses. The aim was to hit a golf ball, past obstacles, into a hole in as few strokes as possible.

4.4 Participants

All participants ($n = 20$; sex: 70% male, 30% female, age: 22 - 60 years; M = 31.5, SD = 9.7) were recruited at university. Participation was voluntary, and took place outside of working hours or study time. Participants were divided into two groups:

First, a control group ($n = 11$; sex: $54,55\%$ male, $45,45\%$ female; Age: 22 - 60 years; M = 32.5, SD = 13.3) where 55.5 % stated to have experience in VR.

Second, an alcohol group ($n = 9$; sex: $88,89\%$ male, $11,11\%$ female; Age: 27 - 35 years; M = 29.9, SD = 2.4) where 60 % stated to have experience in VR.

4.5 Method Application

We measure presence by applying our method described in Section 3, yet first we detail the variables used for the measurements.

4.5.1 Measured Variables

We measured eleven variables in total, six of those through a self-designed questionnaire.

Three objective variables from the questionnaire by asking for *age*, *gender* and *previous experience with VR*. And three subjective variables by asking the following questions:

Q1) "How would you rate your ball control?"
Q2) "How precisely were you able to take up your desired position?"
Q3) "How many minutes did you spend using the application in total?"

Q1) and Q2) were answered using a five point likert scale (1 = very good, 2 = good, 3 = neutral, 4 = bad, 5 = very bad). Q3) was answered in a free field.

Furthermore, three objective variables by manually measuring the *number of snapturns*, *number of teleportations* and *total time spent*. One objective variable by measuring *BAC*, using the *ACE X Alkoholtester*, a breath alcohol tester labeled *Accuracy Class 1* with a precision of ± 0.005 percent [Ros19].

One objective variable by measuring *pupillary distance*, using the app *Dotty EyeMeasure* (Version 1.22) on an iPhone 13 mini (iOS Version 17.2.1), which was used for configuration purposes only.

4.5.2 Measuring Presence

We determine *Flow*, as shown in Equation 1, by subtracting the result of Q3) from the measured time.

$$f = total\ time\ spent - q_3 \qquad (1)$$

Subjective Behaviour, as shown in Equation 2, is calculated by halving the sum of the results of Q1) and Q2).

$$u = \frac{(q_1 + q_2)}{2} \qquad (2)$$

We determine *Objective Behaviour*, as shown in Equation 3, as the sum of the number of *snapturns* s and the number of teleportations t.

$$o = s + t \qquad (3)$$

We determine *Performance*, as shown in Equation 4, with n number of ranges, in our case $n = 3$, $h_i^{\max}$ the number of max shots allowed at the ith hole and h_i number of shots on the ith hole. This evaluates the performance of the holes to a percentage value, where 100% corresponds to clearing each hole in one shot and 0% to the maximum number of attempts required.

$$p = \frac{100}{(\sum_{i=1}^{n} h_i^{\max}) - n} \cdot \left(\sum_{i=1}^{n} h_i - n \right) + 100 \qquad (4)$$

4.6 Study Procedure

Before taking part in the user study, potential participants were informed about possible exclusion criteria (e.g. age, health problems, current medication use, current or previous addiction problems and pregnancy).

The HMD was kept charged during the user study. Backup batteries were available for the controllers. If required, we provided support by answering general questions.

The user study consisted of two rounds. Each round contained seven sub-steps, which are described below. Figure 1 illustrates the execution of the user study.

(1) Information: Participants were informed at the beginning of the user study about the purpose, the individual steps and the right to discontinue the study at any time and for any reason. A written declaration of consent was obtained from all participants. In addition, information was provided in accordance with Art. 13 GDPR.

(2) Measurement: Prior to each round, we measured each participant's current BAC and pupillary distance. In the first round, all participants had to be sober. We used this round as the baseline for the measured values. In the second round, we made a distinction between two groups. The control group was asked to remain sober. The alcohol group was asked to bring and consume alcoholic beverages at their own discretion. To prevent falsification of the BAC test, all participants were asked to refrain from smoking, eating or using a mouth spray for at least 15 minutes before each round.

(3) Preparation: Before the HMD was handed over, the application was started, the pupillary distance was set, the streaming of the visual content from the HMD was started, participants were asked whether they are left- or right-handed, and the HMD and corresponding controller were disinfected.

(4) Customisation: After handing over the HMD and the controller to the participant, we explained how the HMD can be adjusted to the respective head size.

(5) Familiarisation: At the beginning of the VR application, the participant is located in a freely walkable VE. We use this mode to explain the controls and letting them familiarise.

(6) Execution: When the participants communicated that they were ready, we explained the task. Afterwards we started our measurements.

(7) Questionnaire: After completing the task, participants were asked to answer our questionnaire.

Figure 1. Pictures of a user conducting the user study (left) and the authors' parallel perspective while measuring various parameters (right)

5 RESULTS

We conducted a user study to measure the influence of alcohol on *Presence* in VR. The measurements are based on our method which combines objective as well as subjective indicators. In this section we present the obtained results. A critical discussion of these follows in the next section 6.

The levels of BAC ranged from a minimum of 0.07 ‰ to a maximum of 0.93 ‰. The mean concentration was 0.31 ‰, with a standard deviation of 0.33. Six participants registered values below 0.2 ‰, while three participants exceeded the 0.4 ‰ threshold.

Table 1 shows the descriptive statistics for the measured variables. None of the observed trends reached statistical significance.

		Round 1		Round 2	
Group		mean	sd	mean	sd
Control	f	5.29	7.01	3.93	3.70
	u	2.32	0.78	1.82	0.46
	o	29.4	9.99	27.5	11.0
	p	45.5	17.6	62.6	23.8
Alcohol	f	1.11	2.67	1.17	1.99
	u	1.78	0.36	1.61	0.33
	o	53.0	38.2	51.7	35.7
	p	46.5	15.7	63.0	19.7

Table 1. Descriptive Statistics for the measured variables *Flow* (f), *Subjective Behaviour* (u), *Objective Behaviour* (o) and *Performance* (p)

Distinctions emerged between the groups during round 1 for *Subjective Behaviour*, *Objective Behaviour* and *Flow*.

The alcoholised group had lower scores for *Subjective Behaviour* (1.78 vs. 2.32, 95% CI [-1.11, 0.03]), *Objective Behaviour* (53.0 vs. 29.4, 95% CI[-6.01, 53.28]) as well as *Flow* (1.11 vs. 5.29, 95% CI[-9.13, 0.76]). Despite these differences, both groups demonstrated a comparable *Performance* of 46% (95% CI[-14.67, 16.69]).

There is no remarkable change in the mean value for *Flow*, *Subjective Behaviour* and *Objective Behaviour* between rounds 1 and 2 for both groups.

Notably, there was a *Performance* improvement from 45% to 63% (control 95% CI[-35.89, 1.55], alcohol 95% CI[-34.37, 1.37]) between round 1 and 2 for both groups.

6 DISCUSSION

In this section, we discuss the previously presented results, reveal two potential research gaps and point out limitations.

First, we expected measurable effects of alcohol on *Presence* in terms of different mean values between round 1 and 2 for both groups. Instead, our results show no significant changes for *Flow*, *Subjective Behaviour* and *Objective Behaviour*. By taking a closer look at the dataset, we saw that six participants registered a BAC below 0.2 ‰ and only three exceeded 0.4 ‰. As the literature seems unable to define a clear threshold value for measurable effects of BAC in VR [BFV20; Gai+18; IWB17], this indicates a first potential research gap.

Second, we observe different mean values in the first round for *Flow*, *Subjective Behaviour* and *Objective Behaviour* between both groups. We noticed that there is only one woman in the group that consumed alcohol in contrast to the control group, which is balanced. Since the measurements between the groups in round 1 already differ more than the standard deviation, this indicates a second potential research gap namely possible gender differences on *Presence* in VR.

Since *Performance* improved for both groups in the same manner, alcohol appears to have no influence on attributed learning effects in VR.

There are several shortcomings in our study. First and foremost, none of the observed trends reached statistical significance. We mainly attribute this to the limited sample size of the user study. The data set also suffers from an unbalanced distribution of BAC within the intoxicated group, as well as an imbalanced gender composition.

7 CONCLUSION AND FUTURE WORK

Questions related to the use of VR under the influence of alcohol are of increasing relevance. Yet there has been little research on this topic. As alcohol has influence on the human sensory system we expected a measurable influence on presence in VR. Although literature offers various approaches to measure presence in VR none seems adequate.

We presented a method to measure presence in VR in form of four self-developed indicators. To assess the validity of our approach, we conducted a user study ($n = 20$). Even though the results show no significant results, we revealed two potential research gaps: an unclear BAC threshold value for measurable effects on presence in VR and possible gender differences on presence in general.

Besides these two, we see three more approaches for future work. First, the proposed method of this work could be evaluated in a larger user study with more participants, a balanced BAC distribution in the alcoholised group and a balanced gender composition.

Second, the proposed method could be modified by changing the questionnaire (e.g. questions, timing of questions), integrating physiological measures (e.g. heart rate, electrodermal activity or electroencephalograph [Laa+15; Sla+22]), or using more data sources of modern HMDs like eye tracking.

Third, the user study could be replicated in the real world, on a real mini-golf course, to compare the results and examine to what extent VR reflects reality here and how this shows in the chosen metrics.

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