Virtual Reality Graded Exposure Therapy as Treatment for Pain-Related Fear and Disability in Chronic Pain

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Abstract Pain-related fear and concomitant avoidance behavior have been identified as major contributors to development and maintenance of chronic musculoskeletal pain and disability. While graded exposure therapy (GEXP) is advocated as one of the most effective strategies for reducing pain-related fear and disability, its practical utility and large-scale dissemination have been limited. The current chapter describes a novel virtual reality (VR) methodology to optimize exposure-based treatment for individuals with chronic pain, focusing specifically on chronic low back pain (CLBP). Virtual Reality Graded Exposure Therapy (VRGET) promises to address several major limitations characterizing traditional GEXP approaches and to incorporate cutting-edge disability-relevant assessment and intervention. Specifically, VRGET is able to mitigate costs traditionally associated with GEXP treatment, enhance participant engagement with treatment, provide real-time assessment of important metrics such as affective response and kinematic adaptation, and promote generalizability of rehabilitation gains across clinic and home environments.

1 Background and Introduction

Musculoskeletal pain is the dominant type of chronic pain affecting the world population, exerting an enormous impact on individuals, societies, and health care systems (Croft, 2010; World Health Organization, 2003). Musculoskeletal pain conditions are the leading cause of disability in the United States and represent more than half of all chronic conditions among individuals over 50 in developed countries (Edwards et al., 2008). Among musculoskeletal pain conditions, back pain is the most common. In particular, the incidence of low back pain has reached epidemic proportions, affecting up to 84% of adults at least once in their lives (Dagenais, Caro, & Haldeman, 2008). Most acute low back pain episodes are self-limited, with symptoms remitting within a few weeks and calling for little or no intervention. However, it is estimated that up to 10% of low back pain sufferers develop a chronic pain condition characterized by long-term pain and associated disability (Pengal et al., 2003). This minority of the population accrues great healthcare and societal costs, consuming more than 50% of all resources allocated toward back pain (Boersma & Linton, 2005; Nachemson & Jonsson, 2000). In addition to economic burden, physical limitations stemming from back pain often interfere with activities central to one's identity (e.g., as a parent, spouse, friend, worker), thus fostering role loss and identity erosion (Eccleston, De, Williams, & Rogers, 1997; Harris, Morley, & Barton, 2003; Strunin & Boden, 2004).

Despite increasing sophistication of medical interventions, the burden of back pain continues to rise (Edwards et al., 2008), suggesting a need for novel intervention paradigms to complement traditional treatment options. Virtual reality (VR) technology provides a new and promising approach for pain and disability management by capitalizing on advances in current understanding of the biopsychosocial etiology and maintenance of back pain problems.

The organization of this chapter is as follows. Section 1 will present a brief overview of the Fear-Avoidance (FA) model of low back pain (Vlaeyen & Linton, 2000), which has emerged as a leading biopsychosocial formulation of disability development and maintenance following acute back injury. Section 2 will describe the intervention approach informed by this model, namely Graded Exposure in vivo (GEXP) as well as its current status and limitations. In Section 3, there will be a general discussion of virtual reality and its use in non-pain specific exposure therapies and pain distraction. Section 4 will explore areas in which a virtual reality graded exposure therapy (VRGET) may enhance current approaches. The conclusion briefly summarizes the main ideas of this chapter.

Section 1: The Role of Pain-Related Fear in Disability

The FA model offers a cognitive-behavioral account of why some individuals with an acute musculoskeletal injury go on to develop chronic pain and disability, while others do not (Leeuw et al., 2007; Vlaeyen & Linton, 2000). According to the model, fear that movement or physical activity will exacerbate pain or prompt (re)injury – also known as pain-related fear – is underscored by catastrophic appraisals of pain sensations (Grotle, Vollestad, & Brox, 2006; Sieben et al., 2002) that promote a self-perpetuating cycle of behavioral avoidance, hypervigilance, depression, and disuse, resulting in functional disability (see Figure 1).

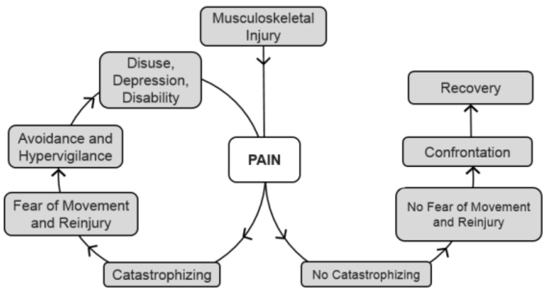

Figure 1. The Fear-Avoidance Model of Low Back Pain.

Pain-related fear has emerged as a robust predictor of pain and disability at acute (George, Fritz, & McNeil, 2006; Grotle, Vollestad, & Brox, 2006; Sieben et al., 2002; Swinkels-Meewisse et al., 2006), subacute (Poiraudeau, 2006, 2006), and chronic (Crombez et al., 1999; Grotle et al., 2004; McCracken et al., 1996; Vlaeyen et al., 1995) stages of back pain. Critically, individuals high in pain-related fear endorse beliefs that pain is a sign of serious tissue damage, as well as high motivation to avoid exertion or activity that might contribute to pain and therefore to perceived physical damage (George, Fritz, & McNeil, 2006; Poiraudeau, 2006a; Swinkels-Meewisse et al., 2006).

Because return to regular physical activity is crucial for successful recovery from acute injury, avoidance is conceptualized as a key mediating variable in the progression from acute to chronic pain sensations (Grotle et al., 2006; Sieben et al., 2002). Consistent with predictions drawn from the FA model, research with individuals suffering from chronic low back pain (CLBP) reliably links pain-related fear with escape from and avoidance of physical activity, resulting in impaired behavioral performance (Vlaeyen et al., 1995). Among individuals with higher pain-related fear, avoidance is reflected in both limited physical exertion and behavioral strategies (e.g., guarded movement patterns) adopted to ostensibly reduce pain/harm (Crombez et al., 1999; McCracken et al., 1996). While some avoidance of physically stressful activity is a natural response to protect damaged tissues following injury, prolonged avoidance of physical activity is known to detrimentally affect various physical/physiological systems (Poiraudeau, 2006), which through multiple mechanisms can serve to maintain disability and actually increase the chance of further injury (Crombez et al., 1999; McCracken et al., 1996). Furthermore, since avoidance behavior occurs in anticipation of, rather than in response to pain, opportunities to receive corrective feedback regarding erroneous catastrophic pain beliefs are limited (Leeuw et al., 2007).

It is important to note that although the current chapter focuses on chronic low back pain as a model for examining the proposed VRGET intervention, pain-related fear has been shown to predict pain, disability, and rehabilitation outcomes across a number of traumatic, chronic, and progressive musculoskeletal disorders. These include conditions such as spinal cord injury (Turner et al., 2002), fibromyalgia (Martinez et al., 2011), and osteoarthritis (Heuts, 2004; Sommer et al., 2009) as well as outcomes following medical and surgical interventions such as total knee replacement (Sullivan et al., 2009). The treatment approach described below (GEXP) has likewise been successfully applied across a range of disabling pain conditions (Vlaeyen et al., 2012).

Section 2: Treating Pain-Related Fear and Avoidance Behavior: Graded Exposure in Vivo

How do high fear CLBP patients recover from avoidance behavior? Evidence suggests that a type of cognitive-behavioral therapy – specifically, graded exposure in vivo (GEXP) – is among the most effective means of reducing pain-related fear, catastrophizing, and disability (Grotle et al., 2004; Martinez et al., 2011; Turner et al., 2002; Vlaeyen et al., 1995). Exposure protocols are typically delivered in outpatient or inpatient settings and involve establishment of a hierarchy of avoided activities and gradual confrontation of these feared activities through “behavioral experiments” intended to correct erroneous pain beliefs (Grotle et al., 2004). These fear hierarchies are idiosyncratic to each individual and are associated with individuals’ beliefs regarding the harm/injury potential of various physical activities. An excerpt from a typical fear hierarchy is presented in Figure 2. Thus a highly fearful individual may assert that picking up a child may “snap the back” or cause serious and irreparable damage.

Fear Hierarchy

Harm Rating		Physical Activity *(Rating*
Extremely harmful to the back	**100**	
		— Pick up a child *(99)*
		— Load groceries into car from shopping cart *(95)*
		— Carry laundry *(80)*
		— Vacuum for extended period *(75)*
		— Perform twisting motion with trunk *(60)*
	50	— Go up and down the stairs *(50)*
		— Bend forward (e.g., tie shoes) *(45)*
		— Reach up (e.g., put away dishes) *(43)*
		— Rake the leaves *(25)*
		— Raise arms above head *(20)*
		— Make bed *(25)*
Not harmful at all to the back	**0**	

Figure 2. Typical hierarchy of feared and avoided activities. Activities higher on the scale are those thought to be more harmful.

The patient works with a dedicated clinician and often a comprehensive rehabilitation team (Vlaeyen et al., 2012). By successive gradual exposure to previously avoided activities, individuals are able to correct catastrophic misinterpretations of pain sensations and specific harm expectancies, leading to decreased fear levels and functional improvements (Grotle et al., 2004 Heuts, 2004; Sommer et al., 2009; Sullivan et al., 2009; Turner et al., 2002). An increasing number of clinical studies and randomized clinical trials demonstrate the utility of exposure in reducing pain-related fear, catastrophizing, and disability in fearful CLBP adults (Boersma et al., 2004 ; Crombez et al., 2012 ; de Jong et al., 2005 ; Leeuw et al., 2008 Linton et al., 2008 ; Vlaeyen et al., 2001; Vlaeyen et al., 2002 ;; Woods & Asmundson, 2008). Outside the clinical setting, a related line of experimental research supports the effects of GEXP, demonstrating that having CLBP patients confront a stressing physical activity leads to a swift correction of over-prediction regarding the pain and harm associated with that specific physical activity (Crombez et al., 2002; Gourbert et al., 2002; Goubert, Crombez, & Danneels, 2005; Goubert, Crombez, & Lysens, 2005; Trost, France, & Thomas, 2008).

Despite considerable promise, existing GEXP protocols are characterized by a (Woods & Asmundson, 2008)number of limitations. First, as delivered in the clinical setting, GEXP protocols are expensive and time consuming, relying on trained interventionists over an indefinite number of sessions (Vlaeyen et al., 2012). Another challenge acknowledged by GEXP developers is that of patient engagement; while empirically most effective, GEXP does not appear to be a preferred manner of treatment by patients and is characterized by a high drop-out rate (Vlaeyen et al., 2012; Geroge & Robinson, 2010). Patient non-adherence is likely due to the anxiety-provoking nature of an intervention designed to challenge fearful pain beliefs (Hadjistavropoulos & Kowalyk, 2004).

Finally, current GEXP protocols offer only marginal metrics for understanding and tracking important aspects of rehabilitative challenges and gains. For example, although cognitive and emotional reappraisal of physical activity is conceptualized as a central mechanism of change in the treatment process, existing GEXP protocols are not able to systematically track patient affective response (i.e., fear or anxiety) to progressive physical challenge (Vlaeyen et al., 2012). In addition, patients with high levels of pain-related fear demonstrate subtle behavioral adjustments (such as guarded movement patterns) that may function as safety behaviors, thus limiting their exposure to the feared stimulus (for example, the maximal execution of a physical activity). As will be discussed below, subtle postural adjustments during behavioral performance may actually be physically detrimental to the pain condition (Thomas & France, 2007). Current GEXP protocols offer no means to assess or intervene on these more subtle forms of avoidance. Finally, GEXP is challenged by the generalizability of treatment gains from the treatment clinic to the home environment, as well across discrete physical activities (Crombez et al., 2002; Gourbert et al., 2002; Goubert, Crombez, & Danneels, 2005; Goubert, Crombez, & Lysens, 2005; Trost, France & Thomas, 2005). Together, these limitations provide a compelling motivation to 1) enhance metrics for scaffolding, tracking, and establishing reliable therapeutic change; and 2) incorporate home-based access to low-cost treatment approaches incorporating GEXP.

Section 3: Virtual Reality as an Instrument of Treatment

Over the past several years, virtual reality (VR) has become incorporated into a number of interventions targeting physical and psychological conditions. For instance, virtual reality applications that focus on assessment and treatment of neurocognitive (Parsons et al., 2009) and affective disorders (Krijin et al., 2004), as well as assessment of their component processes (i.e., attention (Parsons et al., 2007), visuospatial abilities (Parsons et al., 2004), navigation (Armstron et al., 2013), memory (Parsons & Rizzo, 2008) and executive functions (Parsons et al., 2011, Parsons et al., 2012) are currently being developed and tested.

It is important to note that the term “virtual reality” does not limit the researcher to a particular configuration of hardware and software. Instead, VR may be understood as a development of simulations that make use of various combinations of interaction devices and sensory display systems. Typically, the design of these systems is developed with consideration of balancing level of immersiveness with level of invasiveness. Many historical users of VR have opted for highly immersive experiences using more invasive head-mounted displays (HMDs). The invasiveness results from the user wearing an apparatus (i.e., an HMD) on her or his head, which often tethers the user to a computer.

Given the desire for users to have a less invasive experience while exposed to a virtual environment, some researchers have turned to projection systems that use cameras for whole-body tracking and integration of body-state information into various simulations. These systems are noninvasive because the user is not encumbered by the need to wear accessories to enable the tracking of the user’s movements. The increased availability of commercially available interaction devices (e.g., Microsoft Kinect, Nintendo Wii Sony Eyetoy Konami Dance Dance Revolution) has allowed for less invasive VR applications that present three-dimensional (3D) graphic environments on flatscreen monitors. Whilst such non-invasive VR systems involve a lower level of immersion, the phenomenoligical experience of the user is one that involves a high potential for interaction with digital content using naturalistic body actions.

VR technologies have lent themselves particularly well to exposure treatment protocols (as in the case of specific phobias) and, more recently, to the management of acute pain. As will be discussed below, the established utility of VR in these two domains provides a foundation for utilizing VR in treatments of persistent musculoskeletal pain that rely on exposure methodology.

3.1 Virtual Reality Exposure Therapy for Specific Phobias

Virtual reality has emerged as a novel tool for conducting exposure therapy with persons experiencing specific phobias. As part of virtual reality exposure therapy, users are exposed to computer-generated simulations or virtual environments that update in a natural way to the user’s head and body motion. When users interact in a virtual environment, they can be systematically exposed to specific stimuli within a contextually relevant setting (Parsons et al., 2011). Virtual reality exposure comports well with the emotion-processing model, which holds that the fear network must be activated through confrontation with threatening stimuli and that new, incompatible information must be added into the emotional network (Foa & Kozak, 1986; Wilhelm, Pfaltz, & Gross, 2005). Anxiety and fear are concentrated emotional experiences that serve critical functions in organizing necessary survival responses (Fendt & Fanselow, 1999). In properly functioning affective systems, the responses are adaptive. Excessive fear responses, however, can be restrictive and may be a sign of dysregulated anxiety. When exposure to stress occurs early in development and is repeated in persons with a particular genetic disposition, a decreased threshold for developing anxiety may result (Heim & Nemeroff, 1999). Further, over-excitation and deprivation can influence the affective system and may induce changes in the emotional circuitry of the brain that can contribute to stress-related psychopathology (Davidson, Jackson, & Kalin, 2000).

A good deal of research has shown that exposure therapy is effective for reducing negative affective symptoms associated with specific psychopathology (Rothbaum & Schwartz, 2002). Moreover, in vivo exposure therapy has been found to have greater efficacy when compared to imaginal exposure, especially in the treatment of specific phobias (e.g., acrophobia, fear of driving, claustrophobia, aviophobia, and arachnophobia). Exposure to emotional situations and prolonged rehearsal result in the regular activation of cerebral metabolism in brain areas associated with inhibition of maladaptive associative processes (Schwartz, 1998). Identical neural circuits have been found to be involved in emotion regulation across affective disorders (De Raedt, 2006; Mineka, Watson, & Clark, 1998). Systematic and controlled therapeutic exposure to phobic stimuli may enhance emotional regulation through adjustments of inhibitory processes on the amygdala by the medial prefrontal cortex during exposure and structural changes in the hippocampus after successful therapy (Hariri, 2000).

The unique ability of virtual environments to match exposure to the needs of various clinical application areas has been recognized by a number of researchers interested in exposure interventions (Botella et al., 2004; Pull, 2005). Recent quantitative reviews (Opris, Pintea, Garcia-Palacios, Botella, Szamosko, & David, 2012; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008) of virtual reality exposure therapy have concluded that virtual reality exposure has good potential as a treatment approach for anxiety and several specific phobias.

3.2 Virtual Reality for Pain Distraction

A recent use of immersive virtual reality has been its application to pain distraction during acutely painful experiences/interventions (e.g., wound dressing, dental pain (Keefe et al., 2012). Hoffman et al. (2000) contend that VR offers an effective distraction because it immerses the person using an HMD. While wearing the HMD, virtual reality-based tasks are simulated that draw heavily upon conscious attention. These VR-based tasks are understood as distractors that reduce cognitive resources available for perception of and cognitive elaboration on nociceptive input. In turn, decreased attention available for conscious pain processing has been shown to result in patients subjectively reporting less pain (see McCaul & Malott, 1984). Developers of HMD-mediated interventions suggest that HMD-delivered immersive VR can offer a level of distraction that goes beyond that found in simple forms of distraction (e.g., watching videos or playing video games; see Hoffman, Prothero, & Wells, 1998). It is further argued that VR may improve analgesia through the reduction of visual cues associated with a painful procedure (Hoffman et al., 2000; Hoffman et al., 2000). In a recent systematic review of virtual environments designed for pain distraction, results suggest that the use of VR in adjunct with standard pharmacologic analgesics produces lower pain scores (during changes in wound dressing and physical therapy) than standard pharmacologic analgesics alone (Malloy & Milling, 2010).

In the context of FA theory and chronic pain, there are, however, a number of problems with interventions that rely exclusively on distraction. First, although hypervigilance to pain sensations is an aspect of disability development/maintenance (Van Damme, Crombez, & Eccleston, 2004; Van Damme et al., 2010), experimental pain studies suggest that individuals characterized by high fear and catastrophizing may not benefit from distraction to the same extent as their low-fear counterparts (Campbell et al., 2010; Roelofs et al., 2004). Moreover, while people with high fear are particularly vulnerable for development of persistent pain, studies utilizing VR as distraction have to date not assessed participant levels of pain-related fear. A more central concern with distraction stems from the theoretical underpinnings of GEXP and exposure treatments in general. As noted above, fearful individuals may engage in safety-seeking behavior during exposure to feared stimuli (e.g., guarding or bracing during movement), effectively diminishing the effect of exposure (McCraken & Eccleston, 2003; Vlaeyen et al., 2012; Vowles & Thomson, 2011). In this way, distraction from the emotional and cognitive content of fear comprises avoidance behavior and is not advocated by GEXP. In fact, recent GEXP theorizing has advocated drawing on more experiential treatment options (e.g., Acceptance and Commitment Therapy) to facilitate engagement and tolerance of unpleasant emotions, cognitions, and pain sensations (Vlaeyen et al., 2012; Vowles & Thomson, 2011).

Importantly, clinical evidence for the use of VR distraction has stemmed almost exclusively from acute pain interventions (e.g., burn dressing) where immediate analgesia is important (Keefe et al., 2012). However, for many CLBP patients, complete pain relief is rarely an option (McCraken, 1998) and patients who persist in "attempting to solve the problem of pain" show poorer outcomes (Eccleston & Crombez, 2007; Trost et al., 2012). Although increased physical and social engagement may naturally diminish pain experience through distraction processes (as more stimuli vie for an individual's attention), the goal of GEXP is to encourage patients to participate in valued life activities despite continued pain experience. Specifically, GEXP aims to break the association between perception of pain and the appraisal of physical harm or damage. Thus the primarily goal of GEXP is not pain amelioration (as that may be impossible), but functional restoration through behavioral engagement (Vlaeyen et al., 2012).

Finally, the historical uses of VR interventions for pain distraction have primarily involved simulations of environments removed from those in which the patient must function. For example, one virtual environment designed for pain distraction, Snow World, has been successfully employed for acute pain management (Hoffman et al., 2000) and provides the suffering patient opportunity to experience a virtual world far removed from their current situation. In addition, while these virtual distraction environments often include an interactive component (e.g., shooting monsters; see Das et al., 2005), they typically do not include activities consistent with patient real-life goals and activities of daily living. In contrast, exposure methodologies explicitly aim to situate the patient within contexts where treatment gains would be most useful. In this way, a patient fearful of needles would receive the most gain within a phlebotomy office. Analogously, GEXP encourages patients to practice feared back-straining activities within the contexts they would be most relevant, such as the home or workplace.

In line with the context-specificity of GEXP, a common method applied in the rehabilitation settings (within which GEXP is often executed) employs behavioral observation and ratings of human performance in the real world or via physical mock-ups of functional environments (Weiss & Jessel, 1998). Persons with motor and/or neurocognitive impairments are observed and their performance is evaluated within artificially constructed home and work environments (e.g., kitchens, bathrooms, offices, factory settings, etc.). Aside from the economic costs to physically construct these environments and to provide human resources to conduct such evaluations, this approach is limited in the systematic control of real-world stimulus challenges and in its capacity to provide detailed performance data capture.

Section 4: Treating Pain-Related Fear and Avoidance Behavior in Chronic Pain: Virtual Reality Graded Exposure Therapy

In a recent topical review, Keefe et al. (2012) identified and highlighted ways in which VR can be used either alone or in combination with other treatments not just for acute but also for persistent pain conditions. The authors conclude that although research on VR interventions for persistent pain is in its infancy, the use of immersive virtual environments with HMDs hold considerable promise. However, while historical approaches to virtual environments have emphasized HMDs, recent developments in simulation technology have allowed researchers and clinicians greater flexibility in stimulus presentation. Although there are instances where an HMD is still desired (e.g., acute pain management), researchers now have the capacity to provide the user with an ability to interact with digital content using more naturalistic body actions beyond what is possible with traditional VR or game interfaces (e.g., Microsoft Kinect Microsoft, 2011; see also Obdržálek, Kurillo, Ofli, Bajcsy, Seto, Jimison, & Pavel, 2012). The current trend appears increasingly focused upon full-body interaction for the input in conventional as well as serious games. For the user, this results in an interactive experience in a computer-generated simulation that adapts in a fluid and natural manner with head and body motion (Parsons & Courtney, 2011).

Such emerging simulation and serious gaming technologies are promising tools in many domains of assessment and therapy (Parsons, McPherson, & Interrante, 2013; Parsons & Reinebold, 2012), allowing for body-tracking sensors, multimodal interfaces, enhanced graphics, cognitive modeling, motor modeling, affective computing, and real-time graphic generation. As noted above, these advances in simulation technologies are not limited to a prescribed approach or hardware configuration. Instead, this new generation of simulation technologies allow for human-computer interfaces that proffer a user experience with multifarious interaction devices and sensory display systems. Stimuli may be presented in a computer-generated simulation for a given user or for multiplayer scenarios.

In the context of interventions for chronic pain, such technological advances have resulted in new possibilities for combining VR exposure treatments, distraction paradigms, and visuomotor processing with validated treatments for chronic musculoskeletal disability – namely, GEXP. At the University of North Texas, we have developed an adaptive virtual environment for treatment of pain-related fear and avoidance behavior. This project brings together a team of researchers to incorporate cutting-edge pain assessment and intervention into a state-of-the-art interactive/adaptive virtual reality graded exposure therapy protocol. As will be described below, Virtual Reality Graded Exposure Therapy (or, VRGET) serves to combine current approaches to GEXP with the innovative Xbox Kinect system by Microsoft.

The Kinect is one of the most widely used whole-body trackers and has the ability to integrate body-state information into various simulations. Further, Primesense's (2011) camera and depth sensor allow for full-body interaction. The Kinect system uses image, audio, and depth sensors for movement detection, facial expression identification, and speech recognition. The Kinect's interactive technology allows users to interact with simulations using their own bodies as controls. An important advance in the Kinect technology is that unlike previous attempts at gesture or movement-based controls, the patient is not encumbered by the need to wear accessories to enable the tracking of the user's movements. In this way, the Kinect system represents a perfect tool for the treatment of fear of specific physical exertions (e.g., vacuuming, picking up a child) as it inherently relies on (and captures) an individual's physical output.

The VRGET protocol has been designed to offer an adaptive virtual environment that can be explored by patients under the supervision of a trained clinician. In this way, VRGET offers an integration of a clinician's understanding of exposure therapy with advanced interactive multi-media technology that can be focused on delivering therapy optimized for each patient's individual differences. Individual differences in motivating factors are key to the VRGET protocol. As noted above, GEXP seeks to engage the patient in activities consistent with individually valued life goals that have been interrupted by pain and disability (Crombez et al., 2012; Schrooten et al., 2012; Schrooten & Vlaeyen, 2010; Schrooten, Vlaeyen, & Morley, 2012). These goals might include being a helpful spouse or a productive member of the workforce (Morely, Davies, & Barton, 2005). Attention to these goals is critical in the development of an individual hierarchy of avoided activities that is a central component of GEXP (Vlaeyen et al., 2012). Taking this into account, VRGET systems would allow the clinician to manipulate idiosyncratic motivational factors that are believed to have an impact on the recovery of an individual patient (Maclean et al., 2002).

Despite greater informational output, VRGET enhances patient autonomy during exposure (by placing the exposure interface within the home environment) and decreases the requirement for constant monitoring by the clinician. Rather than clinical observation, VRGET offers potential for automated monitoring and evaluation that can be added to standard clinical evaluation methods. As a result, clinical researchers will have a great deal more data for measuring exposure therapy progress. Of note, the monitoring and data-gathering potential of VRGET systems represents a major advance in detection of minor performance variations and affective changes that are not always sufficiently detectable by standard clinical scales that were constructed based on the human observer. Contrariwise, VRGET systems provide for more focused and high-resolution assessment: increased standardization of administration, increased accuracy of timing presentation and response latencies, ease of administration and data collection, and reliable and randomized presentation of stimuli for repeat administrations. In short, as a hybrid of clinical intervention and VR technology, VRGET offers the possibility for a new dimension of interactive exposure treatment, bolstering the clinical effectiveness of traditional GEXP by drawing on some of the inherent attributes of the emerging VR technology. Below, we discuss the major potential contributions of VRGET to traditional exposure approaches.

4.1 Engagement and Reinforcement

As noted above, participant engagement and retention in treatment has been a major problem for traditional GEXP interventions. However, VRGET can integrate reinforcement contingencies for exposure to feared activities that are not part of traditional GEXP approaches. These additional contingencies (e.g., elements drawn from gaming environments) can add to the reward of activity performance, further solidifying treatment gains. In addition, virtual environments allow for rehabilitation scenarios with novel stimuli and positive reinforcers to increase patient motivation (Thornton et al., 2005). The motivational potential of VRGET is evidenced by the success of devices like Sony's PlayStation Move and Nintendo's Wii Remote Plus. While these "off the shelf" systems were developed for entertainment, a number of gaming engines have emerged that provide the monitoring and adaptation capabilities needed for use as rehabilitation applications (Bailey & McInnis, 2011; Pirovano et al., 2012).

From a conceptual vantage, the VRET system aims to place the patient into a state of optimal experience, known as "flow," to trigger a broad recovery process (see Riva, Mantovani, & Gaggioli, 2004). According to Csikszentmihalyi (1990,1997), "flow" is best understood as an optimal state of consciousness that is characterized by a state of focused concentration during an activity. Following the work of Fairclough (2009), we partition the "flow" state of the patient into four quadrants or "zones" (see Figure 3).

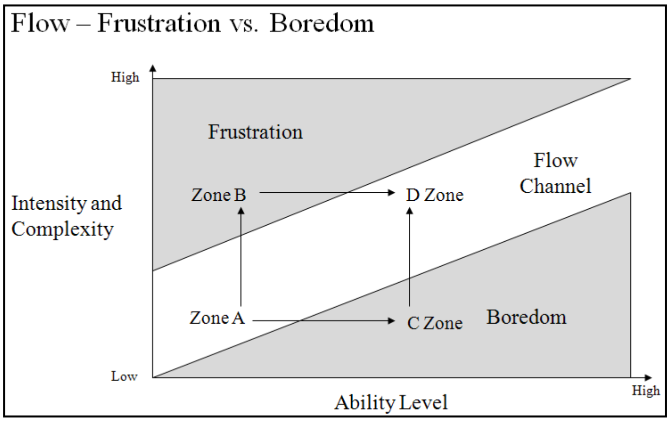

Figure 3. Two-dimensional representation of neuropsychological state

Our approach to VRGET uses the assessment and monitoring capabilities of the Kinect sensors to place the patient in the virtual gaming environment at the optimal starting point for that patient (Zone A). It is important to note that we do not conceptualize the flow of the VRGET to be a static experience. A patient's openness to certain movements (e.g., reaching for an object at a 45 degree angle) tends to be low the first time he or she is immersed in the virtual gaming environment. As the patient's experience of the VRGET protocol increases, his or her fear decreases as a result of successful reaching movements. A potential problem for rehabilitation at this point is that the patient may become bored if the challenge remains constant (Zone C).

Accordingly, as part of VRGET, the challenge will increase, but usually at a different rate than the patient's openness to a new reaching demand. Hence the patient is constantly in a state of flux between the four points shown in Figure 3. At times the patient may begin to disengage (start to experience boredom and move toward Zone C) when the challenge does not increase in pace with his or her skills. At other times, the patient may move toward frustration (Zone B) when he or she is slow to learn the necessary skills. Particularly relevant to Csikszentimihalyi's concept of flow states is Zone B, because it represents a "stretch" zone in which the patient is engaged and his or her ability levels are being increased as they are pushed toward frustration. Fairclough (2009) has explained that this state may be tolerated for short periods (e.g., a learning phases and/or a demanding but rewarding period).

4.2 Assessment of Emotional Responses to Exposure

Fear is conceptualized as the key emotional component to avoidant behavior patterns. According to the FA model, an individual's fear is based upon the erroneous belief that pain signals physical damage and thus an activity that exacerbates pain (e.g., movement) should be avoided (Vlaeyen & Linton, 2000). Theoretically, as patients gradually confront feared activities, maladaptive pain beliefs are challenged and fear responses are extinguished (Vlaeyen et al., 2012). Prospective tracking of participants' fear responses would thus be central to GEXP intervention. However, current protocols rely only on participant self-report of fear in response to activity. Self-report is notoriously sensitive to a host of confounding influences (e.g., the patients' desire to please their treatment provider).

Knowledge of the user-state during exposure to the virtual environment is imperative for optimal assessment and intervention. Different individuals will invariably have different reactions to the VRGET, and without an assessment tool that can be employed online, the clinician will experience difficulties in identifying the causes of these differences, which may lead to a loss of experimental control or clinical effectiveness. For example, a user may become increasingly frustrated with some aspect of the VRGET protocol, but without proper measurement techniques to detect this frustration while it occurs, compensatory measures cannot be taken. While traditional GEXP offers the capability of presenting a realistic simulation of the real world, online assessment of the user's reactions to that environment is vital to maintaining an understanding of how the environment is affecting the user clinically and to preserving experimental control in a research context.

One answer to these issues and limitations is the addition of psychophysiological metrics to the VRGET platform. The psychophysiological signal is continuously available, whereas behavioral data alone may be detached from the user's experience and assessed intermittently. The continuous nature of psychophysiological signals is important for several reasons. First, it allows for greater understanding of how any stimulus in the environment has impacted the user, not only those stimuli that were targeted to produce behavioral responses (Macedonio et al., 2007; Parsons & Courtney, 2011). The addition of psychophysiological metrics to the VRGET platform is important because it allows for a continuous objective measure of the user's state, which can include measures of cognitive workload (Berka et al., 2007), varying stress levels (Fairclough & Venables, 2006; Kobayashi et al., 2007) task engagement (Pope, Bogart, & Bartolome, 1995; Seery, Weisbuch, & Blascovich, 2009), and arousal (Bradley & Lang, 2000; Cuthbert, Bradley, & Lang, 1996; Cuthbert et al., 2000), among others. Additionally, multiple channels of psychophysiological data can be gleaned from various sensors simultaneously, which further increases experimental control by providing a combination of measures so that one measure alone is not the sole basis for design or treatment decisions (Hancock & Szalma, 2003). Some limitations that have restricted use of psychophysiological monitoring during rehabilitation interventions have been a) need for the user to remain stationary, b) cumbersome wires between sensors and a processing unit, c) lack of system integration among sensors, d) wireless communication interference, and e) absent support for data collection and knowledge discovery (Jovanov et al., 2005). However, innovative technological advances in sensors, low-power integrated circuits, and wireless communication capabilities have allowed for the design of miniature, lightweight, and low-cost wearable psychophysiological sensor nodes (Milenkovic, Otto, & Jovanov, 2006) that are readily included in the VRGET protocol.

Another approach to assessment of emotional responses is apparent in a number of motion-detection papers that have emerged as a result of the Microsoft Kinect's capability to generate both RGB images and corresponding depth maps of scenes (Ren et al., 2011; Sempena & Aryan, 2011). Kinect's skeletal tracking capabilities have been leveraged for rehabilitation (Chang, Chen, & Huang, 2011), interactive storytelling, video games (Skalski et al., 2007), and social robots (Gonzalez-Pacheco & Salichs, 2011). In a novel though limited and unvalidated attempt to assess psychophysiology, Burba et al. (2012) used the Kinect to measure the respiratory rate of a person sitting down. It is important to note that the paper mentions problems with tracking when trying to measure the respiratory rate of a person standing. In a more developed study, Martinez and Stiefelhagen (2012) used a Kinect-based method to estimate the respiration rate of subjects from their chest movements. They fixed an infrared (IR) dot pattern that could be detected using the Kinect camera with a matching IR filter. The system was evaluated on nine subjects. These preliminary studies may be extended by isolating the chest cavity using more well-developed methods.

Another possible answer to the limitations of traditional approaches to assessing affect with psychophysiological systems is to use the Kinect system for detection based on facial-expression analysis. Researchers have developed regularized maximum-likelihood deformable model fitting algorithms for 3D face tracking with Kinect that allow for optimal use of Kinect's 2D color video and sampling of depth images at 30 fps (Cai). Mahmond et al. (2011) used Kinect to develop a 3D multi-modal corpus of naturalistic complex mental states, consisting of 108 videos of 12 mental states. Likewise, Zhang et al. (2013) have used Kinect and the Facial Action Coding System (Ekman, Friesen, & Hager, 2002) to collect and establish a 3D multi-modal database for emotion recognition. The resulting database was concluded to be an effective FACS-based model with potential for effective facial-expression interpretation. The Microsoft Avatar Kinect uses facial-expression tracking and arm movements (through skeletal tracking) to allow researchers to control an avatar's head, facial expression, and arm movements. As a participant speaks, smiles, frowns, scowls, etc., her or his voice and facial expressions are recorded and can be enacted by the participant's avatar. Within the Avatar Kinect suite, researchers have access to fifteen unique virtual environments that give context.

Although in the early stages of development, researchers are likewise beginning to make use of the Kinect to monitor emotional body language. There are also projects that explore cultural differences using the tracking offered by the Kinect. In a project focusing on cultural differences and proxemics, Lala et al. (2011) focus on the cultural behavior of virtual agents towards each other and to the user. The researchers ensured that each virtual agent followed prescribed social parameters regarding how to react when interacting with other agents. Results revealed that the cultural dimension differentiating individualism and collectivism was mapped to agent characteristics during a series of simulations.

4.3 Kinematic Tracking of Movement Performance

In addition to ostensibly avoidant behavior, recent evidence suggests that fear may manifest as altered movement strategy among individuals with CLBP. Persons with CLBP display a variety of biomechanical disturbances (Hodges, 2011; Leeuw et al., 2007), including decreased trunk velocity, acceleration, and range of motion (Bishop et al., 1997; Magnusson et al., 1998; Rudy et al., 1995), as well as alterations in joint coordination (Esola et al., 1996 ; Lamoth et al., 2006 ; McClure et al., 1996; Porter & Wilkinson, 1997 ; Shum, Crobie, & Lee, 2005 ; Shum, Crobie, & Lee, 2007 ; Shum, Crosbie, & Lee, 2007) and muscle activity Hodges, 2011. Although such anatomically specific changes are hypothesized to reflect a functional strategy (i.e., to splint/stiffen the spine) in order to enhance protection of damaged tissues shortly after injury (van Dieen, Selen, & Cholewicki, 2003; van Dieen, Cholewicki, & Radebold, 1976) continued restriction of motion and abnormal transfer of loads may predispose spinal structures to further damage, possibly contributing to recurrent or disabling pain experience (Hodges, 2011; van Dieen, Selen, & Cholewicki, 2003; van Dieen, Cholewicki, & Radebold, 1976; MacDonald, Moseley, & Hodges, 2009). Research suggests that individuals with high pain-related fear may be particularly vulnerable to develop and maintain protective motor responses. Studies of subacute and chronic CLBP patients show that high-fear individuals show reduced lumbar flexion during bending (Geisser et al., 2004; Thomas & France, 2008) and maintain guarded spinal motion even as recovery progresses (Thomas & France, 2007). The latter finding suggests that motor and muscular adaptations to pain may be particularly resistant to extinction, even in the absence of painful stimulation (Moseley & Hodges, 2006). This continued motor guarding is hypothesized to owe to continued perception of threat associated with movement (Moseley & Hodges, 2006). A recent investigation by Trost et al. (2012) indicated that high-fear participants manifest restricted spinal motion even following an acute experimental induction of low back pain, suggesting differential postural adaptations among high-fear individuals emerge shortly after pain onset and may require intervention at the acute phase of injury.

Traditional GEXP protocols are not equipped to assess for these more insidious motor disturbances in movement performance. The increased metrics of VRGET protocols allow for monitoring of whole sets of dimensions necessary to describe each participant's height, poses, and movements. The building of a skeleton by Kinect requires a depth image of a participant's body and a sensor algorithm to develop an intermediate representation that maps the body (Shotton et al., 2011). While some parts used to make up the body-map representation are the participant's joints, others are links that connect the joints. These representational parts are coded, and algorithms recognize the codes to assign left and right to sides of the represented body. The Kinect dataset recordings of patient movements can be captured using the OpenNI (http://www.openni.org/) drivers/SDK and are OpenNI-encoded (.ONI). The OpenNI SDK provides a high-level skeleton tracking module that researchers may use to detect and track the captured patient poses and movements. The OpenNI tracking module produces the positions of seventeen joints (head, neck, torso, left and right collar, left and right shoulder, left and right elbow, left and right wrist, left and right hip, left and right knee, and left and right foot), along with the corresponding tracking confidence. The OpenNI tracking module requires initial calibration relative to the patient so that the Kinect can further infer information related to the patient's height and body characteristics. Calibration of the Kinect skeleton requires the captured representation of the patient to remain in a fixed position or "calibration pose" for a few seconds.

With the Kinect's skeletal tracking, clinical researchers can represent a patient's body using a number of points (e.g., joints) representing various body parts: head, neck, shoulders, torso, arms, and legs. Each of these is represented by 3D coordinates. The Kinect uses this information to determine the location and trajectory of all the 3D parameters in real-time, which allows for fluid interactivity. For example, Alexiadis et al. (2011) evaluated the performance of a dancer via Kinect-based skeleton tracking. In their study, three different scores were calculated for a dancer's performance, which were subsequently combined to produce an overall score: 1) Joint Positions: a score for each joint was calculated by considering the modulus of the quaternionic Correlation Coeffcient (CC) for each pair of joint position signals. A total score S_1 was then computed as the weighted mean of the separate joint scores; 2) Joint Velocities: an overall score S_2 was extracted based on the velocities of the joints (instead of their positions) by considering the quaternionic CC for the joint velocity signals; 3) 3D Flow Error: for a given frame, the velocities of the joints were considered as 3D motion (flow) vectors. Alexiadis et al. applied the work found in 2D optical flow literature to 3D velocity vectors in homogenous coordinates and calculated the vectors' inner product to obtain a score for each joint (Barron, Feet, & Beauchemin, 1994) and 4) Combined score: the score was calculated as the weighted mean of the above three. This set of the three weights was selected using an optimization approach. In the same manner, the Kinect system can be calibrated to examine whether a CLBP patient is performing activities in a guarded manner, for instance by reducing velocity during certain physical moments or by maintaining rigid postural control during tasks that call for spinal motion.

4.4 Generalizing Treatment Gains

As noted above, the generalization of treatment gains from the clinic to the home environment has been a major source of concern for GEXP intervention (Vlaeyen et al., 2012). As with kinematic adaptations, research has indicated that individuals with high-pain-related fear are hesitant to abandon their appraisals of the harm potential of physical activity. For example, by engaging in GEXP, a highly fearful patient may learn that bending to tie their shoe is safe, but may hesitate to perform similar flexion as part of a different task (e.g., vacuuming) (Crombez et al., 2002; Gourbert et al., 2002; Goubert, Crombez, & Danneels, 2005; Goubert, Crombez, & Lysens, 2005). Thus, learning may not transfer from one physical task to another, or to a similar task in a different environment (Bouton, 2000). In short, even with exposure, highly fearful participants are hesitant to change their fundamental belief that movement and pain are unsafe.

Current GEXP protocols acknowledge this limitation (Vlaeyen et al., 2012) and suggest a number of approaches to facilitate generalization of learning across activities and contexts. Specifically, clinicians are encouraged to provide homework to be carried out within patients' home environments and to incorporate multiple stimuli as part of exposure treatment (Vlaeyen et al., 2012). In addition, a recent study (Trost, France, & Thomas, 2008) demonstrated that patients can maintain learning effects across a progressively more difficult movement task (rather than across discrete movements). Thus practicing behavior across different environments and creating a gradient of difficulty for discrete activities within an individuals' fear hierarchy are hypothesized to optimize treatment gains. As noted above, the flexibility in simulated environment and maintenance of optimal "flow" engagement offered by the VRGET format further allows variations in grade/degree of exposure that may not be feasible within the constraints of traditional GEXP. That is, treatment "speed" can be optimally graded ("scaffolded") to participant comfort level, thereby facilitating success experiences. After initial orientation, treatment can be monitored and guided in part by the participant, thereby building self-efficacy.

Section 5: Conclusions

Virtual reality technologies are increasingly being harnessed for therapeutic and rehabilitative aims both within the physical and psychological domain. Although most of these VR systems are not commercially available (or, are extremely expensive when available), low-cost, accessible systems (e.g., Kinect, Nintendo Wii) are being tested for rehabilitation applications (Saposnik, Levin, & Outcome Research Canada Working, 2011). By virtue of its intrinsically distracting properties and with the aid of HMDs, VR has demonstrated considerable success in the arena of acute pain management (Keefe et al., 2012). However, as noted above, chronic musculoskeletal pain patients face a number of unique challenges that do not lend themselves well to acute pain treatments, particularly among individuals with high-pain related fear. These challenges have been the targets of interventions guided by biopsychosocial theoretical frameworks. In particular, graded exposure in vivo (GEXP) has emerged among the most successful treatments for individuals most at risk for persistent pain and disability (i.e., individuals characterized by high pain-related fear). By combining VR technology with this empirically validated treatment protocol, we expect that Virtual Reality Graded Exposure Therapy (VRGET) can make major clinical and empirical contributions to the treatment and understanding of chronic musculoskeletal pain conditions.

The flexibility and metrics offered by the Kinect interface are uniquely matched to enhance traditional exposure treatment. Specifically, the noninvasive and interactive format allows for uninhibited physical performance by the participant, which is key for exposure interventions targeting physical performance. This would not be possible using traditional HMD approaches, which can sacrifice ecological validity for immersive distraction. Moreover, by incorporating novel visual cues and gaming elements, VRGET can bolster participant engagement and adherence to an otherwise anxiety provoking intervention. In this way, VRGET capitalizes on elements of distraction that are inherent to VR methodologies without sabotaging the exposure element necessary for treatment gains. Treatment gains can likewise be optimized by the ability of VR simulations to “scaffold” the difficulty of tasks across different contexts. This latter element can address the problem of treatment generalizability demonstrated by the traditional GEXP approach. Finally, the advanced metrics offered by VRGET are useful in at least three ways. First, the system would allow for automated tracking of patient progress and data collection that can be distally examined by a clinician. Second, through addition of psychophysiological measurement or motion tracking, VRGET can examine participant affective response throughout the exposure process; this is particularly key as fear reduction is conceptualized as central to successful treatment. Third, VRGET would allow for tracking of motor responses that are not congruent with successful treatment engagement (e.g., guarding or bracing behavior); such monitoring is not possible within traditional clinical contexts. In summary, VRGET promises to be an affordable and highly accessible treatment option to reduce fear and disability in the context of chronic musculoskeletal pain. Empirical efforts will continue to refine the VRGET methodology toward optimal patient usability and wider dissemination.

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