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Virtual reality and pain management: current trends and future directions

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SUMMARY

Virtual reality (VR) has been used to manage pain and distress associated with a wide variety of known painful medical procedures. In clinical settings and experimental studies, participants immersed in VR experience reduced levels of pain, general distress/unpleasantness and report a desire to use VR again during painful medical procedures. Investigators hypothesize that VR acts as a nonpharmacologic form of analgesia by exerting an array of emotional affective, emotion-based cognitive and attentional processes on the body's intricate pain modulation system. While the exact neurobiological mechanisms behind VR's action remain unclear, investigations are currently underway to examine the complex interplay of cortical activity associated with immersive VR. Recently, new applications, including VR, have been developed to augment evidenced-based interventions, such as hypnosis and biofeedback, for the treatment of chronic pain. This article provides a comprehensive review of the literature, exploring clinical and experimental applications of VR for acute and chronic pain management, focusing specifically on current trends and recent developments. In addition, we propose mechanistic theories highlighting VR distraction and neurobiological explanations, and conclude with new directions in VR research, implications and clinical significance.

Virtual reality (VR) is a state-of-the-art technologically advanced system that allows users to be transported into a 'virtual world.' Users are engaged in a fully immersive VR experience through a combination of technologies, including a head-mounted display (HMD), headphones with sound/music and noise reduction, a rumble pad, joystick or another device for manipulation/navigation of the virtual environment (VE). VR also includes head-tracking systems, which are often built into the HMD. These systems follow the user's head movements, giving them the illusion of being completely surrounded by a virtual world. Multimodal (visual, auditory, tactile and olfactory) stimuli contribute to a sense of actual presence/immersion in the virtual world, thus making the VR experience distinct from passively watching television or movies, or playing a 2D handheld videogame or game console. A variety of VR systems have been developed and investigated from low- to high-tech systems, including nonimmersive 2D VR systems administered without helmets to fully

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immersive VR systems with multimodal stimuli, resulting in mixed outcome efficacy. Figures 1 & 2 show applications of the VR technology.

Originally, VR technology was solely recognized for its entertainment value; however, in the past 10 years, its application has been expanded to a variety of clinical areas, including pain management, physical rehabilitation and the treatment of psychiatric disorders (e.g., phobias, post-traumatic stress disorder and anxiety disorder) [1–4]. It has been most frequently studied in medical settings as a means to attenuate pain perception, anxiety and general distress during painful medical procedures, such as wound care, chemotherapy, dental procedures and routine medical procedures [5–9].

To date, few theories have been proposed regarding the pain-attenuating effects of VR beyond simple distraction. In an attempt to understand the underlying mechanistic origin for VR analgesia, investigators have considered the neurobiological interplay of brain cortices and neurochemistry, as well as emotional, cognitive and attentional processes. While VR has been demonstrated in a variety of settings to effectively decrease pain and distress associated with painful procedures, researchers have only recently begun to deconstruct patient and disease characteristics, specific aspects of VR technology, and to identify neurobiological mechanisms underlying VR.

Melzack and Wall proposed the Gate Control Theory, which suggests that factors such as the level of attention paid to the pain, the emotion associated with the pain and past experience of the pain all play a role in how the pain will be interpreted [10]. McCaul and Malott expanded this theory to state that human beings have a limited capacity of attention and an individual must attend to a painful stimulus in order for it to be perceived as painful [11]. Therefore, if the individual is attending to another stimuli away from the noxious stimuli, they will perceive the painful stimulus as less intense. Wickens proposed the Multiple Resources Theory, which states that resources in different sensory systems function independently [12]. This supports the nature of VR technology, which is based on integrating multimodal (visual, auditory, tactile and olfactory) sensory distractions.

Recently, Gold *et al.* hypothesized that VR analgesia originates from intercortical modulation among signaling pathways of the pain matrix through attention, emotion, memory and other senses (e.g., touch, auditory and visual), thereby producing analgesia [13]. An overall decrease of activities in the pain matrix may be accompanied by increases of activity in the anterior cingulate cortex and orbitofrontal regions of the brain.

While there is substantial research supporting the use of VR for the attenuation of acute pain during medical procedures, the exploration of VR use for chronic pain management is still in its inception. Investigations must be conducted to further understand VR's role in acute and chronic pain management. Current studies are underway to understand the underlying mechanisms behind VR's analgesic effects and to deconstruct the patient (age, gender and pain history), disease and technology (HMD, head tracking and VE) characteristics. Ultimately, understanding the influences and interactions of these independent variables will lead to optimal patient/VR matching, thus, personalizing the interventions to maximize VR's pain-attenuating effects. Hopefully, lessons learned from these early VR investigations will have applications in chronic pain management and other pain rehabilitative conditions. Ultimately, the aim of current VR investigations is to develop flexible environments targeting specific acute and chronic pain conditions, and to promote long-term rehabilitative pain management.

VR for acute pain management

Burn care

The use of VR for pain and anxiety attenuation during burn care procedures and rehabilitation of burn survivors is one of the most widely researched uses of VR technology. Clearly, burn wound care causes a tremendous amount of pain, anxiety and discomfort to patients. In 2000, Hoffman *et al.* reported a case study examining the efficacy of VR compared with a standard video game for two adolescents (16 and 17 years old) undergoing burn wound care [14]. VR was found to decrease pain levels, anxiety and time spent thinking about pain. Das *et al.* conducted a randomized control trial, comparing standard of care (analgesia) with analgesia plus VR for children (5–18 years old) during burn wound care [15]. Analgesia coupled with VR was more effective in reducing pain and distress than analgesia alone. More recently, a water-friendly VR system was investigated during wound debridement for 11 patients (9–40 years), demonstrating that VR lowered pain ratings and increased fun ratings for those who reported feeling engrossed in the VR game [16].

Virtual reality technology has also been studied with burn patients undergoing physical therapy. Hoffman *et al.* examined the use of pharmacologic analgesia alone versus VR in addition to analgesia during physical therapy [17]. Patients in the VR group reported lower ratings of pain and an increased range of motion. In another study, Hoffman *et al.* compared the use of VR to no distraction during physical therapy [18]. After the VR condition, patients reported decreased pain and a greater range of motion. Sharar *et al.* reported results across three studies and concluded that VR in addition to standard analgesia reduced pain intensity, unpleasantness and time spent thinking about pain [19]. Carrougher *et al.* found similar results among burn patients undergoing physical therapy/rehabilitation, with nonsignificant clinical improvements in range of motion [20].

Patterson and colleagues were the first to use VR technology to augment hypnosis (virtual reality hypnosis [VRH]) [21]. This was a novel and cutting-edge approach to the integration of VR with a pre-existing evidence-based treatment for reducing pain and anxiety. Procedurally, VRH is administered by providing the patient with an audio recording of hypnotic induction, suggestions for pain relief and then drifting the participant into the virtual world [22]. Patterson *et al.* studied VR as a means of delivering hypnosis to patients with burns during wound care in a clinical case series of 13 patients [21]. These patients reported lower levels of pain and anxiety. For this study, Patterson used a VR distraction sequence, SnowWorld©, developed by Hoffman, which allows users to glide through a 3D icy canyon while throwing snowballs at virtual snowmen, igloos, robots and penguins. Similarly, Konstantatos *et al.* examined the efficacy of VR relaxation in addition to morphine for pain reduction during burn wound dressing changes. Instead of using a distraction type program, such as SnowWorld, the researchers developed a VR relaxation sequence prepared by psychologists and based on hypnotherapy theory [23]. This provided calming visual scenery, which instructed the participant to concentrate on a moving spiral. Contrary to previous results, this study found an increase in pain intensity for participants receiving VR with morphine during wound care. Mixed findings may be related to the VE, the degree of immersion and varying methodologies. While VR distraction is effective for reducing pain during burn wound care, VR relaxation may not deliver the same result.

In general, VR has been reported to be an effective modality to decrease pain during burn care. A recent systematic review of nine studies by Morris *et al.* found that VR coupled with standard analgesia was effective in reducing pain during burn care in eight of the nine studies [5]. Varying methodologies, patient characteristics and VR technology, may continue to contribute to mixed findings. Nonetheless, continued research in burn care is warranted with VR and VR enhanced interventions for managing the associated pain and anxiety.

Cancer pain

Virtual reality technology has also been studied as a way to decrease pain, unpleasantness and anxiety associated with common painful cancer procedures and treatments, such as chemotherapy, lumbar puncture and port access. A study by Schneider and Workman examined 11 children (aged 10–17 years) receiving chemotherapy with and without VR [24]. A total of 82% of the children stated that treatment with VR was better than previous treatments and that they would like to use VR during future treatments. Sander Wint *et al.* investigated VR use during lumbar puncture with a sample of 30 adolescents (aged 10–19 years) [25]. Although pain scores were lower in the VR condition, differences were not statistically significant. A study by Gershon *et al.*, studying children and adolescents requiring port access, compared VR distraction, non-VR distraction (computer) and standard of care [26]. Findings indicated that VR distraction was significantly better than standard of care in terms of reducing physiological arousal (i.e., pulse rate) and pain ratings. VR has also been demonstrated to decrease symptom distress and perceived time spent receiving chemotherapy, termed the time–elapse compression effect [6,27].

Routine medical procedures

Many routine medical procedures, such as a blood draw, intravenous placement and immunization can be painful and anxiety provoking. Gold *et al.* investigated the use of VR distraction during outpatient blood draw in children [28]. The sample consisted of 100 children (8–12 years old) stratified for age and gender into four conditions: no distraction, cartoon distraction, VR via computer or VR via HMD. The children in all conditions placed their arm through a pass wall for the blood draw in order to control for visual occlusion. Children in the VR HMD group reported a lower frequency of moderate-to-severe pain intensity levels compared with the other three groups (χ^2 [15, N = 100] = 25.54, $p < 0.05$). No significant differences were found in average pain intensity and state anxiety between the four conditions. Gold *et al.* examined the use of VR with 20 children (8–12 years of age) requiring intravenous placement of contrast for an MRI CT scan [9]. Children were randomly assigned to one of two conditions: standard of care (topical anesthetic) or VR presented via HMD plus standard of care. While children in the control condition had a fourfold increase in pain ($p < 0.01$), children in the VR condition reported no significant changes in pain intensity between pre- and postintravenous placement. Furthermore, children, caregivers and nurses were more satisfied with the use of VR for pain management during the procedure.

Furman *et al.* compared VR with watching movies as alternative forms of analgesia in 38 patients during scaling and root planning, a painful dental procedure [7]. Pain scores were significantly lower in the VR group compared with the movie group and controls. Furman *et al.* modeled the study closely on a case study by Hoffman *et al.* [18], which examined two patients who received scaling and root planning, and both reported lower pain ratings during the VR condition than during the movie and control conditions.

VR for chronic pain management

While there is growing evidence supporting VR's effectiveness in managing acute procedural pain, little is known about the use of VR for treating patients with chronic pain and/or for long-term pain rehabilitation. To date, only a few studies have investigated VR for chronic pain management and the data are preliminary.

Sato *et al.* investigated the use of VR for treating complex regional pain syndrome in adults [29]. In this pilot study, a VR mirror visual feedback system was created and applied to the treatment of complex regional pain syndrome in five adult patients (46–74 years old). This was a nonimmersive form of VR, as participants were not engaged in VR through an HMD. However, the game was interactive as the VR mirror visual tracking device followed the participants' hands as they completed target-oriented motor exercises such as reaching out, grasping, transferring and placing. In the study, patients participated in five to eight outpatient sessions, resulting in four of the five patients demonstrating at least 50% reduction in their pain intensity scores. This study demonstrates how VR could be applied for the treatment of chronic pain. Further investigations with larger samples and refined methodologies must be conducted to replicate these results. In addition, future studies should look at the effectiveness of immersive VR programs for the treatment of complex regional pain syndrome and other chronic pain conditions.

Sarig-Bahat *et al.* investigated VR's ability to treat chronic neck pain in 67 patients (22–65 years) with and without symptoms [30]. The investigators used a VR environment, which encouraged patients to increase their range of motion by 'spraying' flies with a virtual spray canister. In theory, the more they engaged in the activity, the greater their range of motion would become. The investigators found that a single session of VR resulted in increased cervical range of motion and decreased neck pain.

Hoffman *et al.* explored whether immersive VR could help reduce pain during repeated physical therapy sessions for burn victims [18]. During three sessions, seven patients (9–32 years of age) came to perform range-of-motion exercises under an occupational therapists' direction. Participants spent an equal amount of time during the session with VR distraction and without. The investigators found that pain ratings were significantly lower when patients were immersed in VR and the magnitude of pain reduction did not decrease over multiple sessions. These findings are promising as they indicate a potential for VR to be applied to long-term physical therapy.

As described in acute pain management, VR has recently been studied to augment the effect of hypnosis for the treatment of chronic pain. In a case study of a 36-year old female with a 5-year history of retractable chronic neuropathic pain, investigators found that following a 6-month trial of VRH, the patient's pain ratings decreased 36% for 3.86 h and unpleasantness decreased 33% for 12.21 h on average across 33 sessions [22]. In addition, when the first ten sessions of VRH were compared with the first ten sessions of previously completed hypnosis (non-VR) treatment, investigators found that VRH led to a reported average of 8.5 h of pain reduction and 4.3 h of being pain free, compared with an average of 1 h of pain reduction and 0 h of being pain free after hypnosis (non-VR). In conclusion, VRH was found to be more effective than hypnosis alone, by reducing pain and prolonging the treatment effects. Although the usage of VR for chronic pain management is still in its infancy, pilot findings are promising.

Experimental pain & VR in healthy populations

A critical line of research is the examination of experimental pain and VR in healthy participants. This paradigm has many advantages, as investigators are attempting to isolate and/or deconstruct critical parameters involved in the clinical efficacy of VR. These studies allow investigators to look at the effects of VR while controlling confounding factors such as clinical pathology, exposure to pain or adjunctive medications, hospital environment, and various other patient and disease characteristics. Therefore, this type of research enables investigators to control and manipulate the effects of the unique characteristics that contribute to VR distraction or modulation.

Experimental pain has been delivered through a variety of mechanical and thermal modalities, including a modified tourniquet [31], an ischemic tourniquet [32], a blood pressure cuff [33], cold pressor [34–36] and a noxious warm or cold thermal pain stimulation (Figure 3) [37]. In general, VR has been demonstrated to be effective in increasing pain tolerance and pain threshold, and decreasing pain intensity, affective distress and pain unpleasantness [31–37].

There is scientific concern that individuals may habituate to VR and, therefore, lose its benefits over repeated exposures. Rutter *et al.* conducted an 8-week trial of once-weekly VR distraction during a cold pressor pain paradigm on 28 adults (18–23 years old) [35]. Results indicated that VR distraction led to significant increases in pain threshold and pain tolerance, and significant decreases in pain intensity, time spent thinking about pain and self-reported anxiety. Unique findings specific to this study demonstrated that the effects of VR remained stable across the eight sessions, indicating that repeated exposure did not alter VR's effectiveness. These findings are similar to a clinical trial of VR versus traditional physical therapy for patients following burn injuries. Hoffman *et al.* demonstrated that VR reduced pain across multiple physical therapy sessions and treatment effects persisted without habituation for patients with burns [18]. Additional studies should investigate whether treatment effects continue across treatment sessions for participants with other pain conditions.

Another line of VR investigation has specifically focused on the technology and differentiating the effects of HMD versus no HMD, and high versus low HMD technology. Dahlquist *et al.* found that the use of an HMD resulted in an increase in pain threshold and pain tolerance for children over the age of 10 years, but had no significant differences for children under 10 years of age [34,36]. Hoffman *et al.* compared a low- versus high-tech VR HMD for pain attenuation during an experimental thermal pain paradigm and found that the high-tech VR helmet group reported greater reductions in 'worst' pain (34%), 'pain unpleasantness' (46%) and 'time spent thinking about pain' (29%), as well as greater fun during the pain stimulus (32%) than the low-tech VR group [38]. Only 29% of participants in the low-tech helmet group, compared with 65% of participants in the high-tech VR helmet group, showed a clinically significant reduction in pain intensity during VR. Together, these results reflect important developmental and technological considerations when evaluating the impact and efficacy of VR. The current results suggest that the use of a HMD with older children resulted in an increase in pain threshold and pain tolerance, while the use of a high-tech VR HMD was more effective at reducing pain than a low-tech VR HMD.

Patterson *et al.* combined posthypnotic suggestion with VR distraction versus VR alone in 103 undergraduate psychology student volunteers (18–40 years old) [21]. After receiving a thermal pain stimulus with no distracter at baseline, each participant received hypnosis or no hypnosis, followed by virtual reality distraction (VRD) or no VRD during another pain stimulus. Patterson *et al.* found that audio hypnosis combined with VRD reduced subjective 'worst pain' and 'pain unpleasantness' by 22 and 25%, respectively, more than VRD alone [21]. Combination therapies, which include VR as a method for delivering hypnosis training, may be promising new therapies for managing pain.

VR & neurobiology

Functional imaging studies of the human brain's response to painful stimuli have shown increases of activities in the anterior cingulate gyrus, the insula, the thalamus, and sometimes in other regions such as the primary somatosensory cortex and the periaqueductal gray matter [39–47]. These brain regions may be considered to host a network of circuitry involved in the bottom-up, top-down and intercortical processing of painful stimuli, or even somewhere, somehow the origin of the experience of pain itself. However, these regions also respond more or less to a range of aversive to nonaversive stimuli, and a wide range of task-driven attention, distraction or affective conditions [40,42,45]. The responses of some subsets of these regions have been related to sensation/pain intensity and pain unpleasantness by imaging with well-controlled psychophysical measures [48–53]. However, difficulties in separating brain regions that process sensory information from those that mediate affective responses is presently an area of active debate. To date, functional imaging or other methods of investigation have not produced an objective, direct brain correlate of the pain experience, nor is there a clear picture of how the brain's sensory and affective mechanisms act together on the dimension of pain in response to potentially aversive stimuli.

Virtual reality has been found to attenuate pain, and this effect has been called 'VR analgesia' [35,54–56]. The subjective ratings of pain reduction by VR has been corroborated with functional MRI (fMRI) data showing reduced brain activity increases in regions commonly strongly activated by experimental thermal pain stimulation (Figure 4). Hoffman's study, however, mainly focuses on whether VR game playing, as a whole, significantly reduces the increase of brain activities in the classic pain areas associated with noxious thermal stimuli. Another published study compared VR with the effects of opioids (hydromorphone injection) on brain activities related to thermal pain stimulation, and found that opioids and VR significantly reduced pain-related brain activity in the insula and thalamus, but not other regions of the pain circuitry [54]. On the other hand, other cognitive tasks have been demonstrated to attenuate brain activity in the classic pain circuitry during experimental pain stimulation. Bantick *et al.* proposed a theory of pain attenuation via distraction (exemplified by an adapted Stroop task) to decrease pain perception as measured by fMRI and subjective pain ratings in eight right-handed volunteers (mean age 30 ± 9 years) [57]. The adaptive counting Stroop task required the subject to count the number of words with incongruent meanings on the display screen. Subjective reports of pain intensity were lower during the Stroop distraction condition. During the distraction task, there was an overall decrease in BOLD signal in the insula, thalamus, hippocampus and midcingulate region of the anterior cingulated cortex, which are known brain regions associated with pain perception. Inversely, an increase in BOLD signal was observed in the perigenual region of the anterior cingulated cortex and orbitofrontal cortex, demonstrating the plausibility of inter-cortical modulation or top-down inhibition of pain signaling. Valet *et al.* hypothesized that the cingulo–frontal cortex may exert top-down influences on the periaqueductal gray matter and posterior thalamus to modulate pain during distraction [58]. Performing the counting Stroop task requires sustained attention plus other high-level cognitive functions. Whether the counting Stroop task's analgesic effect is explained solely by attention 'gating' or via other mechanisms cannot be determined by Bantick's or Valet's data. The increased activity in the cingulo–frontal cortex may be caused by the increased cognitive demand of the task, not simply by the mechanism of attention distraction alone [59]. In other words, attention does not necessitate task loading, but task loading does require attention. Additional studies are required to shed light on these issues to advance our understanding of the underlying cortical processes responsible for pain attenuation.

While known distracting cognitive tasks have demonstrated top-down modulation of pain signaling via frontal cortical processes, VR remains somewhat enigmatic with regard to its underlying neurobiological mechanisms. To date, in addition to the distraction of attention, studies have associated cognitive analgesic effects to cognitive task loading [59], mood [60], expectancy [61] and perceived controllability [62]. A VR environment is capable of manipulating an even more complex set of cognitive and emotional conditions than the presentation of most classic cognitive tasks. Therefore, VR's analgesic effect may originate from the interplay of these classic mechanisms or from something beyond. For example, a VR environment is well known for eliciting a ‘transported’ presence, over and beyond any cognitive tasks the subject is performing at the same time. Elaborate experimental designs capable of isolating the contribution of transported presence are required to illuminate the neural mechanisms underlying VR analgesia.

Current NIH studies

The number of NIH-funded studies investigating the use of VR for pain management has doubled in the past year [101]. Cohen (Georgia State University, USA) is looking at the effectiveness of coaching children in deep-breathing relaxation (biofeedback) through a VR system during fracture manipulation and repair [101]. Patterson (University of Washington, USA) is examining the efficacy of VR combined with hypnosis for patients who have experienced severe physical trauma and pediatric patients undergoing physical therapy postburn. In addition, Patterson will conduct an experimental study using analog electric pain to further explore the mechanisms underlying VR’s analgesic effects [101].

Sharar (University of Washington) will study the neurophysiologic mechanisms underlying VR as compared with other pharmacologic pain management methods. This study will be conducted in a healthy adult population with thermally and/or electrically induced pain. Pain will be rated through subjective measures and fMRI [101]. Similarly, Gold (University of Southern California, Childrens Hospital Los Angeles, USA) will employ fMRI to explore the neurobiological mechanisms involved in VR pain attenuation in healthy adolescents (aged 14–17 years). An experimental fMRI-compatible thermal pain paradigm will be used to evaluate the hypothesis that VR will reduce brain activity in brain regions associated with pain perception (e.g., thalamus, somatosensory and motor cortices, insular cortices, cingulated cortices and basal ganglia) [101]. In addition, the reduction of brain activity observed in regions associated with pain perception during VR will concurrently be associated with increased activity in distal regions of the brain (e.g., prefrontal cortex) commonly associated with attention, emotion, cognition and response inhibition. Sharar and Gold’s studies will provide important insight into VR’s underlying mechanistic effects on neural activity in participants subjected to experimental pain [101].

Wichman Askay (University of Washington) will investigate the use of VRH as treatment for chronic burn pain. Participants must have been burned in the past 2 years, still experience pain and no longer use medication. This pilot study may provide valuable knowledge for the use of VR in the treatment of chronic pain [101].

Conclusion

Virtual reality has consistently been demonstrated to decrease pain, anxiety, unpleasantness, time spent thinking about pain and perceived time spent in a medical procedure. In addition, healthcare providers have routinely commented that VR increases procedural cooperation, while decreasing anxiety and distress. Nurses have commented that it helps children be less nervous and more calm, leading to less challenging and stressful medical procedures. VR in combination with standard of care often facilitates a smoother procedure (i.e., fewer needle pricks/attempts). To date, VR for acute painful medical procedures has shown the best promise as a primary or complementary pain management practice. However, other studies have reported negative effects, mixed findings or limitations owing to age and/or technology.

To date, few studies have researched VR as a complementary intervention for managing chronic pain or facilitating pain rehabilitation. Preliminary studies have demonstrated that VR maintains its efficacy over repeated sessions, speeds up pain rehabilitation, increases the range of motion and extends the duration of treatment effects (i.e., longer perceptions of reduced pain and unpleasantness). As the field advances, VR may decrease the number of needed treatment sessions, and may reduce or eliminate the need for narcotics during painful procedures. VR is showing initial promise for managing chronic pain and facilitating long-term pain rehabilitation; however, numerous scientific questions remain.

Although chronic pain affects an estimated 70 million Americans, it is a tragically overlooked public health problem [102]. The documented burden of chronic pain is greater than that of diabetes, heart disease and cancer combined. A 1998 NIH report concluded that the economic toll of chronic pain is alone estimated at US$100 billion a year in the USA with predicted steady and significant increases in years to come [103]. Future investigations of VR for chronic pain management are warranted given the scope, severity, and especially given the personal and societal burden of the illness. Future studies should continue to deconstruct critical variables identified in VR analgesia and controlled trials should be conducted using rigorous methodologies with standardized outcomes to evaluate the efficacy of VR for chronic pain management.

A new line of VR research has recently emerged augmenting evidence-based therapies, such as biofeedback and hypnosis with VR technology. To this end, investigators are currently researching VRH and VR biofeedback for children and adults with chronic pain. To date, investigators have found that VR and hypnosis used together are more effective than VR or hypnosis alone. Therefore, coupling VR with these therapies might prove to be valuable for the management of chronic pain and long-term pain rehabilitation.

Finally, investigations are currently underway to determine the neurobiological mechanisms underlying VR's ability to decrease pain perception. Current fMRI results indicate that participants who are actively engaged in VR demonstrate inhibition of pain signaling in the critical regions of the pain matrix; although this finding is not novel to VR alone. Similar decreases in cortical activation in the pain matrix during experimentally induced pain have been observed when using adapted Stroop cognitive tasks involving the distraction of attention, task loading [59], mood [60], expectancy [61] and perceived controllability [62]. Therefore, VR researchers are not solely interested in the deactivation of known critical pain regions in the pain matrix, but rather the unique interplay of other peripheral cortical areas that may be influenced by VR. It is hypothesized that frontal lobe/pain inhibitory pathways, critical nerve gating mechanisms and/or other neurochemical processes may be triggered during VR, thus leading to decreased pain, increased top-down inhibition and possibly VR analgesia. Ultimately, understanding the myriad of neurobiological mechanisms underlying VR analgesia will be critical for creating age and developmentally appropriate clinical interventions for acute painful procedures and a variety of chronic pain conditions.

Future perspective

Scientists, clinicians and educators are just beginning to scratch the surface when it comes to current applications of VR for pain management. Historically, VR technology has been expensive, available to few and mostly sought out by researchers and gaming technicians. The current state of VR as a tool for pain management is still in its early developmental stages. With technology rapidly evolving, increased interest in complementary nonpharmacological interventions, and the reported burden and disability associated with increasing rates of chronic pain, VR is quickly gaining attention as a complementary pain management strategy. What was once valued solely as high-tech entertainment equipment has now captured the interest of neuroscientists, clinical researchers and pain management clinicians.

Virtual reality will have a significant impact in the areas of acute and chronic pain management, as well as psychiatric and pain/physical rehabilitation over the next 5–10 years. As the costs associated with VR technology decrease and the flexibility/customizability of the gaming environments increase, VR will have numerous applications for patients with an array of acute and chronic medical conditions. Eventually, as part of a healthcare providers toolkit, VR may be integrated into a variety of medical settings for routine painful medical procedures, physical therapy, pain rehabilitation, chronic pain management and to treat a variety of psychiatric conditions (i.e., anxiety, post-traumatic stress disorder and substance abuse), to name a few. The ability to instantly transport the patient into a virtual world for the purposes of distraction, exposure to a feared situation, or to augment diaphragmatic breathing, guided imagery and/or self-hypnosis makes VR a tremendously powerful tool.

Ultimately, an important advancement is the portability of VR for private practice and eventually home use. At that point, VR will no longer be used solely in a medical setting for painful medical procedures, but will be expanded for the management of chronic pain, physical therapy, long-term rehabilitation and other associated symptoms. In addition, VR may be used to augment and/or deliver other therapies such as hypnosis and biofeedback. The expanding scope of VR is on the rise and is promising for the field of pain management and beyond. Given the advances in neuroscience, such as increased knowledge regarding the connectivity of brain and behavior, pain perception and modulation, and the dynamic interplay between biological and psychological (e.g., attention, memory and emotion) factors implicated in pain perception, VR will emerge as a viable first-line intervention and complementary therapy to pharmacologic agents. We are truly just beginning.

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Practice Points

- Immersive virtual reality (VR) technology often includes a head-mounted display with head tracking, headphones with sound/music and noise reduction, and a joystick, rumble pad or other device for manipulation/navigation.
- VR uses immersive multimodal stimuli, such as visual, auditory, tactile and/or olfactory, to engage the participant in immersive gaming.
- Experiments investigating the neurobiological mechanisms underlying VR analgesia are underway.
- VR can be used to augment other evidence-based clinical interventions, such as hypnosis and biofeedback.
- VR can be used for attenuating pain and distress for a variety of acute painful procedures.
- VR for managing chronic pain and facilitating pain rehabilitation are underway.

Figure 1.
Child playing a virtual reality game with a head-mounted display.

Figure 2.
Participant enjoying a virtual reality game.

Figure 3.
Investigator attaches the Medoc 30 × 30 mm ATS thermal stimulator probe to administer a noxious stimulus.

Figure 4.
Investigators reviewing structural brain MRI.