How body movement influences Virtual Reality analgesia?

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Abstract— **In this study, we tested the hypothesis that increased body movement while steering a virtual reality game leads to the diminished experience of pain. We also investigated the relationship between presence in a virtual environment and pain intensity. 30 students of Wroclaw University participated in the within subject experiment (20 females: average age: 20.55 and 10 males: average age: 25.60). The participants were looking at the game through head mounted displays. In two experimental conditions a participant navigated the game using a computer mouse (a small movement), or a Microsoft Kinect (a large movement). Thermal (cold) stimulation was used to inflict pain. While playing the game, the participants immersed their non-dominant hands in a container with cold water (temperature 0.5 - 1.5°C). Two measures were used to assess the pain experience – the amount of time the participants spent keeping their hands in cold water (pain tolerance), and Visual Analogue Scale (pain intensity). The participants were also filling in the Igroup Presence Questionnaire (IPQ), measuring the sense of presence experienced in a virtual environment.**

The predictions were partly confirmed by the results – the participants were keeping their hands in cold water significantly longer in the large movement condition comparing to the small movement condition. However, there was no significant difference on pain intensity results between the two experimental conditions. Similarly, we failed to find any correlations between IPQ dimensions and the pain measures used in the study. Several possible mechanisms underlying the observed relationship between movement and pain experience are discussed.

Keywords—Virtual Reality; pain; cold pressor test; movement; presence; analgesia

I. INTRODUCTION

Virtual reality (VR) technologies are starting to be widely used in the treatment of pain. During VR treatment patients are wearing head-mounted displays (HMD) and have the opportunity to be immersed and actively participate in a three-dimensional computer generated environment. Numerous research studies confirm the effectiveness of this method (for review see [1, 2, 3]). VR was shown to be an effective tool in studies with clinical populations and in laboratory studies where experimentally induced pain stimuli were used. Some clinical applications include the treatment of pain in children [4] or reduction of pain and stress related to the therapy in cancer patients [5], and dental treatments [6]. Most of the studies are related to acute pain, but there have been also some attempts at using VR for chronic pain treatment [7].

However, the mechanisms of VR analgesia are still not fully known, as well as parameters of Virtual Environment (VE) which contribute to pain alleviation. Several published studies tested various properties of VEs but failed to find significant differences in their effectiveness [8, 9, 10, 11, 12]. Mühlberger et al. [8] studied the effect of VE content on hot/cold pain stimuli endurance. Participants were immersed in „warm" and „cold" VEs, while experiencing hot and cold pain stimulation. The pain reduction effect was similar in both VR conditions, regardless of the content of virtual environment VE that was presented. A study by Dahlquist et al. [9] evaluated the effect of the avatar point of view on cold pressor pain tolerance in young adults. Participants were playing two versions of a racing game *"Need for Speed 2"* – steering a car from 1st and 3rd person's point of view. No significant differences in pain tolerance scores were found between the first-person's and the third-person's view conditions. The strength of the analgesic effect seems to be more related to actions that users perform in a VE, than to the graphical content of a VE. Active participation in a virtual environment was found to be more effective in distracting attention from pain stimuli than passive observation of a recording where someone else played the game [13]. In another study using between group design and thermal pain stimulation participants were gliding on a predetermined path through VE - one group was allowed to look around and interact with the VE, while the other did not have this possibility. Participants in the interactive group have shown greater pain reduction than in the passive group [14].

It is hypothesized that pain alleviating effect of VR is evoked by dragging attention away from painful stimuli. The amount of attention paid to painful stimuli is considered to be an important factor modulating the intensity of experienced pain [15]. Virtual Reality may be an especially effective method for distracting attention by immersing the participant in a simulated environment, and evoking the experience of presence in the VE. Presence can be defined as feeling and acting as if a person is located in the world generated by computer and displayed on the goggles [16, 17]. The relationship between the analgesic effects of VR and the strength of the subjective presence in a virtual environment was investigated by Hoffman et al. [18]. Results of this study indicate that the amount of pain intensity reduction is associated with the feeling of being present in the virtual environment. However, the degree of presence was measured in this study by asking a single question ("While experiencing the virtual world, to what extent did you feel as if you went inside the virtual world?"). Several factors influencing the intensity of presence in a VE are related to the hardware quality: display resolution, size or frame rate. Other factors are more related to how the user interacts with a VE, the interface type, and possible actions in a VE. The extent to which the simulated visual data match proprioception is considered as one of the most important parameters evoking presence [16].

Several published studies report a significant relation between the degree of body engagement and experienced presence in a virtual environment [19, 20]. Slater and others [19] tested a 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 the complexity of a motor task executed in a VE. The extent of body movements was correlated with the reported presence, but results related to the motor task complexity were inconclusive. Bianchi-Berthouze and others [21] state that increased bodily engagement leads to greater affective experience, in addition to an increase in the feeling of presence in a VE. They compared the influence of different interfaces on a player engagement in the game and found that the interface that allowed for more body movement was more effective in grabbing the player's attention and evoking emotional reaction towards the game. Thus, movement may influence VR analgesia not only by inducing presence but also by increasing motivation, or more general emotional engagement in the game.

On the basis of previous literature it can be expected that body engagement will lead to the increased feeling of presence, and this in turn will lead to the decreased intensity of the experienced pain. Both aspects of the above prediction were tested separately, but these two lines of research were not yet combined in order to test if body movement can be successfully used to facilitate VR analgesia, and to better understand mechanisms underlying VR analgesia. In this study, we tested a hypothesis that increased body movement while steering a VR game leads to the increased feeling of presence and to the diminished experience of pain. An independent variable was the type of movement necessary to navigate the VR game: a small movement (computer mouse steering) and a large movement (Kinect, whole arm steering). Dependent variables were pain tolerance (the time participants kept their hand in cold water), pain intensity (ratings on a Visual Analogue Scale), and presence (Igroup Presence Questionnaire results). In previous studies we had investigated the influence of interface on analgesic effect [12], but the results had not been conclusive – therefore in this study we tried to increase the difference in body movement necessary to navigate the game, and used a custom made VE in order to achieve greater control over confounding variables.

II. Method

A. Design

The study was conducted using a within-participants experimental design. Each subject participated in two experimental conditions and navigated the VR game using a computer mouse (a small movement), or a Microsoft Kinect (a large movement). The order of conditions was counterbalanced. While playing the game, the participant's non-dominant hand was put into container with cold water, and participants were asked to remove the hand when the pain becomes unbearable. Apart from the interface, all other aspects of the VR game and the pain stimulus were the same for both conditions. For each condition we measured: (1) the time participants kept their hands in cold water, (2) their VAS pain ratings administered immediately after they removed hands from water, and (3) the feeling of presence measured by Igroup Presence Questionnaire (IPQ). Additionally, we controlled the perceived difficulty of the interface and attitudes towards the game in both conditions. We did not include a non-VR control condition in this experiment, because the study was aimed at comparing the analgesic effectiveness of two VR systems, and not at showing the existence of VR distraction effect in general. We made this decision to minimize the amount of painful stimuli the participants were asked to endure as a part of the experimental procedure. Before conducting this study we have finished two experimental studies using the same display technology and the same virtual environments, where a non-VR control condition was included. Both of these studies have shown the large and significant increase of pain tolerance in VR conditions comparing to the non-VR condition [11, 22]. General pain alleviating effect of a VR was also supported by numerous studies done by others, using similar pain stimulation (a cold pressor test), and various hardware and software VR technologies [13, 9, 23].

We contrasted Kinect and computer mouse steering, because both interfaces require only the use of a dominant limb, and they differ mostly in the amount of movement necessary to navigate the game. The choice was also influenced by practical reasons – both devices are popular computer peripherals, which makes eventual replications and applications of the results easier. Two different measures of pain were collected – pain tolerance (time in water) and pain intensity (VAS). In cold pressor test studies VAS is the most frequently used pain scale (for review see [24]), and its validity was shown not to differ significantly from other commonly used scales [25]. In the majority of these studies, pain intensity was measured directly following the completion of the cold pressor test (CPT), and the same procedure was used in the current study.

B. Participants

30 volunteers, students of Wroclaw universities participated in the study. There were 20 females (average age: 20,55; SD = 1,50; min = 19, max = 24) and 10 males (average age: 25,60; SD = 9, 26 ; min = 18 ; max = 50). Participants were recruited through University's social media pages. They have given

informed consent before the beginning of an experimental session.

C. Materials and Equipment

The experiment was conducted in a University lab. The participants were looking at the game through the head mounted displays: E-Magin Z-800, SVGA resolution, 40 deg diagonal FOV (which equals looking at a 2.7m diagonal movie screen from 3.7 m distance). The weight of the display set was 227g. The participants were hearing stereo sound from HMD's audio output. They were playing a game created by the authors of the study. A player's goal in the game was to glide through 3d space and to move an avatar-arrow in order to hit - collect white spheres, while avoiding red spheres. The participants were gaining points for each white-sphere hit, and losing points for each red-sphere collision. They were told to gain as many points as possible.

Thermal (cold) stimulation was used to inflict pain (cold pressor apparatus). While playing the game, the participants immersed their non-dominant hands in a container with cold water (temperature 0.5-1.5 °C). The apparatus was constructed for the purpose of the study and was equipped with a water circulator, a separate ice container, and a digital thermometer to ensure stable temperature. Similar devices were used in previous published studies on VR pain alleviation [13, 26]. Participants were sitting on a chair equipped with an arm support and a mouse pad. A Kinect device was positioned in front of the participant at 1.5m distance. Kinect steering consisted of slow but vast movements of the arm.

D. Measures

Two measures were used to assess the intensity of the pain experience – the amount of time participants spent keeping their hands in cold water (pain tolerance measure), and Visual Analogue Scale (VAS) - a horizontal 10cm continuous line (pain intensity measure). Each participant immediately after removing the goggles marked the strength of experienced pain, expressed on the scale in centimeters, where 0 represented no pain, and 10 extreme pain.

Participants were also filling in the Igroup Presence Questionnaire (IPQ) - a scale created by Schubert, Friedmann & Regenbrecht to measure the sense of presence experienced in virtual environments. The scale consists of four subscales: Spatial presence – the sense of being located inside a VE; Involvement – the level of engagement in a VE; Realism – the sense of VE realism; General – an additional item measuring the general "sense of being there". The reliability (Cronbach's Alpha) of IPQ is between 0.63 and 0.78 [27].

Additionally, participants answered three questions related to their attitude towards the game, and perceived pleasantness or unpleasantness of the experience. Answers were given on a seven point scale, ranging from: (-3) unpleasant / non-engaging / boring, to: (3) pleasant / engaging / interesting. The fourth additional question was related to the perceived difficulty of steering the game and using the interface and was coded similarly: (-3) very easy (3) very difficult.

E. Procedure

The participants were informed that the purpose of the experiment is to investigate how the body is experienced in virtual reality. They were acquainted with the equipment and procedure, and told that they can withdraw from participation at any moment. At the beginning of the experiment, participants put their hand into the container with cold water for 5 seconds to get acquainted with the stimulus. Then, they practiced playing a VR game with the Kinect steering. A practice phase was terminated when the participant managed to hit 10 white spheres with the avatar-arrow. There was no time limit for the practice phase. After the practice, the two experimental conditions followed in a counterbalanced order. The participants were wearing HMD's and played the game using either Kinect or a computer mouse. After playing for one minute their non-dominant hand was put into the container with cold water. One minute period was chosen on the basis of previously published literature, where similar or shorter times were used [13, 9]. The participants were instructed to remove their hands when the pain becomes unbearable. The experiment was stopped if they kept their hands in cold water for over 4 minutes. Immediately after removing their hand from cold water, the HMD's were taken off and participants assessed the pain intensity on a VAS. They also filled in the IPQ. There was a 15 minute break between conditions in order to warm up the hand. During the break the participants could immerse their hand in another container filled with room temperature water. After the break, the second experimental condition followed. At the end of the whole procedure the participants answered questions about difficulty of steering and pleasantness/unpleasantness of both game experiences.

F. Statistical data analysis

Due to the lack of normal distribution as well as homogeneity of variances, non-parametric statistics were used in the analysis (i.e., Wilcoxon's Signed Rank Test). The effect sizes were calculated using the formula for non-parametric tests for dependent samples ($r = Z/\sqrt{N}$, where N is the number of observations). It was presumed that the effect can be considered small when $r = 0.10$; medium when $r = 0.25$; and large when $r = 0.50$ [28, 29]. Attitudes towards the game, difficulty of the interface and points per minute were tested with parametric statistics. All correlations were computed using Pearson Correlation Coefficient.

There were few missing data points in the IPQ subscales (5 participants, each missing one subscale result). For one participant, the number of points collected in the game was not recorded. Missing data was handled by putting an average value from experimental condition.

III. RESULTS

Participants were keeping their hand in cold water significantly longer in the large movement condition than in the small movement condition. ($N = 26$; $T = 86.5$, $Z = 2.26$, $p = 0.024$, $r = 0.44$). On average, they kept their hand for 25 seconds more. This finding is consistent with the hypothesis that body movement during VR analgesia increases pain tolerance. However, we did not observe a significant

TABLE I. DESCRIPTIVE STATISTICS OF PAIN TOLERANCE AND PAIN INTENSITY

Condition	Pain tolerance		Pain intensity	
	M	SD	M	SD
small movement	74.50	75.48	6.48	2.00
large movement	99.57	95.42	6.27	2.45

difference on VAS results between the two experimental conditions (N = 22, T = 104, Z = 0.73, p = 0.47). The pain tolerance and pain intensity measures were negatively correlated – the longer participants kept their hand in cold water, the smaller intensity of pain they reported on VAS. Such correlation was present in both experimental conditions (large movement: r = -0.38, p < 0.05; small movement: r = -0.42, p < 0.05) (Table 1).

In order to verify the influence of movement on presence, and the influence of presence on pain measures, we computed correlations between IPQ dimensions and the pain measures used in the study, and tested if the IPQ scales differed between experimental conditions. There were no significant correlations in the results. Also, IPQ results did not differ between conditions (spatial: t= -1.96; p = 0.059; inv: t = - 1. 21; p = 0.24; real: t = - 0.37, p = 0.72; g: t = 0.53; p = 0.60) (Table 2).

In order to investigate the perceived difficulty of the interface and attitude towards the game, we tested for the differences of participants' responses in both conditions, and number of points collected while playing the game. The participants rated Kinect steering as significantly more difficult than mouse steering (t = 8.70; p < 0.0001). Also, in the game they collected significantly more points (white sphere hits) while steering with the computer mouse, comparing to Kinect. (t = 4.169; p = 0.0003). However, the number of points was correlated neither with the reported level of difficulty nor with satisfaction from playing the game in a given condition. Satisfaction ratings were not correlated with the perceived level of difficulty. The perceived difficulty did not correlate with any of the IPQ scales. There were no significant differences between conditions on any of the three questions related to satisfaction from playing the game (pleasant: t = 1.65, p = 0.11; engaging: t = - 1.97, p = 0.06; interesting: t = -1.46, p = 0.15) (Table 3).

TABLE II. DESCRIPTIVE STATISTICS OF IGROUP PRESENCE QUESTIONARE

Condition	Igroup Presence Questionnaire (IPQ)							
	Spatial presence		Involvement		Realism		General	
	M	SD	M	SD	M	SD	M	SD
small movement	-0.04	1.27	-0.24	1.56	-0.79	1.29	0.40	2.03
large movement	0.17	1.32	0.03	1.67	-0.71	1.24	0.23	2.06

TABLE III. DESCRIPTIVE STATISTICS OF PERCEIVED DIFFICULTY AND ATTITUDES TOWARDS THE GAME

Condition	Point/min		Pleasant		Engaging		Interesting		Difficult	
	M	SD	M	SD	M	SD	M	SD	M	SD
small movement	64.07	76.94	1.47	1.67	0.77	1.96	0.30	1.95	-1.90	1.18
large movement	32.22	39.54	0.87	1.61	1.67	1.47	0.83	1.90	1.00	1.23

IV. DISCUSSION

The results of this study provide evidence that body engagement during VR analgesia is causally related to greater pain tolerance. The participants kept their hand in cold water significantly longer when they navigated the game using large arm movements, comparing to smaller movements used during mouse steering condition. There are several possible explanations of the relationship between pain endurance level and the amount of movement while playing the game. One possible mechanism, suggested in the introductory section of this paper is related to the concept of presence. Body engagement in a VE can contribute to the feeling of presence [19, 20] and the feeling of presence can, in turn, contribute to the analgesic effect [18]. However, we failed to find correlations between IPQ dimensions and any of the two pain measures. This could mean that the type of movement used in Kinect steering condition was not sufficient to increase the feeling of presence. Maybe whole body movements or more dynamic movements are necessary to create the difference between conditions. But even with the absence of significant difference in presence between conditions, a correlation between IPQ and pain measures could be expected if presence influences the intensity of pain. The lack of such correlation might possibly be explained by the fact that questionnaires, especially when administered after completing the VR session are not a good method of assessing the feeling of presence. Post-experience questionnaire answers can be more related to the participant's mood and attitude towards a VE than actual presence experience. This claim found a support in an experiment done by Slater [30]. The pain stimulation itself could also influence the level of experienced presence. However, in a study by Gutierrez-Martinez et al. [31] using a cold pressor test and a VR distraction, the authors managed to find a negative correlation between pain intensity (VAS) and presence questionnaire results (adapted from [32]). Although it is possible to use questionnaires to find relationship between presence and pain during VR analgesia, we believe that a better solution could be adding physiological or behavioral measures of presence, or administering questionnaires while the participant is still immersed in a VE. Such measures could help to clarify the hypothesized relationship between the body movement, presence and experienced pain.

Alternative interpretation of the results of the current study is that presence may not be a necessary intermediary construct in explaining relations between body engagement and VR analgesia. Such an interpretation was proposed by Dahlquist et al. [9]. The authors of that study suggest that presence is not essential for achieving pain reduction with fast paced dynamic

VEs, which require ongoing motor and cognitive engagement. The authors hypothesize that the amount of presence may be a more important factor in VR analgesia with slow paced Virtual Environments. However, the Virtual Environment used in current study was rather slow paced and the absence of correlations between presence questionnaire and pain measures may lead to two interpretations: Either presence is not related to VR analgesia regardless of the dynamics of a VE, or the problem lies rather in the measures used to test the influence of presence. We consider the latter interpretation as likely and believe that potential problems with measuring presence need to be resolved, before answering the question if presence influences VR analgesia.

Apart from the influence of presence, there is also a more direct possibility of explaining the main finding of this study. Several studies show that physical exercise can increase pain tolerance, a phenomenon termed 'exercise induced hypoalgesia' [33]. The pain reduction effect increases with the exercise intensity [34, 35], and is most often reported in relation to prolonged aerobic exercises that are likely to induce pain by themselves. However, there are also studies showing this effect during isometric exercises, such as handgrip exercise [36]. The proposed explanation links the analgesic effect to endogenous opioid system activation or to exercise-induced rise of blood pressure [37, 38]. During isometric handgrip exercise, increases in blood pressure as large as 9 and 21mmHg were sufficient to evoke pain reduction effect [36]. To address this possibility we have run a pilot study and tested if arm movements used to navigate the game in a large movement condition were related to changes in blood pressure, in comparison with an arm resting condition. We did not find any increase in blood pressure, therefore we consider it unlikely that exercise-induced hypoalgesia was a mechanism responsible for the results of the current study. Also, although in the Kinect steering condition the participant's movements were large, they were relatively slow and not related to intensive muscle contraction. We suggest that subsequent studies on movement and pain VR distraction should control more directly exercise-induced hypoalgesia effect, possibly by measuring the participant's blood pressure before, during and after trials.

Another possible explanation of the current study's finding lies in the novelty of the interface for the participants. Kinect steering was probably more unusual and new than using a computer mouse – and this could lead to greater attentional engagement in the activity. Unfortunately, we did not measure the perceived novelty of Kinect use, but we do know that all participants experienced VR immersion with HMD's for the first time during this experiment. We speculate that the novelty of VR experience as a whole made potential novelty of Kinect use less prominent. There is research showing that efficacy of VR analgesia is not diminishing with repeated use [39], but the influence of movement in repeated VR sessions still needs to be empirically tested.

Although results of the current study show increased pain tolerance while using arm movements to navigate the game, the pain intensity VAS ratings did not differ between experimental conditions. A number of explanations can account for the observed discrepancy between pain tolerance and pain intensity measures. One possible explanation can be constructed along similar lines as previously described problems with assessing presence with questionnaires administered after the VR immersion. Participants filled in VAS after removing the goggles, so their attention was no longer distracted by the game. Moreover, they were implicitly asked to focus on the pain experience in order to assess its intensity. Even though similar procedures have been widely used in VR distraction pain studies [23], we suggest that in further studies VAS should be implemented into the VR application itself and the data collected while the participant is still immersed in the game. Results obtained in this study also show a negative correlation between the pain tolerance and pain intensity data. Such result may seem confusing. On the one hand – it is known that pain experienced during a cold pressor test increases slowly with time [40], so participants who kept their hand longer in cold water can be expected to report more intensive pain when their attention is brought to it. On the other hand, it can be assumed, that participants who kept their hand in cold water longer did so because they felt less pain. The results support latter explanation and suggest that the two measures, although differing, are both related to the process of pain alleviation.

V. LIMITATIONS

The generalizability of the results may be limited by a relatively small sample consisting of University students. Also, in the sample there were more female participants and it is known that sex is related to pain experience during cold pressor test [41, 42]. Although a cold pressor test is considered a good approximation of chronic pain [41], it remains to be tested if the current study findings can be extended to other experimental pain stimuli and (more importantly) to clinical settings and populations. Such populations may suffer from various movement restrictions which will make direct application of the results impossible. For both theoretical and applied purposes, it is necessary to study other types of movement and bodily engagement. One can speculate that other movement parameters apart from its scope are important in decreasing the intensity of pain. Such parameters could be the complexity of movement or the amount of meaningful consequences the movement evokes in a VE. Finally, as mentioned in the discussion section, the way presence was measured in this study might not have been optimal. Improvements can also be made to how VAS is administered. Physiological measures could be collected in order to judge the validity of exercise induced hypoalgesia explanation. Lastly, the two steering methods we used differed in difficulty and this should be better controlled in further experiments.

Despite the limitations, findings of the current study show the existence of causal relationship between the body movement and pain tolerance. Several possible mechanisms underlying that relationship are suggested, although more research is needed to assess their relative importance in the explanation.

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