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How does interface influence the level of analgesia when Virtual Reality distraction is used?

Abstract:

This study investigates the effectiveness of virtual reality (VR) technology in distracting attention from pain. We tested how body engagement related to navigating the virtual environment (VE) influences the intensity of pain. Two different interfaces were used to play the same VE, and a cold pressor test was used for pain stimulation. A mixed design was used for the experiment. Sixty-six undergraduate students participated. One group navigated the game using a rotation sensor, head tracker and foot pedals (Body Movement Interface). Another group navigated only using their hands (Hand Movement Interface). Objective and subjective measures of pain were collected – the amount of time participants kept their hand in a container with cold water, and the participant's assessment of the pain intensity on a visual analog scale (VAS). Participants also filled in questionnaires designed to measure feelings of presence in VE and emotional attitudes towards the game. We found no significant difference between the two used interfaces in their analgesic efficacy. In both groups during VR distraction, participants showed significantly higher levels of pain endurance than without VR distraction.

Keywords:

virtual reality, pain tolerance, analgesia, virtual environment, thermal stimulation

Streszczenie:

Badanie eksperymentalne dotyczy efektywności rzeczywistości wirtualnej jako dystraktora od bodźców bólowych. Testowano wpływ zaangażowania ciała podczas sterowania grą na intensywność odczuwanego bólu. Dwa różne interfejsy zostały użyte do sterowania tym samym środowiskiem wirtualnym. Jedna z grup sterowała grą wykorzystując ruch całego ciała, druga grupa nawigowała wyłącznie za pomocą ruchu ręki. 66 studentów uczestniczyło jako osoby badane. Termiczna stymulacja zimnem została zastosowana jako bodziec bólowy. Miarą efektu analgetycznego był czas zanurzenia w zimnej wodzie ręki osoby badanej, oraz subiektywna ocena intensywności bólu na skali od 1 do 10. Osoby badane wypełniały także kwestionariusz poczucia obecności w środowisku wirtualnym, oraz odpowiadały na pytania dotyczące odczuć wobec gry. Zaobserwowano istotny efekt analgetyczny związany

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z użyciem wirtualnej rzeczywistości. Jednak, nie wykryto istotnych statystycznie różnic w efekcie analgetycznym pomiędzy różnymi metodami sterowania grą.

Słowa kluczowe:
wirtualna rzeczywistość, ból, analgezja, środowisko wirtualne, stymulacja termiczna

Introduction

Virtual Reality technology (VR) is recently becoming more widely used in psychology and therapy. Research on possible applications of VR in psychology began in the late eighties. Currently, with more advanced and accessible technology, and increased knowledge, both the efficacy and scope of VR applications have improved. During VR treatment patients wear head-mounted displays (HMD) and have the opportunity to actively participate in a three-dimensional computer generated environment. One such VR application in psychology is pain alleviation, where VR acts as a distractor dragging a person's attention away from painful stimuli. (Gold *et al.,* 2007; Botella *et al*., 2008).

Several studies confirm the effectiveness of VR as a distractor from pain. (For a review see: Botella *et al*., 2008; Wiederhold & Wiederhold, 2007; Malloy & Milling, 2010). The results of a study done by Twillert and others (2007) showed greater effectiveness of VR distraction, compared with other methods. Authors compared the effectiveness of VR distraction with other types of distraction (like watching a movie). Analgesic efficacy of VR was shown to be effective both with clinical populations and in laboratory studies where experimentally induced pain stimuli were used. Some clinical applications include the treatment of pain in children (Das *et al*., 2005) or reduction of pain and stress associated with the therapy in cancer patients (Gershon *et al*., 2004), and dental treatments (Hoffman *et al*., 2001).

Currently only a few published studies have investigated how the content of virtual environments influences the analgesic effect. Mühlberger and others (2007) studied the effect of different virtual environments on hot/cold pain stimuli endurance. Another similar study was done on a group of post-stroke individuals (Shahrbanian & Simmons, 2008). A study by Dahlquist and others (2010) evaluated the effect of the avatar point of view on cold-pressor pain tolerance in young adults. Czub & Piskorz (2012) tested how the amount of stimulation in VE influences the analgesic effect.

The relationship between the analgesic effects of VR and the strength of the subjective presence in a virtual world was investigated by Hoffman *et al*. (2004). Results of this study indicate that the strength of an analgesic effect is associated with the quality of graphics and sound, and the degree of possible interactions with the virtual world.

Results of other studies further corroborate the hypothesis that active participation in a virtual environment is a more effective distractor from pain stimuli than passive observation of a recording where someone else plays a game (Dahlquist *et al.*, 2007).

Therefore, the level of interaction offered by VE seems to be a good candidate for a parameter differentiating the effectiveness of the analgesic influence, and - in the context of creating more effective VR distraction tools – it may be important to study in greater detail the factors that build interaction in VE.

Several factors can influence the degree of presence in a virtual environment. These factors can be related to the qualities of that virtual environment – like the first or third person perspective, the avatar used, or the graphics quality and complexity of the scene. They can also be connected to the technology that was used – resolution of HMD's, their field of view, or frame rate – which influences interaction in VE if it is experienced as jerky or smooth. Some most important factors influencing presence lie on the border between hardware and software, and are related to interface – means of interaction with a virtual environment, and means of bodily engagement in that interaction. Interface is directly related to proprioception in VE interaction. The extent to which simulated sensory data match proprioception is considered as one of the most important factors influencing presence (Sanchez-Vivez & Slater, 2005). Another crucial factor related to presence is the degree of possible actions in VE - to quote Sanchez-Vivez & Slater – 'the sense of "being there" is grounded on the ability to "do there"'. As authors suggest, participants become present in the virtual environment through meaningful motor activity. Several published studies report a significant relation between the degree of body engagement and experienced presence in the virtual environment (Slater et al., 1998; Slater & Steed, 2000). Slater and others (1998) tested the hypothesis that body movements executed in relation to a given environment enhance the feeling of being present in that environment. They studied two aspects of motor engagement: the extent of body movements, and complexity of the motor task executed in VE.

Bianchi-Berthouze and others (2007) state that increased bodily engagement leads to greater affective experience, in addition to increasing the feeling of presence in VE. They compared the influence of different interfaces on player engagement in the game, and found that the interface that allowed for more body movement was more effective in grabbing player attention, and evoking emotional reaction towards the game.

The focus of our paper is on how different interfaces (engaging the body differently) influence the feeling of presence in VE, and subsequently, influence the analgesic effect.

More precisely, we investigated how the amount of body parts engaged in navigating the VR game influence the experience of pain. We expected that the more body parts that would be engaged, the greater the observed analgesic effect would be.

This experiment is part of a larger research project, the results of which will be presented in Piskorz and others (in preparation) and Czub and others (in preparation). In that project two experimental studies were conducted, and in both of them the same virtual environment was used. However, in each of those studies, there was a different interface to interact with VE.

Materials and Methods

Participants. Sixty-six students from Wroclaw universities participated in the study. In the Body Movement Interface (BMI) group there were 31 participants: 19 females (average age: 21.37; SD 2.34; min 19, max 30) and 12 males (average age: 22.42; SD 1.51; min 20; max 24). In the Hand Movement Interface (HMI) group there were 35 participants - 19 females (age: average 22.21; SD 3.03; min 19, max 33) and 16 males (age: average 22.56; SD 2.94; min 19; max 29).

Virtual reality equipment. Participants received visual and aural stimuli from the game via a virtual reality headset (HMD) - E-magin Z-800. HMD goggles had SVGA resolution – 800x600 pixels per display (1.44 megapixels), view angle - 40 degrees diagonal FOV (which equals seeing a 2.7m diagonal movie screen from 3.7 m distance). The weight of the display set was 227g. Participants were hearing stereo sound from HMD's audio output.

Participants in the BMI group had an opportunity to look around in the virtual environment using an orientation tracker device Polhemus Minuteman. They were also able to rotate the avatar in the environment using the sensor held in their hands and move forwards/backwards with pedals from the USB TRACER GTR steering wheel. With such an interface many participant's body parts were engaged: hand, head and legs.

In the HMI group there was a change of interface: now the participants used a Microsoft Kinect device. Such an interface enabled navigating the game using only the hand movements.

Video game. We designed a game for the participants to play. In the course of the game they moved a 3D arrow into a space filled with spheres. The gamer's task was to hit white spheres with an arrow. Additionally, red spheres were interfering with completing the task. For each contact with a white sphere participants gained one point, and each contact with a red sphere resulted in subtraction of one point.

The pain stimuli apparatus. Thermal pain stimulation was used in the study. The apparatus consisted of a container (25x35cm) filled with cold water (temperature 4.5–5.5°C). The container had two chambers connected to each other: one of them was filled with ice in order to maintain the proper temperature of the water and participants kept the other one in their hand. The container was equipped with a water circulator whose task was to maintain constant temperature in both chambers. The water temperature was monitored by an electronic thermometer. Similar equipment was used in previously published studies (Dahlquist 2007; Forys, Dahlquist 2007).

Visual Analogue Scale (VAS) – a scale built on the basis of a horizontal 10cm continuous line. Each participant immediately after removing the goggles marked the strength of experienced pain, expressed on the scale in centimeters, where 0 was described as slight pain, and 10 as extreme pain.

Behavioral indicator of pain – the number of seconds during which participants kept their hand in cold water.

Igroup Presence Questionnaire (IPQ) - A scale created by Schubert, Friedmann & Regenbrecht for measuring the sense of presence experienced in the virtual environments. The scale consists of four subscales: Spatial presence – the sense of being located inside VE; Involvement – the level of engagement in VE; Realism – the sense of realism of VE; General – an additional item measuring the general "sense of being there". Reliability (Cronbach's Alpha) of IPQ is between 0.63 and 0.78 (Schubert, 2003).

Attitudes towards the game questionnaire (ATG) – a scale created by us to assess the emotional response towards games, and the difficulty of using the interface. The scale consisted of four questions on a scale from -3 to 3. Questions were related to emotions and difficulties experienced during the game. Participants assessed the game as being very frustrating/very pleasant, boring/interesting, engaging/not engaging. Additionally, participants assessed the level of difficulty in steering the game: very easy/very difficult.

Procedure

The experiment was conducted in a room belonging to Wroclaw University Institute of Psychology. The study was carried out according to a mixed design, where one group was playing the game using BMI interface, whereas another group used HMI. Additionally, for each participant, their pain threshold was assessed, in a non-VR condition where participants were undergoing the same procedure as during VR distraction, but were seeing only a blank screen on the goggles. In both groups the order of presentation of VR and non-VR conditions was counterbalanced.

Participants were told that the purpose of the experiment was to study how people feel their bodies in a virtual environment. They were also assured of the possibility to resign from participating at any moment. Participants were then shown the equipment and familiarized with the procedure. They immersed their hands in the cold water for a few seconds in order to become aware of its temperature. Then, detailed instructions of how to play the game were given to them, and they were able to practise navigating the game and using the interface. The participant's task during the practice was to hit several white spheres with an arrow-avatar.

During the experiment, participants wore HMD's and their heads were additionally covered with a black scarf to better isolate them from peripheral stimuli. The participants were instructed to put their hands in the container with cold water, and keep it there until the pain became difficult to bear (they were also told to signal verbally the moment when they remove their hands from the water). Participants were requested not to endure overwhelming pain. The experiment was terminated after four minutes if the participant did not remove their hand earlier. After one minute of playing the game, the participants' non-dominant hand was put in the container with cold water while they continued playing. Immediately after removing their hand from the cold water participants filled the VAS scale, IPQ and ATG questionnaires.

Non VR condition. As in the case of the VR conditions, participants were equipped with an HMD headset and covered with a black scarf. However, no images were displayed, participants saw only a blank screen. The rest of the procedure was identical as in VR conditions, the only difference being that participants did not fill in the IPQ and ATG.

Participants were given at least a 15-minute break between each pain stimulus. During the break they could warm their hand, and they also had the opportunity to put their hand in the container with room temperature water.

Results

Due to the lack of normal distribution in the results, we used non-parametric statistics (U-Mann Whitney test) in the analysis. Effect sizes were calculated using the formula $r = Z/\sqrt{N}$. According to Cohen (1988, 1992) it was assumed that the effect can be considered small when $r = 0.10$; medium when $r = 0.25$; and large when $r = 0.50$.

First, we analyzed the relationship between the used interface and both behavioral and subjective pain indicators. We did not find statistically significant differences, both in relation to behavioral ($U = 498.5$, $Z = 0.37$, $p = 0.71$) and subjective ($U = 506$, $Z = 0.27$, $p = 0.79$) measures. While using both types of interface, participants evinced similar levels of pain endurance – which means that participants in both groups kept their hand in the cold water for similar amounts of time. Also, there were no significant differences in subjective pain ratings between the groups. In both groups pain intensity results concentrated in the middle of the scale (see Table 1, Figure 1, Figure 2).

Table 1. Descriptive statistics of behavioural and subjective pain indicators in non-VR and VR conditions.

	Time of immersion of the hand in the cold water – behavioural indicator		VAS scale – subjective indicator	
	M	SD	M	SD
VR - BMI	126.26	104.02	5.58	2.35
Non-VR - BMI	81.77	88.44	6.65	2.0
VR - HMI	109.35	93.83	5.44	1.82
Non-VR - HMI	60.66	71.31	6.14	1.71

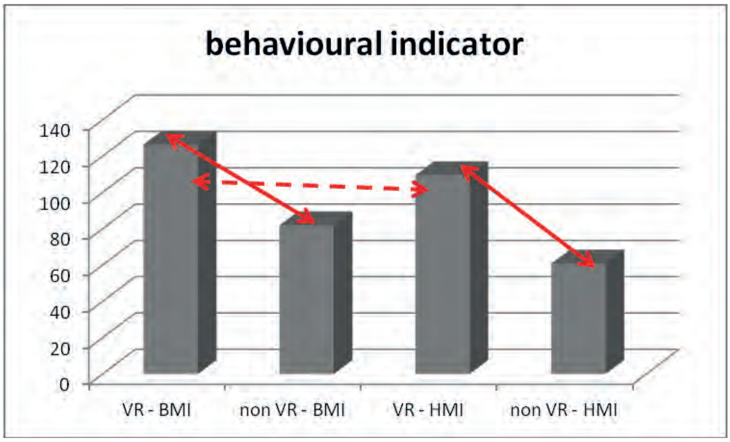

Fig. 1. Means of behavioural pain indicator for BMI and HMI in VR and non-VR conditions. Continuous line denotes statistically significant difference, dashed line – lack of significance.

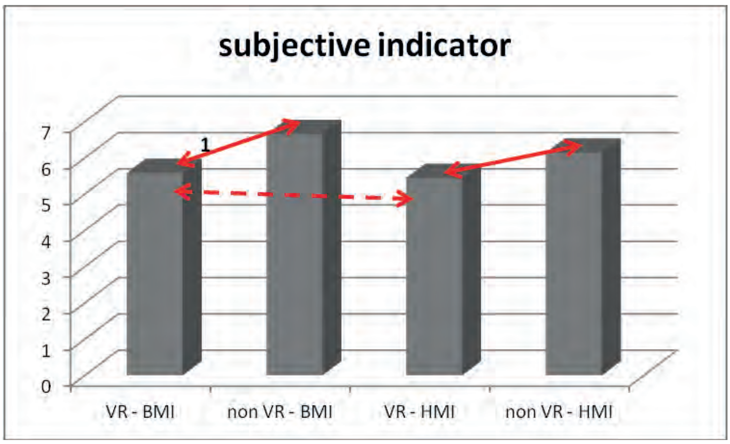

Fig. 2. Means of subjective pain indicator for BMI and HMI in VR and non-VR conditions. Continuous line denotes statistically significant difference, dashed line – lack of significance.

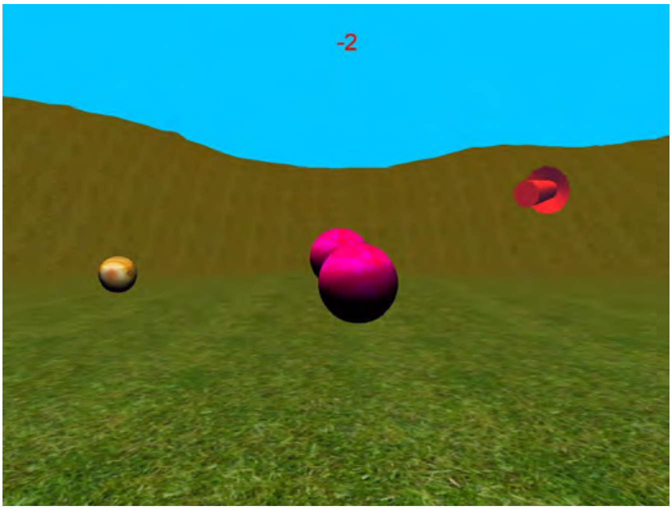

Fig. 3. Screenshot from the game used in the study.

In the next stage of statistical analysis we investigated the relationship between the used interface and emotions experienced during the game. We did not find any statistically significant differences between two groups. Participants were experiencing similar levels of frustration/satisfaction and engagement while using both types of interface.

There were significant differences in the assessment of game difficulty ($U = 202.5$, $Z = 3.65$, $p < 0.001$, $r = 0.47$), and subsequently in the number of points collected in the game ($U = 63$, $Z = -5.92$, $p < 0.0001$; $r = 0.75$). Participants assessed the HMI interface as significantly easier to use, and were collecting greater numbers of points (see Table 2).

Table 2. Descriptive statistics of the ATG questionnaire.

	BMI		HMI	
	M	SD	M	SD
Collected Points	2.17	9.45	54.32	43.35
Difficult	1.07	1.41	-0.53	1.55
Pleasant	0.90	1.52	1.07	1.34
Interesting	0.20	1.71	0.31	1.83
Not engaging	-1.23	1.77	-0.91	1.90

Subsequently we investigated how the interface relates to the level of presence in VE. Comparison of IPQ results did not reveal any significant differences between the two groups (spatial: $U = 475.5$, $Z = -0.65$, $p = 0.52$; involvement: $U = 389$, $Z = -1.22$, $p = 0.22$; realism: $U = 464.5$, $Z = -0.57$, $p = 0.57$; general: $U = 450$, $Z = 1.18$, $p = 0.24$). The two interfaces that were used gave rise to similar experiences of presence in the virtual environment (see Table 3).

Table 3. Descriptive statistics of IPQ in the BMI and HMI groups.

	BMI		HMI	
	M	SD	M	SD
Spatial	3.01	1.32	3.21	1.25
Involvement	2.88	1.19	3.23	1.35
Realism	1.88	1.08	2.08	1.10
General	4.16	1.95	3.66	1.92

In the next stage we compared results of behavioral and subjective pain indicators between VR and non-VR conditions in both groups. The VR condition was compared to the non-VR condition with the use of Wilcoxon's Signed Rank Test. The comparison revealed statistically significant differences in the BMI group between VR and non-VR conditions ($T = 41.5$; $Z = 3.10$; $p < 0.01$, $r = 0.45$). Participants in the BMI group could endure pain for a significantly longer period of time in VR than in non-VR conditions. Similar results were obtained in the HMI group when we compared behavioural pain indicators in non-VR and VR conditions ($T = 57.0$; $Z = 3.61$, $p < 0.001$, $r = 0.47$) (see Table 1, Figure 1).

The next step in our analysis was aimed at examining the influence of immersion in virtual reality on the level of subjective pain ratings. The results of VR and non-VR conditions were compared using Wilcoxon's Signed Rank Test. The results indicated that there was a statistically significant difference between the subjective pain assessment in the non-VR and VR conditions for BMI group ($T = 79.5$; $Z = 2.81$; $p < 0.01$, $r = 0.38$). The participants admitted having felt more pain during the non-VR trials. The comparison of results revealed statistically significant differences also between VR and non-VR conditions for the HMI group ($T = 149.0$; $Z = 2.35$; $p < 0.02$, $r = 0.29$). Participants reported experiencing more intense pain during non-VR conditions (see Table 1, Figure 2).

During the last stage of our analysis we tested whether the order of VR/non-VR conditions influenced behavioural and subjective pain indicators. The results have shown that in the BMI group, the VR condition ($U = 95.5$; $Z = 0.38$; $p = 0.70$), as well as in the non-VR condition ($U = 82$; $Z = 0.95$; $p = 0.34$) the order of testing had no impact on the level of pain tolerance measured as to the period of time during which one's hand was kept in the container with cold water. Subjective pain indicators were also independent from the order of testing (non-VR condition: $U = 77.5$; $Z = 1.14$; $p = 0.25$), and VR condition: $U = 71$; $Z = 1.42$; $p = 0.16$). Also in the HMI group the results indicated that in the case of the non-VR ($U = 125$; $Z = 0.43$; $p = 0.66$), and VR condition ($U = 120$; $Z = 0.22$; $p = 0.83$) the sequence of tests had no significance. The subjective assessment of pain was independent from the order of testing both for the VR condition ($U = 109$; $Z = 0.63$; $p = 0.53$), as well as for the non-VR ($U = 86$; $Z = 1.79$; $p = 0.07$).

Discussion

Results of our study do not support the hypothesis that interface influences the level of presence in the virtual environment. Also the interface does not seem to be related to the amount of pain experienced by the participants. However, several factors might be important in an interpretation of the results. In the BMI group participants navigated the environment using hands, legs, and also were able to look around by moving their heads. In the HMI group participants steered using only their hand. We expected greater bodily engagement, and subsequently a greater analgesic effect in the BMI group. However, the range of hand movements in the HMI group (using Kinect) was greater than in the BMI, and this might have counterbalanced the effect of engaging more body parts in the BMI.

In future studies, differences in body engagement should be better controlled, accounting not only for the area of the body that is engaged but also for the scope and dynamics of movements each interface elicits.

Moreover, participants experienced an unequal level of difficulty while using both interfaces. In the BMI group navigating the game was reported as more difficult than in the HMI group. That may have diminished the level of presence in VE in the BMI group. According to the theory of flow (Csikszentmihalyi, 1990) people engage most in tasks with optimal levels of difficulty. The interface used in the BMI group might have been too difficult to use, and therefore contradicted the effect of multiple body parts engagement. Greater difficulty of gaining points in the game might have weakened players' motivation in the BMI group.

Another factor that might have influenced results was the relation between the avatar arrow and hand movements, which was more natural in HMI – changes of arrow position in virtual three-dimensional space reflected the position of a participant's hand in space. BMI navigation was more abstract and involved rotating the sensor to point the avatar arrow towards a certain direction, and pressing foot pedals to move it forwards or backwards. Thus, the feeling of interface being natural might be a more important feature in evoking a presence than in engaging multiple body parts. Such hypothesis may find support from studies done by Sanchez-Vives and Slater (2005).

It is important to mention several other issues raised by our results. Significant differences in difficulty of using the interfaces did not influence the participants' emotional attitude towards the games. In both groups participants described the game as rather pleasant than frustrating. Nor did the number of points collected in the game influence the emotional attitude towards the game. This may be explained by the fact that the experimental procedure itself (e.g. using head mounted displays) was a new and unusual experience for most of the participants, and that made differences between interfaces less pronounced. Bianchi-Berthouze (2013) suggests that the novelty of interface should be controlled in studies on relations between interface and engagement in the game.

Comparison of VR and non-VR conditions in both groups confirms the efficacy of VR as an analgesic tool (see: Botella et al. 2008, Czub & Piskorz, 2012). A similar analgesic effect was evoked by two different interfaces used in our study.

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