*Anuario de Psicología*
2011, vol. 41, nº 1-3, 67-79


# Non-interactive virtual reality to manage pain*

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*The purpose of the present study is to investigate the impact of a non-interactive virtual reality (VR) intervention on pain related measures and on cognitive variables during a cold-pressor experience. Forty-six healthy participants underwent two consecutive cold-pressor trials, one staring to a virtual figure and one without VR, in counterbalanced order. During the VR intervention, participants were asked to passively imagine the correspondence between a stereoscopic VR figure and the experienced pain. Results showed no significant differences between the VR and no-VR condition for either pain or cognitive measures. The usefulness of a non-interactive VR intervention versus active VR strategies to cope with pain is discussed.*
Keywords: *virtual reality, pain, coping, cold pressor, catastrophizing.*

# Realidad virtual no interactiva para manejar el dolor

*El objetivo del presente estudio es investigar si una intervención no interactiva de realidad virtual (RV) puede influir en medidas relacionadas con el dolor y en los pensamientos relacionados con el dolor durante una experiencia de* cold-pressor. *Cuarenta y seis participantes sanos se sometieron a dos ensayos consecutivos de* cold-pressor*, uno mirando una figura virtual y otro sin RV, en orden contrabalanceado. La intervención de RV sugirió a los participantes imaginar pasivamente la correspondencia entre la experiencia dolorosa y una figura estereoscópica de RV. Los resultados no mostraron diferencias significativas en ninguna de las medidas de dolor ni en las medidas cognitivas entre*

* Acknowledgments: This work was supported by Fundació La Marató de TV3.
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*la condición de RV y sin-RV. Finalmente, se discute la utilidad de las intervenciones con RV no interactiva en comparación con las estrategias activas de RV para el afrontamiento del dolor.*

Palabras clave: *realidad virtual, dolor, afrontamiento,* cold-pressor, catastrofización.

The use of virtual reality (VR) as a non-pharmacological technique to treat pain has focused mainly on distracting subjects' limited attention resources away from the source of discomfort. However, VR may also be able to encourage other strategies for coping with pain, such as exposure, monitoring, and sensory focusing. These alternatives have not been studied in depth; to the best of our knowledge, only the study by Gutiérrez-Maldonado, Gutiérrez-Martínez, Loreto-Quijada & Nieto-Luna (in press) has addressed the effects of a focalization technique that enables users to actively assess the correspondence between the pain experienced and a VR figure representing that pain. In that study, a stereoscopic figure was designed as a visual analog of the pain experienced during a cold-pressor trial which the participant could manipulate interactively using the computer mouse. The initial appearance of the figure was an irregular, sharp-edged polygon, mainly in warm colors (i.e., yellow and red), which was presented together with an undefined acute unpleasant sound. The subject could gradually transform the figure into a pleasant, relaxing environment (a spherical shape, mainly composed of cool colors –blue and white–, combined with a pleasant sound), modeled in accordance with the specialized literature on the design of environments to enhance pain control (Malenbaum, Keefe, Williams, Ulrich & Somers, 2008). Significant findings included an increased in the pain threshold and pain tolerance during the VR condition, even though participants reported only slightly lower levels of pain intensity. VR intervention also significantly reduced participants' subjective ratings of the duration of the cold-pressor trial, and participants showed significant reductions in "in vivo" catastrophizing and a significant increase in self-efficacy to tolerate and reduce pain (Gutiérrez-Maldonado *et al*., in press). Although preliminary, these results suggest that an increased cognitive control over pain may be responsible for the effects of the VR intervention. Participants' control over their pain may have been enhanced by the manipulation of the VR figure since they were instructed to imagine that the figure corresponded the pain experienced. In this case the subject had an active role, but we wondered whether a passive role, in which the subject merely observed how the VR figure changes from a pain state into a non-pain state, would have an effect on the variables studied. Further research is needed to explore the effects of a VR intervention that encourages the correspondence between the VR and the pain experienced but does not include manipulation of the figure, thus the subject will have only a passive role.

The effects of passive exposure to virtual environments have been explored in more depth in the field of distraction research. For example, Hoffman *et al*. (2001)

investigated the degree to which pain associated with periodontal scaling was reduced by distracting two patients with immersive VR or a movie (patients watched the movie "Casablanca" while wearing special personal movie viewing glasses), relative to a no-distraction control. The first patient's pain ratings showed a considerable reduction while in VR compared with the movie and no-distraction control conditions. Although VR was more effective than the movie for the second patient, the movie appeared to provide some pain reduction compared to no-distraction control condition. Another study (Dahlquist *et al*., 2007) compared the effectiveness of interactive and passive distraction delivered via head mounted display (HMD) to children experiencing cold pressor pain. Relative to their own baselines, children demonstrated higher pain thresholds and greater pain tolerance during both passive and interactive distraction, although the effects for pain tolerance were statistically significant only in the interactive condition. A comparison made by Van Twillert, Bremer & Faber (2007) of the within-patient effects of VR with alternative forms of distraction (e.g., TV, music) during a wound care session in 19 participants with severe burns found that VR and TV differed significantly from standard care, and that the effects of VR were superior to those of TV although the differences were not statistically significant. In contrast, another study found that watching TV was more effective than active distraction during venipuncture (Bellieni *et al*., 2006). Although interactivity has been considered a necessary attribute for VR distraction techniques, these mixed results raise many questions about the mandatory components for enhancing VR distraction during painful events and thus for reducing the experience of pain.

The feature of VR interaction remains much less explored in coping strategies other than distraction. A question that remains unanswered is whether a VR intervention in which participants passively imagine the correspondence between a stereoscopic 3-D figure and the pain experienced is effective in pain management. This was the purpose of the current study. We explored the differential impact of a VR intervention that encouraged passive correspondence between a VR figure and the pain experienced during a cold-pressor trial versus a static black presentation (the control condition) on pain-related measures (pain threshold, pain tolerance, pain intensity, time estimation) and specific pain cognitions ("in vivo" catastrophizing and pain self-efficacy). We expected that passive VR intervention would increase the pain-related measures, but would not have any significant effect on the cognitive measures.

## Method

### *Participants*

Participants were undergraduate Psychology students who were awarded course credits in return for their participation. Exclusion criteria were cardiovascular disease,

hypertension, metabolic dysfunctions, pregnancy, Raynaud disease, epilepsy, mental disorders, chronic pain conditions, diseases producing neuropathic pain and use of pain/anti-inflammatory medications within 4 hours prior to the study. Participants were also instructed via email to refrain from using alcohol or other drugs on the day prior to the study.

The sample consisted of 46 participants, 40 female and six male, between 20 and 40 years old (mean age 24.4 years, SD=4.44).

## *Materials and equipment*

### *Cold-pressor apparatus*

Consisting of a plastic tank (34 X 34 X 16 cm.) filled with cold-water. The water temperature was maintained constant at 6°C (± 1), in order to achieve a range of tolerance between 1.5 and 2.5 minutes, (Mitchell, MacDonald & Brodie, 2004; Piira, Hayes, Goodenough & von Baeyer, 2006) time enough to ensure that participants were exposed to the virtual environment for a minimum period. A waterproof thermometer was attached to the inside of the tank used to verify that the water temperature remained constant before and after each trial (the temperature could not be seen by the participant). Another tank with warm water (32 °C) was used to stabilize the hand temperature at the start of each cold-water immersion. A digital thermometer was used to measure hand temperature and an atmospheric thermometer to measure room temperature. The duration of the cold-water immersion was recorded with a stopwatch (more details in the procedure section).

### *Hardware*

A Pentium D with: 3.00 GHz; 1.00 GB RAM; NVIDIA Quadro Fx 4500, 512 Mb ddr3, graphics card. The stereoscopic environment was displayed with two BARCO ID R600 projectors. StereoGraphics Corp polarized 3-D glasses were also used. The stereoscopic colour image was projected on a 2.43 x 1.82 m. screen. Auditory effects were delivered through speakers.

### *Software*

The virtual environment was modeled and animated with the 3D Studio Max 8 program. Adobe Photoshop 7 was used to create the different textures of the object of the environment. Virtools 3.5 (Educational Version) was used to program physical and visual effects over the VR environment.

## *Experimental design*

A within-subjects experimental design was used. Students participated in two consecutive cold-pressor trials, one with VR and one without. During the VR condition, the participants observed the VR environment while immersing their non-dominant hand in the cold-pressor. During the control condition the participants immersed their nondominant hand in the cold-pressor while watching a static black screen. The order of the experimental conditions was randomized and counterbalanced.

## *Virtual reality intervention*

The virtual reality intervention consisted of a stereoscopic figure that appeared on the center of the screen on a black background. The figure was designed to be a visual analog of the pain experienced during the cold-pressor trial. Its initial appearance was modeled according to a series of sensory descriptors (e.g., burning, cutting, sharp, stabbing, stinging) in the McGill Pain Questionnaire (Melzack, 1975). As shown in the caption in figure 1, the initial appearance of the figure was an irregular sharp-edge polygon, mainly in warm colors (i.e., yellow and red), presented together with an undefined non pleasant acute sound. The figure and the sound were manipulated (the polygon gradually became spherical, and comprised mainly cool colors –blue and white–, and combined with a pleasant sound), modeled according to the specialist literature on the design of environments for enhancing pain control (Malenbaum *et al*., 2008). These progressive changes in the environment occurred as the experimenter slid up three controls that appeared in the bottom right-hand corner of the screen: one to change the shape of the figure, one to change the color and one to change the sound. In addition to these changes, the figure was rotated and brought nearer or further away. The experimenter followed a protocol that ensured that the changes in the environment, the rate of the changes, the rotations and movements of the figure were the same for each participant.

## *Measures*

### *Pain threshold*

Pain threshold was defined as the number of seconds of immersion in the cold pressor until the participant reported that the cold sensation began to feel painful.

### *Pain tolerance*.

Pain tolerance was defined as the total number of seconds the participants kept their hand immersed in the cold water.

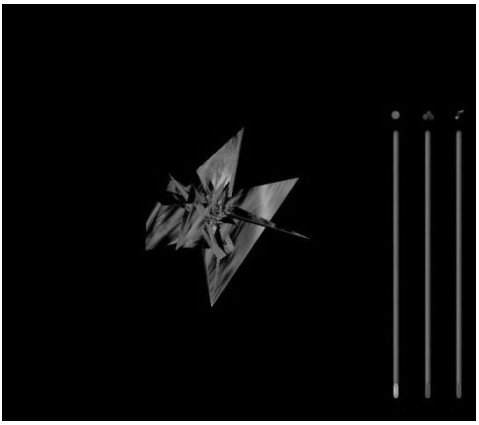

Figure 1. RV intervention with the three slider controls (shape, color, sound) at the lowest point.

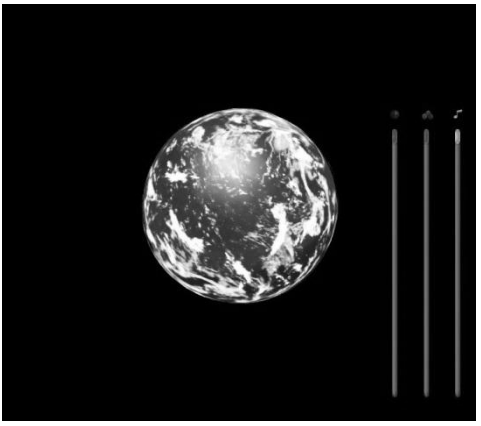

Figure 2. RV intervention with the three slider controls (shape, color, sound) at the highest point.

*Strongest pain intensity*

The strongest pain intensity rating was provided on a visual analogue scale (VAS) by instructing participants to "rate the most intense pain experienced during the hand immersion in the cold water". The VAS consisted of a 10-cm line anchored on the left with "no pain" and on the right with "the most intense pain". Immediately after withdrawal, participants were asked to rate their most intense pain by making a vertical mark along the line. The distance from the left anchor to the vertical mark served as the pain rating.

*Time estimation*

A question referring to time perception was included as a measure of a cognitive component of pain. Previous studies indicate that virtual reality may have an impact on the cognitive construction of pain duration (Hoffman et al., 2004; Patterson, Hoffman, Palacios & Jensen, 2006). Following retrospective time judgment paradigms (Thorn & Hansell, 1993), participants were asked to estimate how long they thought their hand had been in the water at the time of withdrawal. No feedback regarding the amount of time that had actually passed was available to them.

The final value of the variable was calculated subtracting time perception of real tolerance. Time overestimation was defined by time perception above the participant's real tolerance time (positive score), that is, when the participant judged the duration of the cold pressor trial to be longer than it was. Underestima-

tion was defined by time perception below the participant's real tolerance (negative score), that is, the participant judged the duration of the cold pressor trial to be shorter than it was.

*Pain self-efficacy*

Self-efficacy is typically assessed by using a questionnaire that is collected at one time point. Pain self-efficacy in the current study was assessed by two scales devised by Bandura, O'Leary, Taylor, Gauthier & Gossard (1987): Perceived self-efficacy to tolerate pain, and perceived self-efficacy to reduce pain's intensity. In judging their perceived efficacy to tolerate pain, subjects were presented with 20 items representing increasing lengths of cold pressor duration, ranging from 0s to 8 min. Participants were asked to judge their capability to keep their hand submerged in the cold water. The score was the time chosen from among the 20 choices or the time reported by the participant if it was longer than 8 minutes. The items in the scale measuring pain reduction efficacy described four severities of pain ranging from dull to excruciating and for each one participants rated the strength of their perceived self-efficacy to reduce pain on a 3-point scale, ranging from 0 (low) to 2 (high). The total scale ranges from 0 to 8, with higher scores indicating greater self-efficacy to reduce pain. It displayed acceptable internal consistency, both for the VR-cold pressor trial ($\alpha$=0.71) and for the control-cold pressor trial ($\alpha$=0.70).

*"In vivo" pain catastrophizing reports*

"In vivo" reports of pain catastrophizing thoughts were obtained from the *Pain Catastrophizing Scale* (PCS) (Sullivan, Bishop & Pivik, 1995). This scale is a 13-item, 5-point rating scale that requires individuals to recall the frequency of catastrophizing cognitions during past episodes of pain. Three subscales of Helplessness, Rumination, and Magnification represent the dimensions of the catastrophizing construct measured by the PCS. The PCS total scores (range of 0 to 52) offers a good index of the catastrophizing construct, because the three subscales are highly correlated. The PCS has been validated for clinical and nonclinical populations (Osman *et al*., 2000; Sullivan *et al*., 1995). However, recent laboratory-based studies of pain (Dixon, Thorn & Ward, 2004; Edwards, Smith, Stonerock & Haythornthwaite, 2006; Goodin *et al*., 2009) argue for the use of in vivo measures of catastrophizing (i.e. occurring immediately after a pain task with instructions to complete the instrument in accordance with one's preceding experience, instead of previous occurrences of pain, as in the standard instructions). For the current study, standard instructions and items of PCS were modified to assess the catastrophizing cognitions during the cold-water immersions (i.e., "There was nothing I could do to reduce the intensity of the pain" or "I worried all the time about whether the pain would end"). Internal consistency reliabilities were high

for the PCS total score after the VR cold pressor trial ($\alpha$=0.94) and also after the control cold pressor trial ($\alpha$=0.95).

### *Procedure*

This study was approved by the University of Barcelona. The experiment was conducted in a 5 x 5 m laboratory room that was maintained at a temperature between 22 and 23ºC. The participant and two graduate or undergraduate student experimenters were present. On arrival, the participant was asked to sit down and to complete the exclusion criteria form. Each participant completed a Statement of Informed Consent for the 40-minute session containing the appropriate information for participation in a pain investigation (Casarett, Karlawish, Sankar, Hirschman & Asch, 2001). They were asked to remove watches and other jewellery from both hands to prevent them from getting wet.

### *Virtual environment familiarization*

Participants were informed that the main interest of the study was to investigate the influence of several virtual environments on pain perception. Before the cold pressor task started, the virtual environment was shown to the student for approximately 2 to 3 minutes, including the transformations in shape, color, rotation, movement, and sound.

#### *Hand temperature stabilization*

The baseline hand temperature was measured. Participants were then asked to immerse their non-dominant hand in the warm water tank (32º) for 1 minute. Immediately, the hand temperature was taken again. This recording was considered as the target temperature to be reached at the start of second cold-water immersion.

#### *First cold-pressor task*

All participants completed the first cold pressor task under one of the two conditions, VR or non-VR. Participants assigned to the VR condition followed the procedures described below:

Before the cold pressor trial started, the experimenter informed the participants that they had to immerse their non-dominant hand in the cold water up to the wrist, palm-side down, and to leave their hand open (nonfisted). Participants were asked to look at the virtual environment during the immersion. They were encouraged to imagine that the 3-D figure corresponded to the sensations felt in the immersed hand. The experimenter instructed them to keep their hand in the

cold water for as long as possible although they were reminded that they were free to terminate the trial at any moment. Participants were instructed to say, "It hurts now" when their hand began to feel uncomfortable or hurt, and "End" when they decided to remove the hand from the water. The participants were asked to repeat the instructions to make sure they understood them.

Participants were provided with stereoscopic glasses. The nondominant hand was placed above the cold-pressor tank. The lights of the room were turned off and the experimenters remained out of sight behind the participant in order to minimize their influence on the subject's performance. Immediately, the cold pressor trial started and the participant immersed his/her hand in the tank, as instructed. The experimenter followed the protocol of transformations of the VR environment, sliding the controls with the computer mouse to introduce the changes in the figure and using a stopwatch.

For safety reasons, the maximum duration allowed was 5 min, but participants had no knowledge of this limit. The time at which the participant said, "It hurts now" was used as the measure of pain threshold. When the participant said "End", the VR finished and s/he was asked to remove his/her hand. The total time the hand was submerged was used as the measure of pain tolerance. Immediately, the participant was asked to rest the hand on a towel placed on the table and to complete some questions based solely on his/her experience during the cold pressor task with the virtual environment (in this order, the "highest pain intensity VAS", the "time perception estimation", the "self-efficacy scales", the "in vivo" catastrophizing-PCS). After finishing the measures, all participants were instructed to immerse their hand into the container with warm water for approximately five minutes. The hand temperature was again measured, ensuring that it was within 1ºC of the stabilized temperature at the start of the cold water immersion.

Participants assigned to the non-VR condition during the first cold pressor task received the same instructions and procedures, with the exception that they were told to look at the static blank screen in front of them during the immersion.

### *Second cold pressor task*

The second phase of the cold pressor task was procedurally identical to the first one. In accordance with the within-subjects design, participants assigned to receive VR during the first cold pressor task completed the second cold pressor task without VR. Participants who were not assigned to the VR condition in the first task completed the second task with the VR technology.

## *Data analysis*

All time ratings (tolerance, threshold, time estimation, self-efficacy to tolerate pain) were converted from minutes to seconds. Descriptive statistics were com-

puted for the different pain and psychological measures. Within-subjects analyses of variance (ANOVAs and MANOVAs) were used to test the effects of condition (i.e., VR vs. non-VR) with pain threshold, tolerance, most intensity pain, time estimation, "in vivo" pain catastrophizing reports and pain self-efficacy serving as the dependent variables in their respective models.

## Results

Table 1 shows the means and standard deviations of pain threshold, pain tolerance, highest pain intensity, time estimation, self-efficacy to tolerate pain, self-efficacy to reduce pain, and "in vivo" pain catastrophizing reports for both the VR and the no-VR condition. A series of within-subjects ANOVAs were conducted to ascertain the effects of condition (i.e., VR vs. no-VR) on the variables mentioned.

TABLE 1. MEANS AND STANDARD DEVIATIONS OF PAIN THRESHOLD, TOLERANCE, STRONGEST PAIN INTENSITY, TIME ESTIMATION, SELF-EFFICACY FOR TOLERATING PAIN, SELF-EFFICACY FOR REDUCING PAIN AND IN VIVO PAIN CATASTROPHIZING REPORTS FOR BOTH THE VR AND NON-VR CONDITIONS.

| *Measures (range)* | **VR** | | **Non-VR** | |
|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* |
| Threshold (0-300) | 46.59 | 63.68 | 46.70 | 63.37 |
| Tolerance (0-300) | 98.61 | 90.01 | 90.34 | 86.44 |
| Strongest pain intensity (0-100) | 75.45 | 19.56 | 75.35 | 18.22 |
| Time estimation (-300-300) | -38.77 | 62.52 | -26.60 | 58.30 |
| In vivo catastrophizing (0-52) | 17.40 | 11.28 | 17.20 | 12.14 |
| Self-efficacy for tolerating pain (0-480) | 79.84 | 76.58 | 74.34 | 64.98 |
| Self-efficacy for reducing pain (0-8) | 3.74 | 1.32 | 3.57 | 1.31 |

*Note.* VR = virtual reality

No significant differences between the two conditions were found for either pain measure (pain threshold, $F$ (1, 45) < .001, $p$ = .98, $\eta^2$ < .001; pain tolerance, $F$ (1, 45) = 1.26, $p$ = 0.27, $\eta^2$ = .03; VAS intensity, $F$ (1, 45) < .001, $p$ = .96, $\eta^2$ < .001). The only measure that differed slightly between conditions was time estimation. Participants in the VR condition reported slightly higher underestimation of time, $F$ (1, 45) = 3.98, $p$ = .05, $\eta^2$ = .08.

No significant differences in "in vivo" catastrophizing were found between the two conditions, $F$ (1, 44) = .07, $p$ = .80, $\eta^2$ = .00.

A MANOVA indicated that there was no statistically significant difference between the two experimental conditions on the combined perceived self-efficacy

scores, $F$ (2, 44) = 0.60, $p$ = 0.55; Wilks' Lambda = .97; $\eta^2$ = .02. Univariate tests indicated that the participant's self-efficacy to tolerate pain, $F$ (1, 45) = 0.60, $p$ = 0.44, $\eta^2$ = .01, and self-efficacy to reduce pain, $F$ (1, 45) = 0.94, $p$ = 0.33, $\eta^2$ = .02, did not differ significantly between VR and no-VR conditions.

## Discussion

This study investigated whether a VR intervention in which participants passively imagine the correspondence between a VR figure and the pain experienced is effective in managing pain. Participants underwent two cold pressor tasks, one observing a black screen and the other one observing a VR figure representing the pain experienced. Findings showed that, overall, there were no statistical differences for either pain or cognitive measures between passive focalization on a VR figure and observing a black screen. The only slight difference was found in the estimation of time, in which the participants in the VR condition reported a higher underestimation.

Sensory focalization has been considered as a useful strategy for reducing the impact of a pain stimulus. In fact, several experimental studies have shown that focusing on sensory aspects of the pain experience may reduce pain in clinical and nonclinical populations (Roelofs, Peters, van der Zijden & Vlaeyen, 2004). These affirmations are also supported by the evidence found in the study by Gutierrez *et al*. (in press). However comparing these results with the evidence of the present study we could presume that the VR focalization technique is effective when the subject is provided with an illusionary control over the pain experienced; this illusionary control seems to be acquired through the modification that the subjects are allowed to make of the VR figure.

Our results show that asking the subjects just to focus on the noxious stimulus and observe how the virtual pain could be reduced does not provide any beneficial effect in terms of pain and cognitive measures. The factor that seems to be crucial for the positive outcomes of the VR intervention is the subject's interaction. Our findings support the generally established idea that active-coping strategies and greater perceived control over pain are associated with improved pain-related outcomes (Bento *et al*., 2010). This may suggest that active focalization is effective as a strategy for coping with pain, while passive focalization is not.

Even though in the study by Gutierrez *et al*. (in press) the VR intervention led to improvements in the pain and the cognitive measures, we could not rule out the possibility that the observed effects were simply the result of distraction. Nevertheless, the findings of the present study show that looking at a virtual figure representing the pain experienced during a cold pressor task does not improve cognitive measures, not even the pain measures. This evidence contrasts with that found with the VR distraction technique in which active distraction seems to be

better than passive distraction, although passive distraction also had positive effects over the pain measures (Bellieni *et al*., 2006; Dahlquist *et al*., 2007; Hoffman *et al*., 2001; Van Twillert *et al*., 2007).

Although these conclusions are derived from the comparison of two different studies, it may constitute a limitation not to have an interactive condition within the study design that would allow statistical contrasts among the three conditions. Future studies including different control conditions are needed to strengthen the conclusions of the current research.

In summary, the present study contributes to the development of new techniques based on the application of VR to improve cognitive strategies for coping with pain.

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