An Immersive Virtual Reality Platform for Medical Education: Introduction to the Medical Readiness Trainer

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Abstract

The Medical Readiness Trainer (MRT) constitutes a medical education environment, in which, the integration of fully immersive Virtual Reality with highly advanced medical simulation technologies and medical databases exposes the trainee to the vast range of complex medical situations. MRT allows the simultaneous interaction of medically appropriate context, situational realism, and psychological stressors necessary for the dynamic acquisition of manual and diagnostic medical skills. A network of MRT's will allow creation of collaborative virtual environments essential for training of both individual and team/unit medical skills, and for training of medical management and logistic support functions.

Introduction to the Medical Readiness Trainer

Several studies (e.g., Dumay, 1995; Hoffman et al., 1997; Jerant et al., 1995, Knuth et al., 1998. See also Pickett et al., 1998; McCarthy et al., 1998) have demonstrated the acute need for integrative training of medical personnel in manual, diagnostic, and patient management skills. While such training is available to staffs at medical education hospitals, the access to sophisticated training by the personnel working at the remote health facility is still limited. Moreover, even in the ideal setting of a teaching hospital, training is based on "at the bedside (or in the operating-, emergency room)" concept. Hence, none of the currently employed teaching methods provide satisfactory solutions for a truly well integrated system where all aspects of medical knowledge (i.e., theoretical and practical) are employed simultaneously. Consequently, most of the currently employed teaching methods are based on flow chart (semi-static) approaches that fail to incorporate the complexity of medical reality. I.e., the environment where large amounts of information need to be instantaneously combined, analyzed, transformed into a meaningful practical skills-driven activity, and where time represents a critical factor (Kreines et al., 1995; Takabayashi et al., 1995; Kraft et al., 1997; Willy et al., 1998). Finally, despite their increasing popularity, the technology-driven training devices available today are incapable of immersing the trainee in the dynamic, environmental stressors of modern medicine and its demand for the relentless maintenance of intellectual and practical skills (Xiao et al., 1996; Sica et al., 1999).

Virtual Reality, Human Patient Simulators and the Current Medical Training

"Virtual Reality (VR), as part of computer science, allows computer-based models of the real world to be generated, and provides humans with a means to interact with these models through new human-computer interfaces, and, thus to nearly realistically experience these models " (Kaltenborn and Rienhoff, 1993). This concept applies to medicine (Carnarar, 1993), as much as to any other field of human endeavor, where manual skills and intellectual experience need to be perfected through training in complex or potentially dangerous situations. Probably the most forward-looking applications of virtual reality in medicine are those proposed by Satava (Satava, 1994,1995 a, b). Several other authors recognize VR-based education and training as the principal platform for the 21st century (Thalmann and Thalmann, 1994; Kenyon and Afenya, 1995; Hoffman et al., 1995; Hoffman and Vu, 1997). It is also recognized that skills acquired and trained in VR transfer to real life medical operations (Kenyon and Afenya, 1995). In addition to training in procedural and diagnostic skills, (Sailors and East, 1994; Larsson et al., 1997), VR instruction and coaching can season the trainees to hazards and stressors of medical operations in atypical environments, e.g., ships, aircraft, or during man made and natural disasters, etc. (Baker and Ryals, 1996; Mitchell, 1997)]. VR-based training can also prepare/desensitize to the impact of the environmental trauma and enhance the capacity to perform with undiminished medical efficiency irrespectively of the surrounding physical setting (Rothbaum et al., 1997).

In contrast to other VR-based systems (e.g., flight or bridge simulators), the major disadvantage of the current virtual reality medical training environments is their inability to provide the trainee with one of the medically most critical sensory inputs: the experience of tactile and force feedback (Dumay, 1995). While some of these drawbacks have been corrected in a few of the relatively simple systems available commercially, such devices offer only fragmented, single task-oriented solutions. Nonetheless, even with these recognized limitations, several VR-based training tools for exercising, e.g., suture placement skills (Ota et al., 1995), endoscopy (Blezek and Robb, 1997), bronchoscopy (Vining et al., 1996), arthroscopy (Ziegler et al., 1995), orthognatic surgery (Wagner et al., 1997), etc., become increasingly popular. Viewed as independent platforms, Human Patient Simulators (HPS; Christensen et al., 1997; Takashina et al., 1997) alone do not provide the richness of VR environments. However, training using HPS proved highly effective particularly in anesthesia (Fletcher, 1995; Pate-Cornell et al., 1997), in certain aspects of emergency medicine (Sanders et al., 1998), and in medical crisis management (Kurrek and Fish, 1996). The success of HPS training methods in these disciplines is particularly encouraging when viewed in the context of military and emergency medicine. However, the success also points at the significant limitations of "stand-alone" HPS approaches directed at procedure training. The latter deficiencies are eliminated by the introduction of the MRT which provides the trainee both with a sophisticated haptic interface and, by employing fully immersive virtual reality including sound and other sensory inputs, with the critically important environmental stressors (Edgar and Reeves, 1997). Combination of all these elements results in a very rich environment characteristic of complex, fast-paced, and intense medical operations typical of emergency or trauma medicine, in which the sensory input can be excessive and, at times, highly distracting as well.

Emergency and trauma medicine comprise the few medical specialties demanding rapid integration of discrete information elements into a coherent, outcome-oriented action stream subjected to a continuous modification by the variation in the nature of the incoming patient data. Yet, recent studies have shown significant deficiencies in diagnostic techniques not only among internal medicine but also emergency medicine residents (Mangione et al., 1995). Equally disturbing are the deficiencies in the mastery of pre-hospital physical assessment skills demonstrated in emergency medical technicians and combat medics (Vayer et al., 1994; see also DeLorenzo, 1997 and Butler et al., 1997). At the other end of the medical specialty spectrum, a significant erosion of skills has been observed among general practitioners in the areas distant from the metropolitan training centers (Wise et al., 1994). Thus, it is not surprising that many general practitioners find additional refresher training in advanced trauma/life support (ATLS) offered by the university centers a very useful tool in their subsequent approach to trauma patients (Ben-Abraham et al., 1997). Finally, the stress of practicing emergency/trauma medicine appears to have different impact on trained vs. non-trained personnel, as shown by Alagappan et al. (1996) in a study comparing the impact of a 4-week rotation on EM (emergency medicine) versus non-EM residents. While the level of psychological distress increased significantly in the latter group, the reverse trend characterized EM trained physicians. In summary, it is evident that the most optimal form of training will encompass several elements, i.e., a) medical realism; b) appropriate medical content and context; c) skills appropriate to the treated disorder; d) stress imposed by the emergency/trauma medicine patient; e) stress imposed by the environment. It is equally evident that in order to be optimal, such training must result in: a) mastery of manual skills appropriate to the level of medical training; b) mastery of appropriate diagnostic skills; c) ability to maintain mental overview ("mental readiness") of the medical situation despite its continuous fluidity; d) ability to manage intellectual and physical resources and e) ability to function with the maximum efficiency despite external stressor factors.

At present neither PC (personal computer), virtual reality, organ nor human patient-based training systems offer such training capacity or outcomes (although it must be mentioned that PC-based approaches incorporating some of the stressors are developed for other activities within the Armed Forces, see Pickett et al., 1998; McCarthy et al., 1998). Realistic training in management of multiple casualties, training of high level medical personnel responsible for the management of multi-patient facilities (or groups of such facilities) is entirely beyond the capacity of today's computer based educational systems (but see Christie and Levary, 1998). The lack of physical platforms that would allow training and exercising higher echelon medical management associated with relief/humanitarian activities or mass casualty scenarios hampers the development and maintenance of medical readiness at these levels even more (Baker and Ryals, 1996). The pressing needs for realistic training provided in equally realistic environment and under realistic pressure of real life, high intensity medical operations can be addressed through the implementation and evolution of the Medical Readiness Trainer.

The Components of the MRT

Most clinically oriented virtual reality based training applications have been organ- and/or procedure specific, e.g., VR simulators of laparoscopic (Marescaux et al., 1998; Ota et al., 1995), endoscopic (Baillie and Jowell, 1994; Dumay and Jense, 1995; Gessner et al., 1995), arthroscopic (Miller et al., 1995; Ziegler et al., 1995), and even neurosurgical procedures (Auer and Auer, 1998; the latter, however, a version of endoscopy). All of these approaches were addressing VR training using ideal anatomical features, with either minimal or highly unrealistic representation of surgical instruments, and minimal or non-existent instrument-tissue interaction feedback. The latter aspect, i.e., lack of haptic (touch) information that is critical for surgical manipulation of tissue (Lederman and Klatzky, 1993) has been clearly recognized as one of the major shortcomings of virtual reality surgical training (Barnes et al., 1997; Raibert et al., 1998). It must be noted, however, that both commercial (Bronchoscope, HT Medical, Inc. Rockville, MD) and experimental (Rudman et al., 1998) devices incorporating haptic input into virtual reality trainers are now available. Yet, all of these systems are limited to a narrow medical context environment, and do not allow execution and integration of complex, multi-level functions typical of many medical events (e.g., identification and diagnosis, initial stabilization and management, definitive treatment, etc.). The limited medical capacity of these devices is also the source of their inability to provide maximal stress intensity by exposing the trainee to a rapidly and unexpectedly changing procedure environment (e.g., sudden major bleeding requiring clamping of vessels, etc.). In summary, although the definitive studies assessing efficacy of VR based procedure trainers have not emerged yet; their efficacy in medical procedure training may be significant, while their value in training selections of procedure(s) in the broader context of patient management is very limited.

Many of these deficiencies are eliminated when training is performed using Human Patient Simulators (HPS). These integrative devices based on mathematical models, physio-chemical, and artificial interfaces (van Meurs, 1997), are capable of reproducing all medically essential outputs (vital signs, cardiovascular, pulmonary, and neurological parameters, pharmacologically correct drug responses, etc.). The unlimited, user-defined range of medical scenarios based on the parameters of "sudden-onset-disease" allows the trainee to practice rapid-sequence patient management incorporating simultaneous use of manual and diagnostic skills. Several papers describe the usefulness of HPS in training of anesthesiologists and demonstrate performance improvement using both qualitative and quantitative measures (Byrne et al., 1994; Arne et al., 1996; Chopra et al., 1994). In addition, HPS devices serve as ideal "standardized patients" whose use as superior diagnostic/skills training tools is advocated with increasing frequency (Ali et al., 1998; Chalabian and Dunnington, 1997; Bullens et al., 1997). The major drawback of HPS-driven education and training is their "fixed site" aspect that can not provide stress elements other than those related directly to the practiced scenario. Yet, it has been shown that it is the latter aspect that critically affects the performance of the involved personnel (McCarthy et al., 1998). A fully developed Medical Readiness Trainer (MRT) platform will incorporate the growing array of VR environments, simulation technology, and existing medical educational content (clinical medical database, visible human material, training videos, or web oriented computer based training) to create a powerful learning application leveraging the tactile stimulus of the HPS unit and the environmental stressor capabilities of virtual reality.

In the current configuration (FIG 1a), the MRT haptic feedback is provided by a medical simulation device, i.e., the HPS configured as a life size mannequin capable of realistic (and physiologically correct) reproduction of all diagnostically important parameters of a normal and disease-affected human patient. The Virtual

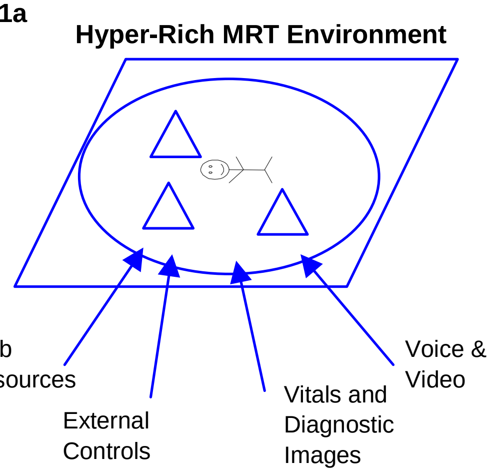
Reality (VR) element utilizes the CAVE™ , i.e., a projection-based VR system, that functions as the carrier of variable situation-based environments and the generator of psychological stessors appropriate for any given scenario. Thus, the Medical Readiness Trainer provides the ultimate training platform that, through the integration of fully immersive VR with highly advanced medical simulation technology exposes the trainee to the vast range of complex medical situations. The integral part of many of these training scenarios is the demand for instantaneous, maximum application of medical skill, psychological and (if needed) physical endurance, i.e., the elements frequently encountered in "real life" emergency and trauma medicine.

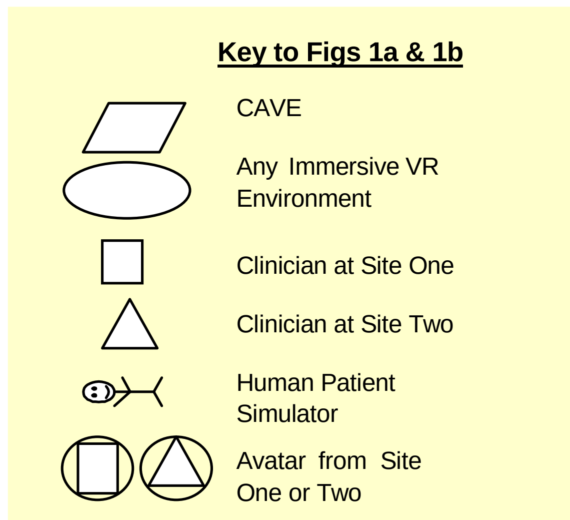
A completely new level of training reality is introduced by a network of MRTs (FIG 1b). Establishing such network comprised of Next Generation Internet (NGI)-connected Medical Readiness Trainers will allow expansion of training capability to the level of multiple patient scenarios, and also permit incorporation of the medical unit management training concept.

The simplest function of an MRT network will be to provide a very efficient "force multiplier" of medical training, where several widely dispersed trainees will participate simultaneously in highly realistic exercises under the guidance and supervision of a remotely placed medical expert. The directing expert will be either physically present in one of the CAVEs or direct the activity from an external Immersa Desk (I-desk) control post placed outside the CAVE environment, but linked to it via an NGI capable network. Thus, even in its basic functional form, the network of MRTs will offer medical readiness training at several discrete levels, i.e., **a**) manual skills/diagnostic training of the personnel centered on each Human Patient Simulator; **b**) training at the level of the attending physician (physician directing the network from within the CAVE network) whose main function is to provide medical supervision and monitoring of lower level staff (residents, technicians, nurses, etc. see Fig. 2). At the highest level of training hierarchy the MRT network will permit to develop and train consistently the command and leadership skills needed to direct several medical teams, each of which is located within their individual MRT unit.

Thus, the nationwide network of MRTs allows senior physicians and medical support personnel (e.g., attending/medical unit commander level) to learn and master critical and complex skills of medical management and logistics required in the environment of multiple casualties, limited facilities and support, etc. The current training for such functions is sporadic, expensive, and its rules are ill-defined. Unsurprisingly, the results are often inadequate and not always operationally useful. The global presence of HPS units and VR CAVEs is the

Fig. 1a





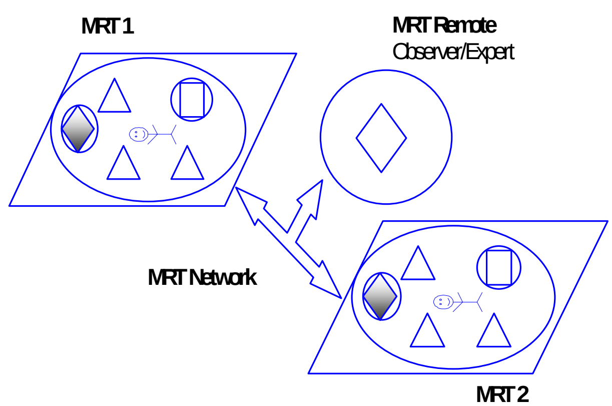


Fig. 1b

Figure 1 a dipicts a stand-alone MRT and figure 1b a simplified diagram of an MRT network. The symbols key applies to both figures. See the text for additional explanations.

foundation that facilitates future development of a global MRT training net providing a highly realistic platform for the development of international medical intervention standards, rules of collaboration within and among multinational medical teams (e.g., during WHO sponsored operations), etc.

While networking MRT is an unquestionably alluring concept, the creation of such a system introduces a new, much higher level of complexity. Presently, the collaborative virtual reality is considered to be one of the most challenging areas of research in the field (Leigh et al, 1997). However, significant pioneering work has already been done in the area of networked CAVE applications (for example, DeFanti et al., 1996; Leigh et al., 1996, Braham et al., 1997).

The preliminary MRT Configuration as a proof of concept

In its preliminary configuration, the MRT consists of a CAVE simulation of a fully immersive model of an existing emergency room at the University of Michigan Hospital and a generic operating suite (FIG 2). A tape recording of the Emergency Room during a busy period provides distracting stressor sounds. As a model of the supporting VR-based training tools a series of bit map flip books was used to render short video clips displayed in two dimensions on floating virtual "billboards" suspended within the virtual immersion space. Similar billboards are used to present ultrasound clips and web pages displaying web-based material from the University of Michigan Health Systems electronic medical record (CareWeb). At the periphery of the virtual ER bay are two virtual light boxes displaying digitized, DICOM-converted x-rays. The trainee can move the images and each of the billboards in and out of the direct field of view as the desired. The cumulative integration of the HPS unit, real monitoring equipment and visual background of a real life emergency room with diagnostic imagery, video clips, and electronically generated images of the medical records created a Hyper-Rich environment imposing a very high degree of situational realism.

MRT Tele-training

The teletraining version of the MRT is centered on the HPS/CAVE concept augmented with a remote control facility utilizing a control tablet and operating via a PPP and a modem/IP connection. The remote control capacity combined with standard H.320 or H.323 telemedicine technology allowed operation of the HPS unit(s) by a distant instructor, and permits transmission to- and execution of the clinical commands by the HPS. The test of the combined remote control facility/CAVE environments was conducted during the exercise with the trainee at the CAVE and the remote experts based at the US Navy Telemedicine Office at the Naval Hospital in Bethesda, MD.

Fig. 2 Prototype MRT configuration. Note billboards and ER fittings.

The exercise, during which three emergency medicine scenarios (cardiac emergency, crush injury, shock) proved the overall validity of the MRT concept, and demonstrated the efficiency of remotely controlled HPS/CAVE based training.

Further exploration of the HPS-based teletraining performed aboard a Coast Guard cutter (USCGC FORWARD) during her deployment as a part of the UNITAS 1999 fleet exercise and at the Roosevelt Roads Naval Hospital in Puerto Rico. Several training sessions were conducted during the ship's transit from Portsmouth, VA to the Roosevelt Roads Naval Station in Puerto Rico demonstrating the viability of HPS units as platforms for conducting Just-In-Time Medical Training. Another series of training sessions conducted at Roosevelt Roads Naval Hospital explored the concept of interactive teletraining. During the latter phase, both the Roosevelt Roads Naval Hospital's connection to the Internet and Plain Old Telephone (POTS) video conferencing technology were used, enabling scenario control and execution by the remote expert (a physician located in Michigan) to observe and coach the trainees in Puerto Rico. The quantitative data collected during the ship/shore deployment indicated a significantly enhanced level of medical preparedness and confidence ($p<0.05$, two way Student t-test; N=30 trainees) following MRT-based training. Further testing of the concept is currently in progress.

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