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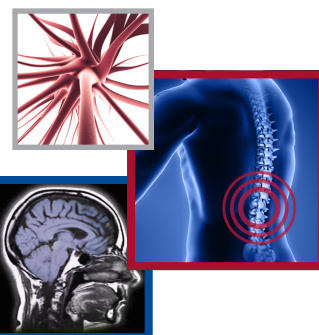


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The promise and challenge of virtual gaming technologies for chronic pain: the case of graded exposure for low back pain

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SUMMARY Virtual reality (VR) technologies have been successfully applied to acute pain interventions and recent reviews have suggested their potential utility in chronic pain. The current review highlights the specific relevance of VR interactive gaming technologies for pain-specific intervention, including their current use across a variety of physical conditions. Using the example of graded-exposure treatment for pain-related fear and disability in chronic low back pain, we discuss ways that VR gaming can be harnessed to optimize existing chronic pain therapies and examine the potential limitations of traditional VR interfaces in the context of chronic pain. We conclude by discussing directions for future research on VR-mediated applications in chronic pain.

Practice points

- Virtual reality (VR) interventions have been successfully applied to acute pain relief and are increasingly examined in the context of chronic pain. The gaming element intrinsic to most VR pain interventions has received little attention but may be central to successful chronic pain management.
- VR gaming technologies have successfully been applied to a variety of health interventions outside of pain, including health education, disease self-management, physical activity promotion, distraction from discomfort and rehabilitation targeting neurocognitive and motor performance.
- We discuss the utility and advantages of integrating VR gaming elements into an existing intervention for chronic pain, namely graded exposure for treatment of pain-related fear and disability in chronic low back pain. The proposed gaming interface would facilitate treatment gains through focus on function rather than distraction, increased engagement and reinforcement, greater access to and dissemination of treatment and capture of important metrics (e.g., nonverbal behavior) overlooked by traditional intervention.

KEYWORDS

• chronic pain • gaming
• graded exposure • low back pain • virtual reality

Background

Over the past two decades, virtual reality (VR) technologies have been incorporated into interventions addressing a variety of medical and psychological conditions [1]. In a recent article, Keefe and colleagues [1] provided an overview of VR-mediated pain intervention, pointing to the possibility

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of extending VR interventions not just to the acute but also to the chronic pain context. In the current review, we characterize the current use of VR in pain intervention and extend discussion of VR to include interactive gaming technologies and their current applications across a variety of physical conditions. We then discuss the possibilities of drawing on VR gaming methodologies to achieve goals central to chronic pain management as well as the limitations of generalizing traditional VR approaches (designed for acute pain) to chronic pain conditions. To illustrate potential applications and challenges we discuss the use of VR gaming methods as part of graded-exposure treatment for pain-related fear and disability in patients with chronic low back pain.

What is virtual reality?

It is useful to highlight that the term ‘virtual reality’ is not confined to a particular configuration of hardware and software. Rather, VR may be understood as ‘simulations that make use of various combinations of interaction devices and sensory display systems’ to accomplish set goals [2]. Numerous types of simulations can be used in VR, including Head Mounted Displays (HMD), large projection displays, motion capture systems, interactive video games (e.g., the Nintendo Wii), or combinations of these systems [2]. The design of VR platforms typically seeks to balance the level of immersiveness with that of invasiveness. For example, the most traditional VR interface – the Head Mounted Display – provides a full 360° immersive visual experience, generating digital imagery in accordance with the changing perspective of the participant or patient.

Virtual reality gaming. The gaming dimension of VR has not typically received attention in discussion of pain therapies. As defined in the literature, to qualify as a ‘video game’ a platform must allow manipulation of images on a digital display; have a system of rewards, incentives and/or objectives; be interactive and/or competitive; and be designed for recreational use (i.e., to be ‘fun’) [3]. In this sense, many reviews discuss ‘virtual reality gaming technology’ and indeed, even the most established VR configurations often take the form of games (Snow World for burn-related pain is a particularly good example of this [4]). Most VR studies do not make a distinction between gaming versus nongaming interventions; however, as will be discussed below, gaming can be conceptualized

as an essential component of many successful VR interventions and holds substantial promise for future applications.

The utility of virtual reality for pain

Acute pain applications. Over the past two decades, strong evidence has accumulated for the application of virtual reality for acute pain relief. Reviews point to the successful reduction of acute pain in three areas, namely, burn care (e.g., wound dressing and debridement), uncomfortable medical procedures (e.g., port access) and experimental pain in healthy participants (for review, see [1,5]). Virtual reality has also been successfully employed to reduce pain experience and improve participation in physical therapies among adults and children following burns or traumatic injury (e.g., [6–8]).

Two aspects of existing acute pain literature are notable. First, existing interventions have almost invariably relied on fully immersive environments facilitated by HMDs. This may owe to the early nature of VR research (as many technological developments in human–digital interaction and portability have been fairly recent) and the fact that the majority of early VR work addressed burn care. Of available clinical studies examining acute pain (excluding experimental pain induction) more than 60% focus on burn pain treatment or rehabilitation [5]. It is reasonable to suggest that the complete absorption facilitated by HMDs may be suited to match the intensity of the pain experience (e.g., burn debridement) or the fairly passive position assumed by a patient during burn care. In this sense, acute pain management does not necessarily involve the degree of active behavioral/physical engagement called for by many chronic pain interventions, which may not be easily facilitated through use of HMD hardware. Second, the majority of VR interventions for acute pain *have taken the form of games*. These have included both custom games (e.g., Snow World [4,6–8]; see also [9–12]) as well as commercially available games (e.g., Nintendo Wii Play ‘Bubble’ [13]; see also [14–16]). Of studies identified in integrative reviews, only a few did not meet criteria for gaming as described above; these studies typically combined noninteractive VR environments with hypnosis induction [17,18].

Chronic pain applications. In comparison to acute pain, VR applications to chronic pain have been limited. To date, four published studies have used virtual limbs to modulate phantom

limb pain [19-21] and complex regional pain syndrome [22], respectively; one case study combined hypnosis and VR for treatment of chronic neuropathic pain [18], and one study successfully reduced chronic itch pain during a single-session VR exposure [23]. In addition, four studies have used VR alone or in combination with Cognitive Behavioral Therapy (CBT) to facilitate both pain relief and functional improvement among participants with fibromyalgia [24], spinal cord injury [25], osteoarthritis of the knee [26] and low back pain [27], respectively. With the exception of studies combining VR with CBT or hypnosis (i.e., [18,24]), all VR interventions for chronic pain have adopted a game format. However, in contrast to acute pain interventions, less than half used a fully immersive environment facilitated by an HMD. None of the studies addressing functional improvement utilized an HMD or immersive environment; as noted above, this may speak to the limited application of current HMD technology to more active behaviorally-oriented interventions. As will be discussed below, this difference may derive from important distinctions in the aims of acute versus chronic pain interventions.

In summary, considerably more evidence exists for the utility of VR intervention in the acute rather than chronic pain context. For chronic pain, the evidence base is still emerging. Existing studies have addressed a number of discrete chronic pain conditions using varied VR approaches. While the results are promising, the diversity of conditions, methodologies and quality of study reporting make it difficult to draw firm conclusions regarding the efficacy of VR for chronic pain.

Mechanisms of pain relief in virtual reality intervention

Existing studies cite attentional processes – specifically distraction – as the main mechanism for pain relief in VR therapies [28,29]. Distraction is defined by the engagement of cognitive and attentional resources that are necessary for pain processing [30]. The visual, auditory and tactile/haptic input provided by interaction with a VR environment is understood to reduce resources available for perception and elaboration of pain, thus diminishing subjective pain experience [28,31].

Although research regarding specific mechanisms of pain relief in VR is still in its infancy, contemporary cognitive-affective-motivational

accounts regarding the role of attention in pain lend support to the importance of gaming elements in VR interventions [32]. Such contemporary theoretical accounts and associated findings suggest that, to optimally compete with pain, distraction must engage central cognitive resources toward specific non pain-related goals [33,34]. Further, as pain inherently comprises an emotional dimension (International Association for the Study of Pain Task Force on Taxonomy, 1994), distraction should optimally facilitate positive affect that is incongruent with pain experience [35]. Several areas of research converge to support the importance of motivational (goal-oriented) and affectively rewarding elements of VR gaming interventions (e.g., [36,37]). In addition, the few experimental studies that have compared gaming versus non-gaming applications of VR in (acute) pain have unanimously found that, in comparison to passive visual input, goal-oriented interaction with a virtual environment is associated with greater pain reduction [13-14,31,38], further supporting game-specific features of successful VR intervention and highlighting a potentially critical mechanism of VR pain relief.

The broader context of virtual reality gaming interventions

Outside of the pain domain, VR gaming technologies are increasingly leveraged to address a wide variety of conditions [3,5,39-41]. VR gaming has been successfully applied to promote health education, disease self-management (e.g., diabetes), physical activity, distraction from discomfort and rehabilitation targeting neuro-cognitive and motor performance, particularly following stroke (see [3,39,42]). Representative outcomes have included enhanced physical performance (e.g., improved balance, range of motion and energy expenditure), improved psychological state (e.g., improved mood and self-esteem, reduced psychological distress) and better health behavior (e.g., improved medication adherence and dietary intake). The health potential of VR gaming technology is reflected by large-scale national initiatives, including a recent partnership between the American Heart Association and Nintendo of America to examine the impact of active gaming on physical health [42,43]. Such collaborations capitalize on the ubiquity of gaming systems within North American households, with estimates ranging from 70 to 90% [3,42].

In terms of literature on nonpain-specific applications of VR gaming, three points are notable. First, as with pain interventions, reviews advise caution regarding the early nature of this research area and the need for greater scientific rigor as well as reduced bias. Second, available research supports the potentially beneficial impact of VR gaming on functional outcomes (i.e., both self-report and objectively assessed indices such as range-of-motion, physical activity, motor control, exercise frequency and endurance (see [3]) as well as utility in addressing chronic health conditions; both such applications are still limited in pain research. Finally, reviews highlight that among therapeutic applications of VR gaming, those targeting *psychological* and/or *physical/behavioral* objectives have demonstrated the most consistent treatment success [3,42–43]. This suggests that treatment for chronic pain may particularly benefit from VR gaming intervention, as pain treatment typically comprises both psychological (e.g., cognitive) and behavioral components.

The challenge & promise of VR gaming for chronic pain: the case of graded exposure for chronic low back pain

Using graded-exposure treatment for pain-related fear and disability in chronic low back pain as an example, in this section we outline the limitations of traditional VR applications in the context of chronic pain and discuss ways that VR gaming can be harnessed to optimize existing pain intervention. Chronic low back pain represents a leading cause of disability in the USA, with enormous direct and indirect societal costs driven primarily by 7–10% of individuals who develop a chronic pain condition [44,45]. Advances in psychosocial and biomedical, treatment have not diminished the incidence or impact of chronic low back pain; both the incidence and expense of back pain are increasingly on the rise [45]. Graded-exposure therapy is the primary intervention deriving from the Fear-Avoidance Model of pain, a leading cognitive-behavioral account of why certain individuals develop chronic pain and disability following acute back injury [46]. According to the model, individuals who endorse catastrophic appraisals of pain stimuli are also likely to report fear of pain and (re)injury due to movement (alternatively known as kinesiophobia, or pain-related fear), a belief that pain signals harm or damage to the back and, therefore, must be avoided.

Accordingly, pain-related fear is associated with hypervigilance to pain sensations and – centrally – *avoidance of physical exertion and specific postural strategies* [47]. Avoidance promotes a self-perpetuating cycle of physical deconditioning, social withdrawal and ultimately functional disability [46,48–52].

Accordingly, graded-exposure treatment is designed to address catastrophic/fearful pain cognitions and avoidance of physical activity. Exposure protocols are delivered in outpatient or inpatient settings and typically begin with psychoeducation and establishment of a hierarchy of feared/avoided activities. These activities are successively confronted through ‘behavioral experiments’ intended to challenge beliefs that pain is inevitably associated with harm or damage to the back and should be avoided. Clinical case studies and randomized clinical trials have demonstrated the effectiveness of graded exposure in high fear chronic low back pain patients [53–58]. A related experimental line of research supports these effects by showing that, upon repeated exposure, high fear participants with chronic low back pain correct initial over-predictions of pain and harm associated with standardized physical activities [49,59–61].

Drawing on features of VR gaming technologies utilized primarily outside of pain research, our research team is testing a novel gaming simulation for treatment of pain-related fear and disability in chronic low back pain. The sections below highlight specific potential advantages of virtual gamification as applied to graded-exposure protocols, likewise highlighting the current conceptual and practical challenges facing VR intervention for chronic pain.

Focusing on function rather than pain relief. While VR gaming shows considerable success in the area of acute pain, to date only a handful of studies have applied VR platforms to chronic pain management. This asymmetry may owe to the differential goals of acute versus chronic pain management, making VR gaming platforms specific to acute pain difficult to generalize to the chronic pain context. As noted, traditional VR interventions are geared to facilitate distraction, allowing patients or participants to (often passively) endure a temporary pain stimulus. While distraction is a powerful tool in the case of both acute and chronic pain, interventions that rely *exclusively* on distraction are insufficient to address the needs of many individuals with chronic pain, for whom pain

is an ongoing (rather than temporary) experience [62]. Accordingly, graded-exposure therapy and other contemporary treatment modalities encourage individuals to participate in valued life activities *in the presence of potentially ongoing pain experience* rather than seeking to escape the pain experience altogether [37,62]. In the case of graded exposure, individuals are encouraged to practice progressively more avoided activities with the aim of breaking the association between perception of pain and appraisal of physical harm.

Despite the central place of function in chronic pain intervention, only three studies to date have used VR to promote functional gains among individuals with chronic pain. Specifically, Villiger and colleagues [25] used an augmented virtual reality gaming system with lower limb sensors to facilitate rehabilitation among individuals with incomplete spinal cord injuries. Utilizing a custom virtual reality game and a pedal board, Lin and colleagues looked to improve proprioceptive functions in patients with bilateral osteoarthritis of the knee [26]. Finally, Kim and colleagues [27] saw improvement in function among female patients with low back pain asked to practice the Nintendo Wii Fit Yoga system. The designs of these studies echo those adapted to promote functional restoration across other conditions that do not have an explicit focus on pain relief (e.g., stroke rehabilitation; [39]). These designs likewise suggest that the goal of functional restoration may be better achieved by motion capture and interactive gaming technologies rather than traditional immersive VR more suited for acute pain relief. The challenge remains to develop VR interventions whose goal – like that of graded exposure – includes restoration of function through behavioral engagement rather than pain relief *per se*.

Facilitating engagement and reinforcement. The distracting, engaging and reinforcing nature of VR games is central to their commercial and therapeutic success. In the case of graded exposure, these elements of gaming technology can be applied to address a central limitation of traditional intervention – that of patient adherence [43,52]. For example, although both clinical and laboratory studies find that exposure is an effective strategy to challenge maladaptive pain appraisals, this method is among the least preferred by patients [52,63]. Studies reveal explicitly low patient preference for graded exposure [63] as well as high drop-out rates, ranging anywhere

from 30–58% [57,64]. Patient non-adherence is hypothesized to derive from the anxiety-provoking (and often painful) nature of this intervention [52]. By contrast, interventions utilizing gaming technologies report strong retention and adherence rates [42], reduced perception of effort and fatigue at a given exercise intensity, as well as increased enjoyment of exercise-related activities [42]. Accordingly, while distraction cannot comprise the *sole source of pain relief*, attentional capture facilitated by rewarding engagement is an essential element to successful participation and adherence to an intervention.

Attention and engagement are facilitated by a number of VR gaming features. First, VR environments are adaptive and can be designed to offer a progressive challenge (be it physical or psychological) that acclimates to players' given performance [65]. This level of adaptation is not easily accommodated through traditional intervention delivery approaches. Similarly, gaming environments can provide real-time participant feedback across a number of domains (e.g., pain expectancy, kinematic strategy – discussed in more detail below) and offers an efficient way to record change in performance over time. Such monitoring and adaptation capabilities already exist in many off-the-shelf systems like Microsoft Kinect, Sony's PlayStation Move and Nintendo's Wii Remote Plus [2,66]. For instance as part of one physical rehabilitation study with young adults, the Kinect system was utilized to provide real-time feedback and encouragement to participants with motor limitations. This led to improved motor performance and motivation across treatment sessions [67]. The gaming literature describes the goal of such scaffolding of participant experience as 'flow' – defined as a state of optimal and focused concentration during an activity [68,69]. As part of such scaffolding, VR modalities for chronic pain can integrate reinforcement contingencies from gaming environments (point systems, accumulated rewards) that can add to the reward of activity performance, increase patient motivation, and solidify treatment gains. For example, in research currently conducted within our lab, participants can monitor their updated treatment gains and progress through a personalized treatment 'dashboard' that keeps track of their accumulated points and treatment module completion. Future studies may examine the potentially reinforcing elements of competitive score tracking among patients.

Leveraging metrics. In addition to real-time adaptation to user performance, VR platforms can capture and store important metrics that cannot easily be detected by a human provider. For instance, evidence suggests that in addition to apparent avoidant behavior, high fear chronic low back pain patients *may develop and maintain protective motor responses* (e.g., reduced lumbar flexion, reduced velocity) intended to splint/stiffen the spine [70]. While initially protective of damaged tissues, continued restriction of motion and accompanying abnormal transfer of loads may actually predispose spinal structures to further damage; in turn, this may contribute to ongoing or recurrent pain experience and disability [71]. Evidence suggests that persistent motor restriction owes to continued perception of threat associated with movement [72]. Traditional exposure interventions for pain and disability are not equipped to address these subtle and potentially insidious adaptations of motor behavior (e.g., enhanced knee flexion to compensate for reduced lumbar flexion while reaching).

The restrictive kinematics of individuals with low back pain and high pain-related fear have been captured using fairly complex motion tracking systems (e.g., Vicon; Vicon, Los Angeles, CA) in specialized research settings [67,70]. However, commercial games like Kinect rely on increasingly sophisticated skeletal tracking capabilities that allow clinical researchers to represent the human body using 3D coordinates; those coordinates subsequently determine the location and trajectory of all 3D parameters in real time, allowing for fluid user interactivity [2]. Further, this can be accomplished without the hindrance of wires or sensors. The Kinect system has recently been evaluated and determined to be (in many circumstances) a viable alternative to more expensive motion capture systems [73]. In short, the challenge falls to traditional chronic pain therapies to attend to avoidance strategies that cannot be easily observed or reported; the challenge for VR platforms adapted for back pain treatment is to detect those strategies in a way that can facilitate clinical intervention. Drawing on the reinforcing/gamification elements described above, recent investigations have utilized the skeletal tracking capabilities of such gaming systems to encourage high fear kinematically-avoidant participants to practice postural strategies they would otherwise avoid (R21AR064430). Further, simply bringing individuals' attention to these 'hidden' avoidant

strategies may have therapeutic value that should be empirically examined.

Promoting access and dissemination. Perhaps the central limitation of existing VR interventions is their restriction to specialized settings and expensive infrastructure. To date, VR interventions for pain have occurred within laboratory or clinic environments and – with the exception of several studies utilizing off-the-shelf gaming – have relied on expensive equipment not accessible to the general public (e.g., HMDs, full-room projection displays). However, the growing commercialization and portability of VR gaming technologies can greatly facilitate patient access, including large-scale dissemination and testing.

In addition to reduced equipment expense, VR gaming technologies may address additional limitations inherent in certain chronic pain treatments. For example, standard exposure protocols are costly in terms of time, resources and manpower for patient and providers alike. Although empirical examination is needed, it is reasonable to suggest that such costs can be reduced using VR platforms. Combined with internet capabilities, VR interventions can allow providers to distally monitor real-time patient progress and treatment adherence. It also opens the door to the development of patient monitoring and treatment algorithms that can adapt to individual needs while simultaneously serving many different users. Further, the evolving internet capabilities of existing gaming engines are expected to facilitate patient-to-patient contact and support forums, building on current progress in web-based treatment approaches.

However, access to VR-capable technology is not enough; VR interventions for chronic pain must address the needs of the target population. For instance, acute VR interventions typically 'situate' participants in simulated environments far removed from those in which they must function. While this facilitates distraction, it does not completely reflect the goal of everyday functional restoration. VR gaming interventions for chronic pain are therefore challenged to incorporate activities consistent with real-life patient goals, which often aim to restore activities of daily living. Moreover, some patient populations – for example, high fear individuals with chronic back pain – can particularly benefit from the ability of VR displays to generate customized digital environments. Specifically, research shows that back pain patients with high fear of movement fail to generalize 'safety learning' across contexts or physical

activities [61]. For example, an individual may learn that bending to tie a shoe is safe for the back but may hesitate to perform a similar amount of lumbar flexion for a different task (e.g., picking up a piece of clothing on the floor). Practicing movement across different activities and contexts is therefore a key to treatment success. In sum, access to relatively inexpensive technology within clinics and home environments can facilitate the efficient practice of challenging physical activities across a variety of simulated settings, thus limiting patient and physician burden. (e.g., travel). Such practice can facilitate the ultimate goal of performing activities in real world contexts.

Future perspective

The therapeutic applications of VR gaming technologies in chronic pain remain subject to numerous empirical questions, some of which research has only recently begun to address. The following questions appear central to continued work in this field. First, studies to date have not addressed individual-difference factors that may affect the acceptability and/or utility of VR gaming for chronic pain management. It is possible that specific individual characteristics (e.g., immersive tendencies, technological literacy, socioeconomic status) may modulate treatment success and access. Variables of import may span psychological as well as demographic characteristics. For instance, women comprise approximately 40% of the gaming community [3]; literature surveyed for the current review revealed that women represented 40–70% of study samples in both acute and chronic pain research. Further, studies addressing functional improvements collectively had the largest representation of women (79%). In addition, studies of VR gaming not specific to pain demonstrate acceptability and efficacy among middle aged and older participants, as well as pediatric samples [3,40]. This finding is in line with the fact that the average game player is 34 years old and 26% are over the age of 50 [3]. In a recent integrative review of randomized controlled trials across a number of health domains, Primack and colleagues [3] reported approximately equal representation of women in gaming study designs; however, the authors identified more consistently positive results for individuals between 20 and 49 years of age. Such demographic-specific findings have potentially significant implications for VR gaming interventions for chronic pain. For instance, low back pain and arthritis (the two most common sources of

pain and disability in the adult population) affect individuals primarily starting in middle age [44]. Further, both conditions are more common in women than men [44].

As noted, research regarding mechanisms and moderating factors in VR-facilitated pain relief and functional restoration is sparse. Given the often differential goals of pain management in the acute versus chronic pain context, future studies are encouraged to examine the psychological, behavioral and technology/design-specific processes underpinning treatment effects. This may include addressing which elements of VR gaming interventions are necessary/essential versus superfluous to treatment gains and maintenance. Additionally, as gaming technologies become increasingly integrated into chronic pain treatment, it is recommended that findings specifically address the potential cost-efficiency of these technologies.

The questions outlined above should not be abandoned in the face of new and exciting technological resources and should become easier to address as various technologies become more available and familiar. Despite these concerns, review of current evidence suggests that VR gaming applications can indeed be extended to chronic pain interventions by keeping in mind the distinct therapeutic needs and challenges of individuals with chronic pain. Further, although the current review focuses on chronic low back pain and graded exposure as a model to examine applications of VR gaming to chronic pain, pain-related fear has been associated with worse pain, disability and rehabilitation outcomes across a number of conditions, including spinal cord injury [74], fibromyalgia and osteoarthritis [50,75], as well as worse outcomes following medical interventions such as total knee replacement [51]. Similarly, graded exposure has been successfully applied to a number of disabling/painful conditions [52]. Accordingly, VR gaming elements can be adapted to facilitate and enhance other established interventions for a variety of chronic pain conditions.

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The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties. No writing assistance was utilized in the production of this manuscript.

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