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Journal of Applied Research in Memory and Cognition

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Online First Publication, September 1, 2022. http://dx.doi.org/10.1037/mac0000055

CITATION

Kloft, L., Otgaar, H., Blokland, A., van Oorsouw, K., Schepers, J., Steinmeyer, S., & Ramaekers, J. G. (2022, September 1). False Memories in the Field: Impact of Substance Intoxication and Sleep Restriction on False Memory Formation. *Journal of Applied Research in Memory and Cognition*. Advance online publication. http://dx.doi.org/10.1037/mac0000055

Journal of Applied Research in Memory and Cognition

ISSN: 2211-3681

https://doi.org/10.1037/mac0000055

EMPIRICAL ARTICLE

False Memories in the Field: Impact of Substance Intoxication and Sleep Restriction on False Memory Formation

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We conducted a field study at a music festival to examine effects of naturally occurring sleep deficits and substance intoxication on false memory formation and susceptibility to suggestion, using two paradigms. In a misinformation task, sleep restriction was associated with increased levels of susceptibility to suggestion and false alarms to nonsuggestive questions for a virtual reality eyewitness scenario. Use of tetrahydrocannabinol and amphetamines was also related to increased false alarms to nonsuggestive questions, indicating that such questions might be sensitive to use of those drugs. In an implantation paradigm, neither sleep restriction, substances, nor exposure to fake social media content increased the likelihood of falsely believing or recollecting a purportedly experienced festival event. However, some people came to falsely believe (13%, $n = 30$) or falsely remember (6%, $n = 14$) the false suggested event. Findings indicate that some established lab effects can also be observed in a less controlled environment.

General Audience Summary

Studies have recently shown that lack of sufficient sleep as well as drug influence can heighten the proneness to go along with suggestions (*susceptibility to suggestion*) or to form memories of events that never happened (*false memories*). People who use drugs often combine multiple substances, such as alcohol, cannabis, and others (*polysubstance use*). Polysubstance effects on false memory and suggestibility are still unexplored and cannot always be easily studied in a lab setting. We conducted a field study at the Lowlands music festival to examine the impact of naturally occurring factors on the susceptibility to suggestion: sleep deficits and substance intoxication. Festival visitors ($N = 277$) witnessed a virtual reality crime and were interviewed using suggestive and nonsuggestive questions about true and false details regarding the crime. People with sleep deficits showed increased levels of suggestibility and incorrect yes-responses to nonsuggestive questions about the scenario. Being under

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The authors thank Richard Benning (Maastricht University) for designing the virtual reality (VR) scenario, Franc Donkers (Maastricht University) for providing the portable VR setup, and Dräger Safety Germany for collecting and analyzing saliva samples, in cooperation with MVZ Labor Dessau GmbH, Dessau, Germany. Further, the authors are grateful to Lowlands Science for the opportunity to conduct this research. Finally, the authors thank Natasha Mason, Jessica Bruijel, Nina Tupper, Rosalie Mourmans, Kayley van Uden, Julia Gros, and Frederick Vinckenbosch for collecting data and being a fantastic festival crew.

All materials have been made publicly available at the Open Science Framework (OSF) and can be accessed at https://osf.io/a7tmp. Data can be obtained by emailing Lilian Kloft.

This research was supported by the Nederlandse Organisatie voor Wetenschappelijk Onderzoek Research Talent Grant 406.16.529 to Lilian Kloft. The funding source had no involvement with any of the steps in producing this article. Stefan Steinmeyer has financial interest in Dräger products, which were used in this research.

Lilian Kloft played the lead role in conceptualization, data curation, formal analysis, funding acquisition, investigation, project administration, writing of original draft, and writing of review and editing and an equal role in methodology. Henry Otgaar played an equal role in conceptualization, methodology, supervision, and writing of review and editing. Arjan Blokland played a supporting role in conceptualization, methodology, supervision, and writing of review and editing. Kim van Oorsouw played a supporting role in methodology and writing of review and editing and an equal role in investigation. Jan Schepers played a supporting role in formal analysis. Stefan Steinmeyer played a supporting role in investigation. Johannes G. Ramaekers played the lead role in supervision; a supporting role in funding acquisition and writing of review and editing; and an equal role in conceptualization, investigation, and methodology.

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influence of multiple substances was not related to memory but being under influence of certain substances was. Influence of tetrahydrocannabinol, the main psychoactive ingredient in cannabis, or amphetamines (stimulant drugs) was related to increased incorrect yes-responses to nonsuggestive questions. This confirms previous findings that these drugs can foster false memory creation. We also interviewed participants about their festival experiences and at one point falsely suggested to participants that they were seen during a certain recent event (that never happened) at the festival. Half the participants had previously viewed social media coverage about the event, which was fake. No relationships were found between sleep deficits, drug use, or exposure to fake news and the likelihood to falsely believe or remember the suggested festival event. However, some people came to falsely believe (13%, $n = 30$) or falsely remember (6%, $n = 14$) the false event. The present study shows that certain types of drugs are associated with some memory impairing effects and can be studied in real-life settings.

Keywords: false memory, suggestibility, sleep restriction, intoxication, implantation

Supplemental materials: https://doi.org/10.1037/mac0000055.supp

Decades of research have revealed the malleability of memory, showing that false memories (FM) can arise after receiving misinformation or external suggestion (e.g., Frenda et al., 2011; Loftus, 2005). FM can range from recalling benign details to entire autobiographical events that were never experienced (e.g., Mazzoni, 2002; Otgaar et al., 2016). Recently, research has shifted toward investigating the impact of drug intoxication and sleep deprivation on FM proneness (e.g., Frenda et al., 2014; Kloft et al., 2019). Given that both recreational use of mind-altering substances (e.g., alcohol, cannabis) and sleep loss tend to be abundant at music festivals (e.g., Mackuľak et al., 2019; Schlicht et al., 1972), we conducted a field study to assess FM formation in visitors of a music festival, using several suggestion-based methods.

FM, suggestibility, and the factors perpetuating them are of interest to the legal field, where reliable testimonies from witnesses or suspects are crucial. A frequently used laboratory method to study suggestion-based FM is the *misinformation paradigm* (Loftus, 2005) which exposes individuals to stimuli (e.g., crime video), followed by misleading information about the stimuli, and finally a memory test to see whether participants report the misinformation (i.e., the *misinformation effect*). Closely related are measures of suggestibility, such as the use of misleading questioning (e.g., posing two incorrect options in a forced-choice test; e.g., van Oorsouw et al., 2019). Another FM method is the *implantation paradigm* (Loftus & Pickrell, 1995), which merges suggestive techniques (e.g., confrontation with fabricated narratives) with social influence (e.g., repeated interviewing) to convince participants of experiencing entire false autobiographical events (Wade et al., 2002). In the field experiment reported here, we adopted a two-fold approach toward testing FM susceptibility. First, by using a misinformation framework, participants experienced a virtual reality (VR) mock crime and were interviewed to measure their *susceptibility* to *misinformation*, *suggestion*, and their tendency to respond falsely to nonsuggestive questions (*control false alarms*). Second, we used a false memory implantation method, suggesting to participants that they experienced an event that recently occurred at the festival, after exposing half of them to fake news material of said event. Here, we measured their false *belief* and false *recollection* of the implanted event.

Substances and False Memory

Understanding how substances affect false memory formation and suggestibility is crucial from a legal–psychological perspective, since many crimes are witnessed or committed by intoxicated individuals (e.g., Evans et al., 2009; Hagsand et al., 2022; Monds et al., 2020; Palmer et al., 2013). Several FM theories have been linked to the memory effects of drugs (see Kloft et al., 2021, for a detailed discussion of theories and predictions), with the most encompassing perhaps being the source-monitoring framework (SMF; Johnson et al., 1993). The SMF dictates that people use internal cues to distinguish genuine experiences from imagined ones (e.g., how vividly do I remember this?). Alcohol, but also other substances such as cannabis (Ranganathan & D'Souza, 2006) and 3,4-methylenedioxy-methamphetamine (MDMA; Kuypers & Ramaekers, 2005), are known to undermine memory formation leading to memory gaps. In the absence of clear internal memory cues, intoxicated people might rely on external, potentially unreliable sources to fill the gaps (Nash & Takarangi, 2011). Following also the discrepancy detection principle (Schooler & Loftus, 1986), amnesia-causing drugs might make people more lenient in their judgments when the original memory for an event is poor and thus hard to separate from other information. When intoxicated people are exposed to misinformation or are interviewed in a suggestive manner, this could lead them to believe in or remember events that never occurred because they are unable to detect discrepancies between the original event and the suggested event (Loftus, 2005; Mazzoni, 2002).

The best-studied substance in the legal context is alcohol, for which studies using misinformation and suggestibility methods have yielded mixed findings (Flowe & Schreiber Compo, 2021; Kloft et al., 2021; Mindthoff et al., 2021). At low-to-moderate levels (0.04%–0.14%), alcohol did not impact the misinformation effect (Flowe et al., 2019; Schreiber Compo et al., 2012), but suggestibility was elevated at high alcohol levels (0.10%–0.25%; van Oorsouw et al., 2015, 2019). However, moderate alcohol levels (0.08%) also appear to affect suggestibility when a delay is interposed between the event during intoxication and its retrieval attempt (Evans et al., 2019). Research on other substances found that cannabis-intoxicated, but not MDMA-intoxicated, participants displayed greatest FM formation in response to questions about VR eyewitness and perpetrator scenarios (Kloft et al., 2020, 2022).

Laboratory studies on substance effects have limitations, such as ethical restrictions sometimes preventing dosage levels that reflect those in the real world. Thus, alcohol laboratory studies mostly employ moderate doses around the legal driving limit (blood alcohol concentrations [BACs] of 0.06%–0.08%), whereas higher levels are frequent in drinkers (e.g., Hagemann et al., 2013). Laboratory studies usually evaluate effects of single substances, whereas in real life, people frequently engage in polydrug use (e.g., Evans et al., 2009;

Winstock et al., 2017). Finally, laboratory studies are often limited to university students as participants (e.g., Pezdek et al., 2020). Naturalistic studies can counter these limitations, thus capturing FM effects of greater intoxication in a diverse crowd (e.g., BACs up to 0.24%; van Oorsouw & Merckelbach, 2012). Additionally, recreational drugs and especially polydrug use is common at music events (Riley et al., 2001). Polysubstance effects on FM and suggestibility are still unexplored and not easily testable in a lab setting, so a field study at a music festival provides a viable solution.

Sleep Restriction and False Memory

Lack of sleep impairs cognitive functioning in a way similar to alcohol (Williamson & Feyer, 2000). Recent studies using the misinformation paradigm demonstrated that reduced sleep might increase the risk for forming FM of details. Frenda et al. (2014) found that both total and partial sleep deprivation tended to increase misinformation reports, and people with restricted sleep were more likely to report having seen a news event of which no footage exists (see also Lo et al., 2016). Sleep-deprived individuals also were especially susceptible to interrogative suggestibility (Blagrove, 1996). Thus, sleep deprivation and restricted sleep during the encoding and retrieval of an event have been linked to increased FM.

The Present Study

The present field study investigated the effects of substance intoxication and sleep restriction on FM formation and the susceptibility to suggestion at a large music festival (*Lowlands*). Since studies cited above have demonstrated that substances such as alcohol, cannabis, and MDMA can undermine memory, and that poor memory and sleep deprivation can lead to heightened suggestibility, we expected that sleep restriction, intoxication by alcohol and other substances, and fake news exposure would increase susceptibility to FM formation.

Method

The study was conducted by researchers from Maastricht University over the 3 days of the Lowlands festival in August 2018 as part of the Lowlands Science initiative and was approved by Lowlands Science as well as the Ethics Review Committee Psychology and Neuroscience. This study was not preregistered.

Participants

All participants attended the Lowlands music festival in the Netherlands and found this study as part of the side attraction "Lowlands Science," an initiative by the organization of the festival. $N = 279$ participants were recruited for and enrolled in the study. Out of those, $N = 276$ completed the entire study procedure (169 females, 60.7%; 3 dropped out after enrolling due to long waiting times). The age range was 16–64 years ($M = 29.36$, $SD = 9.12$). The vast majority of the sample were Dutch native speakers (96.1%). Inclusion criteria were as follows: minimum age 16 years, written informed consent, and passing three screening questions to ensure that participants were oriented in time and space (naming the day, place, and solving a simple math problem). An exclusion criterion was displaying an observably very high level of intoxication through stumbling or aggressive behavior. Participants' levels of education were as follows (highest completed): primary school (0.4%), secondary school (21.7%), vocational training (9.7%), bachelor's/HBO[1] degree (42.2%), master's degree (23.1%), PhD (2.9%).

As the present study was a field study, we collected data as long as festival attendees came along to participate in the study. A sensitivity power analysis using G*Power (Faul et al., 2007) showed that with a sample size of 276, six predictors, an error probability of $\alpha = 0.05$, and a power of 0.80, the study was able to detect an effect of $f^2 = 0.05$ (small effect) in the primary analyses of the misinformation paradigm with reasonable reliability.

Measures

Alcohol and Substance Use

Self-Report. Participants received a questionnaire in which they were asked how many alcoholic beverages they had consumed on the day of testing (beer, wine, liquor/spirits), how many hours ago they had started drinking, whether they had eaten, whether they had had alcohol the day before, whether they had had coffee or an energy drink, and some general questions about experiences with alcohol-induced blackouts. In addition, they were asked to indicate use of any other substances on the day of testing, options were none, cannabis/hashish (natural or synthetic), cocaine, amphetamines (e.g., speed, MDMA/ecstasy), hallucinogens (e.g., ketamine, psilocybin mushrooms, lysergic acid diethylamide [LSD]), opioids (e.g., heroin), sedatives (e.g., benzodiazepines such as Valium, sleeping medication), gamma-hydroxybutyrate (GHB; e.g., liquid ecstasy), other. See Table 1, for these self-report data.

Objective. Breath alcohol concentrations (BrAC; $n = 276$) were collected with a breathalyzer (Dräger Alcotest 6510). To assess other substance use, saliva samples were collected from $N = 277$ participants using the Dräger DrugCheck 3000, a point-of-collection drug testing device based on lateral flow immunochromatographic technology and designed to detect six drug groups in saliva (qualitative assessment). Detected drug groups (target compound) and their cutoff values were as follows: amphetamines (amphetamine) 70 ng/ml, methamphetamines (methamphetamine) 70 ng/ml, cocaine (cocaine) 20 ng/ml, opiates (morphine) 20 ng/ml, cannabis (Δ9-THC) 15 ng/ml, and benzodiazepines (alprazolam) 15 ng/ml. The analytical performance of the device has been investigated (sensitivity $\geq$80%, specificity $\geq$97%), and data will be published elsewhere. An additional sample for drug quantitative analysis was subsequently collected from all participants with a saliva collection device (Dräger DCD 5000) for a laboratory-based confirmatory analysis using ultra-high-performance liquid chromatography and tandem mass spectrometry (UPLC–MS/MS; Böttcher et al., 2019), targeting amphetamine and amphetamine-related substances (15, cutoff 1–5 ng/ml oral fluid [OF]), cocaine and metabolites (3, cutoff 1 ng/ml OF), opiates (7, cutoff 1 ng/ml OF), cannabinoids (THC, cutoff 1 ng/ml OF), and benzodiazepines (14, cutoff 0.1–1 ng/ml OF).

Sleep Restriction

Several self-report measures were used to tap into sleep restriction (see Table 1, for responses). Participants were asked if they felt tired

[1] Hoger beroepsonderwijs, that is, higher professional education taught at vocational universities, equivalent to college education in the United States.

Table 1
Self-Report: Substance Use and Sleep Variables

Variable	Reported response
Number of drinks today	
Beer[a]	39.7%: 0; 34.3%: 1–3; 21.0%: >3
Wine[b]	59.2%: 0; 3.2%: 1–3; 0.4%: >3
Liquor/spirits[c]	53.1%: 0; 18.4%: 1–3; 2.6%: >3
Hours since started drinking[d]	
0–2 hr	24.6%
3–5 hr	27.5%
>5 hr	11.6%
Did not drink today	35.0%
Drank alcohol yesterday	90.6%
Had coffee/energy drink	60.3%
Has eaten	98.6%
Other substances used today	
None	85.9%
Cannabis/Hashish	7.6%
Cocaine	1.4%
Amphetamines	6.5%
Hallucinogens	0.4%
Opioids	0.0%
Sedatives	0.0%
GHB	0.0%
Other	1.8%
Sleep variables	
Tiredness (0–100)	*M*: 40.4; *SD:* 21.7
Number of hours sleep last night	*M*: 5.9; *SD*: 1.7
Number of hours sleep usually	*M*: 7.5; *SD*: 0.8
Slept well last night	65.0%
Enough sleep during past 3 days	36.8%
No. of days at Lowlands	*M*: 2.4; *SD*: 1.0

[a] Missing values 5.1%. [b] Missing values 37.2%. [c] Missing values 26.0%. [d] Missing values 1.4%.

(slider scale, 0–100, rating "tiredness" from *not at all* to *extremely*), if they slept well last night (yes/no), how many hours they slept last night (options: 1 hr, 2 hr, . . . , 10 hr, or >10 hr), how many hours a night they usually sleep (options: 1 hr, 2 hr, . . . , 10 hr, or >10 hr), how many days they had been at Lowlands, and whether they had had enough sleep in the past 3 days (yes/no).

Misinformation Paradigm

To attract a high number of visitors, we used a VR version of a misinformation paradigm as used successfully in previous research (Kloft et al., 2020). Participants experienced a mock crime as an eyewitness in an immersive virtual environment, using the VR headset "HTC Vive." The headset is designed around a standout feature called "room scale" that allows the headset to utilize technology to turn a room into a 3D space within the VR environment. This allows a user to mimic the physical environment around them using motion-tracked handheld controllers to interact and manipulate objects for a fully immersive environment. Participants viewed a VR simulation of a crime taking place. In this scenario, the participant was inside a bar where they could walk around in a 3 × 3 m space. The space was secured by some barrier posts and researchers paid close attention that the participant did not exit this area or run into an object. Instructions given to participants were as follows:

> You will now enter a virtual reality simulation where you will be inside a bar. You can walk around in the bar but please do not walk into objects or people. You have about one minute to walk around and explore the bar. After one minute, a crime will take place. Please just observe what happens. The scenario will end automatically after the crime. Be aware that you are attached to a cable, so please do not make any fast or sudden movements.

Additionally, they were informed that they would be tapped on the shoulder by the experimenter if they were to walk too close toward a wall.

After 1 min, a fight involving a bar customer and two bouncers/security guards broke out. Prior to the physical fight, the "attacker" started shouting loudly and insulting the security personnel, which was purposefully designed in order to attract the visual attention of participants, who were anticipated to automatically orient themselves toward the sound (see https://osf.io/a7tmp, for a video of the VR simulation). The total duration of the simulation was 1.5 min. Following this, participants were interviewed by an experimenter in order to assess both true and false memory and susceptibility to suggestion. Misinformation was introduced directly in the interview through several leading questions. The interview consisted of intermixing suggestive misinformation questions with regular forced-choice recognition questions. Instructions to participants were as follows:

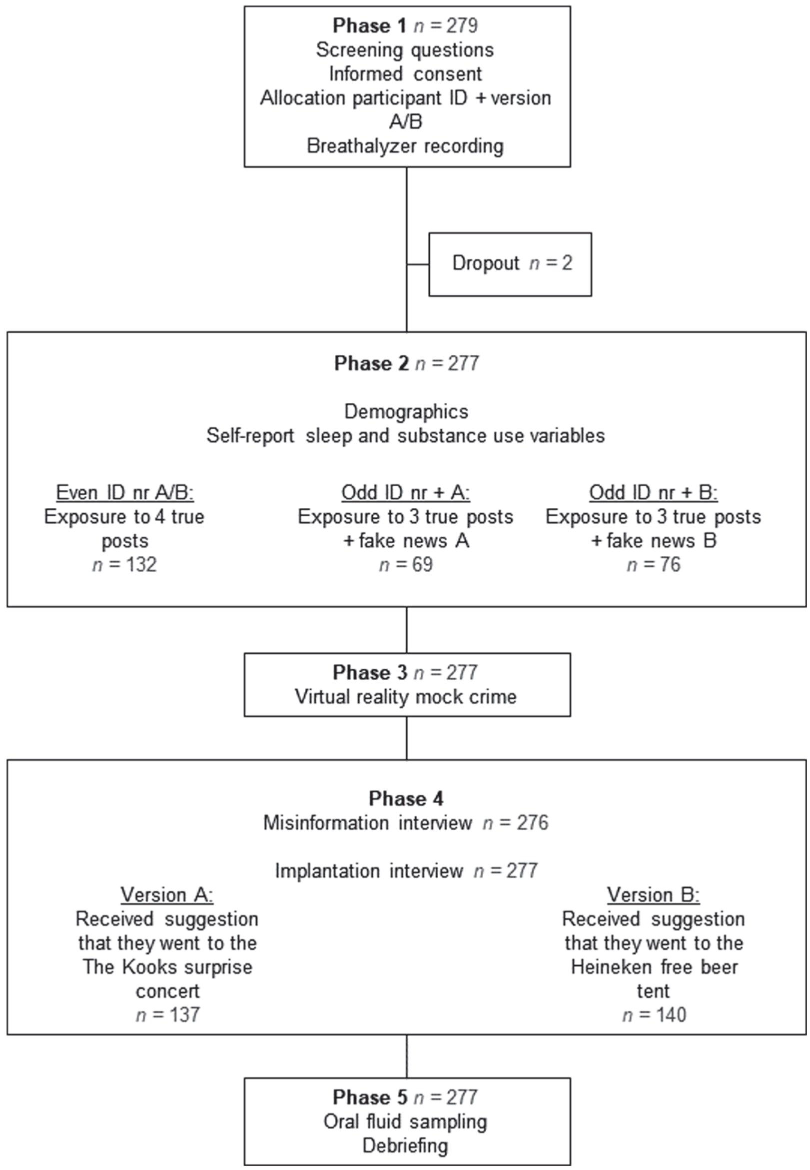
> I would like to ask you a few questions about what just happened in the VR scenario. I would like you to answer with "yes" or "no," if you do not know something just guess, and try to answer as truthful as you can. This only applies to the yes-no questions. There are also some other questions you need to answer.

The latter sentence was specifically mentioned so that people would not simply yield to all false alternative questions that made up the variable *susceptibility to suggestion* (see next paragraph), therefore distorting the score.

The interview consisted out of 31 questions, orally administered through an experimenter each time in the same order (see https://osf.io/a7tmp, for full transcript). There were 15 nonleading questions about truly presented details to measure *true memory* (e.g., "Did the security guard wear a yellow vest?" "Did you see guitars on the walls?"), six leading questions about nonpresented details to measure misinformation susceptibility, henceforth referred to as *misinformation false alarms* (e.g., "The attacker had a black coat on, right?" "Did you see the Elvis poster on the wall?"), and five nonsuggestive questions about nonpresented details to measure baseline false responding, henceforth referred to as *control false alarms* (e.g., "Was there a pizza place next door?" "Were there Christmas decorations in the bar?"). The latter category asked about details that the participant could not have seen (e.g., nothing visible out the window of the bar so no visible pizza place) or details that were unusual or distinct given the bar setting (e.g., Christmas decorations) and were included to ensure the subject is not simply yielding to any type of questions posed by the experimenter. Additionally, *susceptibility to suggestion*[2] was measured as the tendency to yield to five false alternative questions, that is, going along with either of the two incorrect response options (e.g., "Was the lady watching the attack holding a glass of red or white wine?" "Was the backpack on the chair blue or green?," when in fact there was no backpack and the lady was not holding a glass) as employed in previous research (van Oorsouw et al., 2019).

[2] The term was chosen to avoid confusion of our measure with the Gudjonsson Suggestibility Scales that measure interrogative suggestibility (Gudjonsson, 1997).

Figure 1
Study Flow Diagram



Implantation Paradigm

In the first step of this procedure, participants were confronted with a total of four screenshots of Instagram posts related to the festival (see Figure 1, for study flow). At the outset, participants were instructed that they would see some screenshots of social media posts made by other visitors or organizations of the Lowlands festival, and, as a cover story, were asked how likely they would share the post in their own social media feed (scale from 0 to 100). They were explicitly instructed to take into account both the picture content and the caption in order to ensure that they would pay attention to the title of the post. Half of the participants (all with even participant numbers) were presented with only true posts, which had been screenshotted directly from Instagram during the days leading up to the festival (e.g., depicting jewelry to be sold at the festival). The other half (all with odd participant numbers) were exposed to three true posts and one out of two fabricated posts containing fake news (A or B, according to participant number). The fake post in Version A showed a stage where the band "The Kooks" had supposedly given a surprise concert at Lowlands, naming one of the bigger stages of the festival by name. Version B showed a supposed beer tent sponsored by beer manufacturer Heineken that was giving out free (nonalcoholic) beer.[3] In reality, there was no Heineken free beer tent, and the band "The Kooks" did not play at the festival. The fabricated posts were similar in design to the posts depicting true events and displayed comments to add to the illusion of a real post. All posts were presented one by one in randomized

[3] The post had previously been approved by a Heineken Nederland B.V. brand management team member. Readers who wish to view the posts may contact the corresponding author.

order, accompanied by a likelihood-to-share rating scale. Subsequent to each post, a multiple-choice question depicting three options was posed, asking about the caption (title) of the previously viewed post. This served as an attention check to ensure that participants paid attention to the captions.

In a later phase of the research, participants underwent an interview in which they were asked about their experiences at the festival. This interview contained the implantation manipulation, which all participants received, but there were parallel Versions (A or B). In Version A, participants received the suggestion that they had been to the surprise concert by the Kooks, and in Version B, it was suggested that they had been to the Heineken free beer tent. At the outset, participants were told that since the study was focused on memory, it was also of interest how well they would remember things at the festival. They were asked about a total of five events in randomized order. Four were distractor events that visitors might have come across at the festival (e.g., "Did you go to the silent disco?"). The fifth event was the fake event, entailing the implantation manipulation. Here, the experimenter initially asked whether the participant went to the fake event (A: "Did you go to the 'The Kooks' surprise concert?" B: "Did you go to the Heineken free beer tent?"). Subsequently, the experimenter pretended being highly certain that the participant had in fact been at the suggested event, verbally claiming that he/she spotted the participant in the crowd (e.g., "Hey, that's why you seem familiar, I think I saw you there! I'm sure I spotted you in the crowd."). Thus, the manipulation involved some acting on behalf of the experimenter to convince participants, which did not follow a standardized script. For each event, participants were asked to separately rate their *belief* that the event happened, and their *recollection* of it each on an 8-point Likert scale adopted from Scoboria et al. (2004). For example, to assess belief, they were asked "How likely is it that you did in fact go to the Heineken free beer tent?" on a scale from 1 (*definitely did not happen*) to 8 (*definitely did happen*) and to assess recollection "Do you actually remember going to the Heineken free beer tent?" on a scale from 1 (*no memory of event at all*) to 8 (*clear and complete memory of event*). It was explained to participants that when experiencing events, it is possible to believe that an event happened but to not have a vivid memory of it, and vice versa. In addition, for the fake news item, it was logged whether the participant accepted the misinformation (yes/no/maybe but unsure), and whether they came up with additional details (yes/no).

Procedure

The study flow is depicted in Figure 1. The study was set up in a 4 × 6 m lab space within a large container containing multiple labs, as part of the Lowlands Science side attraction. The study was advertised by the festival as a "virtual reality crime study." As a cover story, the study was described as focusing on the VR eyewitness scenario, with the aim of investigating effects of alcohol and lack of sleep on memory for a witnessed criminal event. Additionally, before the exposure to true and fake news, participants were informed that they would view social media posts that were recently posted by other festival visitors. These measures were taken to prevent suspicion.

Given the small lab space, the space was divided into five research stations corresponding to five research phases, each carried out by one to two experimenters, respectively. In Phase 1, when an interested participant approached the lab, they were provided with oral and written information about the study, given the opportunity to ask questions, and asked to sign informed consent. Three screening questions were asked (orientation to space and time, simple math equation) to determine the capability of giving informed consent (none failed). Subsequently, a sticker was attached to the participant's shirt, displaying their participant number and randomization (A or B, randomly allocated). The sticker also contained the main researcher's contact information and a statement that they may contact the team if they wished to withdraw their consent at a later point or to request further information about the study. Participants were then given a sip of water to rinse their mouth before they were breathalyzed. This completed Phase 1.

In Phase 2, participants were sat at a table on one of four laptops and were handed soundproof over-ear headphones to prevent them from overhearing interviews conducted by other experimenters. To allocate which participant received the fake news, we used separate survey versions using the web-based survey tool "Qualtrics." All participants were asked to answer demographic questions and to provide information about their sleep as well as alcohol and drug use. Next, they were shown five Instagram posts: half of the participants received true posts only, and the other half received four true posts and one fake post. Only the participants with odd participant numbers received the version containing fake news (all three versions visible on https://osf.io/a7tmp).

In Phase 3, participants underwent the VR simulation in a 3 × 3 m area separated by barrier poles in the back of the lab. This eyewitness scenario depicts a bar, which the participant can explore, until after 1 min a fight breaks out between some guests. The scenario ends automatically after the perpetrator has run away (total length of 1.5 min).

In Phase 4, participants were interviewed by an experimenter about their experiences at Lowlands (implantation paradigm) and about the VR scenario (misinformation paradigm), using a YUNTAB 10.1-inch PC K17 Android tablet. Participants were also asked to identify the VR perpetrator from a lineup (analyses will be reported elsewhere).

Phase 5 entailed providing participants with two collectors to obtain saliva samples: one for the onsite screening (Dräger DrugCheck 3000) and one for the confirmation analysis (Dräger DCD 5000). The major benefit to testing of saliva is an easy and hygienic sample collection that can occur in the presence of another person without invasion of the donor's privacy. Additionally, it is characterized by reduced risk of sample adulteration, dilution, and substitution. Saliva normally contains the parent drug substance rather than drug metabolites, which makes saliva an attractive matrix for use in detection of recent drug use and in interpretation of possible drug-induced behavioral effects.

This concluded the study, and participants received a debriefing statement as well as the opportunity to ask questions. In accordance with Lowlands Science policy, participants were not reimbursed for their time since only experiments deemed attractive and interesting for participants were accepted in the first place. The entire study was conducted in the English language. Participants also had the opportunity to learn their BrAC level once the study was completed, which for some was a motivation to complete the study.

Statistical Approach

Misinformation Paradigm

Primary Analyses. We calculated the following dependent variables (DVs): hits (proportion correctly recognized true details), misinformation false alarms (proportion falsely recognized misinformation details), control false alarms (proportion falsely recognized nonsuggested details), susceptibility to suggestion (number of items yielded to 0–5). In addition, signal detection parameters were calculated to assess sensitivity as $d' = Z\text{(hits)} - Z\text{(false alarms}^{4})$ with higher values signaling greater discrimination ability, and response bias as $c = -1/2\,[(Z\text{(hits)} + Z\text{(false alarms)}]$, where positive values indicate conservative and negative values liberal response tendencies (Macmillan & Creelman, 2004).

Stepwise multiple regression analyses were conducted to assess whether sleep restriction and substance intoxication predicted memory performance on the six DVs. To control for Type I error, we adopted a corrected α level of .05/6 (divided by the number of DVs), α = .008. In line with Frenda et al. (2014), the number of *hours of sleep* last night was utilized as our measure of sleep restriction (continuous predictor, lower levels representing more sleep restriction). Substance intoxication was operationalized as the *number of active substances* that a participant had recently used, as indicated using the breathalyzer and saliva tests. In a large number of cases, alcohol and/or other substances were detected (see Results section); however, many of the detected concentrations were rather low. Therefore, to identify participants that had recently used a substance and thus could be assumed to be under acute influence, we applied established cutoff thresholds in saliva signaling recent use (e.g., as applied in roadside drug testing) of THC (30 ng/L), cocaine (20 ng/ml), amphetamines (50 ng/ml), and MDMA (50 ng/ml). For alcohol, we set the cutoff at breath alcohol levels of 0.07%. This was based on the combined data of boundary analyses conducted by Sauerland et al. (2018), showing that the optimum BAC boundary is at 0.07% after which memory performance starts to decrease. In addition to that, in some lab studies, memory undermining effects of alcohol were found at levels between 0.06% and 0.08% (Hildebrand Karlén et al., 2014). Combining these two findings led us to choose for the cutoff of 0.07%. Therefore, the variable *number of active substances* represented intoxication above these cutoff values, with higher scores indicating intoxication with more substances. Six cases were excluded from the primary analyses due to use of the following: Ritalin (n = 1), Diphenhydramine (n = 1), Tramadol (n = 1), Oxazepam (n = 1), Methadone (n = 1), Lidocaine (n = 1).

Exploratory Analyses. In the primary analyses, we considered multiple active substances lumped together. However, a fair point of criticism of that approach is that not all substances have equal effects on true and false memory (see Kloft et al., 2021, for a review). Therefore, in exploratory analyses, we aimed to gain a more nuanced picture, zooming in on each substance's effects. We used the above-mentioned impairment cutoff thresholds to identify *active* substance use groups for THC (n = 10), amphetamines (n = 11), MDMA (n = 40), cocaine (n = 9), and alcohol (n = 22).[5] However, it has to be noted that these groups were not mutually exclusive, as, for example, some individuals were positive in saliva for multiple substances, both above and below the cutoff threshold. We also used the dichotomization adopted by Frenda et al. (2014) to identify sleep-restricted individuals (5 hr or less of sleep last night) and non-sleep-restricted individuals (6 hr or more). A control group consisted of individuals who had no sleep restriction and had not used any alcohol or other substances (neither below nor above the cutoff; n = 64). Identifying these groups led to a subsample of n = 140. In a series of six hierarchical stepwise multiple linear regression analyses within this subsample, we tested the effects of substance intoxication with THC, amphetamine, MDMA, cocaine, and alcohol use as binary predictors on the six DVs while controlling for sleep restriction (*hours of sleep* as a covariate; Model 1 = covariate only, Model 2 = all predictors).

For a correlational analysis of BrACs and all DVs, please see the Supplemental Information.

Implantation Paradigm

To obtain an overall picture of the success of our implantation, we first examined the percentages of participants that indicated elevated (>1) belief, elevated recollection, and both elevated belief and recollection in response to manipulation A (The Kooks surprise concert), B (Heineken free beer tent), and both collapsed together. To test the effects of fake news exposure, substance intoxication, and sleep restriction and their interaction on false belief and false recollection, we conducted general linear model (GLM) analyses using a hierarchical approach. Using the categorical predictors fake news exposure (yes/no), sleep restriction (yes/no), and substance intoxication (number of active substances: 0–3), analyses were conducted with initially all interaction terms included in the model. If the highest order term did not meet statistical significance, the analyses were repeated with that term removed. This procedure was repeated, further simplifying the model by removing the highest order term with the largest p value, until no more terms could be removed. Each predictor was also tested in isolation of the others. Participants who had received fake news but did not pass the attention check for the fake news item were excluded from the GLM analyses.

Results

Alcohol and Substance Use

Objective

Breathalyzer results showed a reading of 0.00% for 162 participants, whereas 114 participants had a reading >0.00% (n = 1 missing). Of the ones who tested positive for alcohol, BrACs ranged from 0.008% to 0.15% (M = .048, SD = .029).

According to the saliva tests, 114 participants were positive for any substance, and in total, 170 times was a substance detected. There were participants who used several different substances, explaining the higher number of positive substance tests. The positive tests included the following substances/substance classes: amphetamines (in 26.7% of the whole sample, concentrations above the limit of detection of this substance were detected), cocaine (10.8%), THC (11.9%), ketamine (9.0%), opioids/opiates (1.4%), and benzodiazepines (0.7%; for full details, see "Dräger results" on https://osf.io/a7tmp).

[4] The signal detection analyses were based on all false alarms.

[5] Twenty-six concentrations of ketamine were detected, ranging from 0.2 to 23.6 ng/ml. Recent use of ketamine is signaled by saliva concentrations far exceeding 1,000 ng/ml (Tsui et al., 2012), therefore, it is fair to assume that all concentrations in our sample were negligible and were not taken into account in further analyses.

Self-Report

Table 1 shows an overview of the self-report data. Seventy-nine participants indicated that they had not had any alcohol on the day of testing. There were 238 participants who indicated not having used any substance (other than alcohol), whereas 42 indicated having used one or more substance(s).

Misinformation Paradigm

Primary Analyses

Table 2 displays the summary statistics from the stepwise regression analyses on all DVs, using hours of sleep and number of active substances as predictors. Hours of sleep emerged as the single statistically significant predictor for the memory variables of control false alarms and susceptibility to suggestion. Inspection of the regression coefficients revealed that number of hours of sleep was negatively related to control false alarms and susceptibility to suggestion. In other words, more sleep-restricted individuals displayed higher control false alarm and susceptibility to suggestion rates. However, overall hours of sleep only accounted for 3.9%–4.3% of the variance (see Table 2). The model was not statistically significant for the DVs hits, misinformation false alarms, sensitivity, and response bias.

Exploratory Analyses

For each of the six DVs, hours of sleep was entered in Model 1, and the binary predictors specifying drug use (THC, amphetamines, MDMA, cocaine, alcohol) were entered using the stepwise method in Model 2. Use of THC and use of amphetamines emerged as the only statistically significant predictors of control false alarms, $F(2, 137) = 7.29$, $p < .001$, $R^2 = .096$. Inspection of the regression coefficients showed that both variables were positively related to control false alarms, THC: $\beta = .24$, $t(137) = 2.95$, $p = .004$; amphetamines: $\beta = .22$, $t(137) = 2.66$, $p = .009$, indicating that participants who had been tested positive for THC or amphetamines scored higher on control false alarms. Drug use did not explain any statistically significant portions of the variance in any of the other DVs (all analyses can be retrieved from the OSF: https://osf.io/a7tmp). Table 3 depicts mean scores of each subgroup on all DVs, including the sleep-restricted subgroup for reference.

Implantation Paradigm

$N = 6$ observations were excluded due to a mismatch in fake news and manipulation conditions, leaving $n = 271$ valid observations, that is, participants who were interviewed about events at Lowlands and it was suggested that they had been at the fake event. Out of these participants, $n = 139$ (51.3%) had previously been exposed to fake news. In total (A and B collapsed together), the majority of participants indicated no belief that the suggested event occurred (86.8%, $n = 44$ missing), while 13.2% of those asked had a belief score >1 ($M = 4.5$, $SD = 2.24$). For recollection, the majority did not report any memory of the suggested event (93.8%, $n = 46$ missing), but a proportion of 6.2% indicated an elevated recollection score of >1 ($M = 6.29$, $SD = 2.02$). For results split by Version A versus B, please see Table 4.

Table 2
Misinformation/Susceptibility to Suggestion Primary Analyses: Stepwise Regression

	Descriptives[a]			Model statistics					Coefficients			
Dependent variable	*M*	*SD*	*SE*	*R*	R^2	Significant predictor	*t*	*p*	Unstandardized	*SE*	Standardized	95% CI
Hits (true memory)	0.611	0.132	0.008	0.152	0.023	—	—	—	—	—	—	—
False alarms (misinformation)	0.265	0.176	0.011	0.000	0.000	—	—	—	—	—	—	—
False alarms (control)	0.077	0.121	0.007	0.196	0.039	Hours of sleep	−3.280	0.001	−0.015	0.004	−0.196	[−0.023, −0.006]
Susceptibility to suggestion	2.963	1.51	0.092	0.208	0.043	Hours of sleep	−3.180	0.002	−0.176	0.055	−0.191	[−0.284, −0.067]
Sensitivity *d′*	1.324	0.566	0.034	0.000	0.000	—	—	—	—	—	—	—
Response bias *c*	0.362	0.354	0.021	0.160	0.026	—	—	—	—	—	—	—

Note. *SE* = standard error; CI = confidence interval.
[a] All based on $n = 270$.

Table 3
Misinformation/Susceptibility to Suggestion Parameters by Subgroup, M (SD)

Group (*n*)	Hits	Critical false alarms	Control false alarms	Suggestibility (yield score, 0–5)	Sensitivity	Response bias
Control (64)	.63 (.13)	.27 (.17)	.05 (.09)	2.75 (1.66)	1.43 (.58)	.37 (.36)
MDMA (40)	.63 (.13)	.26 (.18)	.08 (.12)	3.2 (1.24)	1.40 (.57)	.33 (.36)
Amphetamine (11)	.59 (.09)	.21 (.15)	.15 (.13)	2.7 (1.56)	1.22 (.38)	.38 (.31)
Cocaine (9)	.59 (.09)	.28 (.14)	.02 (.06)	3.2 (1.09)	1.30 (.42)	.41 (.28)
THC (10)	.62 (.10)	.27 (.18)	.16 (.16)	3.80 (.79)	1.19 (.57)	.28 (.30)
Alcohol (22)	.58 (.11)	.28 (.16)	.05 (.11)	2.55 (1.60)	1.18 (.36)	.38 (.23)
Sleep-restricted (33)	.61 (.11)	.29 (.16)	.10 (.14)	3.00 (1.68)	1.20 (.51)	.31 (.29)

Note. All based on n = 140. THC = tetrahydrocannabinol.

For the following analyses, 12 observations were excluded due to failure of the attention check. In the series of hierarchical two-way analysis of variance, neither of the categorical predictors *fake news exposure*, *hours of sleep*, and *number of active substances* nor their interaction were statistically significantly associated with false belief or false recollection (all *p*s >.05, see https://osf.io/a7tmp).

Discussion

In this field study, we examined effects of naturally occurring substance intoxication and sleep deficits on false memory formation. In a misinformation paradigm, music festival visitors were exposed to, and subsequently interviewed about, a VR eyewitness scenario. Here, restricted sleep but not the number of substances detected was associated with increased susceptibility to suggestion and false responses to nonsuggestive questions (control false alarms). Exploratory analyses suggested that use of THC and amphetamine elevated the risk of control false alarms. Additionally, we aimed to implant FM of recent festival events, exposing half the participants to fake news of said event. Implanted FM were not affected by fake news exposure, sleep restriction, or intoxication.

Table 4
Results From the Implantation Paradigm Split by Version A Versus B

	A	B
	The Kooks surprise concert	Heineken free beer tent
Dependent variable	*n* (valid percent)	
Received manipulation	132 (49%)	139 (51%)
Said they went to the fake event[a]		
Yes	3 (4%)	8 (6%)
No	79 (96%)	131 (94%)
Belief in fake event[b]		
Some belief (score > 1)	12 (11%)	18 (15%)
No belief (score = 1)	97 (89%)	101 (85%)
Recollection of fake event[c]		
Some recollection (score > 1)	5 (5%)	9 (8%)
No recollection (score = 1)	105 (96%)	106 (92%)
Accepted the misinformation[d]		
Yes	7 (5%)	6 (4%)
No	117 (89%)	123 (89%)
Experimenter unsure	7 (5%	10 (7%)
Came up with additional detail[e]		
Yes	1 (1%)	6 (4%)
No	131 (99%)	132 (96%)

[a] n = 50 missing responses. [b] n = 44 missing responses. [c] n = 46 missing responses. [d] n = 1 missing responses. [e] n = 6 missing responses.

In our misinformation task, sleep restriction was associated with some memory variables, but not others. Reduced sleep predicted a greater susceptibility to suggestion ($R^2 = 4\%$) and higher false alarms for control questions ($R^2 = 4\%$), but was not associated with true memory or misinformation-related false alarms. Our results are partially in line with previous research showing greater levels of FM and interrogative suggestibility in sleep-deprived individuals (Blagrove, 1996). While sleep restriction only explained little variance, it should be noted that in previous research, participants were sleep-deprived for an entire night or restricted to a few hours for multiple nights, with strongest false memory effects after an entire deprived night (Blagrove, 1996; Frenda et al., 2014; Lo et al., 2016). In our sample, all participants had some sleep. Still, our findings add to the growing body of experimentation showing that sleep restriction can amplify false memory creation.

The number of substances that a participant had recently used did not predict memory performance in the misinformation paradigm. Possibly, lumping substances of different pharmacological mechanisms and cognitive effects together was a crude measure of intoxication, thereby nullifying any memory effects. Zooming in on single substances, the use of THC, and the use of amphetamines was related to higher levels of control false alarms when compared to a sober control group, even when controlling for sleep restriction. THC administration prior to memory retrieval has been shown to elevate FM of stimuli such as words, pictures, and details from a VR crime, inducing a response bias particularly for unrelated items (Doss et al., 2018; Hart et al., 2010; Ilan et al., 2004; Kloft et al., 2019, 2020). Similarly, administration of the stimulant dextroamphetamine before retrieval increased false memory rates in a word and a picture memory task (Ballard et al., 2014). Our findings underline that intoxication with THC and amphetamines can foster false responding, and that particularly nonsuggestive questions about nonpresented details seem to be sensitive to drug influence. Control measures of false alarms tend to be treated as by-products in recognition tasks and are used to adjust hit and misinformation rates (Gallo, 2010), but can evidently be informative when it comes to drug intoxication.

In our implantation paradigm, prior exposure to fake Instagram posts did not exacerbate false beliefs or recollections of a fake festival event. Given the short retention interval, providing a visual cue might have backfired and facilitated rejection of the suggested event by enabling participants to rely on their visual memory and distinguish the depicted place from truly visited places. Doctored pictures have been associated with lower rates of implanted FM previously, compared to other suggestive techniques (Garry & Wade, 2005; Scoboria et al., 2017).

Overall, low proportions of participants reported believing or recollecting the fake event to some extent, indicating that the manipulation was not successful when compared to other implantation studies (average FM rates of ca. 30%, Scoboria et al., 2017). However, a crucial difference between our and other studies is that we aimed to implant recent rather than childhood events, with a single suggestive occasion rather than multiple (e.g., Otgaar et al., 2013). Memory of festival events might have still been too well preserved given their relative recentness and event centrality, as people are less suggestible after shorter delays and when information is central rather than peripheral (Loftus et al., 1978; Paz-Alonso & Goodman, 2008). Given the low implanted false memory rate, we recommend caution in interpreting the null results regarding the relationships between sleep, substance use, and false belief and recollection.

Limitations other than those inherent to field studies are that the substance subgroups used in our exploratory analyses were small and sometimes included individuals with polysubstance use (see https://osf.io/a7tmp, for all drug information). Thus, the subgroups might not always have represented the pure effects of a single substance, which can be better achieved through placebo-controlled experiments. Another limitation was that in our misinformation task, participants were instructed to guess if they were unsure when answering questions about the VR crime. This might not reflect how witnesses behave in a real interview context, thus limiting the generalizability of findings—an aspect that could be improved in future studies (see Supplemental Information, for more information).

Concerning practical implications, findings suggest that witness interviews about a crime should preferably happen while being well-rested and sober. Yet, from the alcohol intoxication literature, we learn that sobering up (i.e., introducing a delay before the first interview) reduces memory completeness (Schreiber Compo et al., 2017) and may increase suggestibility (van Oorsouw et al., 2019). However, the use of substances such as THC and amphetamines may increase false responding when individuals are questioned while intoxicated, which could be exacerbated when combined with sleep deprivation. Although, in practice, it is difficult to have the optimal conditions for interviewing intoxicated and/or sleep-deprived witnesses, it is important for interrogators to be aware of the nuanced risks of different drugs on memory.

Additionally, the finding that THC and amphetamines were linked to amplified levels of control false alarms bears relevance to the issue of spontaneous memory errors (Brainerd et al., 2008). That is, apart from the formation of memory errors due to suggestion, false reports might also happen spontaneously. Such false statements might occur when using open-ended questions, but also when using simple yes–no questions are used (Roediger & McDermott, 1995). Police investigations often rely on the use of simple yes–no questions ("Did you also see a different robber?") that might suggest details that were not attended by a witness and might or might not be related to the criminal event. When the police ask about details that are related, but not part of, to the criminal event, our work shows that when under the influence of THC or amphetamines, even without suggestion, the reliability of witness testimonies can be comprised. Furthermore, our findings show that even for details that at first sight are unlikely to be related to the criminal event (e.g., Christmas decorations), participants intoxicated by THC or amphetamines highly endorsed these items. We included these details as control questions to ensure that participants were not just assenting to all questions. Although such control details might not always be asked in police interviews, when they do, the reliability of witness testimonies is not only comprised, but witnesses might also appear less credible.

In sum, in this study, we examined the effects of everyday sleep deficits and psychoactive drug use on false memory creation and suggestibility. We observed several effects that had previously been studied in lab environments, demonstrating the real-world applicability of those effects.

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Received March 16, 2021
Revision received May 29, 2022
Accepted June 29, 2022 ■