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# Effectiveness of Different Virtual Reality Environments on Thermal Pain Distraction

**Abstract:**

This study investigated analgesia mechanisms by using virtual reality (VR) technology. We tested how the content of a virtual environment (VE) influences the intensity of experienced pain. Two different VE's were used – relaxation and stimulation, and pain was triggered by heat stimuli. We used repeated experimental designs for the study. Thirty-two undergraduate psychology students participated, with each person being immersed in two VE's while a heat stimulus was applied to their wrist. Objective and subjective pain measurements were collected on a visual analog scale (VAS) – the temperature of the heat stimulus and the participant's assessment of pain intensity. Participants also filled in questionnaires designed to measure their temperaments and anxiety levels. We also recorded the subject's respiratory rate. We found no significant difference between the two VE's in their analgesic efficacy. Under both VR conditions participants endured significantly higher temperatures than under the no-VR condition. We found no significant differences in the influence of temperament or anxiety on a specific VE efficacy.

**Keywords:** Virtual Reality, Pain Tolerance, Analgesia, Virtual Environment, Thermal Stimulation

## Introduction

Virtual reality (VR) technologies are starting to be widely used in psychology and therapy. Current research on the use of VR in clinical psychology began in

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the late 1980s. Recently, with the refinement of both technology and its application, the effectiveness and scope of VR applications have significantly increased (Riva, 2005, 2010). Research on VR technology in pain treatment began in the late 1990s. The first case study documented analgesic effects of VR during painful medical procedures with burn patients (Hoffman et al., 2000). VR's analgesic effect is supposedly based on having a patient's attention distracted from painful stimuli (Gold et al., 2007; Botella et al., 2008). During VR distraction, patients wear head-mounted displays (HMD) can actively participate in a three-dimensional computer-generated environment. Compared with other methods VR technologies may involve a patient's attention more intensively, and thus can be a significantly more effective tool. Twillert et al. (2007) compared the effectiveness of VR distraction with other types of distraction (like watching a movie). The results showed that VR was a more effective distractor.

Potentially VR has got all the qualities of a good distractor – it might evoke the impression of being immersed in a three-dimensional computer generated world. Users are no longer passive observers of the events taking place on the screen, but become active participants in a virtual world. VR distraction was tested both on clinical populations and in laboratory studies that used experimentally induced pain stimuli. Das et al. (2005) demonstrated analgesic efficacy of VR in the treatment of pain in children. Distraction using VR has also been used to reduce pain and stress associated with cancer therapy (Gershon et al., 2004). VR seems to be an effective analgesic technique for pain associated with dentistry (Hoffman et al., 2001).

In addition to clinical studies, some research focuses on the mechanisms responsible for VR analgesics. Hoffman et al. (2003) showed that analgesic effect occurs under experimentally induced ischemic pain. Respondents declared lower intensity of pain during VR distraction than during its absence. Moreover, the participants were instructed to solve tasks requiring concentration. The level of performance decreased in VR – which indicates that, in the analgesic effect, lack of concentration is at least partly involved.

Hoffman et al. (2004) investigated the relationship between VR analgesics and the strength of one's subjective presence in a virtual world. The results showed that the strength of an analgesic effect is associated with quality graphics and sound, and the degree of possible interactions with the virtual world.

Currently only a few published studies have investigated how the content of virtual environments influences the analgesic effect. Mühlberger et al. (2007) studied the effect of different virtual environments on hot/cold pain stimuli endurance. Participants were immersed in "warm" and "cold" virtual environments, then hot and cold pain stimuli were applied to them. The analgesic effect achieved by VR distraction was similar, regardless of the virtual environment presented. However, some differences in "hot" and "cold" VE analgesic efficacy were found in a study by Shahrbanian & Simmons (2008), done on a group of post-stroke individuals.

A study by Dahlquist et al. (2010) evaluated the effect of the avatar point of view on cold-pressor pain tolerance in young adults. They found no significant differences in pain-tolerance scores between first-person and third-person view distraction.

Botella et al. (2008) in their review summarizing the current state of research on VR analgesia emphasize the need for detailed studies on the mechanisms underlying the analgesic effects, the role of attention, as well as research on the role of individual differences, personality traits and temperament. Gold et al. (2007) suggest that customizing VR environments to match patient characteristics may offer a possible way of VR analgesia enhancement. The authors also propose an alternative -- or complementary to attentional mechanisms -- explanation for VR's analgesic effects. Research indicates that emotions, like attention, can influence the perception of pain and may constitute a modulating factor. According to Rhudy & Meagher (2001), emotional pain modulation can be described in terms of two interactingemotional dimensions - valence and arousal. Emotions with negative valence and moderate arousal tend to increase pain perception, while emotions with negative valence and strong arousal, and emotions with positive valence tend to decrease pain perception (Rhudy & Williams, 2005). To the degree that virtual environments can evoke emotions, these mechanisms should be considered in the explanation of VR analgesia.

Another factor that may influence the efficacy of VR analgesia is temperament. Temperament determines a person's optimal stimulation level, and also what kind of stimulation is preferable or to be avoided (Strelau, 1998, 2006). We hypothesized that temperament influences which virtual environments provide optimal stimulation, which overstimulate a person, and which would not provide enough stimulation to attract a person's attention. Anxiety level is known to be correlated with temperament (Strelau, 2006), and was included as a controlled variable.

The study evaluated how virtual environmental content and properties influence the intensiveness of experienced pain. The investigated feature of virtual environments was the level of stimulation they generated. Analgesia effectiveness with the use of a relaxing environment was compared to analgesia with a stimulating environment. Also, subjective variables were taken into account – controlled variables were temperament and anxiety level.

We hypothesized that virtual environments with different levels of stimulation would lead to different sizes of pain alleviation. We also hypothesized that individual differences in temperament and anxiety may influence the size of pain alleviation produced by stimulating/relaxing virtual environments.

## Dependent and Independent Variables

### *Dependent Variables*

Behavioural measure of pain – temperature at which a subject removed their hand from a pain stimulation apparatus.

Subjective measure of pain – rating pain intensity on a visual analog scale.

### *Independent Variables*

Level of stimulation provided by virtual environment that was used as a distractor.

## Materials and Methods

### *Participants*

Thirty two undergraduate psychology students participated in the study – 21 female, 11 male (age 20 - 26, mean = 22.29; SD = 1.95). All participants were recruited from the University of Wrocław.

### *Apparatus*

Pain stimuli were applied with a TempTest apparatus made by the EIEWIN company. The device consists of a control unit that communicates with a computer, and a heatable aluminum plate (55x25cm). Minimum and maximum temperatures and plate heating rate are adjustable. In the present study minimum temperature was set at 36.6 degrees Celsius, and the plate temperature was raised to 55 deg. Celsius.

### *Virtual Reality Equipment.*

Participants experienced virtual environments – games – through a E-magin Z-800 head mounted displays, connected to the computer. E-magin displays have SVGA resolution – 800x600 pixels per display (1.44 megapixels), view angle - 40 deg diagonal FOV (equal to “viewing a 2.7 m diagonal movie screen from 3.7m distance). The weight of the display set was 227g. Participants were hearing stereo sound from the HMD’s audio output.

### *Video Games.*

The game “Prince of Persia” was used as a relaxing virtual environment – one particular location from that game was chosen – where participants were walking in the natural landscape and listening to soothing music and sounds. The “Split Second” game was used as a stimulating environment – participants took part in a dynamic car race, with lots of explosions and crashes, and loud energetic sound effects. Participants controlled both games with a gamepad (Logitech Rumble Gamepad F510). In both games participants viewed the environment from the 3rd person's perspective – the point of view was positioned behind a human avatar in "Prince of Persia" and behind a car in "Split Second".

*Polygraph*

Participant's abdominal and thoracic respiratory rates were measured using a polygraph (a 6-channel Stoelting CPSII, model 86300). Respiratory rate is a valid indicator of emotional arousal (Nyklicek I, Thayer JF & Van Doorner LJP, 1997; Boiten FA, Frijda NH & Wientjes CJE, 1994 ; Homma & Masaoka, 2008). The procedure that was used made it impossible to measure other physiological data – SCR and heart rate.

*Measures*

*Visual Analogue Scale (VAS)* was used to measure subjective pain intensiveness . This scale is a 20cm line, where the beginning of the line means no pain at all, and the end of the line means a very painful experience. Participants marked the intensiveness of the experienced pain immediately after taking their hands away from the aluminum plate. They filled the scale after the no-VR condition and after the two experimental conditions.

*State – Trait Anxiety Inventory* – (Spielberger et al., 1970) - Polish adaptation (1987). The questionnaire consists of two parts, assessing anxiety as a trait and as a state. Each part consists of 20 statements; participants rated each statement on a 4-point scale, anchored at each end with "I definitely don't agree" and "I definitely agree" (Wrześniewski et al. 2006)

*Pavlovian Temperament Survey - PTS* - Strelau et al. (1995). The questionnaire assessing temperament consists of 57 items, on a 4-point scale anchored at each end with "I definitely don't agree" and "I definitely agree. This inventory measures three behavioral nervous system properties – strength of excitation, strength of inhibition, mobility of nervous processes (Strelau, Zawadzki, 1998).

## Procedure

*Setting*

The study was conducted in the Institute of Psychology laboratory room. At the beginning of the experiment, the participants' pain threshold was measured without any VR distraction. Participants sat on a chair and put the wrist of their dominant hand on the TempTest plate. During both VR conditions participants put their non-dominant hand on the plate and played the games with their dominant hand, using a gamepad.

A repeated-measures experimental design was used for the study. Each participant participated in one no-VR condition and two VR distraction conditions. This design was chosen because of its greater sensitivity to detect experimental manipulation and its ability to minimize uncontrolled systematic variance.

Participants were instructed about the purpose and procedure of the study, gave their informed consent and filled in questionnaires – STAI and PTS. Then they were acquainted with the equipment – a polygraph, TempTest, HMD's and a gamepad.

Participants were told that the purpose of the experiment was to research how people experience their bodies while being immersed in Virtual Reality. Participants were also informed that they may resign at any moment and were instructed about the procedure of the study. They then gave their informed consent and filled in the questionnaires – STAI and PTS. After filling in the questionnaires they were acquainted with the equipment – a polygraph, TempTest, HMD's and a gamepad.

*No-VR Condition*

Respiratory sensors were connected to the participant's body and a pain threshold was measured on the dominant hand using the TempTest apparatus. Participants were instructed to take their hands away from the TempTest plate when the sensations became uncomfortable for them. (The temperature at which they removed their hands was used as an objective measure of pain tolerance). After taking their hands away participants filled in VAS (subjective measure of pain intensity).

*VR Distraction Conditions*

During two VR distraction conditions, participants wore HMD's and their heads were additionally covered with dark cloth to cut off peripheral stimuli. Then the participants began playing the game – they immersed themselves in either the relaxing or stimulating virtual environment. The participants were given one minute to freely explore the VE before being exposed to the pain stimulus. After that, the participants put their non-dominant hand on the TempTest plate. Then they were playing the game until they took their hands away from the TempTest plate. The temperature of the plate during that moment was recorded and the participants' subjective rating of pain on VAS was collected. After a two-minute break, the participants were exposed to the second VE. The procedure was identical to the first. The order of VE conditions was counterbalanced so that half of the participants began with the relaxing VE and then were exposed to the stimulating VE, and the other half were exposed in the opposite order.

## Results

Collected data was not parametric, so two non-parametric statistical tests were used for analysis – the Wilcoxon Signed-Rank Test and U -Mann-Whitney Test. Effect sizes were calculated with the formula r=Z/sqrt N. After Cohen (1988, 1992) we considered the effect as small when $r>0.10$, medium when $r>0.25$, and large when $r>0.50$.

## Preliminary Analysis

The effectiveness of the experimental manipulation was tested using physiological data. We assumed that while immersed in the stimulating VE, participants would have higher respiratory rates (RR) compared to the immersion in the relaxing VE and no-VR condition. In the analysis we used as the mean a one-minute respiratory rate of VE immersion before heat stimulus was applied. The respiratory rate while immersed in the stimulating VE was significantly higher than in the relaxing VE (but only as measured by a thoracic sensor): $T=66$; $p<0.01$; $r=0.42$. Abdominal RR differences did not reach statistical significance: $T=165$; $p=0.39$. The respiratory rate in the stimulating VE was higher than in the no-VR condition: thoracic $T = 14.5$; $p < 0.0001$; $r = 0.57$; abdominal: $T = 31$; $p < 0.0001$, $r = 0.52$. RR in the relaxing VE, however, was also higher than in the no-VR condition: thoracic $T = 61$; $p < 0.01$; $r = 0.43$; abdominal: $T = 18$; $p < 0.0001$; $r = 0.56$. (Table 1).

Table 1. Respiratory Rate Before and During Heat Stimulation.

| | | Before Heat Stimulation | | During Heat Stimulation | |
|---|---|---|---|---|---|
| | | M | SD | M | SD |
| Thoracic RR | No VR | 20.96 | 4.04 | 19.00 | 3.56 |
| | Relaxing VE | 22.64 | 2.89 | 22.36 | 2.91 |
| | Stimulating VE | 25.3 | 2.67 | 23.91 | 3.14 |
| Abd RR | No VR | 20.52 | 3.59 | 18.40 | 2.83 |
| | Relaxing VE | 22.35 | 3.34 | 22.92 | 3.39 |
| | Stimulating VE | 23.6 | 3.04 | 23.37 | 3.64 |

Changes in RR after the onset of heat stimulation were also compared to RR collected during the one-minute period before applying the heat stimulus. During the no-VR condition RR after the onset of heat, stimulation was significantly higher: thoracic ($T = 71$; $p < 0.01$; $r = 0.37$) abdominal ($T = 35$; $p < 0.001$; $r = 0.50$). During VR conditions no significant differences were observed. The stimulating VE: thoracic ($T = 145.5$; $p = 0.30$); abdominal: ($T = 188$; $p = 0.98$). Relaxing VE: thoracic ($T = 174.5$; $p = 0.73$); abdominal: ($T = 124$; $p = 0.12$) (Table 1).

The order in which virtual environments were presenteddid not influence subjective pain ratings as measured by the VAS scale. The stimulating VE presented first vs being presented second: $U = 120$, $p = 0.78$. The relaxing VE presented first vs being presented second $U = 95$, $p = 0.22$. Objective measures of pain also did not reach the level of significance: The stimulating VE presented first vs being presented second: $U = 112$, $p = 0.56$. The relaxing VE presented first vs being presented second: $U = 85$, $p = 0.11$ (Table 2).

Table 2. Objective and Subjective Measures of Pain – In Groups With a Different Order of Presentation.

| VE | Objective Measures | | | | Subjective Measures | | | |
|---|---|---|---|---|---|---|---|---|
| | Stimulating/ Relaxing | | Relaxing/ Stimulating | | Stimulating/ Relaxing | | Relaxing/ Stimulating | |
| | M | SD | M | SD | M | SD | M | SD |
| Stimulating | 45.13 | 4.14 | 45.13 | 2.76 | 11.74 | 4.73 | 11.46 | 4.98 |
| Relaxing | 45.60 | 3.86 | 44.68 | 2.72 | 11.98 | 5.90 | 10.30 | 3.79 |

## The Main Analysis

### *Pain Tolerance*

First we tested the hypothesis that VE distraction would make participants take their wrists from the TempTest plate at higher temperatures than during no-VR. Results confirmed the assumption – immersion in both stimulating and relaxing VE's significantly increased pain endurance: stimulating VE ($T = 60$; $p < 0.001$; $r = 0.46$), relaxing VE ($T = 37.5$; $p < 0.001$; $r = 0.52$).

Table 3. Objective and Subjective Measures of Pain in Different Conditions.

| | Objective Measures | | Subjective Measures | |
|---|---|---|---|---|
| | M | SD | M | SD |
| No VR | 42.39 | 4.88 | 8.73 | 4.10 |
| Stimulating VE | 45.13 | 3.46 | 11.59 | 4.86 |
| Relaxing VE | 45.14 | 3.32 | 11.10 | 5.03 |

There was a significant difference in the subjective ratings of pain between no-VR and VE. In both VE's , participants reported more intense pain (stimulating VE: $T = 45$; $p < 0.001$; $r = 0.51$; relaxing VE: $T = 71$; $p < 0.001$; $r = 0.44$). Subjective reports were adequate to higher temperatures of the TempTest which the participants endured during VE.

The content of VE – stimulating vs relaxing – did not influence the level of pain tolerance. Our hypothesis was not confirmed by the results, namely that there was no significant difference between VE conditions in the highest endured TempTest temperature ($T = 251$; $p = 0.81$) or subjective ratings on the VAS scale ($T = 225$; $p = 0.47$ ).

We have not found any significant correlations between temperament and pain ratings – objective and subjective. Neither temperament nor anxiety level influenced the way people experienced pain in both VE and – interestingly – in no-VR.

Also, we have not found significant correlations between gender and pain ratings – as measured both by the VAS and TempTest temperature. No-VR: (TempTest: $U = 67.5$, $p = 0.06$ ; VAS: $U = 70$, $p = 0.14$). Stimulating VE (TempTest: $U = 80$, $p = 0.16$; VAS: $U = 97$, $p = 0.48$). Relaxing VE (TempTest: $U = 104$, $p = 0.66$; VAS: $U = 94.5$, $p = 0.42$) (Table 4).

Table 4. Objective and Subjective Measures of Pain in Different Conditions – Gender Differences.

| | Objective Measures | | | | Subjective Measures | | | |
|---|---|---|---|---|---|---|---|---|
| | Male | | Female | | Male | | Female | |
| | M | SD | M | SD | M | SD | M | SD |
| No VR | 44.33 | 4.47 | 41.37 | 4.87 | 7.14 | 3.94 | 9.49 | 4.05 |
| Stimulating VE | 45.92 | 3.44 | 44.71 | 3.49 | 10.70 | 5.47 | 12.08 | 4.44 |
| Relaxing VE | 45.41 | 3.34 | 45.00 | 3.38 | 10.00 | 5.19 | 11.74 | 4.84 |

## Discussion

Our results confirm the influence of VR distraction on pain endurance. Participants in both VR conditions removed their wrists from the TempTest plate at higher temperatures than in the no-VR condition. The results indicate, however, that the stimulating vs relaxing quality of VE does not differentiate the intensity of experienced pain and pain endurance. However,  obtained results may also be explained by the difficulty of the participants to relax in a laboratory and experimental setting. Being immersed in VE with the use of HMD's was novel for all the participants. Also, the participants were not previously examined with a polygraph, which also contributed to the novelty and made it difficult for them to relax. The above-mentioned interpretation is confirmed by physiological measures (respiratory rate) indicating that participants were more aroused in the relaxing VE than in the no-VR.  It is also possible that the relaxing VE was not properly chosen. It consisted of one particular location in the "Prince of Persia" game – some participants knew the game and tried to move beyond the chosen location – and this possibility was blocked during the experiment. The inability to leave the location may have caused frustration in some participants.

According to Rhudy (2001, 2005) two aspects of emotion are connected with the analgesic effect – valence and arousal. In this study we tried to control arousal, but we did not control valence. There is a possibility that the specific mixture of arousal and emotional valence generated by VE influences the analgesic effect.

Our results also indicate that there are no significant gender differences in VR pain alleviation. These results can partly be explained by the type of pain-stimuli used, namely thermal pain. This type of pain evokes similar responses in both sexes (Giles & Walker, 2000). It is also possible that the VE chosen for the study evoked similar emotional responses in both men and women, and attracted their attention similarly. Because of the small number of male participants, these results can only be regarded as a suggestion for further research.

Somewhat surprisingly, we did not find any significant relations between temperament and pain endurance on one hand, and preference for a specific VE on the other. This result is difficult to explain, because according to the theory of temperament there should be interpersonal-temperamental differences concerning reactions to aversive stimuli and optimal levels of stimulation (Strelau, 1998, 2006). We propose that in subsequent studies other measures of temperament should be used.

Our results indicate that subjective ratings of pain were adequate to the actual temperature of the TempTest plate. The participants in VR endured higher plate temperatures, but adequately assessed the intensity of the heat. One possible explanation is that participants preferred to remain engaged in playing the game despite the pain – that is rather a behavioral reaction to pain, than to the experience of pain itself. But results can also be explained by the fact that subjective measures were collected after participants removed the goggles – that is, when VR distraction was no longer at work. VR may be an effective analgesic tool only during the time when a person is immersed in it. In subsequent studies a modified procedure is needed to test this hypothesis – a procedure where participants assess the intensity of pain while still immersed in VR.

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