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Influence of memory on experienced pain during Virtual Reality analgesia

Abstract:

Virtual Reality (VR) technology can be applied during pain treatment, acting as an effective distractor from pain stimuli. In our paper we investigate how memory influences experienced intensity of thermal pain stimuli. An experiment (within subject design) was conducted on 35 students from various Wroclaw universities. A cold pressor test was used for pain stimulation. Participants were immersed in customized virtual environments, created for this particular study. The environments differed at the level of memory engagement while playing a game. Pain measures were determined by the length of time participants kept their hands in cold water (pain tolerance), and their pain rating intensity was measured on the VAS scale (pain intensity). Participants were asked to put their hand in a container with cold water and keep it there until the pain became difficult to bear.

In both VR conditions participants kept their hands in the cold water significantly longer than in a non-VR (control) condition. Results of pain intensity measures were in conclusive. We did not find any significant differences in effectiveness in the virtual environments that were used.

Keywords:

virtual reality, pain, attention distraction, cold pressor test, video games, memory

Streszczenie:

Rzeczywistość wirtualna może być zastosowana jako efektywne narzędzie odwracania uwagi od bodźców bólowych. W przeprowadzonym badaniu testowano wpływ zaangażowania pamięci na poziom odczuwania bólu. Termiczna stymulacja zimnem została zastosowana jako bodziec bólowy. W eksperymencie wzięło udział 35 studentów Uniwersytetu Wrocławskiego. Osoby badane dwukrotnie (model grup zależnych) zostały zanurzone w wirtualne środowiska, które różniły się poziomem wykorzystywania procesów pamięciowych. Przeprowadzono również pomiar kontrolny, czyli miarę tolerancji bólu osób badanych bez zanurzenia w wirtualne środowisko. Poziom odczuwanego bólu mierzono na dwa sposoby: czas zanurzenia ręki w zimnej wodzie oraz ocena intensywności bólu na

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skali VAS. W obu warunkach eksperymentalnych osoby badane trzymały rękę w zimnej wodzie istotnie dłużej niż podczas pomiaru kontrolnego. Pomiędzy zastosowanymi środowiskami wirtualnymi nie wystąpiły jednak różnice w poziomie mierzonych wskaźników bólu, czyli poziom zaangażowania procesów pamięciowych nie wpłynął na efekt analgetyczny.

Słowa kluczowe:
wirtualna rzeczywistość, ból, dystrakcja uwagi, stymulacja termiczna,gry komputerowe, procesy pamięciowe

Introduction

Virtual Reality technology, and its possible applications, in the domain of psychology is a widely researched and growing field of study. Several published studies indicate that Virtual Reality technology can be effectively used in alleviating pain. (Czub & Piskorz, 2012; for review also see: Botella *et al*., 2008; Wiederhold & Wiederhold, 2007; Malloy & Milling, 2010).While being immersed in VR, patients actively participate in a three-dimensional computer generated environment, which responds consistently to their actions. Usually, immersion is achieved through the use of head mounted displays (HMD), which allow for a more engaging experience. Effectiveness of VR in alleviating pain was tested both in clinical populations and in laboratory studies, where experimentally induced pain stimuli were used. Gershon *et al*. (2004) demonstrated the possible use of Virtual Reality to reduce pain and stress associated with therapy in cancer patients. Hoffman and colleagues (2001) have shown it can be an effective tool during dental treatments. VR can also be used effectively in the treatment of pain in children (Das *et al*., 2005).

It is widely assumed that VR pain alleviating effects act through attentional mechanisms by dragging patient's attention away from painful stimuli. (Gold *et al.,* 2007; Botella *et al*., 2008). Active engagement in VR activity, and the medium's immersive nature, involves the patient's attention more intensively (compared with other methods) – and thus can be a significantly more effective tool in pain alleviation.

Systematically comparing the effectiveness of VR distraction with other distractions (like watching a movie) has shown VR's greater effectiveness (Van Twillert *et al*., 2007).

Known factors that influence the analgesic effect are: the subjective strengths in a virtual world, graphics and sound quality, and the degree of possible interactions with the virtual world (Hoffman *et al*., 2004).

Active participation in the virtual environment was found more effective in alleviating pain, than passive observation in someone else's game play. (Dahlquist *et al.,*2007). Point of view taken within the game (first person vs. third person view) did not influence

the alleviating effect (Dahlquist *et al.,* 2010). However, only a few published studies investigate how the virtual environment relates to the pain experience.

The majority of research using VR as a distractor is based on the assumption that the main factors decreasing pain are the following: the sense of "being there", and cognitive engagement and motor activity. Virtual environments used in previous studies stimulated mainly visual-motor coordination. To the best of our knowledge, no research has verified whether memory while being immersed in VE improves pain distraction.

However, results of several studies not related to VR analgesia suggest a relation between memory level processes and intensity of experienced pain (Buhle &Wager, 2010; Yamasaki *et al.,* 2000). Memory engaging tasks were effective in dragging participant's attention away from painful stimuli.

On the other hand, according to the load theory of attention, increasing the cognitive load should result in diminished ability to ignore distractors (Lavie, 2010). We interpret the VR game as a distraction from pain, but it's also possible to assume a different perspective – and perceive the pain as a distraction from playing the game. Load theory of attention has strong predictions regarding distractors under a cognitive load, but the theory has not yet been tested using painful stimuli as distractors.

In the following experiment we attempt to verify the influence of memory engagement on experienced pain. We test the hypothesis that memory engagement changes the intensity of experienced pain during VR immersion.

Methods

Participants

Thirty-five volunteers (students from various Wroclaw universities) participated in the study. This group included 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). The experimental procedure was approved by the local ethics committee. Participants gave their informed consent before the experimental session began.

Apparatus

Virtual reality equipment. The participants engaged in the virtual environment 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 deg diagonal FOV (which equals seeing a 2.7 m diagonal movie screen from 3.7 m distance). The display set weighed 227g. Participants heard stereo sound from HMD's audio output.

The participants used Microsoft Kinect controller. They navigated the avatar-sphere in three dimensions with their dominant hand. Hand movements in 3D space were translated to avatar sphere movements in virtual 3D space.

Video game. The participants played games designed by us. During the game they navigated a 3D sphere-avatar in a space filled with coloured spheres. In the first VR environment (memory VR condition) the participants' task was to memorize group elements that made the same sounds upon hitting them with an avatar sphere. The game's rules were similar to the ones in the popular "Memory" game. In the VR game used in the current study the player navigated an avatar-sphere and pointed to multiple white spheres which then produced different sounds. At the same time the player had to avoid three red spheres in order not to lose points.

In the second VR environment (no-memory VR condition) the gamer's task was to hit white spheres with an avatar-sphere. Additionally, red spheres were interfering with completing the task. Upon creating the two environments the researchers' aim was to make these two as similar as possible, with the only difference being to employ memory processes in one of them.

The pain stimuli apparatus. The study used thermal (cold) stimulation. Thee 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 water temperature and in the other one the participants were immersing their hands. A water circulator was mounted within the container in order to maintain constant temperature in both chambers. The water temperature was monitored with an electronic thermometer. Similar equipment had been used in previously published studies (Dahlquist, 2007; Forys, Dahlquist, 2007).

Measures

Visual Analogue Scale (VAS) – measure of pain intensity. The scale is a horizontal continuous line, 100mm in length. Participants marked the strength of experienced pain, expressed on the scale in millimeters, where 0 stands for slight pain, and 100 for extreme pain. Each participant marked the scale three times: once without VR - to assess the pain threshold, and twice after exposure to the pain stimulus during immersion in high and low interaction VE.

Pain tolerance – the period of time during which participants kept their hand in cold water.

Igroup Presence Questionnaire (IPQ). A scale created by Schubert, Friedmann & Regenbrecht for measuring sense of presence experienced in the virtual environment. The scale consists of four subscales: Spatial presence – the sense of being present in VE; Involvement – the engagement level in VE; Realism – how real VE seemed; General –

an additional item measuring the general "sense of being there". IPQ's reliability (Cronbach's Alpha) is between 0.63 and 0.78 (Schubert, 2003). There is no Polish IPQ adaptation, we therefore translated the items.

Design and Procedure

A within-subject design was used in the experiment. Participants experienced two experimental conditions (memory task *vs*. high interaction). In addition, the participants' pain threshold established during non-VR constituted the baseline measurement.

The experiment was conducted in a room belonging to Wroclaw University Institute of Psychology. Participants were told that the experiment purpose was to investigate experiences of one's own body in virtual reality. Participants were also informed that they could withdraw from participation at any moment and without any particular reason. The equipment and procedure was then presented to them. They immersed their hands in cold water for a few seconds in order to feel its temperature. They were also given thorough instructions on how to play the game in each virtual environment, and practiced playing in order to learn how to navigate the game and how to use the interface. The participants, while wearing the HMD headset and using hand movements recorded by Kinect, practised hitting white spheres with an avatar-sphere. The training phase ended after they were able to hit five white spheres in a row.

After training, participants were asked to fill in a short personal data survey, and upon its completion were exposed to three experimental conditions. The presentation of conditions was counterbalanced (Latin square).

During all experimental conditions participants wore HMD headsets and their heads were covered with a black scarf to better isolate them from peripheral stimuli. They were instructed to put their hand in the container with cold water, and keep it there until the pain became difficult to bear (they were also asked to verbally communicate the moment when they removed their hand from the water). They were requested not to withstand overwhelming or unbearable pain. The experiment was terminated after four minutes if the participant did not remove their hand earlier.

After one minute playing the game, the participants' non-dominant hand was immersed in the cold water while they continued playing. After finishing the trial (that is after participants removed their hand from the cold water) they assessed their experienced pain on the VAS scale, and filled in the *Igroup Presence Questionnaire*.

Both VR procedures were identical.

Non VR condition

During the non-VR condition, participants were seated in such a way that enabled them to put their dominant hand into the cold water container. Identical to VR conditions, participants wore an HMD headset and had their heads were covered with a black scarf.

However, no images were displayed, and participants saw a blank screen. After one minute their dominant hand was immersed in the cold water. Similarly to VR conditions, they were instructed to inform us verbally and take their hand out of the container when the pain became difficult to bear. The trial was stopped after four minutes if the participant had not removed the hand earlier. Upon ending the trial, participants assessed their level of experienced pain on the VAS scale.

Between each experimental condition participants were given a 15 minute break during which they could warm their hands. They were provided with a container filled with room temperature water, and could put their hands in it.

Statistics

Non-parametric statistics were used for analysis (i.e. Friedman's ANOVA, Spearman's Rank Correlation Coefficient, Median Test, Wilcoxon's Signed Rank Test, and Mann-Whitney U-test). Non-parametric statistics were dictated by a lack of normal distribution (data distribution was bimodal) as well as homogeneous the results. Using the formula for non-parametric test of significance for dependent ($r = Z/\sqrt{N}$, where N is the number of observations) and independent samples ($r = Z/\sqrt{N}$, where N is the number of participants), the authors calculated the effect sizes. According to Cohen's assumptions (1988, 1992) the effect was considered small when $r = 0.10$; medium when $r = 0.25$; and big when $r = 0.50$.

Results

Preliminary analyses

The first step in statistical analysis focused on verifying whether the sequence of conditions influenced tolerance to pain.

The analysis tested pain tolerance and pain intensity as a function of succeeding measurements. The succession of measures influenced neither tolerance to pain results (median test, Chi square = 0.71; df = 2; p = 0.70) nor pain intensity ratings (median test, Chi square = 0.94; df = 2; p = 0.62).

Main analyses

Paintolerance. The results confirmed that VR is effective as a distractor. Its main effect: major differences were found in tolerance to pain between the three examined conditions (Friedman's ANOVA (df = 2) = 14.13; $p < 0.001$). Further analyses carried out with Wilcoxon's Signed Rank Test revealed that both no-memory VR ($T = 57.0$; $Z = 3.61$, $p < 0.001$, effect size: $r = 0.47$), and memory VR ($T = 51.5$; $Z = 3.72$; $p < 0.001$, effect size: $r = 0.48$) increased the participants' pain tolerance in comparison with the non-VR condition. In both cases participants managed to keep their hands in cold water for a substantially longer period of time (see Table 1).

Table 1. Descriptive statistics of pain tolerance measures in non VR and VR conditions.

	Time of immersion of hand in the cold water – pain tolerance			
	Average of ranks	Sum of ranks	M	SD
Non VR	1.52	48.50	63.50	74.00
No-memory VR	2.13	68.00	112.63	95.81
Memory VR	2.36	75.50	115.13	90.19

The next step in analysis examined the influence of immersion in virtual reality on pain intensity ratings. The main effect between the three examined environments did not occur (Friedman's ANOVA (df = 2) = 2.90; p = 0.24) (see Table 2).

With the sample size we used (N=35), we had 80% chance for detecting the effect size Cohen d = 0.44, assuming that the effect exists. Therefore, our sample size was sufficient to detect medium effect sizes.

Table 2. Descriptive statistics of pain intensity measures in non VR and VR conditions.

	VAS scale – pain intensity			
	Average of ranks	Sum of ranks	M	SD
Non VR	2.23	71.50	6.21	1.77
No-memory VR	1.83	58.50	5.46	1.87
Memory VR	1.94	62.00	5.63	2.05

Pain vs. virtual reality type. The results did not confirm our initial assumptions: the type of virtual environment was not a differentiating factor with respect to the participants' tolerance to pain. Participants kept their hands in cold water for a similar time period both in no-memory VR and in memory VR (Wilcoxon's Signed Rank test; T = 124; Z = 0.74, p = 0.46).

Participants who kept their hand in cold water for four min (upper limit) were four in no-VR condition, nine in no-memory VR and ten in memory VR condition. No data was excluded from the analysis.

A similar outcome was obtained from a comparison with subjectively assessed pain intensity (VAS scale). In both VR conditions participants reported similar pain intensity (Wilcoxon's Signed Rank test; T = 206; Z = 0.54, p = 0.59).

Other results. Finally, correlations between the following variables were examined: pain tolerance and pain intensity measures, and all dimensions of immersion in virtual reality from IPQ. Reliability (Cronbach's Alpha) results in our study were 0.82.

Statistically significant differences were discovered while correlating the memory VR results with IPQ scales: spatial presence positively correlated with pain intensity indicators ($r = 0.37$, $p < 0.05$); involvement positively correlated with virtual games experiment ($r = 0.35$, $p < 0.05$), even though this correlation was not a major one. The IPQ questionnaire results were compared with the database (Schubert *et al.*, Viaud-Delmon, website), and confirmed their similarity to those achieved by other researchers.

Pain sensitive and pain tolerant. Participants were divided into pain sensitive and pain tolerant groups: those who achieved results below 100 seconds in the non-VR were classified as pain sensitive, whereas those with results higher than 100 seconds were classified as pain tolerant. Participant results classified as pain sensitive were clustered around 30 seconds mean; there were no scores in the 60-100 seconds range, and all participants who scored above 100 seconds were classified as pain tolerant. The first group comprised 28 participants, and the second one only seven.

First it was examined whether statistical differences in pain tolerance and pain intensity measures existed between the pain sensitive and pain tolerant groups. This was performed in order to test if the pain tolerant/pain sensitive division is valid across all conditions. It revealed that both groups differ significantly in terms of pain tolerance measures. Pain sensitive group members could bear to keep their hands in cold water for a significantly shorter time than the pain tolerant group members (no-memory VR: $U = 25$, $Z = -2.94$, $p < 0.01$, effect size: $r = -0.50$; memory VR: $U = 43.5$, $Z = -2.07$, $p < 0.01$, effect size: $= -0.36$). The comparison of pain intensity measures, however, did not disclose any major differences. In both experiment conditions, both groups assessed the level of experienced pain similarly (no- memory VR: $U = 84$, $Z = -0.43$, $p = 0.67$; memory VR: $U = 81.5$, $Z = -0.40$, $p = 0.69$) (see Table3).

Table 3. Descriptive statistics of pain tolerance and pain intensity measures in the pain sensitive and pain tolerant groups.

	pain sensitive group	pain tolerant group
	Sum of ranks	Sum of ranks
Time - No-memory VR	403*	192*
VAS - No-memory VR	462	133
Time - Memory VR	394.5**	166.5**
VAS - Memory VR	432.5	128.5

*p<0.01; **p<0.05

Subsequently, both groups were compared regarding the IPQ results. It was determined that the groups substantially differed only in one measure and only in one experiment condition – the one requiring high interaction: participants belonging to the pain tolerant group showed a higher general immersion factor score than those belonging to the pain sensitive group (high interaction: $U = 40$, $Z = -2.37$, $p < 0.05$, effect size: $r = -0.40$). Other measures did not differentiate those two groups.

Discussion

Previously published research on cognitive tasks influencing pain experience suggests that the involvement of memory processes can decrease experienced pain intensity (Buhle & Wager, 2010; Yamasaki *et al.,* 2000). Contrary to the above, our results suggest that increased memory load could lead to greater difficulty in ignoring distractors (Lavie, 2010). However, results presented in this paper show that interacting memory with the virtual environment does not increase or decrease the analgesic effect of VR distraction. Lackingan increase in the analgesic effect could be explained by the fact that distraction effects may not add up when different cognitive and perceptual processes are involved. On the other hand, lack of a decrease in the analgesic effect could indicate that noxious stimuli are not processed in the same way as other kinds of distractors. Load theory has not yet been tested in this context; so its predictions may not extend to processing of noxious distractors. It is also possible that the task we used was not demanding enough, and thus did not engage memory functions sufficiently. Bantick and colleagues (2001) have shown that the degree of cognitive challenge may be related to the pain experience.

The results of pain intensity measures were not in accordance with the results of pain tolerance measures. Though great differences emerged in pain tolerance measures between non-VR and VR conditions, differences in pain intensity measures were not discovered. In most studies (*e.g.* Muhlberger *et al.,* 2007; Dahlquist *et al.,* 2010) concerning the relation between VR distraction and pain, researchers used only one method to measure pain: pain intensity, or pain tolerance. However, our results suggest that these two measures represent two different variables and thus are not directly comparable.

It was hypothesized that the sense of presence in VE is related to an analgesic effect (Hofmann 2004). However, results presented by Dahlquist and colleagues (2010) does not support this hypothesis. Similarly, our results do not confirm a direct relation between virtual reality and tolerance to pain. In accordance with Dahlquist and colleagues (2010), we suggest that engaged cognitive and motor processes, as well as a high paced game, are more significant in distraction from pain than the "sense of being there."

The participants that qualified based on non-VR results as pain tolerant displayed a definitely higher pain tolerance in both VR conditions than participants qualified as pain sensitive. Our result supports a stable division for pain sensitive and pain tolerant people in the cold-pressor task paradigm.

Limitations

Our paper may suggest that engaging memory processes is not related to an analgesic effect. However, we did not directly measure memory performance, and more studies are needed to fully confirm the lack of relationship between memory and VR analgesia. In addition to memory, other potential differentiating factors, like personality variables, motor engagement and different interfaces still remain to be examined with regard to their influence on pain experience.

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