The Meditation Chamber: Towards Self-Modulation

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The Meditation Chamber is an immersive virtual environment (VE), initially created to enhance and augment the existing methods of training users how to meditate, and by extension, to realize the benefits from meditation practice, including the reduction of stress, anxiety and pain. Its innovative combination of immersive virtual reality (VR) and biofeedback technologies added interoceptive or dimensions of inner senses to the already sensorially rich affordances of VR. Because the Meditation Chamber enabled users to become aware of autonomic senses that they are not normally conscious of, and to manipulate them in real-time, we found that it did enhance users' abilities to learn how to meditate, particularly those who had never meditated. We describe the Meditation Chamber, scientific methods of evaluation and findings, and discuss first-person phenomenological aspects, its long-term applicability for users who have chronic pain, and future directions.

INTRODUCTION

The *Meditation Chamber* was a project in service of our long-term research interest in the biopsychosocial aspects of chronic pain (Gatchel, 2009). It is a training system and engineering artifact that can be evaluated on engineering terms – questions of effectiveness and efficiency can be answered using scientific methods, as we have outlined. However, it can also be viewed as a tool for exploring ideas of subjectivity as they relate to the physiological states that are inextricably intertwined with subjective experience. Meditation and pain are subjective experiences that take on manifold dimensions that are difficult to communicate or measure (Scarry, 1987). As a means of exploring the subjective aspects of chronic pain, we are embarking on a follow-up project, the *Virtual Meditative Walk.* It builds upon some of the techniques of the *Meditation Chamber* to enable people who endure chronic pain to be able to better manage it. These two systems form part of a larger agenda to help people express and potentially manage their bio-subjective experiences over time. The knowledge gained in developing and analyzing these two VEs may provide a baseline and framework for understanding VR experiences among diverse knowledge bases. Thus, our approach is a phenomenological one that builds upon the work of Maurice Merleau-Ponty and, more recently, Francisco Varela, Evan Thompson (Varela, Thompson & Rosch, 1992) and others[1]. Because this approach accounts for the interrelations among mind, body and world, it closely parallels the biopsychosocial approach that is at the core of current pain management (Gatchel, 2009). Because felt experience is the subject of this type of phenomenology, it offers a method that necessarily accounts for the subjective aspects of chronic pain, as well as the objective aspects that can be measured scientifically.

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[1] Contemporary phenomenologists who continue the work of Merleau-Ponty and are referred to in our research include: Patricia Benner, Robert Bosnak, Andy Clark, Thomas Csordas, Paul Dourish, Herbert Dreyfus, Natalie duPraz, Diana Fosha, Raymond Gibbs, Mark Hansen, Shaun Gallagher, Don Idhe, Mark Johnson, Drew Leder, Alva Noe, Gail Weiss, Iris Young, and Dan Zahavi, to cite a few.

The research described in the present chapter contributes a new approach to VR-based pain research, because it specifically focuses on the longitudinal aspect of persistent, chronic pain rather than on acute, short-term pain that is addressed by what is termed VR pain distraction. Thus, rather than characterizing the *Meditation Chamber* and the subsequent research it spawned as "pain distraction," we focus on the way it affords users the ability to manage their attention and awareness so that they may exert agency over their on-going experience of pain. We term this "self-modulation."

THE MEDITATION CHAMBER

The *Meditation Chamber* was an immersive virtual environment that was originally created by long-time VR researchers Larry Hodges, Diane Gromala, Chris Shaw, and Fleming Seay. It was subsequently refined and used at *Virtually Better,* a VR clinic that was founded by Hodges, and expanded upon by the Transforming Pain Research Group (Transforming Pain Research Group, 2010), directed by Gromala, a Canada Research Chair.

Reported briefly at Enactive 2007 (Shaw, Gromala & Seay, 2007), the goal of the *Meditation Chamber* was to design, build and test an immersive VE that used biometrically-interactive visuals, audio and tactile cues to create, guide and maintain a user's meditation experience. It is not necessary to use technology to meditate of course. However, the widespread use of CDs, DVDs, and online resources suggests that technology may be a useful way to enhance and reinforce the practices of meditation. More importantly, we discovered that immersive VR, integrated with biofeedback technologies, offer something unique — it enables users to see their intentional efforts to affect their continuously changing autonomic states. While standard biofeedback techniques also offer visual and auditory feedback, the simplistic monotones or waveforms are not immersive or aesthetically engaging. Thus, VR and biofeedback technologies were combined to determine if the immersion and biometrically-driven real-time feedback could help users achieve a meditative state. Biofeedback was considered to be potentially useful for enabling users to get real-time feedback and to gain a sense of agency or control over three aspects of their autonomic functions: heart rate, respiration, and galvanic skin response. Although biofeedback cannot, of course, offer a confirmation of being in a meditative state, it can indicate relative changes in physiological arousal and, after decades of testing, is considered to be a reasonably reliable indicator of reaching a meditative state provided there is additional questioning of the participants.[2]

IMAGE GOES HERE

[2] The most reliable measure is electroencephalography (EEG); however, this device requires 24 or more carefully measured points of direct contact on the scalp, and thus was not immediately viable for a large group of users. Further, EEG measures of a meditative state are very close to those of an incipient epileptic seizure.

Figure 1. The Meditation Chamber.
Users wear a head-mounted display (HMD) that provides them with stereoscopic imagery and sound. Interaction primarily occurs as users strive to manipulate their physiological states via biofeedback. Biometric sensors are attached to two fingers with Velcro; these sensors tracked galvanic skin response and heart rate. A flexible chest band tracked respiration.

In the *Meditation Chamber*, users sat in a comfortable, semi-reclining chair and experienced a VE that took them through three phases of a virtual experience. Prior to the first phase, users were first fitted with a head-mounted display (HMD) and three biometric sensors that measured galvanic skin response (GSR), respiration and heart rate. Once seated comfortably, users entered the first phase of the meditation chamber: as they were presented with a visual display of a sun (Figure 2), the system's interactive "vocal coach" asked them to relax. The biofeedback device measured their GSR in real-time, which directly affected the imagery: as the user began to relax and their GSR declined, the rate at which the sun moved would increase until the sun went beneath the horizon giving way to a peaceful night scene, complete with chirping crickets. If the user was unable to become relaxed or their GSR increased, the sunset would slow down. The second part of this relaxation phase operated in the same way as the first, but depicted a moonrise instead of a sunset. As the user relaxed and lowered their GSR, the moon would rise higher and higher into the sky. The user's GSR measure determined the frame-rate at which the sunset / moonrise animation would play. In this phase, users reported that they became aware of their intentional efforts to relax because they understood that the visuals were responding to their continuously changing physiological state.

In the second phase, users were taken through a set of muscle tension and relaxation exercises, again by the system's vocal coach. 3D graphics of a human body were rendered and displayed from a first-person perspective (Figure 3). Thus, the 3D body that users saw corresponded to their physical body. The user was coached to flex, hold, and release a set of eight different muscle groups including the legs, arms, abdominals, and shoulders. Each muscle group sequence was accompanied by gender appropriate visuals depicting the described motion, usually from a first person perspective. This phase was not interactive, but instead asked the user to listen to the narrator's instructions while mimicking the movement examples visually presented to them on the screen. The system's creators and users noted that this was a strong and compelling illusion. The authors intend to expand upon this by including sensors on the users' wrists, knees and feet to strengthen the illusion of a one-to-one correspondence, or an embodied "felt sense."

In the third phase, users were taken through a guided meditation and breathing exercise, interacting with soothing visual imagery and ambient sound. As users approached what is considered an acceptable biometric approximation of a meditative state, the volume of the sound decreased, while the interactive visuals dissolved to black; often, users simply closed their eyes. After a prescribed amount of time meditating, the vocal coach gently suggested that users end their meditative session.

The system was installed at the Emerging Technologies exhibition at SIGGRAPH, a five-day conference. Since many users at this conference were familiar with technology, every effort was made to avoid situations in which users could "game" the system — from the video that explained the known benefits of meditation, viewed by users as they waited for their sessions, to the design of the system itself. 411 users filled in preand post-experience questionnaires that asked them to rate their level of relaxation before and after their session in the *Meditation Chamber.* Throughout their sessions, the system tracked users' biometric measures; this data was offered to users at the end of their session, in the form of a printout. Surprisingly, most users asked for their printouts and remained to study it, often asking questions and expressing recognition of when they "felt" or became aware of their abilities to lower their respiration, heart rate and GSR.

IMAGE GOES HERE		**IMAGE GOES HERE**

Figure 2. The Meditation Chamber, phase one. Users' continually changing physiological states first affect a setting sun and then a rising moon.

Figure 3. The Meditation Chamber, phase two. A first-person display of the user, male or female, mirrors their actions during the progressive muscle relaxation phase.

Findings indicated that the majority of the 411 users reported their levels of relaxation increased after experiencing the *Meditation Chamber,* especially users who had never meditated. Users rated their level of relaxation from 1 (very anxious) to 10 (very relaxed). The average pre-session relaxation self-rating was 5.63, with a Standard Deviation (SD) of 1.75. The average post-session relaxation self-rating was 8.00, with a Standard Deviation of 1.69. A t-test showed that post-session relaxation ratings ($M=8.00$, $SD=1.69$) were significantly higher than pre-session ratings ($M=5.63$, $SD=1.75$), $t(410) = -24.45$, $p=.0001$. This indicates that the *Meditation Chamber* is effective at promoting the kinds of relaxation that consistently parallels meditation.

The extensive amount of biometric data collected from the SIGGRAPH attendees (Shaw, Gromala & Seay, 2007) was subsequently subjected to analysis. The analysis revealed a distinction between novices (i.e., users who had never meditated or had attempted to do so only a few times) and experts (i.e., those who regularly meditate). Only 25% of users had biometric profiles that fell between the two. This was surprising, since we expected to find a smoother continuum. To use GSR data as an example, just over half of the participants exhibited what can be called a "novice" GSR pattern or profile. This means that their GSR level started relatively high, descended through the first phase of the experience, increased and showed peaks in the muscle relaxation phase, and then began to decline again in the final phase, ending up at or more frequently beneath the low established in the first phase. Breathing patterns in novice profiles tended to be steadier and deeper in the final phase than in the first phase. In the expert profile, precipitous drops in GSR occur during the first phase, entered a very low and often flat GSR state before the muscle relaxation phase began. This flat-line state was typically maintained throughout the remaining two phases, and was accompanied by a very steady but not necessarily deep breathing pattern. Individuals who exhibited the expert GSR profile also showed a very consistent respiration rate and amplitude throughout the experience.

IMAGE GOES HERE

Figure 4. The Meditation Chamber. *Sample GSR graphs typical of the novice (left two) and expert (right) profiles. Vertical lines indicate transition points from one phase to the next.*

Most user reports were positive: 30% had enthusiastic written comments. Twelve negative comments had to do with the heaviness of the HMD and the noise from the other exhibits. The positive comments were that users felt relaxed, even though many initially wrote that they did not expect to. Several VR experts expressed strong skepticism, including experts such as Randy Pausch. After their sessions in the *Meditation Chamber,* all but one of these vocal skeptics expressed strong enthusiasm; the remaining one was mildly positive. We also discovered that the standard profiles of expert meditators vs. novices were strongly correlated with the self-reported experience in the questionnaire. Finally, a skeptic might suggest that our findings were simply the result of giving conference-goers a place to sit and relax. To address this concern, we later tested a baseline condition. Here, users sat quietly in a room, wearing the biofeedback hardware for the same duration of time. In this condition, users did not wear a head-mounted display, nor did they receive the *Meditation Chamber* experience. We found that half of these baseline-condition subjects experienced increases in GSR. These tests confirmed that our findings were not simply the result of providing a place to sit and relax.

These findings, along with our other work on chronic pain (e.g., Gromala, 2000) and VR (e.g., Gromala & Sharir, 1996), suggest that VR assisted meditation may enhance learning to relax and meditate, and by extension, may be particularly suited to the needs of those who have chronic pain. This is because methods of "self-modulation," such as learning to relax and to meditate, are the primary ways that chronic pain sufferers themselves can manage their own pain at will. All other methods of managing chronic pain — from pharmacology to physiotherapy, massage, acupuncture, and psychotherapy, for instance, — rely on the interventions and expertise of others. Furthermore, one of the most often reported aspects of chronic pain that lead to depression among this group of people is a sense of helplessness (Gatchel et al., 2007): that results from a lack of cure, and the difficulty of treating and managing this degenerative condition. Therefore, the ability to self-modulate or exert some form of self-directed control over chronic pain may afford those who live with chronic pain to gain a greater sense of agency. Indeed, subsequent informal reviews of these data by several experts in mindfulness meditation, some physicians who specialize in chronic pain, and some sufferers of chronic pain confirmed that the *Meditation Chamber* is a promising adjunctive tool for managing chronic pain. Thus, the Transforming Pain Research Group is in the process of refining the *Meditation Chamber,* and is developing a more rigorous approach to evaluation. Most importantly, we have now started working with a group of those who live with chronic pain, so that we might study them over longer periods of time.

APPLICABILITY TO CHRONIC PAIN

In medicine, immersive VR applications have proven useful for surgical training and planning, and as a therapeutic modality. Research that focused on VR as a therapeutic modality, showed that, if implemented correctly, it could successfully treat phobias (Brinkman, vander Mast, & de Vliegher, 2008), fears (Rothbaum, Hodges, Smith, Lee, & Price, 2000; Krijn et al., 2007), anxiety (Robillard, Bouchard, Fournier, & Renaud, 2003), post-traumatic stress disorder (PTSD) (Emmelkamp, 2006), and acute pain (Hoffman & Patterson, 2005), to name a few. Remarkably, an approach to reducing acute or short-term pain that utilizes VR has proven to be more effective than traditional pharmacological treatments using opioids (Hoffman & Patterson, 2005). Although the mechanism for the effectiveness of VR in addressing short-term pain is not well understood (Mahrer & Gold, 2009), it has been termed "pain distraction," and more recently, a "non-pharmacological form of analgesia" (Steele et al., 2003). While many forms of media such as video games may provide distraction, VR has been demonstrated to be more effective (Hoffman, 2009) at relieving acute pain. This might be because VR can isolate users from their everyday surroundings to a greater degree than a video game or headphones used during dental procedures. It may also be because VR affords a multi-sensory experience described as "presence" (Hoffman et al., 2004b). It is thought that the stronger the sense of presence, the stronger the effects of distraction. However, explaining why VR is more effective than opioids as "pain distraction" may be problematic according to studies of attention in neuroscience and psychology (Lutz, Slagter, Dunne, & Davidson, 2008). Whatever the mechanism of effectiveness may be, work in the domain termed VR pain distraction has almost exclusively addressed its effects on acute or short-term pain.

The approach described as VR pain distraction bears limitations. Though it is demonstrably effective as a non-pharmacological analgesia during medical procedures, it is still in a nascent stage of development. Tested on small populations, the exact mechanisms for its effectiveness remain unclear, with methodological approaches that span computer science, psychology and medicine (Mahrer & Gold, 2009). Distraction is a short-term strategy for diverting attention that occurs and is measured during a VR experience itself (McCaul & Malott, 1984; Hoffman et al., 2004a). Current approaches do not account for what may persist beyond the VR experience, and do not track outcomes over time. Despite the growing number of hospitals and clinics that use VR, it remains relatively specialized and inaccessible when compared to desktop or laptop computers or mobile devices. In addition, according to studies of attention in neuroscience and psychology, the kind of distraction offered by most approaches to VR pain distraction do not meet the criteria known to be effective over time (Lutz, Slagter, Dunne & Davidson, 2008). In addition, differing approaches to pain modulated by VR have not been compared or evaluated.

Finally, investigations concerning the design and effect of differing forms of "content" remain an under-examined area. For example, in the earliest work in pain distraction for those who suffered from burns, the "content", or what users saw and heard, was a VE involving snow and wind (Hoffman, Patterson, & Carrougher, 2000). While this appears to be obviously appropriate, the effects of this choice of "content" versus some other choice have not been studied. Similarly, in VEs designed to treat arachnophobia, the "visual rhetoric" of the spider has not been examined (Hoffman, Garcia-Palacios, Carlin, Furness, & Botella-Arbona, 2003). What roles might the kind of spider and its form of representation play? Is a photorealistic spider approach more effective than a cartoon-like rendering? Would the VE provide more therapeutic benefit if the spider morphed from more abstract forms to more photorealistic forms in parallel to the subject's increasing exposure times? VEs that progress from VR to AR suggest that this area of investigation is promising (Botella et al., 2005). Of course, one cannot expect all the implications of VR pain distraction to be addressed immediately or by one expert or field — VR pain distraction is still in its infancy. Therefore, because this area of research addresses issues of subjectivity (Scarry, 1987) and culture (Morris, 1993), scholars of Design and Media Studies (e.g., Bolter & Gromala, 2005), and other subdisciplines of the

Humanities (e.g., Elkins, 1999) would appear to be well-suited to contribute to this research domain.

In contrast to pain distraction, we are investigating "pain self-modulation," defined as the ability of those who suffer from chronic pain to consciously and physiologically exert control over their experience of pain. Thus, we integrate VR and biofeedback in training users how to meditate, drawing upon the knowledge gained from decades of study of this learned ability in biofeedback and meditation practices. Long recognized in alternative and complementary medicine, this measurable ability to "self-modulate" pain and stress has been supported by standard medical research, particularly over the last decade. In the form of "mindful meditation," this ability has also been popularized by the work of Kabat-Zinn (2006), among other scholars and practitioners of biofeedback, pain medicine, prevention and wellness (Schatman & Campbell, 2007).

CHRONIC PAIN

Chronic pain is defined as pain that persists or recurs for six months or longer (Russo & Brose, 1998). According to conservative estimates, one in five North Americans is affected by chronic pain, and it ranks among the top five reasons for disability (Blyth et al., 2001). Similar rates are reported in Europe and developing nations. It is one of the most complex experiences that humans face, affecting bodies, minds and culture (Melzack, 1990). In recognition of this, as early as the 1950s, the practice of pain medicine made moves to a multidisciplinary approach attending to mind, body and social issues. (Schatman & Campbell, 2007). Chronic pain is notoriously difficult to diagnose and to treat, and becomes irreversible and often degenerative over time. The body itself changes, while psychological states are also affected (Melzack & Wall, 1996). Those who have chronic pain have difficulty in accessing treatment, and face social stigma and isolation as their abilities to work, play, socialize and maintain mobility diminish (Gatchel et al., 2007). High rates of depression are common, and when those who have chronic pain attempt suicide, they are "more successful [sic] than others at risk" (Gatchel et al., 2007). Thus, the approach to treatment in centres for pain medicine is generally not conceived of as a short-term cure, but as a long-term set of strategies for *managing* chronic pain, usually by multidisciplinary teams. These teams comprise physicians who represent various areas of expertise, nurses, psychologists and other healthcare practitioners. A review of centres for pain medicine in North America revealed that mindfulness meditation is a commonly recommended tool for self-managing pain (Pridmore, 2002).

Moreover, because chronic pain is commonly considered a symptom rather than a long-term illness and because it does not immediately threaten life (Williams, Wilkinson, Stott, & Menkes, 2008), treatment and disability compensation remain elusive (Loeser et al., 2001); thus, it has been termed the "silent epidemic" (Canadian Pain Coalition, 2007). For these reasons, chronic pain remains an under-explored area in treatment and medical and wellness research.

FROM DISTRACTION TO SELF-MODULATION VIA MEDITATION

Extending discoveries that we made in the *Meditation Chamber* and in our other VR work, our Transforming Pain Research Group focuses on the long-term benefits of VR and pain "self-modulation," for those who suffer from persistent, chronic pain. It is more akin to exposure therapy, where the experiences in VR are considered to be part of a long-term process that is ultimately effective in day-to-day life. The goals for both approaches are long-term, with an emphasis on training mind and body, and developing a greater sense of self-agency.

Researchers in VR pain distraction describe the analgesic effect in terms of "modulation." The term modulation here refers to the effect VR has on the patient (Hoffman et al., 2004a) — the emphasis is on the technology's ability to produce a strong distraction, rather than on the users' abilities to alter their experience of pain through a process learned in VR.

We posit a shift in approach and conceptualization, one that emphasizes the *user's* ability to learn how to *self-modulate* their experience of chronic pain, using VR as a training simulation, which enhances a user's ability to learn. In training, users may then take this new ability outside of VR and activate it at will. Thus, we define "pain self-modulation" as the ability of those who suffer from pain to consciously and physiologically exert control over their experience of pain, an ability achieved through VR, biofeedback and meditation. This is a measurable ability, increasingly supported and accepted by standard medical research. Though the long-term efficacy of training in VR simulations is well established, evaluation of the long-term effects of training users to self-modulate their pain is in a nascent stage. The goal of our work is to set a foundation for research in this under-examined area.

FUTURE RESEARCH DIRECTIONS

Through the Transforming Pain Research Group, we are continuing to explore the use of VR and biofeedback technology to address chronic pain. Dr. Pamela Squire, a physician whose specialty is in complex pain, and neuroscientist Dr. Steven J. Barnes have joined our group, adding significant expertise and enhancing our methodological approaches. Our current research initiatives include a VR application that extends the sitting forms of meditation used in the *Meditation Chamber*. In this work-in-progress, entitled the *Virtual Meditative Walk (see Figure 5.),* a self-regulated treadmill is added to our VR and biofeedback technology. Instead of sitting, users of the *Virtual Meditative Walk* learn how to meditate while they walk through virtual landscapes, which are displayed stereoscopically and binaurally. Simultaneously, real-time feedback of users' physiological states alters these visuals and sound. This is arguably a more intense practice of meditation, as the meditators are in constant motion.

In one phase of this work, two major strategies for learning how to self-modulate one's experience of chronic pain are being compared and measured: the guided imagery and muscle tension and relaxation used in the *Meditation Chamber* with mindfulness meditation (Kabat-Zinn, 2006). In a second phase, the role of GSR is expanded in order to assess users' learned abilities to self-modulate their experience of chronic pain. This is in response to recent research in pain medicine (Gatchel, 2009). In addition, in order to assess whether users can increase their pain thresholds, and if so, to what degree, we are adding DNIC (diffuse noxious inhibitory controls), a measurement tool well-known in medical research (Villanueva, 2009). Both enhanced GSR and DNIC measures will be compared to users' self-reporting of their pain levels. In a third phase, the most suitable kinds of interaction techniques and comparisons of the roles of media forms will be investigated. These are important aspects, since focusing attention is key to learning how to mediate and self-modulate the experience of chronic pain. Many factors in designing the relations between technological performance and interactive media – such as lag time and optical distortions – affect priopriocептive and vestibular systems (De Boeck, Raymaekers, & Coninx, 2006). The result hinders the experience, leaving an immersant feeling displaced within the virtual environment (Song, 2009). In the context of meditation, such phenomena prove to be highly detrimental in self-directing and maintaining attention. Such displacement can also profoundly affect an immersant's consciousness of their body schema (Gromala, 2000), which is crucial for meditation.

Finally, we are developing easily accessible ways to reinforce and track what users learn in VR through applications developed for computers and mobile devices.

IMAGE GOES HERE

Figure 5. Virtual Meditative Walk

The longitudinal aspects of this research are vitally important, since chronic pain is an on-going and usually degenerative condition. Our research approach contributes to VR research in several ways. First, it uniquely focuses on long-term, chronic pain through an approach we term "self-modulation." Second, in the way we are integrating VR with biofeedback and meditation, we address the six ways that are recommended for coping with chronic pain relaxation, biofeedback, cognitive restructuring, problem-solving, distraction and exercise (Turk & Nash, 1993). Third, our phenomenological approach both provides an approach that can account for the multidisciplinary range of expertise in our group, and strongly parallels the biopsychosocial approach to chronic pain – the approach most widely used in pain management. Because of these alignments, our research may prove to be a useful tool in the long-term management of chronic pain.

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KEY TERMS & DEFINITIONS

Acute Pain. Pain that arises quickly, and that can usually be directly attributed to present injury or disease. Although it can be severe, it is generally defined to exist no longer than 30 days.

Biofeedback. A method of treatment that enables users to become aware of and influence various physiological functions of which they are normally unaware. Instruments monitor and provide visual or sonic information about the continuously changing functions, such as heart rate, respiration, galvanic skin response, blood pressure and brain wave activity, to name a few.

Chronic Pain. Pain that persists or recurs for six months or longer. In many cases, the cause of the pain is difficult to diagnose. Recent research suggests that chronic pain is not a symptom, but a systemic dysfunction or hypersensitivity. Over long periods of time, chronic pain is degenerative in complex physical, psychological and social ways.

Meditation. A practice in which the practitioner attempts to get beyond the reflexive, “thinking” mind into a deeper state of relaxation or awareness.

Pain Distraction. The act of directing conscious effort upon a task, thus directing attention away from a painful action or experience.

Pain Modulation. The reduction of the sensation of pain by the act of intervention by pharmacological or other methods.

Virtual Reality. An interactive, three-dimensional, computer simulated environment presented through a stereoscopic, wide field-of-view visual display such as a head-mounted display (HMD), or a multi-screen surrounding projection (CAVE). Spatialized sound and haptics are sometimes used to enhance the simulation.