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Testing a virtual reality intervention for pain control

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Abstract

Background: This study aimed (1) to assess the validity of a virtual reality (VR) intervention designed specifically to gain control over pain, (2) to test whether the association between the virtual environment and pain can be potentiated using a differential conditioning procedure, and (3) to examine the effects of this VR intervention in a cold pressor experiment.
Methods: The VR intervention was based on a figure representing pain. This figure could be manipulated until reaching a no-pain state. Participants were 64 undergraduate students, who were asked to evaluate this environment in terms of arousal and valence. A differential conditioning procedure was then applied, in which the pain figure was paired with electric shock and the no-pain figure was presented without shock. Afterwards, participants performed a cold pressor task.
Results: In the initial testing, the pain figure was evaluated as more arousing and more unpleasant than the no-pain figure. After the conditioning procedure, these ratings significantly increased; with the pain figure being rated as more anxiety eliciting and a better predictor of shocks than the no-pain figure. During cold pressor, the interaction with the conditioned VR figure led to significant increases in pain threshold and tolerance, as well as a significantly greater underestimation of time, but it did not affect pain intensity.
Conclusions: These results provide preliminary support for the use of our VR intervention to gain control over pain.

1. Introduction

The use of virtual reality (VR) for pain control is a recent development that is attracting increasing interest. In the vast majority of studies, the rationale for the use of VR is attention distraction. Indeed, VR is thought to be very effective in attracting attention since it implies multiple sensory modalities and an active involvement in the virtual environment (Hoffman et al., 2000).

From this perspective, VR has been shown to be effective for pain reduction, mainly in experimental studies but also during painful medical procedures (e.g., changing dressings in burn patients or during painful procedures in cancer patients). More specifically, VR has been found to reduce pain intensity, anxiety, distress and time spent thinking about pain. It has also been demonstrated that the use of VR can increase pain tolerance and pain thresholds (see, for example, the following reviews: Wismeijer and Vingerhoets, 2005; Malloy and Milling, 2010, Li et al., 2011). A further point of interest is that VR rarely produces negative side effects; indeed, most participants perceive it as enjoyable (e.g., Miró et al., 2007).

Despite these positive results, however, there is a lack of studies on the use of VR for purposes other than pain distraction. Sato et al. (2010) used VR in patients with complex regional pain syndrome as a way of conducting mirror therapy, and they found it to be effective. In other recent studies, VR has been used

What it is already known about this topic?
- It is already known that virtual reality techniques help patients to withstand pain. Virtual reality increases pain threshold and pain tolerance.

What does this study add?
- The majority of the studies have used virtual reality as an attention distraction technique. The present study creates and tests a new modality for pain control using virtual reality. Thus extends the use of virtual reality in the pain field.

in combination with hypnosis, in what has been referred to as 'Virtual Reality Hypnosis' (VRH). Preliminary results showed that VRH was effective for different pain problems, such as chronic neuropathic pain (Oneal et al., 2008), wound care in burn patients (Patterson et al., 2004) and for people with a physical trauma (Patterson et al., 2010). These studies notwithstanding further research are needed to explore alternative uses of VR in order to broaden its usefulness.

In light of the above, we created a VR intervention whose aim was to increase pain control. The VR pain control intervention consists of a VR figure that represent the pain experience, and which subjects can manipulate from a pain state to a no-pain state. The main aim of the present study is to provide a preliminary experimental assessment of the validity of this VR intervention. More specifically, the objectives were as follows: (1) to assess whether participants associated the created figure as would be expected (i.e., pain state with pain and no-pain state with no pain), (2) to test if this association can be potentiated through a classical conditioning procedure, and (3) to test if the VR intervention changes the pain experience in a cold pressor experiment. The study hypotheses were that the figure would be adequately associated and that this association would be improved through the classical conditioning procedure, and also that the VR control intervention would reduce the pain experience during the cold pressor task. Therefore, this is an exploratory study in which we seek to determine the basic properties of this VR intervention and to test whether learning can be potentiated.

2. Methods

2.1 Participants

The sample comprised 64 participants (58 women, six men) aged between 19 and 31 years [mean 22.75 years, standard deviation (SD) = 2.61]. Exclusion criteria were cardiovascular disease, hypertension, metabolic dysfunctions, pregnancy, Raynaud's disease, epilepsy, mental disorders, chronic pain conditions, diseases producing neuropathic pain and the use of pain/anti-inflammatory medications in the 4 h prior to the study. Participants were also instructed to refrain from alcohol or other psychoactive drugs on the day prior to the study. Participants were psychology undergraduates who were awarded course credits for participation.

2.2 Apparatus and equipment

2.2.1 Shocker stimulator

Electric shocks, used as unconditioned stimuli (US) in the conditioning procedure (see 'Phase II' in the procedure section), were administered with an isolated square-wave stimulator (Lafayette 82415-IS; Lafayette Instrument Neuroscience, Lafayette, IN, USA). This delivered constant-voltage electric shocks (a 1 s duration pulse) through two disposable, adhesive, round electrodes attached to the inner surface of the participant's non-dominant arm.

2.2.2 Cold pressor apparatus

Experimental pain (see 'Phase III' in the procedure section) was induced by the immersion of the non-dominant hand in a plastic tank (34 × 34 × 16 cm) filled with cold water. The water temperature was maintained at 6 °C (± 1). This level was selected to ensure a range of tolerance between 1 min and 3 min (Mitchell et al., 2004; Piira et al., 2006), time enough to ensure that participants interacted with the VR stereoscopic figures. A waterproof thermometer was attached to the inside of the tank and used to ensure 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 for stabilization of hand temperature at the start of each cold-water immersion. A digital thermometer to measure hand temperature and an atmospheric thermometer to measure room temperature were used. The room temperature was maintained at 22 °C. The duration of the cold-water immersion was recorded with a stopwatch (for further details, see the Procedure section).

2.2.3 Hardware

The VR stereoscopic figures were displayed with two BARCO ID R600 projectors (BARCO Inc., Xenia, OH, USA) controlled by a computer (Pentium IV, 3.00 GHz; 2.00 GB RAM; NVIDIA Quadro Fx 4500, 512 Mb ddr3, graphics card). They were projected onto a 2.43 × 1.82 m screen with a resolution of 1024 × 768 pixels. The distance between the participant, who was provided with StereoGraphics Corp polarized 3D glasses, and the screen was 2 m.

2.2.4 Software

The VR stereoscopic figures were modelled and animated with 3D Studio Max 8. Adobe Photoshop 7 was used to

create the different textures. Virtools 3.5 (Educational Version) was used to programme physical and visual effects, such that the participant could interactively manipulate the VR figure.

2.3 Measures

2.3.1 Phase I

To preliminarily test the VR figure, two verbal ratings (arousal and valence) referring to the pain and no-pain figures were collected. Perceived *arousal* for each of the two figures was rated on a 21-point scale anchored by 'very calm' (−100) and 'very aroused' (+100). *Valence*, the level of discomfort caused by the pain, was also assessed with a 21-point scale, anchored by 'very pleasant' (+100) and 'very unpleasant' (−100).

2.3.2 Phase II

After the differential VR conditioning procedure, ratings of arousal and valence caused by the (conditioned stimulus) CS+ and CS- were again assessed using the abovementioned scales. *Anxiety* and *unconditioned stimulus-expectancy* were also assessed at this time. The former was rated according to the extent to which the participant felt anxious during the presentation of the CS+ and CS−. An 11-point rating scale anchored by 'not anxious at all' (0) and 'very anxious' (100) was used for this purpose. For *unconditioned stimulus-expectancy* ratings, participants were asked to indicate the extent to which they expected an electric shock following presentation of the CS+ and following presentation of the CS− during the acquisition phase. An 11-point rating scale anchored by 'never' (0) and 'always' (100) was used here. These four ratings were chosen because they are commonly used in human Pavlovian conditioning research (e.g., Lipp et al., 2001; Hermans et al., 2002).

2.3.3 Phase III

Four measures (pain threshold, pain tolerance, strongest pain intensity and time estimation) were collected in relation to the cold pressor experience. Pain *threshold* was defined as the number of seconds of immersion in the cold pressor tank until the participant reported that the cold sensation first began to feel painful. Pain *tolerance* was defined as the total number of seconds the participant kept his/her hand immersed in the cold water. The strongest pain *intensity* was assessed with a visual analogue scale (VAS) on which participants had to rate their most painful experience during the hand immersion in cold water. This VAS consisted of a 10 cm line with two anchors: 'no pain' and 'the most intense pain'. Finally, and following retrospective *time estimation* paradigms (Thorn and Hansell, 1993), participants were asked to estimate how long they thought they had had their hand in the water at the time of withdrawal.

2.4 Procedure

All the procedures were reviewed and approved by the ethics committee of the University of Barcelona and participants had to sign an informed consent form which contained the appropriate information for participation in a pain study (Casarett et al., 2001). A within-subject experimental design was used for a three-phase experiment conducted in a single session that lasted approximately 60 min. Participants were run individually.

2.4.1 Phase I. Preliminary testing of the VR intervention

The VR intervention designed for the study consisted of a stereoscopic figure that appeared in the centre of the screen with a black background. The initial appearance of the figure was modelled according to certain sensory descriptors (e.g., burning, cutting, sharp, stabbing, stinging) from the McGill Pain Questionnaire (Melzack, 1975). Following these descriptors, the initial appearance of the figure was constructed as an irregular sharp-edged polygon (see Fig. 1), mainly in hot colours (i.e., yellow and red). This figure was presented together with an unpleasant sound (a tone of 600 Hz at 80 dB). The purpose of this initial figure was to represent a state of pain. This initial environment could be gradually manipulated to achieve a pleasant and quiet environment (analogous to a state of no pain). This pleasant environment contained a spherical shape composed mainly of cold colours (blue and white) with a certain resemblance to natural scenery (see Fig. 2). This figure was combined

Figure 1 Image capture of the pain figure.

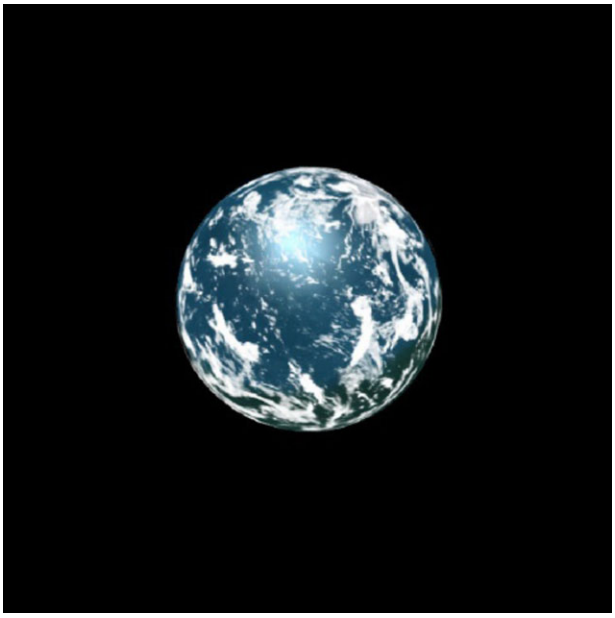

Figure 2 Image capture of the no-pain figure.

with a quiet sound, produced by a generative music engine, and was modelled in line with the literature on the design of environments to enhance pain control (Malenbaum et al., 2008).

To test if the specific modelling of the figures was actually associated with a pain state (Fig. 1) and a no-pain state (Fig. 2), the two figures were presented to subjects, who were then asked to rate the arousal and valence of each one.

2.4.2 Phase II. Differential VR conditioning procedure

Once the arousal and valence of the two figures had been recorded in Phase I, the experimenter placed the electrodes on the participant's forearm and told him/her that he/she would be receiving a series of shocks of increasing intensity in order to determine the voltage level of the shocks that would be delivered during the subsequent task. The shock voltage selection was performed as follows: starting with 20 V the experimenter gradually increased the voltage of each subsequent shock in 20 V steps until the participant reported that the shock was unpleasant enough but not painful. The minimum and maximum voltages selected by participants were 40 V and 100 V.

Subsequent to shock voltage selection, the aversive differential delay conditioning procedure was applied. Both figures served as a conditioned stimulus (CS) and were presented individually, centred on the screen, for a fixed duration of 8 s. Figure 1 (the pain figure, CS+) was always simultaneous to the presentation of an electric shock (US) of the previously selected intensity. Figure 2 (the no-pain figure, CS−) was presented alone and was directly followed by the inter-trial interval (30 s.) In total, each CS was presented 10 times in a quasi-random order, with the constraint that the same stimulus could not appear consecutively more than twice.

After the acquisition phase, the participant was asked to rate again the arousal and valence of the CS+ and CS−. It was stressed that their rating could have remained the same or have changed in comparison to their previous ratings, and that we were only interested in how they rated these stimuli at this very moment. They were then asked to provide the anxiety ratings and the US-expectancy ratings for the CS+ and CS− on separate 11-point rating scales (see Measures section).

2.4.3 Phase III. Cold pressor task

All participants completed two cold pressor tasks in counterbalanced order, one under the VR intervention condition and the other under the Control condition. In the VR intervention condition, the experimenter explained to participants that in this new phase they had the opportunity to manipulate the irregularly shaped VR polygon in order to achieve the pleasant, calm state (i.e., Fig. 2; no-pain figure). This would be done by using the mouse with their dominant hand, while immersing their non-dominant hand in the cold pressor tank.

Approximately 2 to 3 min were spent teaching them the possible interactions with the irregular VR polygon that they could have by using the three slider controls that appeared on the screen after clicking the right bottom of the mouse. They were asked to use the three slider controls to practice how they could gradually manipulate the shape, colour and sound of the VR figure, as well as rotate it and move it nearer or further away by dragging the mouse. They were also asked to become aware of how the pain felt during the subsequent cold pressor task could be changed by changing the VR figure.

Once participants were familiar with the possible interactions with the VR stereoscopic figure, the procedure for the cold pressor task was explained. The experimenter told 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 (non-fisted). The experimenter continued by saying that the study required 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 time. Participants were instructed to say 'It hurts now' when their hand began to feel uncomfortable or hurt, and 'End' when they decided to remove their hand from the water. All participants were asked to repeat the instructions to make sure they understood them. Then, the participant's baseline hand temperature was measured. Participants were then asked to immerse their non-dominant hand in a warm water tank (32 °C) for 1 min, after which their hand temperature was immediately taken again. Next, each participant was provided with stereoscopic glasses. The non-dominant hand was placed above the cold pressor tank and

Table 1 Means and standard deviations of arousal and valence ratings for the CS+ and CS– pre- and post-conditioning.

	CS+		CS–	
	Pre	Post	Pre	Post
Arousal ratings	5.94 (35.40)	51.09 (31.58)	–37.50 (36.08)	–61.88 (33.75)
Valence ratings	–2.50 (35.77)	39.53 (29.52)	–37.19 (37.14)	–58.44 (31.38)

the dominant hand above the mouse. The lights of the room were turned off and the experimenter remained out of sight behind the participant in order to minimize any influence which his presence might have on performance. The cold pressor trial was then immediately started and the participant immersed his/her hand in the tank, as instructed. As noted above, participants could use the mouse to control the appearance of the VR stereoscopic figure, as well as its position and the sound of the virtual world, but if the slider controls were not used the figure and the sound were automatically transformed over time to the spherical shape. For safety reasons the maximum permitted duration of immersion was 5 min, although participants were unaware of this. At the end of the trial, participants were asked to rest their hand on a towel placed on the table. They were then immediately asked to indicate the strongest pain intensity on a virtual analogue scale (see Measures section) and respond to the time estimation question. After completing the measures, all participants were instructed to immerse their hand in the warm water tank for approximately 5 min. Their hand temperature was again measured, ensuring that it was within 1 °C of the stabilized temperature at the start of the cold-water immersion.

In the control condition, subjects received the same instructions and followed the same procedure for the cold pressor task as described above; with the exception that they were told that during the immersion they had to look at a static blank screen in front of them.

2.5 Data analysis

Prior to analysing the data, a time value for the difference between time estimation and actual tolerance was computed in order to quantify whether time overestimation (time estimation higher than actual tolerance: positive score) or time underestimation (time estimation lower than actual tolerance: negative score) had occurred.

Descriptive statistics were computed for the preliminary test of the VR intervention, for both the conditioning and the cold pressor measures. Data from the preliminary test of the VR intervention and the aversive VR conditioning procedure (arousal and valence scores) were analysed using a 2×2 repeated measured analyses of variance with time (pre-conditioning/post-conditioning) and stimulus type (CS+/CS–) as within-subjects variables. Having evaluated the conditioning procedure, within-subjects univariate analyses of variance were then used to test the effects of the experimental conditions (VR intervention vs. Control condition) on pain threshold, tolerance, strongest pain intensity and time estimation. Prior to conducting the within-subject analyses, independent *t*-tests were applied to determine whether the order in which subjects participated in the VR and non-VR cold pressor trials affected their scores. No order effects were found (all $p > 0.05$).

3. Results

3.1 Phases I and II

Table 1 shows the means and SDs of arousal and valence ratings for the CS+ and CS– at pre- (Phase I) and post-conditioning (Phase II). As can be seen, the pain figure was rated as more arousing and as having a more negative valence (the differences were significant; see below).

The univariate analyses for the arousal ratings showed a main effect of stimulus type (F (1, 63) = 224.33, $p < 0.00$, $\eta^2 = 0.78$), as well as a main effect of the variable time (F (1, 63) = 10.33, $p < 0.01$, $\eta^2 = 0.78$). The interaction between stimulus type and time was also significant (F (1, 63) = 109.33, $p < 0.00$, $\eta^2 = 0.63$). Taken together, these results suggest that the CS+ was perceived as more arousing than the CS– at both the pre- and post-conditioning phase, and also that the difference between the two stimuli was greater after the conditioning procedure (see Fig. 3). The valence ratings likewise showed a significant effect of stimulus type (F (1, 63) = 234.91, $p < 0.00$, $\eta^2 = 0.79$), a main effect of time, (F (1, 63) = 12.85, $p < 0.01$, $\eta^2 = 0.17$) and a significant stimulus type × time interaction (F (1, 63) = 107.63, $p < 0.00$, $\eta^2 = 0.63$). These results indicate that regardless of the time of evaluation the CS– was considered significantly more pleasant than the CS+. However, after the conditioning procedure, the difference between the stimuli was significantly greater (see Fig. 4).

Anxiety and unconditioned stimulus-expectancy were assessed after the conditioning procedure. The results showed that the CS+ ($M = 61.56$, $SD = 26.20$) elicited significantly more anxiety than did the CS– ($M = 9.69$, $SD = 13.91$) (t (63) = 16.64, $p < 0.01$). Moreover, there were also significant differences for the US-expectancy ratings after acquisition

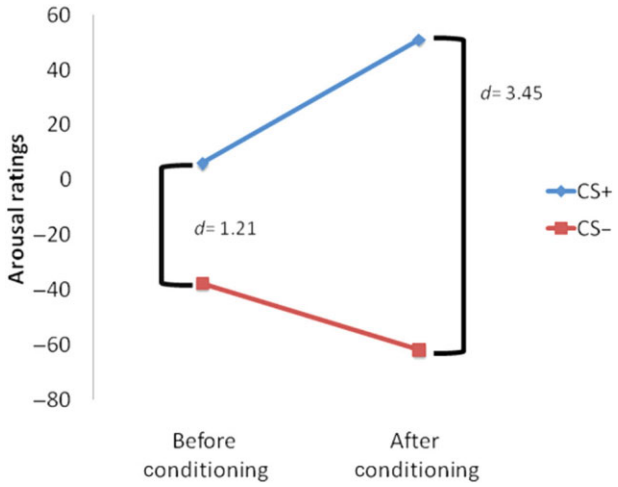

Figure 3 Mean arousal scores for the CS+ and CS– before and after conditioning. Effect sizes for the difference between the CS+ and CS– before and after conditioning are included.

(M = 95.31 and $SD = 10.07$ for the CS+ and M = 8.28 and $SD = 12.02$ for the CS–; t (63) = 34.86, $p < 0.01$).

3.2 Phase III

Table 2 shows the means and standard deviations for pain threshold, pain tolerance, strongest pain intensity and time estimation reports during the cold pressor tasks for both the VR intervention and Control conditions. The results revealed that participants had significantly higher pain thresholds (F (1, 63) = 5.46, $p < 0.05$, $\eta^2 = 0.08$) and pain tolerance (F (1, 63) = 14.03, $p < 0.01$, $\eta^2 = 0.18$) under the VR condition (see Table 1). However, no significant differences were found in VAS intensity ratings (F (1, 63) = 0.44, $p = 0.51$). Finally, concerning time estimation, the results showed that participants in the VR intervention condition made significantly greater underestimations of time (F (1, 63) = 6.20, $p < 0.05$, $\eta^2 = 0.09$).

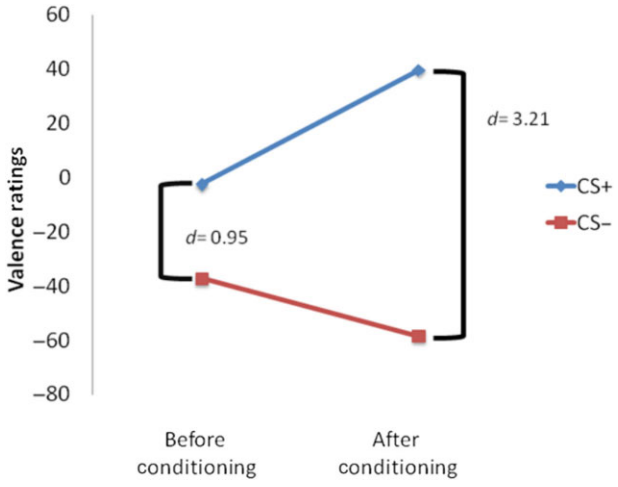

Figure 4 Mean valence scores for the CS+ and CS– before and after conditioning. Effect sizes for the difference between the CS+ and CS– before and after conditioning are included.

4. Discussion

This study had three related aims. The first was to conduct a preliminary test of a virtual figure designed to represent the pain experience. This figure could be gradually changed from a pain to a no-pain figure. Results showed that prior to the conditioning procedure, the extreme state figure reflecting pain was evaluated as significantly more arousing and more unpleasant than the extreme state figure representing no pain. Although further studies are needed, these preliminary results suggest that the environment was modelled adequately, in terms of differential sensory descriptors, and also that it could be used to represent the pain experience in a virtual world.

As regards the second objective, the present study shows that the experience of repeated contingent presentations of a VR stereoscopic stimulus representing pain (pain figure, CS+) and an aversive electrical stimulus (US) altered the meaning of the CS+ in two different ways. First, the CS+ by itself became a more negative stimulus, as evidenced by the arousal, valence and anxiety ratings. In addition, the CS+ became a valid predictor of the US, as indicated by the expectancy ratings. These results suggest that the experiences associated with the VR intervention created here can be potentiated through a simple learning procedure. We believe that this kind of learning procedure, which aims to increase the identification between a person's own representation and a virtual one, could enhance the effects of our VR intervention by making it easier for participants to transfer

Table 2 Means and standard deviations of pain threshold, tolerance, strongest pain intensity and time estimation reports for both the VR intervention and the Control condition.

	VR intervention		Control condition	
Measures (range)	M	SD	M	SD
Threshold (0–300 s)	33.21	22.77	24.86	32.74
Tolerance (0–300 s)	64.70	45.77	43.58	37.56
Strongest pain intensity (0–100)	78.75	13.92	77.87	11.96
Time estimation (–300–300)	–14.01	39.72	–2.36	22.58

M, mean; SD, standard deviation; VR, virtual reality.

the virtual experience to the real world. However, this assumption would need to be confirmed through a specific study comparing a group that followed the conditioning procedure with a group that did not. Moreover, if learning does have an effect it would also be necessary to explore other non-invasive procedures to potentiate the relationships between the virtual experience and the real-pain experience.

Regarding the third objective involving the cold pressor experiment, the VR intervention was found to have a positive effect on pain threshold and pain tolerance. These results are consistent with other VR laboratory studies (Tse et al., 2002; Dahlquist et al., 2007; Rutter et al., 2009). However, our intervention did not affect pain intensity. This may be due to the fact that our intervention is not designed to divert attention away from pain, but rather to enable the person to gain control over pain by controlling the virtual pain experience, with subjects being asked to focus on the pain experience. In a similar context, Nouwen et al. (2006) conducted a cold pressor study with healthy participants and chronic back pain patients who were randomly assigned to a focused attention condition or a distraction condition. At the start of the cold pressor task, participants in the focused attention condition showed higher levels of pain intensity than did those in the distraction condition (this being the case for both healthy and chronic pain participants). However, the difference in pain intensity levels between the two conditions was reduced as time went on. The authors concluded that distraction might be more effective for shorter periods, while focused attention would be better for longer periods of pain. Further evidence is needed to clarify this issue, and we would need to conduct an additional study with a distraction condition in order to compare our results with those obtained in our VR intervention.

Moreover, the results for pain intensity may have been due to the form in which we assessed this variable. Following previous studies (e.g., Hoffman et al., 2006; Patterson et al., 2006), we asked participants to rate the strongest pain intensity they felt during the cold pressor task. It would have been useful to ask participants to rate the overall pain intensity during the cold pressor, as some studies have done (e.g. Raudenbush et al., 2009; Rutter et al., 2009). An overall pain intensity rating might have been more sensitive to pain intensity changes during the cold pressor task, and we might have found differences in pain intensity between the two experimental conditions using this measure. However, this is just a tentative hypothesis that needs to be tested in a future study.

With respect to time estimation, our results show that participants underestimated time in both conditions (VR intervention and Control condition), although the magnitude of the underestimation was significantly higher in the VR intervention condition. These results are consistent with those obtained in other experimental studies using a cold pressor task and which reported an association between pain and underestimation of time (e.g., Hellstrom and Carlsson, 1997; Thorn and Hansell, 1993). However, our findings are of specific interest because they show that our VR intervention can be effective in reducing the perceived duration of the pain experience. Such a reduction could be especially important for chronic pain patients, contributing to a better quality of life and a reduced need for analgesic medication.

The present study does have a number of limitations. Although the effects of the VR intervention on the cold pressor pain stimulus were notable, one cannot assume that this intervention would be equally effective in clinical situations in which patients have no control over the duration of the pain they experience, or in people who have a long history of pain. A further limitation concerns the characteristics of the sample, i.e., university students, most of whom were female, as this limits the generalizability of the findings. Further studies including a broader range of participants are now needed in order to add to the literature regarding pain management in diverse populations.

In spite of these limitations, this preliminary study has shown that a simple VR intervention can be useful for pain control. Furthermore, the results suggest that VR could be more widely used in the pain field, specifically in chronic pain patients for purposes other than distraction. If future research confirms these preliminary results in both clinical and non-clinical populations, the intervention described here could become a useful tool for increasing perceived control over pain.

Author contributions

All co-authors have contributed significantly to the design and development of the work submitted for consideration. All of them discussed the results and commented on the manuscript.

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