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Virtual reality induces symptoms of depersonalization and derealization: A longitudinal randomised control trial

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ABSTRACT

Trusting reports on internet forums, a substantial number of people have developed unpleasant symptoms of depersonalization (DP) and derealization (DR) after virtual reality (VR) consumption. Likewise, one case series study indicates that even after one single VR session, transient DPDR experiences may occur. Despite these indications, little is otherwise known about the risk of developing DPDR from VR consumption. Therefore, we carried out the present longitudinal randomised controlled trial (N = 80), which examined, whether VR-gaming induces higher DPDR effects than classical PC gaming, and if so, how long DPDR effects persist. DPDR effects were assessed immediately before gaming (T0), immediately after gaming (T1), one day after gaming (T2) and one week after gaming (T3). Moreover, given evidence for an emotional hyporeagibility under DPDR, the participants' emotional and physiological (EDA, HRV) reagibility towards emotional pictures was assessed immediately after gaming. Likewise, to study whether certain personality traits might be associated with the occurrence of VR-induced DPDR effects, we administered a personality inventory to our participants. Results reveal that, after VR gaming, a significantly stronger DPDR experience was reported in the VR group than PC group at T1, while at T2 and T3, no significant DPDR group differences were detectable. Furthermore, no significant group differences were found in respect to emotional and physiological reagibility, nor were any correlations between personality traits and DPDR symptoms found. In summary, although our study provides further evidence that VR consumption can transiently induce DPDR-like symptoms, we find no evidence that these DPDR effects persist in the long term.

1. Introduction

Virtual reality (VR) is an innovative technology that enables a computer-generated simulation of highly immersive, interactive and reality-close environments. While VR had a niche existence for decades, it has become popular at least since 2013, when the first affordable, high-quality head-mounted displays (e.g. the Oculus Rift and HTC VIVE) entered the end consumer market. While in 2018, already ~21.9 million US citizens had experiences with VR, this number raised to ~45.3 million in 2020, and for 2023, 70.2 million US-American VR consumers are expected (ARtillery Intelligence, 2020). The novel aspect about VR is, that it may induce a particularly vivid sense of realness and presence towards computer-mediated virtual environments, which could not be evoked in this intensity by any other digital technology before, and whose immersiveness is likely to increase in the future even further.

As novel, promising and potent VR is as a technology, as huge might be its potential risks to also cause side effects. In fact, some investigations of side effects of VR have been carried out, e.g. related to cybersickness (Chang et al., 2020; Dużmańska et al., 2018), or the possible induction of aggressive behavior by VR gaming, which could be negated (Drummond et al., 2021; Ferguson et al., 2022). Other potential side effects are so far largely unexplored. Instead, as philosopher Thomas Metzinger recently put it, the current situation of VR rather resembles a "kind of mass experiment" (Michel, 2016) to which humanity becomes exposed.

As outlined below, several indications, for instance, exist that VR might induce symptoms of depersonalization (DP) and derealization (DR). While DP describes a feeling of alienation and unrealness towards the own self, DR describes a feeling of unrealness or detachment from reality (American Psychiatric Association, 2013).

DPDR symptoms are described to occur as a secondary symptom within the scope of other mental disorders, as a singular mental disorder,

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and as a relatively frequent phenomenon in healthy people, for example as a mere transient stress response (Hunter et al., 2004). Depending on the persistency and intensity of the DPDR symptoms, a massive suffering and loss of quality of life have been reported in individuals affected by DPDR (Baker et al., 2003).

One indication that VR might cause DPDR symptoms are numerous web forum reports, in which VR consumers complain about their DPDR experiences after VR gaming. One VR consumer, for instance, reports that after VR gaming, he first perceived his hands to be unreal, and then, he felt being completely alienated from his own body and to be detached from reality (HappyHimitsu222, 2016). In line with this, another forum user states that, after consuming VR, his arms felt like fake and the (real) world started to feel unreal (lippidude, 2021). These and similar symptom descriptions can repeatedly be found in various web forums.

Moreover, besides these unaudited single case reports, also some experimental evidence exists that VR might induce transient DPDR symptoms. Such evidence comes, for instance, from a study by Aardema et al. (2010), in which n = 30 healthy participants were immersed into a virtual environment for a total of 25 min, during which the participants had to complete a counting task. Immediately before and after this single VR session, the participants were surveyed about potential momentary DPDR symptoms. The outcome was that, on average, participants reported a significant raise of DPDR symptoms and concomitant decrease of feeling present in objective reality, from before to after the VR session. It bears mentioning, however, that the DPDR symptoms reported were significantly lower in intensity than those typically reported in the context of mental illness.

While Aardema et al.'s study (2010) provides important first empirical evidence that VR might induce DPDR symptoms, the study had some methodological flaws. First, Aardema et al.'s study investigated the induction of VR-induced DPDR experiences in a pre-post design without any control group or control conditions. This is suboptimal, because no information can be gained about the specificity of the found effect. The question remains, for instance, whether the induction of DPDR experiences specifically relies on immersive VR environments, or if DPDR experiences are similarly inducible by other digital media, too. Second, only immediate effects of VR on reality experiencing were investigated, while no long-term investigation was conducted. However, to assess possible risks of VR, it is crucial to not only consider immediate DPDR effects, but also potential long-term effects. Third, Aardema et al.'s study (2010) only assessed the participant's phenomenal experiences of reality, but it did not acquire any physiological DPDR measures. It would be interesting to examine, though, whether VR-induced DPDR experiences are accompanied by psychophysiological changes. Given general evidence for a reduced autonomic responsiveness under DPDR, especially towards (negative) emotional stimuli (Dewe et al., 2016; Sierra et al., 2002), it would be interesting to see, whether a similar physiological hyporeagibility also occurs under VR-induced DPDR experiences. Fourth, no investigation of a possible impact of personality traits on the development of DPDR symptoms was conducted. Such an investigation would, however, be desirable since the literature suggests a correlation between dissociative experiences and personality traits, especially for neuroticism (De Silva & Ward, 1993; Kwapil et al., 2002; Ruiz et al., 1999), but also for other personality traits (Ruiz et al., 1999). Hence, it would be interesting to know, whether some personality traits particularly increase the vulnerability to VR-induced DPDR.

In the present longitudinal randomized control trial (RCT), we complemented Aardema et al.'s (2010) study and investigated whether VR-gaming induces higher DPDR-experiences than classical PC gaming, and if so, how long these effects persist. Moreover, given the evidence for a reduced emotional responsiveness and physiological hypoarousal under DPDR (Dewe et al., 2016; Sierra et al., 2002), we examined, whether VR gaming induces similar physiological effects when participants become confronted with emotional images. In addition, we investigated, whether certain personality traits are particularly related with trait DPDR and VR-induced DPDR.

2. Materials and methods

2.1. Participants

Participants (n = 86) were recruited via posters and other publicly accessible media (cf. 2.12. for a sample size calculation). They all were screened for eligibility, out of which n = 80 participants (38 female) were included into the study (see Table 1, for demographic and clinical data). To partake in the study, participants were required to have a normal or corrected-to-normal vision, no present psychiatric or neurological disorder and to give written informed consent to the study. All participants were paid for their participation. Participants that fully completed the study, received an expense allowance of 30€. Participants that prematurely terminated the study, received a part payment. The study was approved by the local medical ethics committee of the University of Bonn (protocol number: 240/18).

2.2. Study design

The study was carried out as a longitudinal RCT with two intervention groups (VR group, PC group) and four measurement time points. Both interventions consisted of playing an identical computer game either via a head-mounted display (HMD) in case of the VR group or via a classic computer screen in case of the PC group. The four measurement points consisted in DPDR-assessments immediately before gaming (T0), immediately after gaming (T1), one day after gaming (T2) and one week after gaming (T3). Participants were randomly assigned to the two groups.

2.3. General procedure

Fig. 1 gives a compact overview of the study procedure. After the participants had been informed about the study and given their consent, they first underwent an eligibility assessment (cf. 2.4). Next, in case they were considered eligible, they underwent a DPDR baseline assessment (T0) by filling out various DPDR-questionnaires (cf. 2.6).

After that, the participants entered the VR room where the game playing took place. Before the participants, however, started playing,

Table 1
Demographic and questionnaire data.

	PC (40)	VR (40)	
Female: n (%)	16 (40%)	22 (55%)	
Age: mean (SD)	24.20 (3.24)	24.15 (3.61)	
Questionnaire data	n = 39	n = 34	*t*-test
CDS-Trait	8.05 (11.75)	6.61 (9.53)	$T(71) = 0.57$; $p = .570$; d = 0.13; g = 0.13
BDI	2.59 (2.74)	2.74 (3.73)	$T(71) = -0.19$; $p = .849$; d = −0.05; g = −0.04
DSS	0.74 (1.33)	0.52 (1.09)	$T(70) = 0.79$; $p = .435$; d = 0.19; g = 0.18
VRSQ	6.47 (8.84)	31.13 (23.39)	$T(71) = -6.11$; $p < .001$; d = −1.43; g = −1.42
Difficulty of Game Control	0.64 (0.99)	1.82 (0.90)	$T(71) = -5.31$; $p < .001$; d = −1.25; g = −1.23
Previous experience VR	0.67 (0.70)	0.62 (0.70)	$T(71) = 0.30$; $p = .766$; d = 0.07; g = 0.07
Previous experience PC	2.08 (1.04)	2.09 (0.87)	$T(71) = -0.05$; $p = .960$; d = −0.01; g = −0.01
Neuroticism	13.67 (7.69)	14.70 (5.69)	$T(68) = -0.63$; $p = .534$; d = −0.15; g = −0.15

Abbreviations: CDS, Cambridge Depersonalization Scale; BDI, Becks Depression Inventory; DSS, Depersonalization Severity Scale; VRSQ, Virtual Reality Sickness Questionnaire.

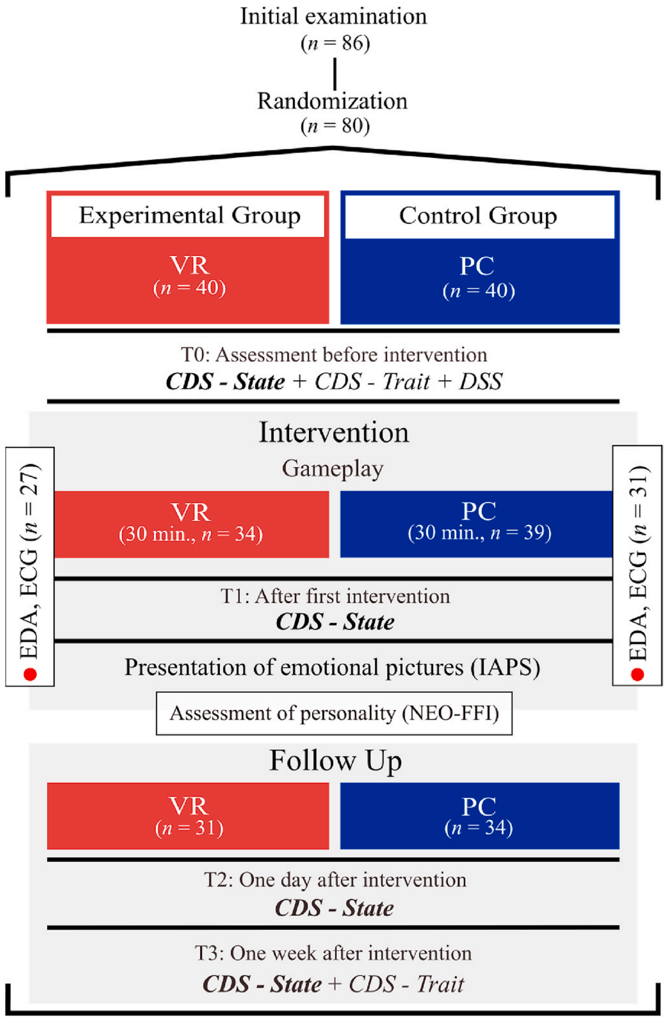

Fig. 1. General Procedure.
First, a standardised psychological examination was performed, followed by randomization of eligible participants. Next, the depersonalization/derealization (DPDR) level at baseline (T0) was assessed via the trait and state versions of the Cambridge Depersonalization Scale (CDS-Trait, CDS-State) and the Depersonalization Severity Scale (DSS). After that, the experiment with the VR or PC game took place, before the second DPDR assessment (T1) was captured and the participant's emotional responsiveness was measured based on the International Affective Picture System (IAPS). To this end, electrodermal activity (EDA) and an electrocardiogram (ECG) were recorded. Moreover, character traits were assessed via the NEO Five-factor inventory (NEO-FFI). Likewise, follow up screenings on DPDR symptomatology were conducted one day (T2) and one week (T3) after the intervention.

they were first prepared for the concomitant electrophysiological recordings (cf. 2.8, 2.9), acquainted with the computer game used (cf. 2.5), and undergoing a 1-min resting phase, during which they had to relax. Next, the participants played the game for 30 min. Immediately after that, the participants were again surveyed about their momentary DPDR experiences (T1). Moreover, the participants were shown various emotional pictures and had to report their emotional stance towards these pictures (cf. 2.7). Also, they had to fill out some post-experimental questionnaires (cf. 2.10). Finally, before the participants left the VR room, they were given a further set of DPDR questionnaires, which they were required to fill out at home one day (T2) and one week after the experiment (T3). The whole experiment, including the clinical assessment phase, lasted around 3 h.

2.4. Eligibility assessment

To exclusively include mentally healthy participants into the study, an extensive psychopathological assessment was carried out before the experiment based on the German versions of the "Structured Clinical Interview for DSM-IV" for Axis I disorders (SKID I; Wittchen et al., 1997) and Axis II disorders (SKID II; Fydrich et al., 1997). Only those persons who did not presently meet the diagnostic criteria for any Axis I or II disorder were retained in the study.

Moreover, to preclude other potential reasons for exclusion and further characterize the study population, the following questionnaires were additionally administered:

- *Becks Depression Inventory II* (BDI-II): A popular 21-item self-report inventory for assessing symptoms of depression in the last two weeks, with a total range from 0 (no depression) to 63 (severe depression). The German version (Kühner et al., 2007) of BDI-II was used and filled in during pretesting.
- *Cambridge Depersonalization Scale – Trait Version* (CDS-Trait): A 29-item questionnaire that assesses the frequency and occurrence durations of DPDR symptoms over the last six months. Regarding DPDR frequency, a maximum value of 116 can be reached by the CDS-Trait, whereas for the occurrence of DPDR symptoms a maximum value of 174 is reachable. The German version of the CDS-Trait (Michal et al., 2004) was used and administered before and one week after the experiment.
- *Depersonalization Severity Scale* (DSS): Another 6-item questionnaire, which evaluates the occurrence and severity of DPDR-symptoms over the whole lifetime (Michal et al., 2010). The maximum score achievable is 18. The DSS was filled in before the experiment.
- *Demographic questionnaire*: A lab-internal, self-designed questionnaire that gathered some biographical data (birth, gender, previous experiences with VR and PC games etc.) relevant for the study, and that was filled before the actual experiment.
- *NEO Five-factor inventory (NEO-FFI)*: A frequently used personality questionnaire to examine character traits based on the five-factor model of personality. The NEO-FFI contains 60 items with a maximum score of 48 to reach for each of the five character domains. The German version of the NEO-FFI (Borkenau, P, Ostendorf, 1993) was used and administered after the experiment.

The most important outcomes and group comparisons for these questionnaires can be found in Table 1.

2.5. Interventions

For both groups, the computer game The Elder Scrolls® V: Skyrim™ from Bethesda Game Studios® was used as intervention. Skyrim™ is a wide-spread action/fantasy role-playing game with more than 30 million copies sold (Suellentrop, 2016). The choice fell on this game not only because of its large prevalence, but also because of its high immersiveness and VR-compatibility. Regardless of their group allocation, all participants played the same entrance scene of Skyrim™, in which the player has to flee a dragon through underground tunnels and dungeons. This scene was chosen, because it induces a high level of arousal and experiential vividness, requires no previous game experiences, and its game control is sufficiently easy.

Depending on their group allocation, the participants played this Skyrim™ scene either via a HMD (VR group) or via a classical computer screen (PC group). The HMD used, was the HTC VIVE Business (HTC Corporation, Taoyuan City, Taiwan), a customary HMD with a per eye image resolution of 1,080 × 1,200 pixels, 90 Hz screen refresh rate and 110°' field of view. The gaming notebook used for the PC group was the Dell Alienware 17 R5 (Dell Technologies, Round Rock, USA), which has a screen resolution of 1920 × 1080 pixels and a 60 Hz screen refresh rate. Participants of the VR group were seated in the middle of the VR room on a swivel chair and controlled the game via Vive Controllers, while participants of the PC group sat directly in front of the notebook and controlled the game via mouse and keyboard. Regardless of the gaming mode, the Skyrim™ scene was viewed from a first person perspective and the participants played the scene for around 30 min, following Aardema et al. (2010) that revealed a significant DPDR effect after 25-min VR experience.

2.6. DPDR baseline and endpoint assessment

To identify potential VR-induced DPDR symptoms, the participant's momentary presence of DPDR symptoms was assessed immediately before (T0) and three times after the interventions (T1-T3). For all four measurement points, the German state version of the Cambridge Depersonalization Scale (CDS-State; Michal et al., 2004) was administered. This 22-items questionnaire captures momentary symptoms of DPDR and has been applied in various previous studies (e.g. Aardema et al., 2010; Hunter et al., 2005). The total range is from 0 (no DPDR symptoms) to 100 (severe DPDR symptoms). T1 was defined as the primary endpoint and the CDS-State score as the primary study outcome. In the calculation of CDS-State sum score, the last item of the CDS-State ("I still have the same disconcerting feelings I had when I first started answering the questions") was, however, disregarded, since several subjects later stated that it was not understandable whether 100% (in the sense of "yes") or the corresponding level (e.g. "10% as all the time") should be chosen. Possibly, the German translation of this CDS-State item should be refined for future use. For the statistical analysis, the difference between T0 and all other endpoints was calculated.

2.7. Emotional responsiveness

Given that many DPDR patients bewail an emotional numbness (Dewe et al., 2016; Sierra et al., 2002), we wondered, whether a VR-induced DPDR symptomatology also becomes manifest in a transiently alleviated responsiveness to emotional stimuli. To address this research question, we presented a subset of 48 pictures from the International Affective Picture System (IAPS; Bradley & Lang, 2007) to our participants immediately after T1. The IAPS is a collection of widely used emotional pictures in psychological research and has been validated as consistently eliciting specific emotional responses (Silva, 2011; Verschuere et al., 2001). The subset presented, was selected based on an IAPS categorization study (Mikels et al., 2005), such that six representative images were taken from each of the following eight subcategories: fear, sadness, disgust, anger, awe, excitement, contentment and amusement. Pictures from the first four subcategories were considered to elicit a negative affect and pictures from the last four subcategories a positive affect. All pictures were presented in a random order using Matlab 2018a (Mathworks, Natick, MA, USA). Before each picture, a fixation cross was shown for 1 s, while the pictures itself were presented for 7 s. Immediately after each picture, the participants' emotional arousal and valence towards this particular picture was surveyed. Emotional arousal was assessed by the question *"How emotionally touching did you find this picture?"* (response options: 'absolutely not touching', 'not very much touching', 'a little touching', 'very touching', 'very strongly touching') and emotional valence by the question *"Did you find the picture more emotional-positive or emotional-negative?"* (response options: 'very negative', 'negative', 'neutral', 'positive', 'very positive'). All answers were directly answered by the participants via keyboard input. For the statistical analysis, we separately derived an "emotional arousal" and "emotional valence" mean value for both groups and both image categories (negative pictures, positive pictures).

2.8. Electrodermal responsiveness

Further confirmation of emotional numbness is provided by studies suggesting an attenuated psycho-physiological response under DPDR (Dewe et al., 2016; Sierra et al., 2002). Therefore, we also analyzed the participants' electrodermal activity (EDA) during the IAPS picture presentation and hypothesized that participants of the VR group would show significantly weaker phasic EDA responses towards the presented pictures than participants of the PC group. Hardware-wise, the participant's EDA was recorded via the Nexus 10 device (Mind Media BV, Herten, Netherlands), whereby two EDA sensors were attached at the proximal phalanxes of the annual and little finger of the non-dominant hand. The cable of the sensors was fixed at the participants' arms with tape, so that it would not be disturbing during gameplay.

Software-wise, the EDA was recorded via LabStreamingLayer (LSL; https://github.com/sccn/labstreaminlayer), using a self-adapted SDK provided by the manufacturer. The later offline analysis of the EDA data was performed in Matlab 2018a using EEGLAB 14.1.2 b (Delorme & Makeig, 2004) and LEDALAB 3.4.9 (Benedek & Kaernbach, 2010a; 2010b). EEGLAB was used for importing the EDA datasets into Matlab and LEDALAB for decomposing the EDA datasets into their phasic and tonic EDA parts, using a Continuous Decomposition Analysis. The phasic EDA was retained and baseline-corrected by calculating its relative change to a 1-min baseline phase that was recorded before the actual experiment (cf. 2.3). Next, the baseline-corrected EDA was segmented from 0 s to +7 s relative to each IAPS picture onset. For the statistical analysis, the mean EDA amplitude across pictures between +3 s and + 6 s relative to the IAPS picture onsets was separately calculated for both groups and both image categories (negative pictures, positive pictures).

2.9. Cardiological analyses

In addition to the EDA findings, there is also evidence that DPDR is accompanied by cardiological changes, in particular, by a reduced heart rate variability (HRV; Owens et al., 2015). To evaluate, whether such changes also appear in a VR-induced DPDR symptomatology, we recorded ECGs during the IAPS picture presentation, again using the Nexus 10 device and LSL. The three ECG sensors used, were attached under the left and right clavicle and under the left costal arch. To prevent a slipping during gameplay, the sensors were additionally fixed with tape.

For the ECG offline analysis, the ECG data were first imported into Matlab 2018a and then further preprocessed by the Matlab toolbox HRVTool (version Ic7d529; Vollmer, 2019). Preprocessing was conducted semi-automatically and involved a removal of heart beats resulting in RR intervals with more than a 20% deviation from the adjacent intervals and of all extra-systoles. Next, after the continuous ECG datasets had been cleaned, the following ECG parameters were automatically extracted by the toolbox and used for the statistical analyses: standard deviation of NN intervals (SDNN), heart rate variability based on relative RR intervals (rrHRV; Vollmer, 2015) and, for additional exploratory analysis, heart rate (HR).

2.10. Post-experimental surveys

2.10.1. Cybersickness

To explore potential symptoms of cybersickness during gaming, all participants filled out the Virtual Reality Sickness Questionnaire (VRSQ) by Kim et al. (2018), with a maximum achievable score of 27, after the end of the intervention, along with the NEO-FFI.

2.10.2. Perceptual realness towards gaming environment

Moreover, to examine whether the level of perceptual realness experienced during gaming correlates with the level of DPDR-symptomatology experienced after gaming, we asked a subsample of 34 participants 14 PC, 20 VR) the question "How real did you perceive the environment of the game to be?", providing the following answer opportunities: 'not at all', 'little', 'medium', 'very'.

2.10.3. Difficulty of game control

To confirm, that participants were able to control the game, we also asked one question about the difficulty of the games control ("Did you have any problems with the control during the game?"), with a maximum score of 3 (very much).

2.11. Missing data handling

Complete datasets could not be collected from all participants. Seven participants dropped out during the intervention, six from the VR group due to cybersickness, and one from the PC group due to technical problems. The data of these participants were not included in any of the analyses. Moreover, the DSS was not filled in properly by one participant of the VR group, the NEO-FFI by one participant of the PC group and two participants of the VR group, and the CDS-State T1 by one participant of the PC group. The follow up questionnaires were returned by 34 participants of the PC group and 31 participants of the VR group. Out of these, five within each group did not fill in the CDS-Trait properly. Moreover, one participant of the VR group did not fill out the CDS-State T2. Likewise, within each group, one participant missed to fill out the CDS-State T3. Due to a recording error, the analysis of the physiological data had to be restricted to 27 participants of the VR group and 31 of the PC group. Missing items within the NEO-FFI, CDS-State or -Trait questionnaires were replaced by singular imputation. Missing data on the final outcome level was handled by pairwise deletion (i.e. all observations were included, for which there was data for the respecting analysis).

2.12. Statistical analyses

While the CDS-State score was set as the primary outcome parameter, the following parameters served as secondary outcome parameters: self-rated emotional arousal, self-rated emotional valence, EDA amplitudes, HRV values and perceptual realness. Five major statistical analysis were conducted:

First, to identify potential VR-induced DPDR symptoms, a 3 × 2 mixed ANOVA with a between-subjects factor 'Group' (PC group vs. VR group) and a within-subjects factor 'Time' (T1, T2, T3) was carried out on the CDS-State sum scores. In case of significant main or interaction effects, these effects were followed up by pairwise comparisons (one-tailed t-tests). The primary endpoint of interest was T1.

Second, to study the emotional and electrodermal responsiveness towards the IAPS pictures, three separate 2 × 2 mixed ANOVAs with the between-subjects factor 'Group' and a within-subjects factor 'Emotion Type' (negative vs. positive) were carried out on the emotional arousal, emotional valence and EDA amplitude values.

Third, to search for potential group changes in respect to cardiologic characteristics, three two-tailed t-tests were separately performed on the participants' heart rate, SDNN and rrHRV values.

Fourth, to explore differences in perceptual realness between groups, a two-tailed *t*-test was performed.

Finally, to check for potential relationships between DPDR trait symptomatology (CDS-Trait), DPDR state symptomatology (CDS-State), perceptual realness (one-item questionnaire), emotional vividness (emotional arousal, emotional valence), electrodermal responsiveness (EDA amplitude values) and NEO-FFI personality traits (Neuroticism, Extraversion, Openness, Conscientiousness, Extraversion, Agreeableness), various correlation analyses were carried out between these measures.

All statistics were calculated in Matlab 2018.

To determine our sample size we carried out an a priori power analysis by means of G*Power (G*Power 3.1; Faul et al., 2007). The analysis was conducted for the *t*-test on our primary outcome parameter CDS-State with an α-error of 0.05 and a Power of 0.8. According to Cohen (1988) an effect size from d = 0.5 can be considered medium and from 0.8 large, so that we chose an estimated effect size of d = 0.65. The resulting recommended sample size of n = 30 participants per group was rounded up to n = 40, as several dropouts were expected.

As measures of effect size for all our *t*-tests we calculated Cohen's d (Cohen, 1988), as well as the corrected effect size Hedges' g (Hedges & Olkin, 1985, for clarifications and discussion, see; Lakens, 2013).

3. Results

3.1. DPDR endpoint assessments

Fig. 2 depicts the CDS-State scores for the three endpoints T1 (directly after gaming), T2 (one day after gaming) and T3 (one week after gaming), as differential values to T0 (baseline assessment). The 3 × 2 mixed ANOVA showed a main effect of 'Group' (F (1, 59) = 7.85, p = .007, $\eta^2 = 0.118$), in that across time, the CDS-State scores were rated higher in the VR group (M = 1.70; SD = 3.61) than PC group (M = 0.44; SD = 2.09). Moreover, the ANOVA revealed a main effect of 'Time' (F (2, 118) = 28.65, p = <.001, $\eta^2 = 0.327$) and an interaction effect between 'Time' and 'Group' (F (2, 118) = 3.81, p = .025, $\eta^2 = 0.061$). The main effect of 'Time' was followed up by one-tailed t-tests on pooled CDS-State scores across groups, which revealed that the CDS-State scores were rated higher at T1 than T2 (t (134) = 4.69, p = <.001; d = 0.82; g = 0.82) and higher at T1 than T3 (t (133) = 5.21, p = <.001; d = 0.93; g = 0.92), while no significant differences were found between T2 and T3 (t (125) = 1.20, p = .117; d = 0.21; g = 0.21). The interaction effect, in turn, was followed up by separate one-tailed t-tests between groups on each endpoint. While for T1, the CDS-State scores were rated significantly higher in the VR than PC group (t (70) = −2.99, p = .002; d = −0.71; g = −0.70), no significant group differences were found for T2 (t (62) = −1.42, p = .081; d = −0.36; g = - 0.35) and T3 (t (61) = −1.31, p = .098; d = −0.33; g = −0.32).

A comparison of absolute scores immediately before and after the intervention revealed a significant increase in CDS scores within both, the PC (t (75) = −2.00, p = .025; d = −0.45; g = −0.45) and the VR group (t (66) = −4.50, p = <.001; d = −1.09; g = −1.08).

3.2. Emotional responsiveness

Fig. 3 depicts the reported levels of emotional arousal (left panel) and emotional valence (right panel) towards the presented IAPS pictures. Regarding emotional arousal, the 2 × 2 mixed ANOVA revealed a

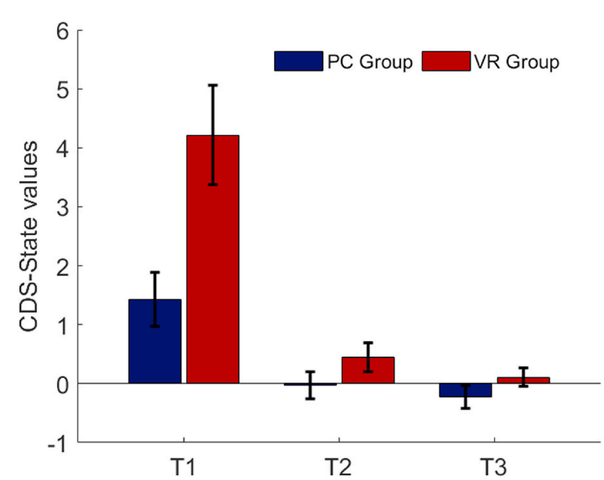

Fig. 2. Results of VR-induced depersonalization and derealization (DPDR). DPDR symptoms were assessed via the state version of the Cambridge Depersonalization Scale (CDS-State), immediately before (T0), directly after (T1), a day after (T2) and a week after (T3) the experiment. All depicted values are differential values to T0. At T1, the CDS-values were significantly higher in the VR group than in the PC group (p = .002). For T2 and T3, in turn, no statistically significant results could be deduced (T2: p = .081; T3: p = .098).

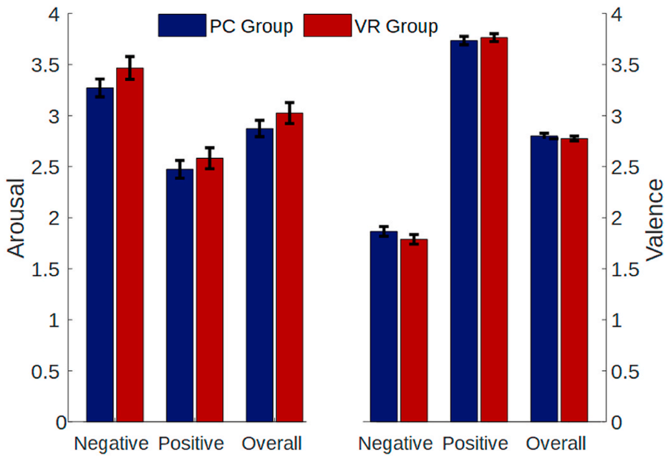

Fig. 3. Results of emotional responsiveness.
Participants' subjective emotional arousal (left panel) and valence ratings (right panel) during the presentation of negative and positive pictures from the International Affective Picture System (IAPS). The IAPS pictures were presented immediately after the two compared interventions. For both, emotional arousal and valence, a value of 4 was the maximum achievable score.

significant main effect of 'Emotion Type' (F (1,71) = 337.24, p = <.001, $\eta^2 = 0.826$) in that the emotional arousal level was reported to be higher towards negatively-charged (M = 3.36, SD = 0.60) than positively-charged (M = 2.52, SD = 0.57) pictures. No significant group difference (F (1, 71) = 1,39 p = .243, $\eta^2 = 0.019$) nor an interaction (F (1, 71) = 0.92, p = .341, $\eta^2 = 0.013$) was found.

Regarding emotional valence, the ANOVA again revealed a main effect of 'Emotion Type' (F (1,71) = 1427.76, p = <.001, $\eta^2 = 0.953$) with more positive valence ratings towards positively-charged (M = 3.75; SD = 0.24) than negatively-charged pictures (M = 1.83; SD = 0.29). Again, no significant group difference (F (1, 71) = 0.47, p = .494, $\eta^2 = 0.007$) and no significant interaction effect (F (1, 71) = 1.08, p = .302, $\eta^2 = 0.015$) was found.

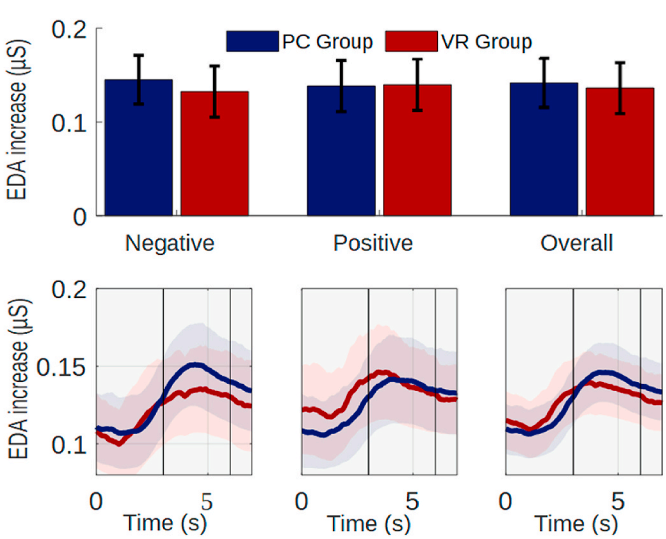

Fig. 4. Electrodermal activity results.
Upper panel. Baseline-corrected EDA waveforms (±SEMs) across participants during emotional picture presentation. Time point zero indicates the onset of the presented emotional pictures of the respecting emotional category. Lower panel. Mean phasic EDA amplitude (±SEMs) for the time interval between +3 and + 6 s.

3.3. Electrodermal responsiveness

Fig. 4 depicts the results of the EDA analysis. As can be seen, a phasic increase of EDA relative to the IAPS pictures was present in both groups and both image categories. The 2 × 2 mixed ANOVA neither revealed a significant effect of 'Group' (F (1, 56) = 0.02, p = .883, $\eta^2 < 0.001$), nor of 'Emotion Type' (F (1, 56) = 0.00, p = .954, $\eta^2 < 0.001$) nor an interaction effect (F (1, 56) = 1.36, p = .248, $\eta^2 = 0.024$).

3.4. Cardiological analyses

The results for the three different extracted ECG parameters are presented in Fig. 5. The two-tailed t-tests carried out, neither revealed a group difference in respect to the participant's HR (t (56) = 1.37, p = .178; d = 0.36; g = 0.35), SDNN (t (56) = −0.87, p = .391; d = −0.23; g = −0.22) nor rrHRV (t (56) = −0.41, p = .685; d = −0.11; g = −0.11).

3.5. Perceptual realness

The levels of perceptual realness that the participants reported towards the respecting gaming environments are reported in Fig. 6. A t-test revealed (t (32) = −2.82, p = .008; d = −0.98; g = −0.97) that the participants of the VR group reported higher experiential realness levels (M = 1.55; SD = 0.76) than participants of the PC group (M = 0.79; SD = 0.80).

3.6. Correlation analyses

Pearson correlations between the different primary and secondary outcome measures are depicted in Table 2. Except for positive correlations between CDS-State and CDS-Trait values in either groups (VR: r = 0.40, p = .021; PC: r = 0.58, p = < .001), no other significant correlations were found. Table 3, in turn, depicts the Pearson correlations between the CDS-State/Trait values and NEO-FFI personality traits. Also here, no statistically significant correlation was found for any conducted comparison, except for the Neuroticism vs. CDS-Trait comparison in the PC group (r = 0.36, p = .029).

4. Discussion

In this longitudinal RCT, we examined the immediate and longer-lasting effects of a single VR session on the sense of reality in healthy

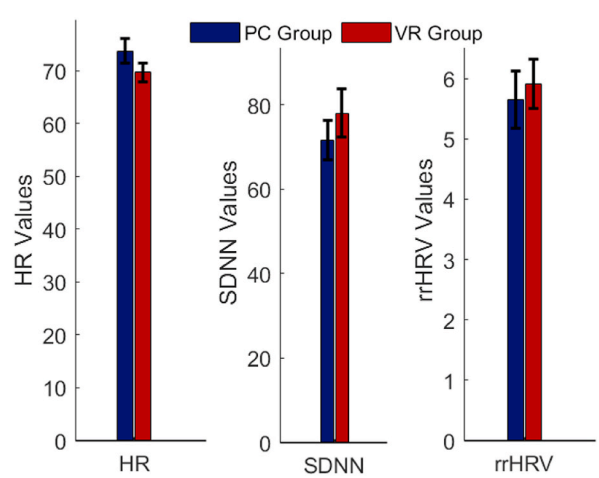

Fig. 5. Cardiological results.
Cardiological outcomes for the ECG during emotional picture presentation. Depicted are the mean values (±SEMs) in both groups for the average heart rate (HR, left) and two heart rate variability measures: standard deviation of NN intervals (SDNN) and relative RR intervals (rrHRV).

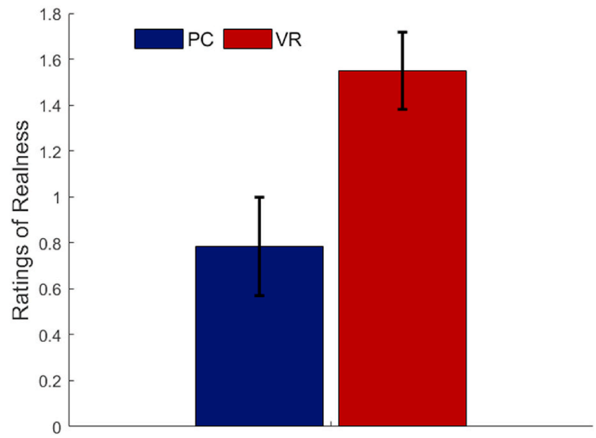

Fig. 6. Perceptual realness towards game environment.
Participants' ratings of perceived realism towards the two different game environments. Answers were given on a four-point Likert scale ranging between 'not at all' (0) and 'very' (3). Values in the VR group were significantly higher compared to the PC group (p = <.01).

participants. More specifically, we let a group of n = 40 healthy participants play the game Skyrim™ under VR and an equal-sized control group play the same game on a regular computer screen. Using the CDS-State, we assessed the participants' DPDR experiences immediately before gaming (T0), immediately after gaming (T1), one day after gaming (T2) and one week after gaming (T3). Moreover, immediately after gaming, we assessed the participants' physiological and emotional reagibility towards emotional pictures, given the evidence for an emotional and physiological hyporeagibility under DPDR.

Virtual reality induces immediate DPDR symptoms. Regarding our primary DPDR outcome measure (CDS-State) and primary endpoint (T1), our study reveals two important results: First, in both groups, the reported level of DPDR significantly increased from T0 to T1. That is, after both, PC gaming and VR gaming, the amount of DPDR experience was reported to be stronger than during baseline. Second, participants of the VR group reported a significantly stronger increase in DPDR symptoms than participants of the PC group. While the first result complies with Aardema et al.'s (2010) findings that a single VR session already might induce DPDR symptoms, the second result exceeds Aardema et al. results in demonstrating that both, VR gaming and PC gaming induce DPDR experiences, but that the level of induced DPDR is clearly stronger after VR gaming than PC gaming.

Why PC gaming, and in particular VR gaming, induces DPDR after-effects, we may only speculate. A first intuitive explanation, however, is that, on the phenomenological level, the reported DPDR experiences signal computational uncertainty with the currently instantiated reality model, which arises due to the new existence of an alternative reality model. In other words: That the subject of experience was just immersed into a "new virtual reality", but is now thrown back into its "old ordinary reality", might result in a transient predictive uncertainty as to which of the two competing reality models is now actually the more veridical one. While this explanation is provisional and awaits further theoretical elaboration, it generally appears compatible with Metzinger's phenomenal transparency concept (Madary & Metzinger, 2016; Metzinger, 2018) and with new predictive coding accounts (Limanowski & Blankenburg, 2013; Limanowski & Friston, 2018) on how (self)--consciousness and reality experiencing is constituted.

A less theoretical alternative explanation would be that the DPDR experiences just occurred as a non-specific stress symptom in response to the interventions. As stated, it is a known problem of VR that it induces symptoms of cybersickness (e.g. disorientation, eye fatigue, and

Table 2
Results of correlation analysis.

Item (*N*)	CDS-State	CDS-Trait	Realness	Arousal	Valence	EDA	SDNN
PC group							
CDS-State (38)		0.58***	0.50	0.15	0.01	−0.04	0.27
CDS-Trait (39)	0.58***		0.13	0.16	0.09	0.14	−0.16
Realness (38)	0.50	0.13		0.27	−0.44	−0.26	−0.16
Arousal (39)	0.15	0.16	0.27		0.13	−0.08	0.22
Valence (39)	0.01	0.09	−0.44	0.13		0.31	0.12
EDA (31)	−0.04	0.14	−0.26	−0.08	0.31		0.13
SDNN (31)	0.27	−0.16	−0.16	0.22	0.12	0.13	
VR group							
CDS-State (34)		0.40*	0.38	0.07	0.07	−0.17	0.25
CDS-Trait (34)	0.40*		0.04	−0.21	0.02	−0.13	0.28
Realness (32)	0.38	0.04		0.19	0.26	0.01	0.29
Arousal (34)	0.07	−0.21	0.19		0.05	−0.07	−0.10
Valence (34)	0.07	0.02	0.26	0.05		0.16	−0.18
EDA (27)	−0.17	−0.13	0.01	−0.07	0.16		−0.26
SDNN (27)	0.25	0.28	0.29	−0.10	−0.18	−0.26	

Pearson correlations (r) between primary and secondary outcome measures. CDS-State, Cambridge Depersonalization Scale State; CDS-Trait, Cambridge Depersonalization Scale Trait, EDA, Electrodermal Activity; SDNN, Standard Deviation of the NN-Interval.*p = <.05, ***p = <.001.

Table 3
Correlations of the NEO-FFI domains.

Item (*N*)	Neuroticism	Openness	Conscientiousness	Extraversion	Agreeableness
PC					
CDS-State (38)	0.16	0.17	0.07	0.00	−0.11
CDS-Trait (39)	0.36*	0.16	0.06	−0.05	−0.13
VR					
CDS-State (34)	0.04	0.01	−0.06	0.33	0.03
CDS-Trait (34)	0.08	−0.03	−0.21	0.05	−0.10

Pearson correlations (r) between DPDR measures and NEO-FFI personality traits. CDS-State, Cambridge Depersonalization Scale State; CDS-Trait, Cambridge Depersonalization Scale Trait.*p = <.05.

nausea), perhaps due to a sensory conflict between visual, proprioceptive and vestibular modalities (for critical discussions, see Chang et al., 2020; Dużmańska et al., 2018). Hence, perhaps, cybersickness or some multisensory conflicts also contributed to the observed DPDR symptoms in our participants.

In the clinical evaluation of the current results, it should, however, be noted that our participants achieved significantly lower CDS-State values than is typically the case for persons with an actual depersonalization disorder. Whereas the CDS-State value in our VR group averaged M = 4.65 (SD = 5.36) at our primary measurement point T1, the CDS-State value in individuals suffering from DPDR is typically significantly higher. For instance, on a treatment study by Hunter et al. (2005) with only DPDR sufferers, patients had a mean CDS-State value of 38.8 (SD = 21.8) before therapy. Hence, it can be assumed that our subjects did not experience DPDR symptoms to a clinically relevant extent.

No evidence for long lasting DPDR effects. Regarding the other two endpoints T2 and T3, we found no significant group differences. Instead, we only found a trend towards higher values in the VR group in both cases (for T2: p = .081; for T3: p = .098). Therefore, the results may be interpreted in two directions: First, it could be that VR elicits DPDR experiences but that these experiences quickly diminish within the next few hours after the experiment. Thus, in this case, no long-lasting DPDR side effects are to be expected. Or, VR might also elicit long-lasting DPDR effects, but our sample size was too small to detect these effects (e.g. because of the high dropout rates during the experiment and during the follow-ups).

No evidence for a VR-induced emotional or psychophysiological hyporeagibility. Contrary to our expectations, we did not find any significant group differences in respect to our emotional and physiological reagibility measures. In particular, we did not find any evidence for an emotional or psychophysiological hyporeagibility after VR gaming as compared to PC gaming. While at first glance, one might assume that these null findings are also due to too low sample sizes, at second glance this appears doubtful, because the descriptive data do not even indicate any statistical trend. Instead, the descriptive data, partly even point into a non-expected direction. For instance, while for self-rated emotional arousal, we expected lower emotional arousal after VR than PC gaming, given the evidence for an emotional hyporeagibility under DPDR (Dewe et al., 2016; Sierra et al., 2002), the descriptive data, rather indicate higher emotional arousal after VR than PC gaming. Therefore, our suspicion is rather that some other (uncontrolled) effects may have counteracted the expected hyporeagibility effect. One counteracting effect might, for instance, have been that participants of the VR group had to move more than participants of the PC group, given the different gaming mode, and therefore their general level of arousal (including cybersickness) increased. Also, it might be that due to the higher immersiveness, emotional arousal was higher during VR than PC gaming, and this increase in emotional arousal then persisted into the post-intervention phase.

Does perceptual realness contribute to VR-induced DPDR? Another finding is that the level of perceptual realness towards the Skyrim™ game environment was rated significantly higher in the VR group than PC group. This finding is little surprising and confirms that VR is particularly potent in inducing illusions of presence and realness towards non-physical virtual environments, presumably due to its high immersiveness (i.e. its "*technical capability* […] *to deliver a surrounding and convincing environment with which the participant can interact*"; Sanchez-Vives & Slater, 2005). Moreover, this finding perhaps explains why VR gaming induces stronger DPDR experiences than PC gaming: Assuming that the observed DPDR symptoms come about by the (transient) instantiation of a new reality model towards the "virtual world" that casts into doubt the ordinary, pre-existing reality model, the more convincing the newly-instantiated reality model feels like, the higher should be the level of doubt (DPDR symptoms) with the old reality model. That is, the DPDR symptoms were stronger after VR gaming than PC gaming, because VR-induced stronger levels of realness towards the newly experienced virtual world, which casts into doubt the so far experienced ordinary world. To some extent, this presumed relationship between perceptual realness during gaming and DPDR aftereffects, also appears to manifest in the correlation coefficients between perceptual realness scores and CDS-States scores. Although not (yet) significant, positive associations of medium strength were found between perceptual realness and CDS-State scores for both, PC-gaming (r = 0.50) and VR-gaming (r = 0.38). Further studies are necessary to investigate the relationship between perceptual realness during VR immersion and DPDR aftereffects.

No evidence for a higher VR-induced DPDR risk of specific personality traits. Regarding personality traits, we only found a correlation between Neuroticism and CDS-Trait values in the PC group, but no correlations between any personality trait and CDS-State values at T1. Hence, our study does not reveal any evidence that people with a certain personality trait are particularly susceptible to developing DPDR after consuming VR. It should, however, be noted that we only included mentally healthy people without any personality disorders into our study. Hence, the extreme areas of the individual personality dimensions were likely under-represented.

What we found, however, is a positive and significant correlation between CDS-Trait scores and CDS-State scores, in both the VR group (r = 0.40) and the PC group (r = 0.58). That is, those participants who reported a stronger DPDR trait vulnerability before our experiment, were more prone to our two gaming interventions and reported higher levels of DPDR symptoms after the experiment. This finding complies with similar findings in Aardema et al. study (2010) and indicates that people with a high DPDR trait level are particularly vulnerable to developing DPDR symptoms after VR experience and should therefore be particularly careful in consuming VR.

5. Limitations and future directions

One limitation of our study is the occurrence of cybersickness in the VR group that resulted in a relatively high dropout rate (17,5%). As a consequence, we lost statistical power and might have missed further statistical effects, for example regarding potential long-term effects. While the problem of cybersickness might potentially be attenuated by choosing a VR intervention with less movement and interaction requirements, the question arises whether such intervention would still be sufficiently representative for the prototypical VR games currently available.

Another shortcoming is that our study only included healthy, adult participants. For future research, it would be desirable to also study other population samples. In particular, it appears crucial to examine clinical populations (e.g. persons with psychosis, depression or dissociative disorders), in order to determine whether these populations are particularly at risk for DPDR experiences from VR consumption. Moreover, it would also be interesting to study the impact of VR on DPDR experiences in children and adolescents, since it is likely for this subgroup to increasingly encounter the fast spreading technology (see e.g. Bailey & Bailenson, 2017). The change of reality experience through VR gaming under the influence of alcohol or other drugs should also be evaluated, for example by surveys among users. In this way, mutually reinforcing effects could possibly be identified.

A third limitation is that our participants only underwent one 30 min VR intervention. While this short period of time already sufficed to transiently induce DPDR experiences, the question remains, whether a more regular VR consume intensifies or attenuates the occurrence of DPDR symptoms. On the one hand, more regular consume could lead to a habituation effect e.g. due to increased media literacy, with a decline of the DPDR experiences over time. On the other hand, experiences could be gradually exacerbated, experiences could be gradually exacerbated by increasing submersion into VR. Likewise, our study only evaluated one specific VR game, while many further VR interventions exist. This pertains, for instance, sports (Neumann et al., 2017), VR-assisted healthcare interventions (Riva & Serino, 2020), construction management (Ahmed, 2018), VR pornography (Orel, 2020; Simon & Greitemeyer, 2019), VR-assisted educational programs (Jensen & Konradsen, 2017; Kavanagh et al., 2017), and various occupational VR applications (Toptal Research, 2019; Weiss & Jessel, 1998). Also for these VR interventions, in particular those that concern occupational safety issues, it would be advisable to investigate their potential risk of inducing DPDR symptoms.

Moreover, it should be considered that our study mainly focused on DPDR symptoms after VR consumption, not during VR consumption. It would, however, also be interesting to investigate whether DPDR symptoms already emerge during VR consumption, and if so, due to what mechanisms. One question that, for instance, arises in this context is to what extent the co-representation of the VR user itself (e.g., through a first-perspectival presentation of an embodiable avatar) in the virtual environment is more likely to produce an increase or reduction of DP. Likewise, the question arises to what extent the exposure to and interaction with virtual objects or avatars (e.g., fellow players) might cause alienation phenomena. In this context, the "cues-filtered-out" thesis (Culnan & Markus, 1987) appears interesting, according to which computer-mediated communication (CMC) shows a lower media richness than natural face-to-face communication (for a critical discussion, see Walther, 1996). This thesis is certainly to be relativized today, among other things, because CMC today enables significantly more communication channels than mere text messaging. Nevertheless, existing VR systems are still insufficiently able to multimodally imitate "real world" conversations. The Uncanny Valley effect (Shin et al., 2019), for instance, shows that when VR avatars display a strong but insufficient human resemblance and behavior, a particularly strong emotional aversion to these avatars occurs.

Besides technology assessment studies, the opportunities of VR should, however, also be highlighted. As recently pointed out by Thomas Metzinger in a perspective article (Metzinger, 2018), perceptual realness naturally varies on a continuum between states of opacity and transparency, and a potential strength of VR might be to systematically control this continuum of realness (i.e. to control the level of realness a participant currently perceives). If this succeeded, many research questions regarding (self)-consciousness and reality-experiencing could be examined in a very fine-grained and systematic manner. Similarly, as already suggested by Aardema et al. (2010), the possibility could arise to use VR-induced DPDR therapeutically, e.g., in the context of a psychoeducation or exposure exercise, with the aim of gradually establishing tolerance to different states of consciousness.

6. Conclusion

In summary, our study gives further evidence for the induction of DPDR symptoms by VR techniques and is the first study to proof this finding in comparison with an adequate control group. However, in their intensity, the DPDR effects found do not seem clinically relevant and based on our data, no evidence for a DPDR long-term effect after single VR consumption can be provided. Our study underlines the need for further investigation on VR-induced DPDR experiences, in particular regarding effects of regular consumption and occupational VR applications.

Author contributions

CP designed the experiment under the supervision of **NB**. **CP** collected the data. **CP** analyzed the data under the supervision of **NB**. **CP**, **NB**, **KK** and **MP** wrote major parts of the manuscript. **AP** and **SL** contributed to, reviewed, and edited the manuscript. All authors contributed to the article and approved the submitted version.

Data availability statement

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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