G. Riva, Ph.D.

Applied Technology
for Neuro-Psychology Lab.
Istituto Auxologico Italiano
Milan, Italy

Review Paper

Medical Applications of Virtual Environments

Abstract: Technologies that were hardly used ten years ago, such as the Internet, e-mail, and video teleconferencing are becoming familiar methods for diagnosis, therapy, education and training. However, the possible impact of virtual reality (VR) on health care is even higher than the one offered by the new communication technologies. In fact, VR is a technology, a communication interface and an experience: a communication interface based on interactive 3D visualization, able to collect and integrate in single real-like experience different inputs and data sets.

The first health care applications of VR started in the early ‘90s with the need for medical staff to visualize complex medical data, particularly during surgery and for surgery planning. A couple of years later, the scope of VR applications in medicine has broadened to include neuropsychological assessment and rehabilitation.

This paper intends to investigate the role of VR in medicine, presenting some of the most interesting applications actually developed in the area. Moreover, it discusses the clinical principles, technological devices and safety issues associated with the use of virtual reality in medicine.

1 Introduction

As recently noted by Satava and Jones [1], the advantages of virtual environments (VEs) to health care can be summarized in a single word: revolutionary. Since the development of methods of electronic communication, clinicians have been using information and communication technologies in health care: telegraphy, telephony, radio and television have been used for distance medicine since the mid 19th century [2]. However, rapid and far-reaching technological advances are changing the ways in which people relate, communicate, and live. Technologies that were hardly used ten years ago, such as the Internet, e-mail, and video teleconferencing are becoming familiar methods for diagnosis, therapy, education and training. However, the possible impact of virtual reality (VR) on health care is even higher than the one offered by the new communication technologies. In fact, VR is a technology, a communication interface and an experience. This is why research in the virtual reality field is moving fast. If we check the two leading clinical databases – MEDLINE and PSYCINFO – using the “virtual reality” keyword we can find 829 papers listed in MEDLINE and 693 in PSYCINFO (all fields query, accessed Aug. 8, 2002).

From the analysis of the retrieved papers we can find that the first health care applications of VR started in the early ‘90s with the need for medical staff to visualize complex medical data, particularly during surgery and for surgery planning [3]. Actually, surgery-related applications of VR fall mainly into three classes: surgery training, surgical planning and augmented reality for surgery sessions in open surgery, endoscopy, and radiosurgery. A couple of years later, the scope of VR applications in medicine has broadened to include neuropsychological assessment and rehabilitation [4, 5].

In recent years, VR has generated both great excitement and great confusion. These factors are evident in the extensive material published in both scientific and popular press, and in the unrealistic expectations on the part of the health care professionals. In this paper we try to outline the current state of research and technology that is relevant to the development of VEs in medicine. Moreover, we discuss the clinical principles, technological devices and safety issues associated with the use of virtual reality in medicine.

2 The role of VR in health care

2.1 The two faces of VR in health care

For many health care professionals VR is first of all a technology. Since 1986, when Jaron Lamier used the term for the first time, VR has usually been described as a collection of technological devices: a computer capable of interactive 3D visualization, a head-mounted display and data gloves equipped with one or more position trackers. The trackers sense the position and orientation of the user and reports that information to the computer that updates (in real time) the images for display.

However, the analysis of the different VR applications clearly shows that the focus on technological devices is different according to the goals of the health care provider.

For instance, Rubino et al. [6], McCloy and Stone [7], and Székely and Satava [8] in their reviews share the same vision of VR: "a collection of technologies that allow people to interact efficiently with 3D computerized databases in real time using their natural senses and skills" [7]. This definition lacks any reference to head mounted displays and instrumented clothing such as gloves or suits. In fact, less than 20% of VR health care applications in medicine actually use any immersive equipment.

However, if we shift our attention to behavioral sciences, where immersive devices are used by more than 50% of the applications, VR is described as "an advanced form of human-computer interface that allows the user to interact with and become immersed in a computer-generated environment in a naturalistic fashion" [9]. In fact, to achieve the feeling of "being there" the VR applications use specialized devices such as head-mounted displays, tracking systems, earphones, gloves, and sometimes haptic-feedback devices.

These two definitions underline two different visions of VR. For physicians and surgeons, the ultimate goal of VR is the presentation of virtual objects to all of the human senses in a way identical to their natural counterpart [8]. As noted by Satava and Jones [1], as more and more of the medical technologies become information-based, it will be possible to represent a patient with higher fidelity to a point that the image may become a surrogate for the patient – the *medical avatar*. In this sense, an effective VR system should offer real-like body parts or avatars that interact with external devices such as surgical instruments as close as possible to their real models.

For clinical psychologists and rehabilitation specialists the ultimate goal is radically different [10, 11]. They use VR to provide a new human-computer interaction paradigm in which users are no longer simply external observers of images on a computer screen but are active participants within a computer-generated three-dimensional virtual world. Within the VE the patient has the possibility of learning to manage a problematic situation related to his/her disturbance. The key characteristics of virtual environments for these professionals are both the high level of control of the interaction with the tool without the constraints usually found in computer systems, and the enriched experience provided to the patient [9]. Virtual environments are highly flexible and programmable. They enable the therapist to present a wide variety of controlled stimuli, such as a fearful situation, and to measure and monitor a wide variety of responses made by the user. This flexibility can be used to provide systematic restorative training that optimizes the degree of transfer of training or generalization of learning to the person's real world environment [12].

Moreover, virtual reality systems open the input channel to the full range of human gestures: in rehabilitation it is possible to monitor movements or actions from any body part or many body parts at the same time. On the other side, with disabled patients feedbacks and prompts can be translated into alternate and/or multiple senses [13].

2.2 VR as communication interface

As we have just seen, if we consider VR mainly as a technology, we have two different visions of VR related to the final goal of the health care professional. But what do these two visions have in common?

The starting point for answering to this question is a definition of VR presented by Heim. According to this author [14], VR is "an immersive, interactive system based on computable information… an experience that describes many life activities in the information age" (p.6). In particular, he describes the VR experience around its "three I's": immersion, interactivity and information intensity. Developing this position, Bricken [15] identifies the core characteristic of VR in the inclusive relationship between the participant and the virtual environment, where direct experience of the immersive environment constitutes communication. According to this position, VR can be considered as the leading edge of a general evolution of present communication interfaces like television, computer and telephone [16, 17]. The main characteristic of this evolution is the full immersion of the human sensorimotor channels into a vivid and global communication experience [18].

Following this approach, it is also possible to define VR in terms of human experience [19] "a real or simulated environment in which a perceiver experiences telepresence," where telepresence can be described as the "experience of presence in an environment by means of a communication medium" (pp.78-80).

This position better clarifies the possible role of VR in medicine: a communication interface based on interactive 3D visualization, able to collect and integrate different inputs and data sets in a single real-like experience. It is up to the health care provider to decide if the VR application will be more focused on the integration of different data sets or on the realism of the virtual experience (or "sense of presence"). Considering VR as a communication interface also helps health care developers to focus their efforts.

Most of the work in this area is trying to improve the efficacy of a VE by providing the user with a more "realistic" experience, such as adding physical qualities to virtual objects or improving graphical resolution. But is this focus on the graphical characteristics really so important for the effectiveness of a medical VE?

Probably, apart from some high-end surgical applications, the answer is no. More than the richness of available images, the sensation of presence depends on the level of interaction/ interactivity which actors have in both "real" and simulated environments [20]. According to Sastry and Boyd [20] a VE, particularly when it is used for real world applications, is effective when "the user is able to navigate, select, pick, move and manipulate an object much more naturally (pp.235). In this sense, emphasis shifts from quality of image to freedom of interaction, from the graphic perfection of the system to the affordances provided to the users in the environment [21].

This approach has recently received the status of international standard, through the International Organization for Standardization's ISO 13407 "Human centered design for interactive systems". According to the ISO 13407 standard [22], human-centered design requires:

- the active involvement of users;
- clear understanding of use and task requirements;
- appropriate allocation of function;
- the iteration of design solutions;
- a multi-disciplinary design team;

and it is based around the following processes:

- Understand and specify the context of use;
- Specify the user and organizational requirements;
- Produce designs and prototypes;
- Carry out user-based assessment.

A sample of VE developed using the ISO 13407 guidelines is the IERAPSI surgical training system [7, 23].

3 Applications of Virtual Reality in Medicine

3. 1 Medical education

The teaching of anatomy is mainly illustrative, and the application of VR to such teaching has great potential. Through 3-D visualization of massive volumes of information and databases, clinicians and students can understand important physiological principles or basic anatomy. For instance, VR can be used to explore the organs by "flying" around, behind, or even inside them. In this sense VEs can be used both as didactic and experiential educational tools, allowing a deeper understanding of the interrelationship of anatomical structures that cannot be achieved by any other means, including cadaveric dissection.

A significant step towards the creation of VR anatomy textbooks was the acquisition of the Visible Human male and female data made in August of 1991 by the University of Colorado School of Medicine [24]. The Visible Human female data set contains 5189 digital anatomical images obtained at 0.33-mm intervals (39 Gbyte). The male data set contains 1971 digital axial anatomical images obtained at 1.0-mm intervals (15 Gbyte). [25]. Actually, the US National Library of Medicine in partnership with other US government research agencies has begun the development of a tool kit of computational programs capable of automatically performing many of the basic data handling functions required for using Visible Human data in applications [26].

The National Library of Medicine made the data sets available under a no-cost license agreement over the Internet. This allowed the creation of a huge number of educational VEs. In their recent edited book, Westwood and colleagues [27] report more than ten different educational and visualization applications.

In the future we can expect the development of different VR dynamic models illustrating how various organs and systems move during normal or diseased states, or how they respond to various externally applied forces (e.g., the touch of a scalpel).

3.2 Surgical simulation and planning

Surgeons know well that in training there is no alternative to hands-on practice. However, students wishing to learn laparoscopic procedures face a tough path [28]: usually they start using laparoscopic cholecystectomy trainers consisting of a black box in which endoscopic instruments are passed through rubber gaskets. After, the students begin practicing these techniques on inanimate tissues, when cost and availability allow. Obviously, there is a substantial difference for students between training with artificial or inanimate tissues and supervised procedures on real patients. This is why in the early 1990s, different research teams tried to develop VE simulators [29, 30]. The science of virtual reality provides an entirely new opportunity in the area of simulation of surgical skills using computers for training, evaluation, and eventually certification [31]. However, the first simulators were limited by low-resolution graphics, the lack of tactile input and force feedback and the lack of realistic deformation of organs. In the last years a new generation of simulators has appeared that has showed improved training efficacy over traditional methods. For instance, a randomized trial using the Minimally Invasive Surgery Training-Virtual Reality (MIST-VR) trainer [32] showed that

Fig. 1. Minimally Invasive Surgery Training-Virtual Reality (MIST-VR) trainer (Mentice Medical Simulation AB, Gothenburg, Sweden).

Virtual reality simulation was effective in training the novice to perform basic laparoscopic tasks (see Figure 1).

Another typical use of visualization applications is the planning of surgical and neuro-surgical procedures [33-35]. The planning of these procedures usually relies on the studies of series of two-dimensional MR (Magnetic Resonance) and/or CT (Computer Tomography) images, which have to be mentally integrated by surgeons into a three-dimensional concept. This mental transformation is difficult, since complex anatomy is represented in different scanning modalities, on separate image series, usually found in different sites/departments. A VR-based system is capable of incorporating different scanning modalities coming from different sites providing a simple to use interactive three-dimensional view. Within the Virtual Collaborative Clinic project, NASA researchers developed Cyberscalpel, a typical VR based surgical system for planning and practice [36]. To plan the operation of a patient with cancer of the jaw, the upper and lower jaws were reconstructed using Cyberscalpel starting from a CT scan. The scan was reduced to 20000 polygons and the final model was used to prove how fibular bone could be sectioned to mimic and replace the jaw pieces.

3.3 Virtual Endoscopy

Every year the screening for cancer requires the performance of over 2 million video colonoscopic procedures. However, these procedures are not perfect:

- all endoscopic procedures are invasive;
- the patients are subject to complications such as perforation, bleeding, etc.
- the cost for a typical colonoscopy is significant.

To overcome these problems, different researchers are investigating the possibility of virtual endoscopy [6, 37]. Virtual endoscopy is a new procedure that fuses computed tomography with advanced techniques for rendering three-dimensional images to produce views of the organ similar to those obtained during "real" endoscopy. A virtual endoscopy is performed by using a standard CT scan or MRI scan [1], reconstructing the organ of interest into a 3-D model, and then performing a fly through it. Typical examples include the colon, stomach, esophagus, tracheo-bronchial tree (bronchoscopy), sinus bladder, ureter and kidneys (cystoscopy), pancreas or biliary tree.

Virtual endoscopy is completely non-invasive and thus without known complications. The actual cost is less than traditional endoscopy, since it is performed in the same place and manner as all imaging modalities, utilizes the same staff, and has no consumable materials.

3.4 VR in neuro-psychological assessment and rehabilitation

VR is starting to play an important role in clinical psychology [38, 39], which is expected to increase in the next years. According to a recent positioning paper on the future of psychotherapy [40], the use of VR and computerized therapies are ranked respectively 3rd and 5th out of 38 psychotherapy interventions that are predicted to increase in the next 10 years.

In most VEs for clinical psychology, VR is used to simulate the real world and to assure the researcher full control of all the parameters implied. VR constitutes a highly flexible tool, which makes it possible to program an enormous variety of procedures of intervention on psychological distress. The possibility of structuring a large amount of controlled stimuli and, simultaneously, of monitoring the possible responses generated by the user of the virtual world offers a considerable increase in the likelihood of therapeutic effectiveness, as compared to traditional procedures [17]. In particular, a key advantage offered by VR is the possibility for the patient to manage a problematic situation related to his/her disturbance successfully. Using VR in this way, the patient is more likely not only to gain an awareness of his/her need to do something to create change but also to experience a greater sense of personal efficacy.

In general, these techniques are used as triggers for a broader empowerment process. In psychological literature *empowerment* is considered a multifaceted construct reflecting the different dimensions of being psychologically enabled, and is conceived as a positive additive function of the following three dimensions [41]

- *perceived control*: includes beliefs about authority, decision-making skills, availability of resources, autonomy in the scheduling and performance of work, etc;
- *perceived competence*: reflects role-mastery, which besides requiring the skillful accomplishment of one or more assigned tasks, also requires successful coping with non-routine role-related situations;
- *goal internalization*: this dimension captures the energizing property of a worthy cause or exciting vision provided by organizational leadership.

Virtual reality can be considered the preferred environment for the empowerment process, since it is a special, sheltered setting where patients can start to explore and act without feeling threatened. In this sense the virtual experience is an "empowering environment" that therapy provides for patients. As noted by Botella [42], nothing the patient fears can "really" happen to them in VR. With such assurance, they can freely explore, experiment, feel, live, and experience feelings and/or thoughts. VR thus becomes a very useful intermediate step between the therapist's office and the real world.

Even if the clinical rationale behind the use of VR is now clear, much of this research growth, however, has been in the form of feasibility studies and pilot trials. As a result there is still limited convincing evidence available from controlled studies (see Table 1), of the clinical advantages of this approach. Up to now the clinical effectiveness of VR was only verified in the treatment of these four psychological disorders: acrophobia, body image disturbances, binge eating disorders (see Figure 2, next page) and fear of flying.

Table 1. Controlled Trials with more than 10 patients/users included in Medline/PsycInfo.

Workstation	**Indicative Prices (as 01 Aug 02)**
SGI Origin 3200, R12K Graphic Card, 8x400MHz processors, 8 Gbyte RAM, 220 Gbyte Hard Disk	US$ 5000
SGI Octane2, V12 Graphic Card, 2x400MHz processors, 512 Mbyte Ram, 18 Gbyte Hard Disk	US$ 23000
Xeon branded PC, 2x2.7 Ghz processors, 512 Mbyte Ram, 80 Gbyte Hard Disk and 17" monitor	US$ 3800
Pentium IV or Athlon XP branded PC, 2.7 Ghz processor, 512 Mbyte Ram, 80 Gbyte Hard Disk and 17" monitor	US$ 2200
Consumer graphic cards	
GeForce NV30 128 Mbyte Vram AGP	US$ 400
Radeon 9700 128 Mbyte Vram AGP	US$ 400
Professional graphic cards	
Quadro4 900XGL 128 Mbyte Vram AGP	US$ 1200
Fire GL X1 256 Mbyte Vram AGP	US$ 1200
Tracking system	
Polhemus Fastrak	US$ 7000
Ascension PC Flock of Birds	US$ 2200
Intersense Intertrax 2	US$ 1100
3D Shutter Glasses	
StereoEyes Wireless	US$ 320
Elsa 3D Revelator IR	US$ 180
VRex Cordless	US$ 100
Head Mounted Display	
Kaiser Proview XL 40/50 (XGA resolution – 3D, wide fov)	US$ 50000
N-visor Datavisor Hi-res (XGA resolution – 2D, wide fov)	US$ 35000
Daeyang I-Visor DH4400 VP 3D (SVGA resolution – 3D)	US$ 1900
Olympus Eye-Trek FMD-700 (SVGA resolution – 2D)	US$ 1300
Daeyang I-Visor DH4400 VP (SVGA resolution – 2D)	US$ 1200
Olympus Eyetrek 250 W (Video output only – 2D)	US$ 600
Sony Glasstron PLM-A35 (Video output only – 2D)	US$ 500
VR Gloves	
Pinch Glove	US$ 2000
5DT Right Hand	US$ 650

In the cognitive rehabilitation area the situation is even worse. Even if different case studies and review papers suggest the use of VR in this area [9, 12, 43-47] there are no controlled clinical trials to support this position. A better situation can be found in the assessment of cognitive functions in persons with acquired brain injuries. In this area VR assessment tools are effective and characterized by good psychometric properties [48-52]. A typical example of these applications is ARCANA. Using a standard tool (Wisconsin Card Sorting Test - WCST) of neuropsychological assessment as a model, Pugnetti and colleagues have created ARCANA: a virtual building in which the patient has to use environmental clues in the selection of appropriate choices (doorways) to navigate through the building. The doorway choices vary according to the categories of shape, color, and number of portholes. The patient is also required to refer to the previous doorway for clues to appropriately make his/her next choice. After the choice criteria are changed, the patient must shift the cognitive set, analyze clues, and devise a new choice strategy. The parameters of this system are fully adjustable so that training applications can follow initial standardized assessments.

4 VR Hardware and Software

For many years one of the main obstacles to the development of VR applications was the price of the equipment: a typical VR system required a costly fridge-size Silicon Graphic workstation in the range of 150000 US$ and up. Even if high-end applications still require powerful workstations such as SGI Origin or

Fig.2. The Virtual Reality for Eating Disorders Modification - VREDIM (Istituto Auxologico Italiano I.R.C.C.S., Milan, Italy).

Octane (see Table 2), during the last two years about 60% of the VR applications for health care were developed for use on PC platforms.

The significant advances in PC hardware that have been made over the last five years are transforming PC-based VR into reality. The cost of a basic desktop VR system has gone down by many thousand dollars since that time, and the functionality has improved dramatically in terms of graphics processing power. A simple immersive VR system now may cost less than 6000 US$ (see Table 1).

The availability of powerful PC engines based on such computing work-horses as Intel's Xeon and IBM G4/G5 processors, and the emergence of reasonably priced Direct 3D and OpenGL-based 3D accelerator cards allow high-end PCs to process and display interactive 3D simulations in real time.

While a standard Celeron/Duron processor with as little as 64 Mbytes of RAM can provide sufficient processing power for a simple VR simulation, a fast Pentium IV/Athlon XP-based PC (2.2 Ghz or faster) with 256 Mbytes of RAM, can transport users to a convincing virtual environment, while a dual Xeon configuration (2.4 Ghz or faster) with 1 Gbyte of RAM, OpenGL acceleration and 128 Mbytes of VRAM running Windows XP Pro rivals the horsepower of a mid-level graphics workstation.

The graphics card landscape is also evolving quickly. In particular, two advancements are interesting for VR users: the inclusion of a VGA-to-TV converter and tuner, the Accelerated Graphics Port (AGP) and the new faster 3D chips (GeForce NV30/35, Radeon 9700/9800) with 128 Mbytes or more of dedicated video Ram (VRam).

- *Accelerated Graphics Port (AGP):* The accelerated graphics port is a high-speed, point-to-point connection between the system chip set and the graphics chip. AGP provides a high-speed pipeline between the graphics accelerator and the PC's system memory: using an AGP connection, a graphics chip is able to access system memory directly through the system chip set at memory-bus speeds, reducing latency and substantially increasing performance versus standard PCI-memory transfers. The graphics card gains access to system RAM to store and execute texture bitmaps, which allows more detailed textures of unlimited size while speeding 3-D rendering. When textures are large, AGP can make the difference between smooth or choppy frame rates in 3-D rendering.

- *Faster 3D cards*: In VR, performance is critical. VEs gave mainstream 3-D acceleration its start, and developers have been adding a sense of realistic depth to their creations for years. However, the addition of a *z*-axis in rendering, as opposed to simply drawing on an *x*, *y*-coordinate plane, requires more sophisticated horsepower. In addition, VR applications contain more complex objects and complex *textures*: bitmap renderings of detailed surfaces (bricks, sand, or transparent water) that heighten realism. To exploit this potential, a fast graphics card with a lot of video Ram is a must. Happily, the new chip sets (GeForce NV30/35 and Radeon 9700) included in consumer graphics cards have 8 times more video Ram and 3,5 times more 3-D acceleration than the first generation of chips (GeForce and Radeon VE) for a price tag of less than US$500. Also, professional graphics cards received a significant speed bump. New Open GL cards such as the Quadro 4 900XGL or the FireGLX1 offer graphics power that rival the one provided by Unix graphic workstations.

- *VGA-to-TV converter*: One welcomed feature of the new graphics cards is the inclusion of a VGA-to-TV (NTSC or PAL) converter and TV tuner right on the card. This feature lets you display computer data on a standard

Table 2. VR Hardware.

Authors	Paper	Sample
Emmelkamp, P.M.G., Bruynzeel, M., Drost, L., & van der Mast, C.A.P.G.	(2001) Virtual reality treatment in acrophobia: A comparison with exposure in Vivo, *Cyberpsychol Behav, 4*(3), 335-339.	10 acrophobia patients
Ali, M.R., Mowery, Y., Kaplan, B., DeMaria, E.J.	(2002) Training the novice in laparoscopy. *Surg Endosc, 16 (8), 1, 1210-1216.*	27 high school students
Emmelkamp, P.M.G., Krijn, M., Hulsbosch, A.M., de Vries, S., Schuemie, M.J., van der Mast, C.A.P.G.	(2002) Virtual reality treatment versus exposure in vivo: a comparative evaluation in acrophobia, *Behav Res Ther,* 40, 509–516.	33 acrophobia patients
Grundman, J. A., Wigton, R. S., & Nickol, D.	(2000). A controlled trial of an interactive, web-based virtual reality program for teaching physical diagnosis skills to medical students. *Acad Med, 75*(10 Suppl), S47-49.	121 medical students
Hoffman, H. G., Patterson, D. R., & Carrougher, G. J.	(2000). Use of virtual reality for adjunctive treatment of adult burn pain during physical therapy: a controlled study. *Clin J Pain, 16*(3), 244-250.	12 burn patients
Riva, G., Bacchetta, M., Baruffi, M., & Molinari, E.	(2001). Virtual reality-based multidimensional therapy for the treatment of body image disturbances in obesity: a controlled study. *Cyberpsychol Behav, 4*(4), 511-526.	28 obese patients
Riva, G., Bacchetta, M., Baruffi, M., & Molinari, E.	Virtual reality-based multidimensional therapy for the treatment of body image disturbances in binge eating disorders: A preliminary controlled study *IEEE Transactions on Information Technology in Biomedicine, in press, 2002.*	20 binge eating patients
Rothbaum, B. O., Hodges, L. F., Kooper, R., Opdyke, D., & et al.	(1995). Effectiveness of computer-generated (virtual reality) graded exposure in the treatment of acrophobia. *American Journal of Psychiatry, 152*(4), 626-628.	17 college students
Rothbaum, B. O., Hodges, L., Smith, S., Lee, J. H., & Price, L.	(2000). A controlled study of virtual reality exposure therapy for the fear of flying. *J Consult Clin Psychol, 68*(6), 1020-1026.	49 fear of flying patients
Torkington, J., Smith, S. G., Rees, B. I., & Darzi, A.	(2001). Skill transfer from virtual reality to a real laparoscopic task. *Surg Endosc, 15*(10), 1076-1079.	30 medical students
Wiederhold, B.K., Jang, D.P., Kim, S.I., & Wiederhold, M.D.	(2002). Physiological monitoring as an objective tool in virtual reality therapy, *Cyberpsychol Behav. 5*(1) 77-82.	36 fear of flying patients, 22 non-phobics
Wiederhold, B.K., Jang, D.P., Kim, S.I., & Wiederhold, M.D.	(2002). A controlled trial comparing physiological responses during virtual reality exposure and imaginal exposure in flight phobics. *IEEE Transactions on Information Technology in Biomedicine, in press, 2002.*	30 fear of flying patients

television without the need for an external scan converter (usually US$100 or more). Business users can then give PC-based presentations with TVs as large-screen monitors, and home users can play computer games on their TV sets. However this feature is also useful for VR users: thanks to the converter it is possible to use - without any extra hardware - the new low-cost DVD oriented head-mounted displays from Olympus (EyeTrek, 600 US$) or Sony (Glasstron PLM-A35, 500 US$).

On the software side, an interesting low cost solution is the use of 3D engines included in commercial 3D games for developing simple virtual environments. Many 3D games (US$ 50 each), such as Quake 3 or Unreal, include level editors that allow the user to customize the environments and the avatars. Moreover, Discreet has released the free software, *gmax*™, which allows the professional customization of 3D games. Intended to be a fully capable 3D level editing, modeling, animation, and texture-mapping tool, *gmax* ships with a full suite of professional 3D content and animation features. Discreet approved game developers can publish *gmax* "game packs", which customize the downloadable version of *gmax* into a fully featured level editor for supported game titles. Using this software, it is possible to edit and create 3D environments, materials, 3D objects, weapons, images and lights.

Obviously, level editing does not allow full control of the environment. In particular, the user interaction with the 3D objects is usually very limited. To overcome this limitation, now there are different VR development toolkits available for PCs, ranging from high-end authoring toolkits that require significant programming experience to simple "hobbyist" packages. Despite the differences in the types of virtual worlds these products can deliver, the various tools are based on the same VR-development model: they allow users to create or import 3D objects, to apply behavioral attributes such as weight and gravity to the objects, and to program the objects to respond to the user via visual and or audio events. Ranging in prices from free (http://www.alice.org) to US $5000 (Virtools Dev 2.1 or Sense 8 WorldUp R5), the toolkits are the most functional of the available VR software options. While some of them rely exclusively on C or C++ programming to build a virtual world, others offer simpler point-and-click operations to develop a simulation. Using VR toolkits, it is also possible to bring in files from a wide array of software packages, such as Wavefront, 3D Studio, EDS Unigraphics, Pro Engineer, and Intergraph EMS, and they can also import VRML and Multigen databases as well as animation scripts and sounds.

5 Challenges and Open Issues

5.1 Technical challenges

Even if the significant advances in computer and graphic technology drastically improved the characteristics of a typical VE, VR is still limited by the maturity of the systems available. Even today, no off-the-shelf solutions are available. So, the set up of a VR system usually requires a lot of patience for dealing with conflicting hardware or lacking drivers. Nearly every VR system requires a dedicated staff member or at least a computer technician to keep the system running smoothly. Moreover, much VR technology is still uncomfortable or unpleasant to use. In particular here are some current VR technology limitations for users [53]:

- Virtual acoustic displays that require a great deal of computational resources in order to simulate a small number of sources;
- Force and tactile displays, still in their infancies, with limited functionality;
- Image generators that can't provide low-latency rendering of head tracked complex scenes, requiring severe trade-offs between performance & scene quality;
- Position trackers with small working volumes, inadequate robustness, and problems of latency and poor registration.
- HMDs with limited field of view, and encumbering form factor;

As we have seen, a typical area for VR applications is surgery. However, there have been few developments in the area of tactile feedback. The ability to feel tissue is important. Procedures that require palpitation, such as artery localization and tumor detection, are extremely difficult when the only form of haptic exploration is in the form of forces transmitted through long, clumsy instruments. As noted by Moline [54], "The ability to remotely sense small scale shape information and feel forces that mesh with natural hand motions would greatly improve the performance of minimally invasive surgery and bring a greater sense of realism to virtual trainers" (p. 21).

5.2 Safety Issues

The introduction of patients and clinicians to VEs raises particular safety and ethical issues [28]. In fact, despite developments in VR technology, some users still experience health and safety problems associated with VR use [55]. The key concern from the literature is VR-induced sickness, which could lead to problems [56] including:

- symptoms of motion sickness;
- strain on the ocular system;
- degraded limb and postural control;
- reduced sense of presence;
- the development of responses inappropriate for the real world, which might lead to negative training.

The improved quality of VR systems is drastically reducing the occurrence of simulation sickness. For instance, a recent review of clinical applications of VR reported instances of simulation sickness are few and nearly all are transient and minor [4]. In general, for a large proportion of VR users these effects are mild and subside quickly [55].

Nonetheless, patients exposed to virtual reality environments may have disabilities that increase their susceptibility to side effects. Precautions should be taken to ensure the safety and well being of patients, including established protocols for monitoring and controlling exposure to virtual reality environments.

Strategies are needed to detect any adverse effects of exposure, some of which may be difficult to anticipate, at an early stage. According to Lewis & Griffin [56] exposure management protocols for patients in virtual environments should include:

- Screening procedures to detect individuals who may present particular risks.
- Procedures for managing patient exposure to VR applications to ensure rapid adaptation with minimum symptoms.
- Procedures for monitoring unexpected side effects and for ensuring that the system meets its design objectives.

Finally, the effect of VEs on cognition is not fully understood. In a recent report, the US National Advisory Mental Health Council [57] suggested that "Research is needed to understand both the positive and the negative effects [of VEs]... on children's and adult's perceptual and cognitive skills." Such research will require the merging of knowledge from a variety of disciplines including (but not limited to) neuropsychology, neuroimaging, educational theory and technology, human factors, medicine, and computer science.

5.3 Research and clinical issues

In the last five years there has been a steady growth in the use of virtual reality in health care due to the advances in information technology and to the decline in costs [58]. As we have seen, using the "virtual reality" keyword we can find 829 papers listed in MEDLINE and 693 in PSYCINFO (accessed Aug. 8 2002). Much of this growth, however, has been in the form of feasibility studies and pilot trials.

The "best" evidence in evaluating the efficacy of a therapy/approach is the results of randomized, controlled clinical trials. However, if we check the available literature we can find only twelve controlled trials (see Table 2).

Three tested the training possibilities offered by VR: in surgical training and in teaching physical diagnosis skills. Eight verified the effectiveness of VR in the treatment of four psychological disorders: acrophobia, body image disturbances, binge eating disorders and fear of flying. The final study analyzed the use of VR in the treatment of adult burn pain.

Why there are so few controlled trials in VR research? There are three possible answers .

First, the lack of standardization in VR devices and software. To date, very few of the various VR systems available are interoperable. This makes their use in contexts other than those in which they were developed difficult.

Second, the lack of standardized protocols that can be shared by the community of researchers. If we check the two clinical databases, we can find only four published clinical protocols: for the treatment of eating disorders [59], fear of flying [60], fear of public speaking [61] and panic disorders [62].

Finally, the costs required for the set-up trials. As we have just seen, the lack of interoperable systems added to the lack of clinical protocols force most researchers to spend a lot of time and money in designing and developing their own VR application: many of them can be considered “one-off” creations tied to proprietary hardware and software, which have been tuned by a process of trial and error. According to the European funded project VEPSY Updated [63], the cost required for designing a clinical VR application from scratch and testing it on clinical patients using controlled trials may range between 150000 and 200000 US$. As noted by a recent report prepared by the US National Research Council [64], “the government support has been the single most important source of sustained funding for innovative research in both computer graphics and VR. Beginning in the 1960s with its investments in computer modeling, flight simulators, and visualization techniques, and continuing through current developments in virtual worlds, the federal government has made significant investments in military, civilian, and university research that laid the groundwork for one of today’s most dynamic technologies. The commercial payoffs have included numerous companies formed around federally funded research in graphics and VR.” (p. 227). In Europe, the most important source of funding for health care VR applications was the European Commission through its Information Society Technology programme. However, in the last five years the funds for VR research coming from the European Commission has been between one-third and one-fifth of the total amount distributed by the US government.

6. Conclusions

In general, the review of current applications show that VR can be considered a useful tool in diagnosis, therapy, education and training. However, several barriers still remain. The PC-based systems, while inexpensive and easy-to-use, still suffer from a lack of flexibility and capabilities necessary to individualize environments for each patient [65]. On the other hand, in most circumstances the clinical skills of the therapist remain the most important factor in the successful use of VR systems. It is clear that building new and additional virtual environments is important so therapists will continue to investigate applying these tools in their day-to-day clinical practice [4]. Further, many of the actual VR applications are in the clinical investigation or laboratory stage, as clearly shown by the lack of controlled trials.

Significant efforts are still required to move VR into commercial success and therefore routine clinical use. Possible future scenarios will involve multi-disciplinary teams of engineers, computer programmers, and therapists working together to treat specific clinical problems. Finally, communication networks have the potential to transform VEs into shared worlds in which individuals, objects, and processes interact without regard to their location. In the future, such networks will probably merge VR and telemedicine applications allowing us to use VE for such purposes as distance learning, distributed training, and e-therapy.

It is hoped that by bringing together this community of experts, further stimulation of interest from granting agencies will be accelerated. Information on advances in VR technology must be made available to the health care community in a format that is easy-to-understand and invites participation [66]. Future potential applications of VR are really only limited by the imaginations of talented individuals.

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Address of the author:
Prof. Giuseppe Riva, Ph.D.
Dipartimento di Psicologia
Università Cattolica del Sacro Cuore
Largo Gemelli 1
20123 Milan, Italy
Tel: +39-02-58216892
Fax: +39-02-70034918
E-mail: auxo.psylab@auxologico.it
Web site: http://www.atnplab.com