

The Use of Virtual Reality and Audiovisual Eyeglass Systems as Adjunct Analgesic Techniques: A Review of the Literature

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ABSTRACT

Background: This review focuses on the application of technologically advanced methods of audiovisual distraction as adjunct analgesic techniques; more specifically, (a) virtual reality (VR) and (b) audiovisual (A/V) eyeglass systems (A/V distraction). **Purpose:** It is assumed that distraction taxes the patient's limited attention capacity, resulting in the withdrawal of attention from the noxious stimulus with a subsequent reduction in pain. **Methods:** Twenty studies evaluating the analgesic potential of both methods in different patient groups and in healthy volunteers were identified in the scientific literature. **Results:** Although the majority of these studies are hampered by serious methodological drawbacks, particularly a small number of participants, the results nevertheless strongly suggest that both VR and A/V distraction can be a very promising analgesic technique that may be used safely and effectively for the reduction of pain and discomfort during medical procedures. An additional important aspect is that few negative side effects have been reported. **Conclusions:** Directions for future research are presented.

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INTRODUCTION

For over a decade, distraction has been investigated and successfully applied in clinical practice to reduce pain associated with medical procedures (1–3). Successful traditional distraction techniques include, for example, watching movies (4), listening to music (5), counting objects in the room (6), and nonmedical conversation (7). The application of distraction is based on the assumption that pain perception has a large psychological component in that the amount of attention directed to the

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noxious stimuli modulates the perceived pain. Distraction techniques tax the patient's limited attention capacity, resulting in the withdrawal of attention away from the noxious stimulus. Although the precise mechanism of distraction is not yet well understood (8,9), cognitive-affective attention models (10) may explain this phenomenon.

It has been hypothesized that the ideal distractor would require an optimal amount of attention involving multiple sensory modalities (visual, auditory, and kinesthetic) (8), active emotional involvement (11), and participation of the patient to compete with the signals from the noxious stimuli. Recently developed distraction techniques that use advanced audiovisual (A/V) technology more likely meet these requirements than the traditional distraction methods mentioned earlier.

Some of these new techniques use only visual stimuli, but the majority apply visual stimuli in combination with audio stimulation and distract the patient by exposing him or her to two-dimensional (2-D) or three-dimensional (3-D) videos. These techniques are referred to as virtual reality (VR) audiovisual systems, A/V eyeglass systems, or simply A/V distraction.

However, these A/V distraction techniques do not allow any interaction between the users and the stimuli they are exposed to, and no use is made of kinesthetic stimuli. The most recent and most advanced distraction technique is VR, which makes up for this lack of interaction and kinesthetic stimulation. VR refers to a human–computer interface that enables the user to interact dynamically with the computer-generated environment. In contrast to the less complex A/V distraction, VR uses sophisticated systems such as head-mounted, wide field-of-view, 3-D displays (HMDs) and motion sensing systems that measure the user's head and hand positions. These enable users to interact with the virtual environment (VE).

The stimuli used for VR and A/V distraction range from simple entertaining fantasy worlds, Nintendo® games, and special 2-D or 3-D videos (for A/V distraction) to simulated 3-D virtual real-life situations with high ecological validity (for VR) (12). Users can choose to fly planes, drive cars, ski down mountaintops, explore houses, and much more. Many features and components can be added to or removed from the equipment depending on the available budget.

This article focuses on the specific application of VR and A/V distraction as analgesic techniques. This application may

be superior to traditional distraction because it offers more immersive images due to the occlusive headsets that project the images right in front of the eyes of the user and, depending on the model used, block out real-world (visual, auditory, or both) stimuli. VR even combines the audio, visual, and kinesthetic sensory modalities. Therefore VR, being the most immersive of all, is expected to be superior to the less technologically advanced A/V distraction methods.

In this context, the concept of presence also appears to be particularly relevant. *Presence* is commonly referred to as the sense of being in the VE rather than in the real physical place where the person's body is actually located (13–16). It is usually operationalized by a set of questions assessing the amount of realism the user attributed to the virtual world and the extent to which the user felt like she or he was wrapped up in the VE. If presence levels are low, patients are not adequately immersed in the virtual world. Unfortunately, to date there is still no consensus on the definition of presence and how it should be measured (14,17). It also remains to be established which are the most important factors that determine the degree of presence. An extensive discussion of the presence construct can be found in Draper, Kabur, and Usher (18).

Depending on how immersive the presented stimuli are, the person's attention will be more or less "drained" from the real world, leaving less attention available to process other real-world, including painful, stimuli. This leads to the hypothesis that the more immersive the stimuli, the higher the presence and the larger the pain reduction will be. McCaffery and Pasero (19) labeled this phenomenon as *sensory shielding*: The user is shielded from pain by the increased sensory input originating from the distraction. Immersion is particularly increased during VR because the use of HMDs prevents patients from seeing what is happening in the real world and directs the focus on what is going on in the virtual world.

VR and A/V distraction thus may be expected to have the potential to improve the analgesic effectiveness of the traditional distraction techniques. In particular, as pointed out by Keefe, Buffington, Studts, and Rumble (20), VR has an enormous potential to facilitate medical treatment efforts. Therefore, the objective of this review is to answer the following questions:

1. Are VR and A/V distraction effective as adjunct analgesic techniques, and are its effects clinically relevant and applicable in a wide range of medical problems and procedures?
2. Is A/V distraction superior to the traditional distraction techniques, and is VR more effective than A/V distraction?
3. Are there any known negative side effects or contraindications?

METHOD

An elaborate literature search was executed in the Medline, PsycINFO, and Web of Science databases until March 2004 using a variety of combinations of keywords (such as *distraction*,

audiovisual, *eyeglass*, *VR*, *virtual*, *pain*, and *analgesic*) to cover the whole range of both VR and A/V distraction. Only peer-reviewed articles written in English, Dutch, German, French, or Spanish were considered. There were no age constraints. In addition, a broad Internet search was executed using the Google search engine (<http://www.google.com>) with the same keywords as mentioned earlier. Identified Web pages were studied and searched for useful information or cross links. In addition, from all identified relevant articles (whether eligible for this review), the reference list was checked to possibly identify new relevant material. A report was found eligible for this review if any form of VR or A/V distraction was the explicit independent variable and pain the explicit primary (or secondary, provided an adequate operationalization) outcome measure.

RESULTS

After scrutinizing all articles and abstracts and discarding inappropriate articles (mostly because the focus was on VR as a diagnostic or educational tool rather than as an analgesic, therapeutic tool), 22 studies remained. Ten of them proved to be on VR, and the remaining 12 studied A/V distraction. Two of the latter were subsequently discarded because they were not published in a (peer-reviewed) scientific journal. Finally, 20 studies remained, which we believe compose the complete body of peer-reviewed literature on the topic.

Table 1 summarizes the included studies, indicating study sample characteristics, methodology, equipment specifications, dependent variables, and the results. The studies are arranged by patient population and, if applicable, additionally categorized in VR or A/V distraction, respectively, to allow easy comparison between both methods. VR was performed with burn patients ($n = 5$) (21–25); dental patients ($n = 1$) (26); cancer patients undergoing subcutaneous venous port access ($n = 2$) (27,28); a patient with cerebral palsy participating in a physiotherapy program following single-event, multilevel surgery ($n = 1$) (29); and healthy volunteers in a laboratory setting where pain was induced by a tourniquet ($n = 1$) (30). A/V distraction has been studied in patients undergoing gastric laboratory procedures ($n = 2$) (31,32), leg ulcer patients ($n = 1$) (33), cancer patients undergoing lumbar punctures ($n = 1$) (34), and dental patients ($n = 3$) (35–37). In addition, there are three reports of testing A/V distraction in the laboratory using a cold pressure test or a tourniquet (38–40). It is remarkable that all but one (25) research report are published either in specific pain journals or in journals focused on the broader application of computer technology. To date, no articles have been published in behavioral medicine, psychosomatic, or health psychology journals.

Table 1 shows that sample sizes range from 1 (25,27,29) to 72 participants (40), 35% of the studies have samples of less than 10 participants (21,23–27,29), and the average sample size is 23.35 participants ($SD = 20.76$, $Mdn = 23.50$). A total of 467 patients were studied; 108 patients were exposed to VR, and the remaining 359 used A/V distraction. All but one study (31) included a control condition, either including a within-subjects

TABLE 1
Schematic Overview of Studies Reviewed for This Article

Medical Procedure	Authors	Study Participants	VR Equipment	A/V Equipment	Conditions	Dependent Variables	Results in VR Condition
Burn patients undergoing wound debridement	Hoffman, Doctor, Patterson, Carrougher, & Furness (21)	N = 2; ages 16 and 17 years • 1 patient selected for unusually high pain levels	• HMD • Motion sensing system • Sound effects • SpiderWorld VE		VR vs. Nintendo; treatment order randomized and counterbalanced	• Several pain measures ^a • Nausea • Presence • Object realism • Anxiety ↓	• All pain measures ↓ • Nausea nonexistent • Presence ↑ • Object realism ↑ • Anxiety ↓
	Hoffman, Patterson, & Carrougher (22)	N = 12; age range 19–47 years • Patients reported prior difficulty coping with pain	• HMD • Motion sensing system • Sound effects • SpiderWorld VE		VR vs. no distraction; treatment order randomized and counterbalanced	• Several pain measures ^a • Nausea • Presence • Object realism • Anxiety • ROM	• All pain measures ↓ • Nausea nearly nonexistent • Anxiety <i>ns</i> • ROM ≥
	Hoffman, Patterson, Carrougher, Nakamura, Moore, Garcia-Palacios, & Furness (23)	N = 1; age = 32 years • Patient reported prior difficulty coping with pain	• HMD • Motion sensing system • Sound effects • SpiderWorld VE		VR vs. no distraction; treatment order randomized and counterbalanced	• Several pain measures ^a • Nausea • Presence • Object realism • Anxiety • ROM	• All pain measures ↓ • Nausea nearly nonexistent • Anxiety <i>ns</i> • ROM ≥ in all sessions • Presence and object realism remained high across sessions • No decrease in analgesic effect across sessions
	Hoffman, Patterson, Carrougher, & Sharar (24)	N = 7; age range 9–32 years • Patients reported prior difficulty coping with pain	• HMD • Motion sensing system • Sound effects • SpiderWorld and SnowWorld VE		VR vs. no distraction; treatment order randomized and counterbalanced	• Several pain measures ^a • Nausea • Presence • Object realism • ROM	• All pain measures ↓ • Nausea nearly nonexistent • Presence and object realism remained high across sessions • ROM in all but one session ↑ • No decrease in analgesic effect across sessions

Hoffman, Patterson, Magula, Carrougher, Zeltzer, Dagadakis, & Sharar (25)	<i>N</i> = 1; age = 40 years	<ul style="list-style-type: none"> Water friendly-HMD (using fiber optics instead of miniature LCD screens) Sound effects Snow World VE 	VR vs. no distraction; treatment order randomized	<ul style="list-style-type: none"> Amount time spent thinking about pain Worst pain (sensory pain) Unpleasantness (affective pain) Amount of fun during wound care Nausea Presence Object realism 	<ul style="list-style-type: none"> All pain measures ↓ Nausea nonexistent Fun high (9 of 10) during VR condition while low (2 of 10) during control condition Moderate rating of presence Moderate to high object realism 	
Patients undergoing gastric laboratory procedures	Kozarek, Raltz, Neal, Wilbur, Stewart, & Ragsdale (26)	<i>N</i> = 50, age range 18–81 years	LCD glasses <ul style="list-style-type: none"> Sound Travelogue over Washington VE 	No control condition	Discomfort ^b <ul style="list-style-type: none"> 82% reported improved tolerance 82% would use it again in the future 66% had previous no-A/V experiences, from them 79% preferred A/V 	
Patients undergoing dental treatment	Lembo, Fitzgerald, Matin, Woo, Mayer, & Naliboff (27)	<i>N</i> = 37; age range 50–74 years	<ul style="list-style-type: none"> LCD glasses Sound Ocean shore line VE 	Non-VR audiovisual stimulation vs. non-VR audio stimulation alone and no stimulation (control); random treatment assignment	<ul style="list-style-type: none"> Abdominal discomfort^c Several stress symptoms^d: arousal, stress, anxiety, anger, fatigue, attention 	<p>Compared to the other two conditions, in non-VR A/V condition: lower intensity of abdominal symptoms</p> <ul style="list-style-type: none"> Arousal ↑ Anxiety ↓ Anger ↓ Attention ↑
Patients undergoing dental treatment	Hoffman, Garcia-Palacios, Patterson, Jensen, Furness, & Ammons (28)	<i>N</i> = 2; ages 51 and 56 years <ul style="list-style-type: none"> Patients reported prior difficulty coping with pain and showed problematic avoidance behavior 	<ul style="list-style-type: none"> HMD Sound effects SnowWorld VE 	VR vs. movie condition, treatment order randomized and counterbalanced	<ul style="list-style-type: none"> Several pain measures^a Nausea Presence Object realism 	<ul style="list-style-type: none"> All pain measures ↓ Nausea nearly nonexistent Presence higher in VR than in movie condition Object realism higher in VR for Patient A yet higher for the movie for Patient B

(continued)

TABLE 1 (Continued)

Medical Procedure	Authors	Study Participants	VR Equipment	A/V Equipment	Conditions	Dependent Variables	Results in VR Condition
	Bentsen, Svensson, & Wenzel (29)	N = 23; age range 20–49 years • Participants volunteered for dental treatment	• LCD glasses • No sound • Roller-skating VE		Non-VR visual stimulation vs. no distraction; condition order randomized	• Pain intensity ^e • Unpleasantness ^e	• No significant differences
	Bentsen, Wenzel, & Svensson (30)	N = 26; age range 29–92 years	• LCD glasses • Sound • Music videos		Non-VR audiovisual stimulation vs. N ₂ O and no distraction; condition order randomized	• Pain intensity ^e • Unpleasantness ^e	• No significant differences of non-VR audiovisual stimulation and N ₂ O on dependent variables • No significant differences between non-VR audiovisual stimulation and N ₂ O
	Frere, Crout, Yorty, & McNeil (31)	N = 27; mean age = 44.3 years, SD = 20.2	• LCD glasses • Sound • Various scenic and activity segments		Non-VR audiovisual stimulation vs. no distraction; condition order randomized	• Pain ^f • Anxiety ^g • Perceived procedure duration • Pulse rate • Systolic and diastolic BP • Respiration rate	• Pain ↓ • Anxiety ↓ • Most patients preferred using non-VR audiovisual stimulation than traditional treatment • Systolic BP ↓
Patients undergoing port access	Gershon, Zimand, Lemos, Rothbaum, & Hodges (32)	N = 1; age = 8 years	• HMD • Sound effects • Virtual Gorilla VE		VR vs. non-VR distraction and no distraction	• Pain intensity ^h • Anxiety ⁱ • Pulse rate ^j	• Patient's, nurse's, and parents' pain ratings ↓ • Anxiety ↑ • Pulse rate ↓
	Gershon, Zimand, Pickering, Lemos, Rothbaum, & Hodges (33)	N = 59; age range 7–19 years	• HMD • Sound effects • Virtual Gorilla VE		VR vs non-VR distraction and no distraction; random treatment assignment	• Pain intensity ^h • Anxiety ⁱ • Pulse rate ^j	• Nurse's pain ratings ↓ • Anxiety ↓ • Pulse rate ↓

Patients undergoing a lumbar puncture	Sander Wint, Eshelman, Steele, & Guzzetta (34)	$N = 30$; age range 10–19 years	<ul style="list-style-type: none"> • LCD glasses • Sound • Video with skiing, drag racing, Paris stroll, and natural scenery 	Non-VR audiovisual stimulation vs. no distraction; random treatment assignment	<ul style="list-style-type: none"> • Pain intensity^e • Subjective evaluation of the distraction experience^k 	<ul style="list-style-type: none"> • No significant differences in pain intensity • 69% of experimental group indicated favorable LP compared to 42% of control group • 94% of experimental group wants to use VR again
Patients with leg ulcer undergoing debridement and wound dressing	Tse, Ng, & Chung (35)	$N = 33$; mean age = 78.8 years, $SD = 9.8$	<ul style="list-style-type: none"> • LCD glasses • No sound • Possibility to choose from opera, cartoons, or mountains and waterfall 	<ul style="list-style-type: none"> • Non-VR visual stimulation vs static blank screen • Condition order randomized • Crossover design 	<ul style="list-style-type: none"> • Pain intensity^e • Degree of enjoyment^l • Recall of content 	<ul style="list-style-type: none"> • Pain ↓ • No effect of gender, residency, or underlying medical condition on net VAS improvement • No correlation of degree of enjoyment or memory content with net VAS improvement
Patient with cerebral palsy participating in physiotherapy program following Single-event multilevel surgery	Steele, Grimmer, Thomas, Mulley, Fullton, & Hoffman (29)	$N = 1$; age 16 years	<ul style="list-style-type: none"> • HMD • Motion sensing system • Handheld trigger to shoot a virtual gun 	VR vs. no distraction; condition order randomized	<ul style="list-style-type: none"> • Average pain using 5-point VAS • ROM 	<ul style="list-style-type: none"> • Pain lower in VR • ROM <i>ns</i>
Healthy volunteers in laboratory setting with pain induced by a tourniquet or cold pressure test	Hoffman, García-Palacios, Kapa, Beecher, & Sharar (37)	$N = 22$; adults (age data not provided)	<ul style="list-style-type: none"> • HMD • Motion sensing system • Tactile augmentation • Sound effects • SpiderWorld VE 	<ul style="list-style-type: none"> • VR vs. no distraction + VR with tactile augmentation vs. VR without tactile augmentation 	<ul style="list-style-type: none"> • Several pain measures^a • Nausea • Presence • Object realism • Anxiety 	<ul style="list-style-type: none"> • All pain measures ↓ • Nausea nearly nonexistent • No significant differences in presence between both experimental conditions • Anxiety <i>ns</i>

(continued)

TABLE 1 (Continued)

Medical Procedure	Authors	Study Participants	VR Equipment	A/V Equipment	Conditions	Dependent Variables	Results in VR Condition
	Bentsen, Svensson, & Wenzel (38)	N = 24; age range 21–33 years		<ul style="list-style-type: none"> • LCD glasses • No sound • Roller-skating VE 	3-D vs. 2-D and no video glasses; condition order randomized	<ul style="list-style-type: none"> • Pain intensity^e • Unpleasantness^e 	<ul style="list-style-type: none"> • 3-D vs. control for men: • Pain intensity ↓ • Unpleasantness ↓ • 2-D vs. control for women: • Unpleasantness ↓
	Bentsen, Svensson, & Wenzel (39)	N = 37; age range 19–28 years		<ul style="list-style-type: none"> • LCD glasses • No sound • Roller-skating VE 	3-D video-glasses with a priori positive, negative, or neutral information about effect on dependent variables; random treatment assignment using balanced groups	<ul style="list-style-type: none"> • Pain intensity^e • Unpleasantness^e 	<ul style="list-style-type: none"> • No effect of a priori information on analgesia • Pain intensity ↓ • No difference in analgesic effect at 4 weeks follow up
	Tse, Ng, Chung, & Wong (40)	N = 72; M age = 20.97 years, SD = 1.97		<ul style="list-style-type: none"> • LCD glasses • No sound • Natural scenery VE (mountains and waterfall) 	<ul style="list-style-type: none"> • Non-VR visual stimulation vs. no stimulation • Condition order randomized • Crossover design 	<ul style="list-style-type: none"> • Pain threshold^m • Pain tolerance^m • Nausea^e • Degree of immersion^e 	<ul style="list-style-type: none"> • Pain threshold ↑ • Pain tolerance ↑ • Nausea nearly nonexistent • Positive correlation between degree of immersion and net improvement of pain threshold

Note. VR = virtual reality; VE = virtual environment; HMD = head-mounted display; LCD = liquid crystal display; ROM = maximum range of motion; BP = blood pressure; HR = heart rate; A/V = audiovisual; VAS = Visual Analogue Scale.

^aWorst pain, average pain, time thinking about pain, unpleasantness, and bothersomeness. All variables measured using 100 mm VAS. ^b5-point Likert scale ranging from 1 (*unbearable*) to 5 (*reasonably comfortable*). ^cVAS with intensity descriptors ranging from faint to severely intense (amount of mm not specified). ^dStress Symptom Ratings questionnaire. ^e100 mm VAS. ^fFear of Pain Questionnaire–III (49). ^gDental Fear Survey (50). ^hChildren’s Hospital of Eastern Ontario Pain Scale (51). ⁱMultidimensional Anxiety Scale for Children (52). ^jUsing a pulse-oxygen monitor. ^k10-item investigator-developed questionnaire with open-ended (e.g., “What were you thinking about during the spinal tap?”) and response set questions (e.g., “Compared to your last spinal tap, was this spinal tap extremely difficult, difficult, less difficult, or much less difficult?”) ^lNumerical anchors ranging from 0 (*not enjoy at all*) to 10 (*very much enjoy*). ^m7-point Likert scale ranging from 0 (*nothing*) to 6 (*intolerable/stop*).

(randomized order of condition) or between-subject (randomized allocation to conditions) design.

In all 10 studies that applied VR, it proved effective in most if not all patients, whereas in all but 3 studies using A/V distraction (34–36), a significant analgesic effect was found compared to the control condition. In some A/V distraction studies (31,34,37), patients were asked whether they would like to use the eyeglasses during future treatments. Patients generally indicated to prefer future treatment with the eyeglasses, with percentages ranging from 79% (31) to 100% (37).

Except for the VR case study by Gershon et al. (27) in which anxiety increased, anxiety ratings did not change (22,23,30) or decreased (21,28,32,37) during exposure. Remarkably, the studies showing no change in anxiety all used VR. Finally, the studies that also included nausea ratings (21–26,30,40) demonstrated that this side effect was negligible to nonexistent.

DISCUSSION

The aim of this article was to provide an overview and critical evaluation of the use of VR and A/V distraction as adjunct analgesic techniques during painful medical procedures. To achieve this aim, we formulated three questions. The first question consisted of two parts: First, we asked if VR and A/V distraction are effective analgesic techniques and, if so, whether the analgesic effect is clinically relevant; second, we wondered whether these types of distractions are applicable in a wide range of medical problems and procedures. The results of the included studies strongly suggest that both VR and A/V distraction may indeed significantly reduce pain associated with a multitude of medical interventions. The induced analgesia was, in almost all cases, clinically relevant both for VR and the less sophisticated A/V techniques. Especially patients who reported very high to unbearable pain levels appeared to benefit greatly. However, one should also be aware that almost all studies are hampered by serious methodological shortcomings such as very small samples and patient selection bias. These are discussed later. Nevertheless, given the promising results of these studies, further exploration of this application using more appropriately designed studies is highly recommended.

Regarding the second part of the first question, the applicability of VR and A/V distraction, the diversity of patients and medical procedures studied for this review shows that they can be used in almost any condition in which the patient is conscious. The most important limitation seems to concern medical conditions that prevent the use of the necessary equipment such as the HMD, virtual glasses, or earphones (e.g., patients with burns on their upper face or ears). For example, in the study by Steele et al. (29), after several sessions the researchers had to change equipment, as the type of HMD proved inappropriate to use in the supine position required for the physiotherapeutic treatment. An additional practical aspect is that the HMD and earphones severely limit the communication between the patient and the health professional. This means that the health providers may not receive optimal feedback from the patients regarding

their actions (e.g., see 37). For some specific treatments, this might be rather important.

The second question focused on the supposed analgesic superiority of VR and A/V distraction to traditional distraction (such as music, reading, playing games, etc.) and the issue of whether VR is superior to the less advanced A/V distraction. Unfortunately, no studies were found that compared the effectiveness of VR and A/V distraction with traditional distraction techniques. Therefore, no quantitative comparison could be made. Regarding the relative effectiveness of VR in comparison to A/V distraction, only two case studies (21,32) have compared VR to playing a Nintendo video game and to watching a movie via LCD glasses, respectively. Both studies showed that VR caused the largest analgesic effect. The key to the explanation of these findings probably lies in the amount of immersion and its relation with presence and analgesic effectiveness.

Regarding immersion, we mentioned earlier that the ideal distractor is hypothesized to require an optimal amount of attention, involving multiple sensory modalities and active user (emotional) participation (8,11). The simultaneous stimulation of the auditory and visual senses (A/V distraction) or of the auditory, visual, and tactile senses (VR) presumably causes a greater involvement and, therefore, more effective distraction than traditional techniques. Therefore, VR and A/V distraction can be expected to be more effective than traditional distraction and VR more effective than A/V distraction. Even mere visual stimulation presented with these new technologies can be expected to be more immersive than traditional distraction due to the occlusive eyeglasses or HMD that display the stimuli in a dominant fashion, creating more involvement than when simply reading a book or watching TV. It may be worthwhile to examine in future studies which specific characteristics of the content of the emitted stimuli determine the analgesic effect, to be able to optimize it. An example of such an investigation is the study by De Wied and Verbaten (41), who found that emotionally positive distractors have a greater pain-reducing capacity than emotionally negative distractors and that emotionally negative stimuli without pain cues improve pain tolerance more than those with pain cues.

Although there is a considerable body of technological literature available on the factors that influence the degree of immersion or presence of VEs (42–45), the picture concerning this issue is still far from clear and complete. More important, the psychological aspects are increasingly being taken into consideration as well. This might bring a halt to the concern raised by Barfield, Zeltzer, Sheridan, and Slater (as cited in 42), who stated that, although the technological advances to create VEs have been outstanding, there is a lack of a conceptual and analytical system that directs the research in this area. Most investigators agree that VR and A/V distraction involve many subjective experiences and processes, making this *par excellence* a field of research that requires the integration of technology and psychology.

For example, the psychological aspects of VR or A/V distraction have been examined by Baños et al. (42), who demon-

strated that participants with higher scores on absorption and dissociation attributed more reality to the VE, experienced the stimulation as more realistic, and were more able to forget about the real world. This finding suggests that specific personality features are very important determinants of immersion and presence, possibly limiting the effectiveness of technological improvements. Aptly tuning the type of stimulation with the user's interests (a variation on the well-known "person–environment fit" notion) might optimize the analgesic potential, although the vast majority of the patients in the here-reviewed studies responded very well to the selected stimuli.

Another potentially problematic, psychological factor affecting immersion is habituation, which may occur when the same VE or A/V stimuli are used repeatedly in the same patient (8). However, in the two studies by Hoffman et al. (23,24) that included repetitive VR exposure, no decrease in analgesic effectiveness over sessions was reported, and both presence and realism of objects ratings remained high. In addition, something as simple as regularly changing scenes (e.g., from a cockpit to a house) might increase and maintain immersion due to the novelty effect.

The precise relation between immersion, presence, and analgesic effectiveness also has to be addressed in future research. Most studies implicitly assume a direct positive relationship between level of immersion, presence, and analgesic effectiveness; however, to date, little data bear on this important relationship. In a laboratory study with healthy volunteers, Hoffman, García-Palacios, Everett, and Sharar (46) directly studied the effect of immersion on pain reduction by comparing the pain scores of high-technology VR versus low-technology VR. They found that the high-technology VR group "felt considerably more present in the VE and reported more effective pain reduction than the group receiving low-technology VR" (p. 4). The findings of another VR study by Hoffman, Patterson, and Carrougher (22) also suggest that the higher the presence in VR, the higher the amount of pain and anxiety reduction. However, these findings were based on only three patients. Finally, using A/V distraction, Tse, Ng, Chung, and Wong (40) found a positive relation between degree of immersion and net improvement of pain tolerance in healthy volunteers.

Although no figures regarding the cost effectiveness of VR and A/V distraction as analgesic are currently available, most studies did not need expensive or extremely sophisticated equipment (VR would be by far the most expensive method), suggesting that the application of this technology can be a relative cost-effective technique to reduce pain. The case studies by Hoffman, Doctor, Patterson, Carrougher, and Furness (21) and Hoffman et al. (26) indeed suggested that VR caused the largest analgesic effect, but these preliminary findings do not allow VR to be regarded as unconditionally more effective. More research is needed to establish if or when VR is superior to A/V distraction.

The last question focused on the existence of possible negative side effects or contraindications, in particular, simulator sickness. The close proximity and the relatively fuzzy quality of the images might cause nausea, at least in sensitive individu-

als. VR programs running on low-technology equipment (i.e., computers with low-quality central processor units or graphics cards) might be more likely to cause nausea (Hoffman, personal communication, June 27, 2002). In nausea-prone individuals such as cancer patients receiving chemotherapy, simulator sickness might aggravate the nausea. Also, patients who need to spend considerable time with VR or A/V distraction (e.g., burn patients) may be at increased risk. However, the results of the reviewed studies strongly suggest that simulator sickness is nearly nonexistent, even in the case of frequent and lengthy use of VR. Schultheis, Himmelstein, and Rizzo (12) reported that simulator sickness was also minimal (< 10%) in multiple sclerosis and traumatic brain injury patients. Therefore, simulator sickness does not seem to be a serious negative side effect, although we do recommend to monitor it closely, especially in specific patient groups and in those who repeatedly use VR or A/V distraction of longer duration.

The literature does not explicitly uncover possible contraindications. However, it might be useful to consider the patient's anxiety level. Most articles measuring anxiety reported that anxiety levels either decreased (21,28,32,37) or did not show any change (22,23,30). Only in the case study by Gershon et al. (27), anxiety during port access actually increased in the VR condition. The authors suggest that this might be caused by the HMD preventing the boy from seeing what the nurse is doing, therefore increasing uncertainty and feelings of uncontrollability. This important issue needs further attention because the effectiveness of immersive VR also depends on the degree of the patient's visual field reduction to the images of the virtual world. Hoffman et al. (22) reported that some patients initially tensed up when entering VR and needed some time to adjust to being in the VE. It might be interesting to examine which personality characteristics may be associated with these increased anxiety levels. It is tempting to speculate that patients with a confronting or monitoring coping style might perceive the reduction of the visual field and the associated loss of awareness of the health provider's activities as a loss of control, resulting in increased anxiety. In contrast, patients who have a more passive or avoidant coping style will most likely experience considerably less anxiety.

The application of A/V-induced analgesia in a clinical setting is being investigated only recently. Therefore, the underlying mechanism of VR- and A/V distraction-induced analgesia remains unclear. Hoffman et al. (30) tested the hypothesis that VR would reduce pain by shifting attention away from the real world to the virtual world by applying a divided attention task. The participants' poorer performance during VR exposure suggests that VR is indeed attention grabbing and that it draws attention away from real-world phenomena. Circumstantial evidence for this mechanism is provided by the A/V distraction study by Frere, Crout, Yorty, and McNeil (37) in which two dental patients did not complete the study because the distraction "did not allow them to concentrate on their ... techniques to control gagging" (p. 1037). In this light, it is also interesting to mention a pioneer case study by Patterson, Tininenko, Schmidt, and Sharar (47) that successfully used VR to induce hypnosis to con-

control pain and anxiety in a burn patient. Therefore, it is tentative to assume that VR and A/V distraction are indeed attention grabbing and that distraction is the underlying mechanism for the induced analgesia.

In the articles included for this review, Melzack and Wall's (48) gate control theory has often been brought forward as the main explicative model. An alternative explicative model is the cognitive-affective model of the interruptive function of pain by Eccleston and Crombez (10), which models pain as a selection for escape over other competing demands for attention. To understand coping with pain, Eccleston and Crombez (10) focused on the dynamic switching between pain and other attentional demands that are present in the environment in which the pain occurs (i.e., "the efficient recovery from interruption by pain by the fast switching of attention away from pain and back to the interrupted task" [p. 362]). Therefore, we feel that this attention-competing hypothesis is the most serious candidate to guide this research.

With the results found in the studies so far, future research can move beyond its current pioneering phase and put more emphasis on methodology, because most of the reviewed studies are clinical studies with severe methodological limitations. A major methodological flaw seen in most studies concerned the use of very small samples, therefore severely limiting the generalizability of the results. However, the other side of the coin is that the included patients often reported extremely high pain levels. This patient selection bias, therefore, seems warranted, because patients with high levels of pain are generally thought to be less easily distracted. If VR and A/V distraction works even in these patients, it will most likely work as well in patients with lower pain levels. On the other hand, such a patient selection bias may also facilitate regression toward the mean effects. Therefore, this must be anticipated and adequately dealt with by, for example, introducing appropriate control conditions and counterbalancing the treatment order.

Another issue is that, understandably, none of the studies used a double-blind design. Although we agree that using a double-blind design is problematic when using VR or A/V distraction, we nevertheless feel that more effort could be spent to reduce any unwanted experimenter or participant effects.

Finally, both VR and A/V distraction were often compared with a no-distraction condition (standard care), which may inflate the analgesic effectiveness. Therefore, more adequate and equivalent comparison groups should be included. More specifically, VR should be compared to A/V distraction more often to estimate its superior analgesic potential. To generate VR, relatively expensive equipment is used; therefore, its superiority above other less sophisticated and expensive techniques must be proven to justify the investments needed.

In conclusion, the reviewed studies strongly support that VR and A/V distraction are clinically viable techniques with a high potential to alleviate pain associated with different medical diagnostic and therapeutic procedures. Both VR and A/V distraction have proved to be effective in the majority of patients and seem to be safe techniques that do not require any previous education or training from the patient. They can be used effec-

tively in children, adolescents, and adults by adjusting the images to the according developmental stage. However, still much research needs to be done to obtain a clearer picture of its full potential strengths and limitations.

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