FULL RESEARCH PAPER

Virtual reality gaming for pain distraction - Investigation of attentional and psychophysiological effects

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FULL RESEARCH PAPER: Virtual reality has been shown to be a powerful method to divert attention away from pain (Malloy & Milling, 2010a) and has been used successfully to temporally relieve patients from pain in clinical settings. However, little is known about the underlying attentional processes involved in pain processing in virtual reality. Therefore, as one of the first studies, this project investigates the role of especially cognitive factors influencing distraction from pain. N = 90 healthy participants played the video game *Subnautica* in two virtual reality conditions (high vs. low cognitive load). To assess the distraction effect pain thresholds and psychophysiological measures were assessed during play. Additionally, executive functions and self-reported measures on, e.g., presence, simulation sickness and pain-related subjects were assessed. Results suggest that interactive virtual reality games are a potential tool to alter pain processing, regardless of the level of cognitive load.

Keywords: virtual reality, gaming, pain regulation, distraction effect

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Introduction and current study

Both acute and chronic pain are serious and highly prevalent health issues of global dimensions regardless of sex, age or socioeconomic status (Goldberg & McGee, 2011) most commonly treated with analgesic drugs (e.g., side effects, tolerance, or dependence). Due to many drawbacks associated with pharmaceuticals (e.g., side effects, tolerance, or dependence) new, alternative treatment options are developed. One method that has been proven to be highly effective in reducing pain is attentional diversion via virtual reality (VR), i.e., shifting attention away from pain perception towards the virtual world (Hoffman et al., 2004; Mallari et al., 2019; Malloy & Milling, 2010b, reporting medium to large effect sizes). Like other forms of distraction, the analgesic effect of VR is assumed to result from a competition between pain-related processes and the immersive and attention-demanding properties of VR for limited attentional resources (Johnson, 2005).

The majority of studies on the analgesic effect of VR has been conducted in clinical or rehabilitation settings, however, less is known about the VR distraction effect of healthy adults in experimental pain studies (Malloy & Milling, 2010b). Although experimental studies allow for better standardization and confounds control, the few existing ones assessed the distraction effect solely by one ex post facto rating of the perceived pain intensity (Gold and Mahrer, 2018; Loreto-Quijada et al., 2014). Moreover, it is unclear which role cognitive load of VR plays in modulating the size of the distraction effect. While studies unrelated to VR have shown pain-reducing effects of completing a cognitively demanding task (Buhle & Wager, 2010; Paris et al., 2013), the effects of cognitive load in VR are less conclusive: For example, Demeter et al. (2018) were unable to show a greater distraction effect for a more demanding playing condition in *EyeToy*. In contrast, Fairclough et al. (2020) observed greater pain tolerance when playing a more demanding condition of a racing game. To the best of our knowledge, this very recent study is also the first one to integrate the concept of immersion and presence to explain pain distraction. Although the authors believe that besides challenge-based immersion also the top-down processes of sensory immersion are related to pain perception, manipulating screen size (9” vs. 40”), hardware (2D screens vs. 3D head-mounted display), or volume (about 12 dB vs. 58 dB) failed to influence pain tolerance.

Therefore, the present study first and foremost assesses the extent of the hypoalgesic effect of VR games with different cognitive demand:

H1: The distraction effect from pain will be greater when playing a more demanding VR game (vs. a less demanding game or vs. a non-interactive baseline session).

To further broaden our methods beyond subjective measures, psychophysiological markers that are indicative of both pain (Handwerker & Kobal, 1993) and immersive experiences (Liebold et al., 2017) were integrated as well. As prior results suggest autonomic activation to be related with game demand and immersion and thus possibly explain analgesic effects (Fairclough et al., 2020), we further propose:

H2: Psychophysiological reactions will be stronger when experiencing pain in a more demanding VR game (vs. a less demanding game or vs. a non-interactive baseline session).

Unrelated to gaming or VR several important inter-individual differences that might influence pain distraction effects, such as executive functions (Bjekić et al., 2018a; Oosterman et al., 2010a; Katrien Verhoeven et al., 2011), pain-related cognitions (Campbell et al., 2010; Prins et al., 2014; Verhoeven et al., 2010) have been suggested yielding mixed results. Furthermore gender effects suggest that females benefit from a larger distraction effect (Demeter et al., 2015). We therefore hypothesize:

H3: Executive functions, pain-related cognitions and gender influence the distraction effect in VR.

Findings will extend prior research on the underlying mechanisms and function of the distraction effect in VR and allow for further advances concerning the application of VR in clinical interventions.

Participants

A total of 101 participants took part in a laboratory study at the University of Luxembourg. Participants are recruited via email and posters on campus. Additionally, the study was advertised on national, public radio. Inclusion criteria were being between 18 and 35 years old, either fluent in German or English to participate. Interested people with a diagnosis of photosensitive epilepsy, neurodermitis or other skin-related diseases on the non-dominant lower calf were excluded from the study. Participants with a history or a current diagnosis of psychiatric or neurological conditions, with acute or chronic pain (*n* = 4), neuropathy or using analgesics, anticonvulsants, narcotics, antidepressants, or anxiolytics, were allowed to participate, but data was not analyzed. Furthermore, participants had to be excluded due to motion sickness (*n* = 4), an average pain threshold of almost 50°C (*n* = 2), or technical problem (*n* = 1) leading to a final sample of *N* = 90 participants. Half of the participants identified themselves as female (*n* = 45, males *n* = 45) and the overall age was *M* = 23.46 years (*SD* = 3.28).

Procedure

After signing an informed consent including information on the purpose of the study, participants completed questions on basic demographics, their gaming habits, and skills, attitudes towards pain, ADHD symptoms and emotion regulation. This was followed by a battery of computerized tests measuring executive functions and further questionnaires on stress, anxiety and depression symptoms, medication intake, and pain-related subjects. Before entering the VR setting, participants were cabled with electrodes and a thermode, which was used to induce pain, was attached the lower, non-dominant calf. Prior to playing, participants were placed in VR setting to get used to the environment and their individual pain thresholds at rest (baseline or passive control condition [PCC]) was measured. Subsequently participants played two sessions (high [HLC] vs. low cognitive load condition [LLC] in randomized order) of the video game *Subnautica* lasting 10-minutes each. Pain thresholds were recorded as well and after each session perceived cognitive load, spatial presence and sickness symptoms were assessed. Breaks between VR sessions were at least 5 minutes long to prevent pain habituation. Participants were then debriefed and receive remuneration (25€ gift vouchers each) and optional course credit. Overall, the procedure took 100 minutes.

Measures

Gaming and VR. Participants reported their daily playing time, their experience with computers, VR (no, basic, advanced, or expert experience) and gaming (no, casual, regular, or expert gamer). Gaming skill was measured using the self-report Game Playing Skill Scale (GaPS; Bracken & Skalski, 2006; 7 items, e.g., “I am a very good video game player”). Items were rated on a 5-point scale (1 = *strongly disagree*, 5 = *strongly agree*). After each playing session the Spatial Presence Experience Scale (SPES; Hartmann et al., 2015; 8 items, e.g., “I felt as though I was physically present in the environment of the presentation”) assessing the degree of perceived presence in VR was presented. Items were rated on a 5-point scale (1 = *do not agree at all*, 5 = *fully agree*). Furthermore, simulation sickness symptoms were measured three times (beginning of experiment and after each playing session) using the Simulator Sickness Questionnaire (SSQ; Kennedy et al., 1993; 16 items, e.g., “general discomfort”). Items were rated on a 4-point scale (1 = *not at all*, 2 = *a little*, 3 = *average*, 4 = *a lot*). Total sum scores were calculated in line with Bouchard et al. (2007).

Pain-related measures. To assess individual differences in dealing with pain, we used three self-report measures: the Fear of Pain Questionnaire-III (FPQ; McNeil & Rainwater, 1998; 30 items)*,* self-report inventory that measures general fear of several painful experiences (e.g., 'breaking your leg'). Items were rated on a 5-point scale (1 = *not at all*, 5 = *extreme*). The Pain Catastrophizing Scale (PCS; Sullivan et al., 1995; 13 items) assesses the level of catastrophizing when being in pain on a 5-point scale (0 = *not at all*, 4 = *all the time*; e.g., “I keep thinking about how much it hurts”). Lastly, the Pain Vigilance and Awareness Questionnaire (PVAQ; McCracken, 1997; 16 items) measures general vigilance and awareness to pain with items rated on a 6-point scale (0 = *never*, 5 = *always*).

Executive functions. Three different executive functions were measured using the software *PEBL* (Mueller & Piper, 2014), i.e., the Corsi block tapping task in a backwards and forwards condition, the Flanker task, and the Go/No-Go task. The *Corsi block tapping task* (Corsi, 1972.; Kessels et al., 2000) assesses visuo-spatial short-term memory (forward condition) and working memory (backwards condition; Lezak et al., 2012). Participants had to memorise and reproduce sequences of squares in a particular order. A first sequence of two squares was extended every third trial up to a maximum of nine squares. Once two trials of the same length were answered incorrectly, the task ended measuring the block span, i.e. the longest length at which at least one sequence was correctly recalled.

The *Eriksen flanker task* assesses interference control and selective attention, i.e. the ability to concentrate on one stimulus while ignoring distractors (Friedman and Miyake, 2004) and was used in a modified version (Stins et al., 2007). Participants had to correctly identify the direction of a target arrow, which was presented horizontally between four other arrows. In congruent conditions (40 trials) target and flanking arrows pointed in the same direction, in incongruent conditions (40 trials) in the opposite directions. The flanker effect is calculated by subtracting the mean reaction time of congruent trials from the mean reaction time of incongruent trials. Higher scores indicate less efficient interference control and worse selective attention.

The *Go/No-Go task* (Nosek and Banaji, 2001) assesses response inhibition, i.e. the ability to suppress inappropriate actions (Mostofsky & Simmonds, 2008) and was administered using Bezdjian et al.'s (2009) version. Participants had to respond to the letter "P" and to withhold their response to the letter "R" for 160 trials. For the following 160 trials, the letters, i.e., the *go* and *nogo* stimuli were reversed. Performance was computed by the percentage of errors, i.e. pressing in response to *nogo* stimuli. Therefore, lower percentages indicate better response inhibition.

Pain thresholds. Thresholds were measured using a 30x30mm thermode (*PATHWAY ATS*) attached to the lower calf of the non-dominant leg. Baseline temperature was 32°C increasing with 0.5°C/s to maximum 50°C. Participants were instructed to press a foot switch placed under their dominant foot as soon as they perceived pain. Upon the participant's response, the respective temperature was recorded and the thermode returned to baseline temperature with 10°C/s. In sum, 35 thresholds were measured (5 during baseline measurement [PCC], 15 during the low cognitive load condition [LLC], 15 during the high cognitive load condition [HLC]). Inter-trial pauses were randomized between 45 and 50 seconds.

Psychophysiological measures. Electrocardiography (ECG) and electrodermal activity (EDA) were recorded with 1Hz sampling rate using a *BIOPAC MP150* system and the software *Acqknowledge*. ECG lead-II electrodes were attached to the chest according to the Einthoven triangle after preparing the skin with an abrasive pad and 70% isopropyl-alcohol. As the common EDA measuring spot, i.e., the palm, was unfortunately occupied by the game controller, we cabled as suggested by van Dooren et al. (2012) the inner side of the foot after preparing the skin with water.

Further measures. As this project involved an interdisciplinary team, further questionnaires that are not analysed and interpreted within this publication were administered: ADHD Self-Report Symptom Checklist, Difficulties in Emotion Regulation Strategies Questionnaire (DERS; Gratz & Roemer, 2004), and the Depression Anxiety Stress Scale-21 (Henry & Crawford, 2005).

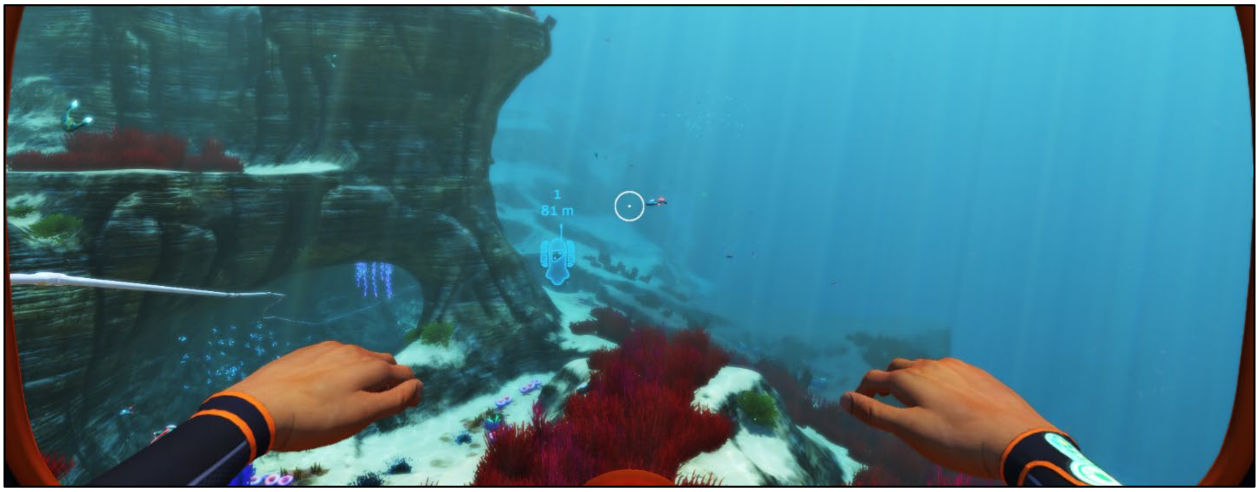
Stimulus material

Participants were placed in the underwater video game *Subnautica* using the *htc Vive* and an *Xbox* controller with adjusted settings (e.g., unlimited oxygen, invincibility, and reduced swimming speed). During the baseline measuring (PCC), participants were placed stationary on an inflatable island swimming on the water surface and could familiarize themselves with the setting by watching the sea and the sky. In the low cognitive load condition (LLC) participants had to follow an underwater pipe. The high cognitive load condition (HLC) included the same navigation task, but in addition, a sequence of eight beacons with single digit numbers were presented and had to be memorized. The sequence was taken from the WAIS-IV Digit Span

Sequential Test (Wechsler, 2008) and had to be recalled directly after playing. For exemplary screenshots of the stimulus material, see Figure 1.

Figure 1

Screenshot from the stimulus material (*Subnautica*) used in the high cognitive load condition.



Note: left: pipeline to follow, middle: beacon displaying a number of the digit sequence (i.e., 1). Recall accuracy was calculated using the Damerau-Levensthein distance (Damerau, 1964) indicating better performance with lower values. As a manipulation check, participants rated a single item measuring cognitive load after both playing conditions (Leppink et al., 2013), i.e., “the task I was working on was ...”, 1 = *very, very easy* to 9 = *very, very difficult*.

Data analyses

Threshold data was screened for outliers, i.e., two *SD* above/below the group *M*, which led to a removal of 23 trials. Removed thresholds were either ≤ 37°C indicating an accidental response (Wasner & Brock, 2008) or very close to 50°C, i.e., trials without any response. Participants with an average pain threshold of ≥ 48.90°C were removed completely from analyses (see Participants) indicating hypoalgesia. Psychophysiological data were screened for artifacts which led to the removal of several datasets (i.e., *n* = 1 for PCC EDA, *n* = 4 for PCC ECG, *n* = 2 for LLC EDA, *n* = 4 for LLC ECG, *n* = 1 for HLC EDA, and *n* = 2 for HLC ECG).

Remaining EDA raw data was treated with a smoothing routine (1 Hz FIR-low-pass filter) and converted to phasic responses. Furthermore, raw ECG data was used to retrieve RR-intervals as a measure of heart rate variability. Unfortunately, due to the COVID-19 pandemic further analyses of the psychophysiological data had to be suspended for six months. However, we are confident to present results in May 2021. Aggregated baseline-corrected EDA and cardiac response curves will be compared using trend analyses and amplitude comparisons in *IBM SPSS* along fixed time intervals around trial responses.

From raw threshold data a difference score was calculated (ΔVR-Pain) by subtracting average PCC thresholds from average LLC and HLC thresholds, respectively. The resulting difference scores were then correlated using non-parametric partial Spearman correlation with averaged PCC thresholds as a covariate, as normality assumptions were not met for most variables. This method allows to control for the fact that depending on the PCC thresholds more or less increment was possible (Vickers & Altman, 2001). For instance, a participant with already high temperatures in the PCC condition had less “room to improve” before reaching the maximum of 50°C. Also, a 1°C increase in “colder” temperatures (e.g., 39° to 40°C) is not necessarily equivalent to an increase in “hotter” temperatures (e.g., 46°C to 47°C) when it comes to pain perception (Lord, 1956). Partial correlations hold the effect of a third variable constant (i.e., averaged PCC thresholds) allowing an examination of the distraction effect unrelated to it.

Results

Although most participants were at least advanced computer users (65.56%), 56.57% stated to have no prior VR experience. Average gaming time per day was less than one hour ($M = 0.96$, $SD = 1.47$), however, self-reported gaming skill was above average ($M = 2.72$, $SD = 1.19$; scale 1 to 5). Presence scores were high for both playing sessions ($M_{LLC} = 3.56$, $SD_{LLC} = 0.79$;

$M_{HLC} = 3.35$, $SD_{HLC} = 0.84$; scale 1 to 5). In contrast, simulation sickness scores were very low at all times of measuring (T_0: $M = 4.32$, SD = 5.41; after LLC: $M = 4.93$, SD = 5.26; after HLC: $M = 4.88$, SD = 4.95; possible sum score ranged from 0 to 48). Comparing cognitive load reported after LLC and HLC indicated a successful manipulation of task difficulty, $t(89) = 15.60$, $p < .001$, as the high load condition was indeed perceived as more demanding ($M_{HLC} = 4.64$, $SD_{HLC} = 1.57$ vs. $M_{LLC} = 1.78$, $SD_{LLC} = 0.99$; scale 1 to 9). Average pain-related cognitions (PCS, FPQ, and PVAQ) and results on executive functions tasks (Corsi, flanker, and Go/No-Go) can be found in Table 1.

Table 1

Descriptive statistics of executive functions and pain-related cognitions

Measure	*M*	*SD*
Executive functions		
Corsi forward block span	6.48	1.36
Corsi backward block span	6.69	1.50
Flanker effect	41.63	20.22
Go/NoGo effect [a]	31.36	15.44
Pain-related cognitions		
FPQ-III	82.33	17.63
PCS	17.96	9.43
PVAQ	35.77	12.75

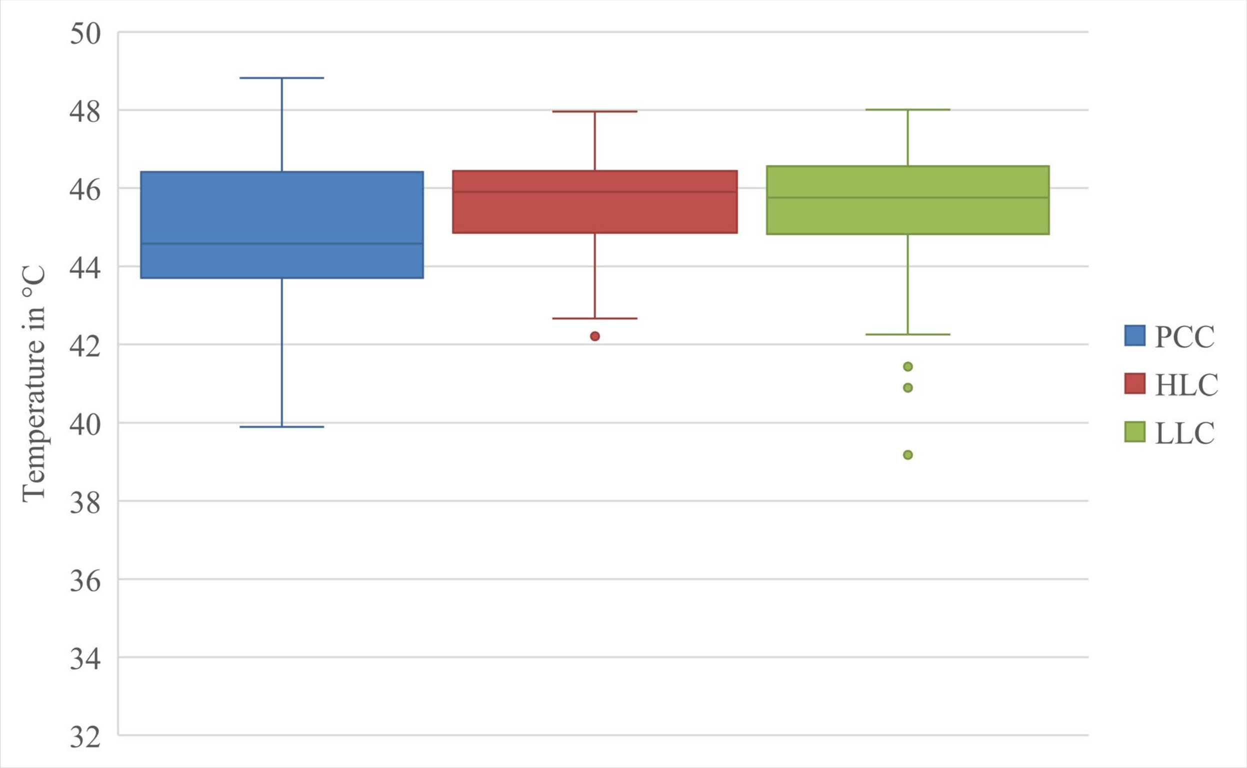
Note: $N = 90$ for each, except for [a] N = 89 as data of one participant could not be retrieved due to technical problems.

To test a possible distraction effect in pain thresholds, PCC, LLC, and HLC were compared in a repeated measures ANOVA (rmANOVA). Gender was already integrated as a between-factor as earlier studies indicated a greater distraction effect for females (Demeter et al., 2015). Results showed a significant main effect of condition, $F(2, 176) = 18.59$, $p < .001$, η_p^2

= .174, but no main effect for gender, $F(1,88) = 2.37$, $p = .128$, $\eta_p^2 = .026$. The interaction effect was marginally significant, $F(2, 176) = 3.29$, $p = .052$, $\eta_p^2 = .036$. Comparing our three conditions significant differences were found between PCC and both playing condition (PCC vs. LLC: *MD* = -0.743, 95% CI [-1.189, -0.298]; PCC vs. HLC: *MD* = -0.858, 95% CI [-1.251, -0.465]), however, LLC and HLC did not differ ($p = .816$; *MD* = -0.115, 95% CI [-0.368, 0.138]). For a graphical comparison of the thresholds, see Figure 2.

Figure 2

Boxplots of average temperature in °C (pain threshold) during all conditions.



Note: PCC = passive control condition, HLC = high load condition, LLC = low load condition.

As stated above, due to the COVID-19 pandemic analyses of our psychophysiological measures had to be paused, therefore no results can be reported yet. However, we are confident to present them at the International Communication Association Conference in 2021.

Two-tailed partial Spearman correlations indicated negative relationships between ΔVR-Pain and pain-related cognitions (i.e., FPQ [only subscale medical pain] and PCS). In contrast, a positive correlation was found for ΔVR-Pain and errors in the Go/NoGo task. All other relations to the ΔVR-Pain score were non-significant (see Table 2).

Table 2

Correlations of individual characteristics and ΔVR-Pain.

Pain-related cognitions	ΔVR-Pain	Executive functions	ΔVR-Pain
FPQ-III Total	-.181	Corsi forward	.074
Severe pain	.040	Corsi backward	.095
Minor pain	-.207	Flanker effect	-.052
Medical pain	-.315**	Go/NoGo effect	.211*
PCS Total	-.222*	Perceived cognitive load	-.024
Rumination	-.134	Digit recall performance [a]	.036
Magnification	-.244*		
Helplessness	-.220*		
PVAQ Total	-.133		

Note: *significant at 0.05 level; ** significant at 0.01 level; [a] memory task performance in high load condition.

Discussion

This project investigated pain distraction in VR with a focus on the influence of cognitive load and inter-individual differences. In line with prior research (Dahlquist et al., 2010; Hayashi et al., 2019; Law et al., 2010), we found greater pain thresholds for the two interactive playing condition compared to a passive control condition. However, in contrast to our hypothesis, but in line with Demeter et al. (2018) no difference was found between the cognitive load conditions.

To join the author's argumentation, we would suspect our two tasks (LLC, HLC) to be too similar in terms of task demand to create a significant difference in pain perception. Although it should be stated that self-reported cognitive load was indeed significantly greater for HLC and only 38.4% were able to recall the number sequence correctly. Given the fact that in our sample VR experience was very low, we would argue for a ceiling effect in the two interactive conditions, meaning that the vivid underwater VR was sufficiently distracting, and thus the digit task was unable to create enough variance in pain perception. However, ΔVR-Pain was unrelated to any gaming or VR experience, indicating equal pain distraction benefits for inexperienced users.

In contrast to Demeter et al. (2015), gender did not influence the distraction effect in our study. However, performance in the Go/No-Go task and ΔVR-Pain were related, suggesting that that participants with poorer response inhibition benefited more from the distraction effect. The latter finding is inconsistent with many other studies (e.g., Bjekić et al., 2018b; Oosterman et al., 2010b), but could be explained by our approach to assess the distraction effect, i.e., measuring thresholds during the distractive task in contrast to pain evaluations after the distraction. This methodological difference could have led to a greater focus on top-down attentional resources. Furthermore, our results suggested a connection between ΔVR-Pain and pain-related cognitions, meaning that participants with greater fear of pain and pain catastrophizing benefited to a lesser extent from the distraction. This is in line with previous findings (Horn et al., 2014; K. Verhoeven et al., 2012) and can be explained by a possible hypervigilance to pain (Van Damme et al., 2004).

In summary, our findings support a growing number of studies reporting analgesic effects of VR environments. This illustrates that VR and gaming are not restricted to entertainment purposes only and can serve as a promising alternative or addition to standard pain treatment. Despite our hypothesis a more demanding VR did not lead to a greater distraction effect. However, interactive playing significantly distracted from pain compared to a passive condition. Notably, our study assessed the distraction effect not by post hoc self-evaluation (e.g., Demeter et al., 2015; Gold & Mahrer, 2018), but through repeated measurement of pain thresholds in combination with psychophysiological markers. The integration of several individual characteristics allowed us to explore which factors do or do not affect pain distraction in (dis)advantageous ways.

Nevertheless, several limitations should be mentioned. As we recruited a rather young (age 18 to 35, mostly students) and healthy sample, results cannot necessarily be generalized to other populations. Prior research indicated that elderly people, who are more likely to suffer from pain, differ in technology acceptance (Dogruel et al., 2015), and pain management (Zhou et al., 2015). Therefore, further studies should replicate the analgesic effect of VR in older populations as well. Secondly, our baseline measurement (PCC) which allowed participant to familiarize with the VR environment was always completed first. Although explorative analyses of measurement time did not show increasing thresholds over time, it is unclear to what extent habituation and desensitization affected our results. Moreover, our passive control condition might have been too distinct from the two playing conditions in terms of sensory and visual properties (i.e., sitting on the water surface vs. swimming through a lively underwater world) whereas LLC and HLC might have been too similar. Therefore, further studies should carefully operationalize different VR settings allowing both for enough comparability, but also sufficient variance.

Overall, our findings support the analgesic effect of VR, depending on interactivity of the setting, pain-related cognitions of the user and response inhibition abilities, but unrelated to gender, task demand or VR and gaming experience.

Authors statement

The current study was founded by the doctoral school of the University of Luxembourg. All procedures were in accordance with the ethical standards of the responsible institution committee on human experimentation. The authors declare no conflict of interest.

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