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Virtual reality applications to work

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Abstract

Virtual reality (VR) entails the use of advanced technologies, including computers and various multimedia peripherals, to produce a simulated (i.e. virtual) environment that users perceive as comparable to real world objects and events. With the aid of specially designed transducers and sensors, users interact with displayed images, moving and manipulating virtual objects, and performing other actions in a way that engenders a feeling of actual presence (immersion) in the simulated environment. The unique features and flexibility of VR give it extraordinary potential for use in work-related applications. It permits users to experience and interact with a life-like model or environment, in safety and at convenient times, while providing a degree of control over the simulation that is usually not possible in the real-life situation. The work-related applications that appear to be most promising are those that employ virtual reality for visualization and representation, distance communication and education, hands-on training, and orientation and navigation. This article presents an overview to the concepts of VR focusing on its applications in a variety of work settings. Issues related to potential difficulties in using VR including side effects and the transfer of skills learned in the virtual environment to the real world are also reviewed. © 1998 Elsevier Science Ireland Ltd. All rights reserved.

Keywords: Virtual reality; Virtual environments; Transfer; Side effects; Computer simulation; Immersion

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Imagine the following scenario. The city planners and inspectors want to explore your company's new urban shopping development, to help them complete their environmental impact assessment before construction begins. As Assistant Project Manager, you have arranged a tour of a computer-simulated prototype.

You walk into your office, sit down at a table, and turn on the Dome. A large image projected on the wall extends the table 'through the screen'. The other participants are already there, each represented around the table by an animated figure, a virtual

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human that presents the appropriate gestures, facial expressions and body language of the actual participant.

You hear a familiar voice behind you. Turning around, you are pleased to see that the chief architect's image has just arrived. It's already evening at her office in Tokyo, so you hadn't expected her to attend. You've never met her in person, only via these immersive company meetings. She speaks with a British accent. You wonder whether you are hearing her directly, or through an automatic translator.

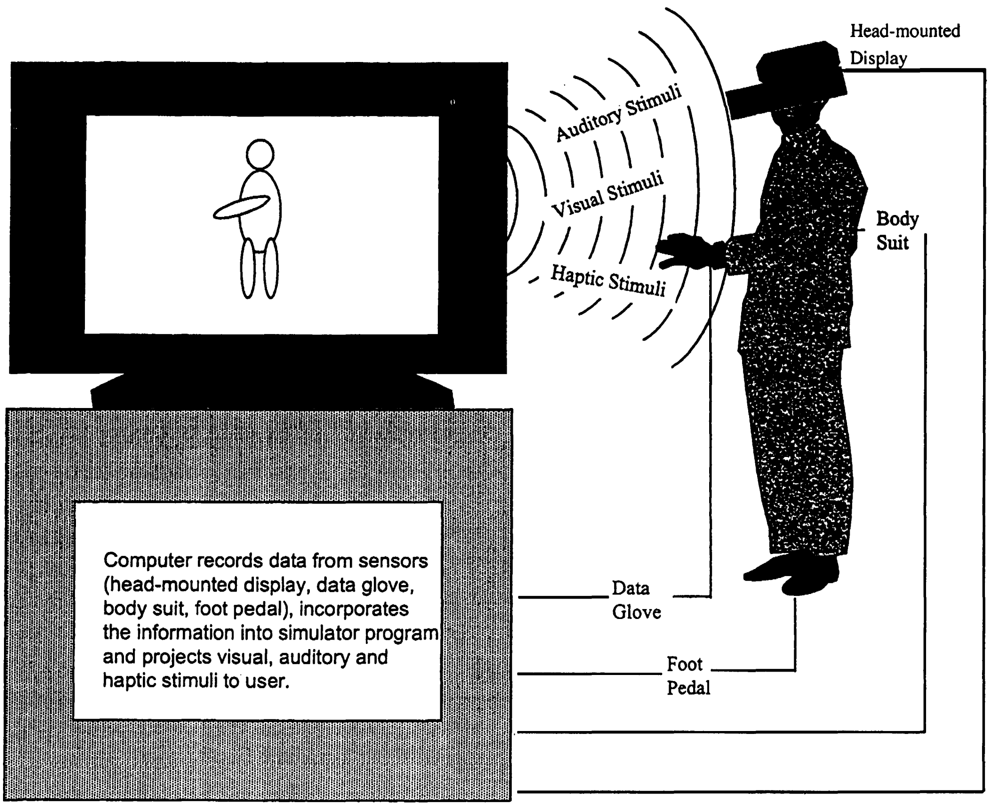
After the usual greetings and preliminaries, the group takes a virtual walk-through of the proposed mall, the sounds of your footsteps reverberating through the spacious, brightly lit virtual corridors. The city planners seem impressed with the layout, and you decide to take them on a simulated drive-through around the perimeter. You step into the underground parking garage, and together you assume seats in the virtual car. Unfortunately, as you are pulling out of the garage, one of the inspectors notices that there are only two fire escapes. He browses the building code on his PC and projects the relevant information on the garage wall to the left. Shamefaced at forgetting such an obvious requirement, you quickly begin to sketch in a third exit-way, the computer vision system tracking your hand movements as they move through the air. The faces of the other figures register impatience, with only the architect sending a private word of encouragement. The addition completed, you open the door to the new stairwell and lead them through it to the outside, the architect complimenting you on your choice of tiles. The city planners are clearly pleased with the outdoor landscaping, particularly the water-park, one enthusiastic official even donning his cyberglove to feel the cool water. A few more on-the-spot alterations are made to the height of the southern wing when it was observed to block the view of a historic landmark, and then the project was approved for immediate construction. As you say goodbye and close the Dome, you call up your boss to tell him the good news, and begin preparing for this afternoon's meeting with the team in Brazil.

Although this scenario may seem highly speculative, the features described are already being tested and implemented individually. It gives some idea of the work-related possibilities offered by what is popularly known as 'virtual reality'. This paper details some of the applications envisioned for this new technology, attempting to present a realistic appraisal of its potential application to work settings.

1. What is virtual reality?

Virtual reality (VR) entails the use of advanced technologies, including computers and various multimedia peripherals, to produce a simulated (i.e. virtual) environment that users perceive as comparable to real world objects and events. With the aid of specially designed transducers and sensors, users interact with displayed images, moving and manipulating virtual objects, and performing other actions in a way that engenders a feeling of actual presence in the simulated environment (see Fig. 1). This is accomplished by having the simulation adjust to movements of the user's body, so that the sensory cues always correspond to what users would expect were they performing the action in the real world. For example, the software ensures that the visual scene is always appropriate to the particular direction in which the user happens to be looking. Visual feedback is often supplemented by auditory cues that appear to remain in particular locations independent of changes in head position and the presentation of appropriately timed haptic, proprioceptive and vestibular information.

Despite the fact that virtual reality has greatly changed the way in which people are able to interact with and manipulate information, the technology is, in fact, an outgrowth of earlier generations of computing, and some of its core components have been in use for some time. It is a natural outcome of the continued development of computer technology, including the availability of larger random access memory (RAM), faster processing speed, higher capacity storage media, diverse input interfaces, assorted multimedia peripherals, such as digital cameras, sound and graphics cards and high speed CD-ROMs, and a burgeoning software industry that is scrambling to develop more realistic three-dimensional applications.



Computer records data from sensors (head-mounted display, data glove, body suit, foot pedal), incorporates the information into simulator program and projects visual, auditory and haptic stimuli to user.

Fig. 1. Schematic illustration of an immersive virtual reality system.

One of the cardinal features of virtual reality is the provision of a sense of actual presence in and control over the simulated environment. This feature is achieved to greater or lesser extents in the various applications of virtual reality, depending upon the goals of the particular application and the cost and technical complexity its developers are willing and able to assume. In the most technically advanced applications of virtual reality, known as 'immersive' VR, the user is essentially isolated from the outside world and fully enveloped within the computer-generated environment. Multimedia peripherals such as visual display units and speakers are integrated into a helmet worn by the user, presenting stimuli appropriate to the simulated setting. At the same time, the system tracks the user's responses to the stimuli from the virtual environment via position and force sensors mounted to the helmet and a hand-held control device, data glove and/or body suit, and modifies the simulation accordingly. For example, if a user turns to look backwards over the left shoulder, a sensor will detect the change in position and orientation of the head, and adjust the visual display so that the display corresponds to what the user would see from that pose if the scene were real. If the user reaches out toward an object in the virtual environment, sensors sensitive to movements of the fingers and to the position of the hand enable the system to detect when the user's hand intersects with the virtual object, and adjust the display to mimic pushing, lifting, or rotation of the object. The user may also be stimulated by electromechanical pin-arrays that excite cutaneous receptors and by inflatable air chambers that excite deep pressure receptors of the fingertips and palm of the hand.

Although prices are rapidly decreasing, immersive VR systems still cost upwards of hundreds of thousands of dollars (Rizzo et al., 1997). However, since not all applications require immersion to the extent presented above, more affordable, non-immersive VR systems provide practical alternatives. These allow the user to navigate through and interact with a three-dimensional computer-generated display, but do not engender the same sense of actually being fully immersed and enveloped within the simulated environment. The most popular of these systems use conventional desktop computer systems. Users view the simulated display much as they would an ordinary computer monitor and interact through standard or special-purpose input devices such as a keyboard, three-dimensional-mouse, trackball, joystick, force ball or voice. Three dimensions are represented through the use of simulation software employing perspective, object rotation, object interposition, relative size, shading, etc. Sound is presented via external loudspeakers, and a sensor can also be added at minimal cost to track head position.

The boundary between immersive and non-immersive systems is not clear-cut, since the creative use of display and auditory peripherals can promote the sense of presence even in the absence of the ability to fully control the virtual environment. In projected VR, for example, users see images of themselves overlaid on the simulated environment, and a movement tracking device captures the actions of the user and superimposes them so that he or she can interact with the virtual world. In CAVE (Johnson et al., 1998), the simulated environment is projected onto the walls of a small room, allowing different people to share the same VR experience simultaneously. CUBBY (Djajadiningrat et al., 1997) uses three orthogonal screens and a small infra-red tracker attached to the user's head or eyeglasses. The system utilizes the simple depth cue of movement parallax to create the perception that objects are in front of the screen and available for direct manipulation, providing a key benefit of immersive VR without expensive equipment and intensive computation. Other VR technologies merely supplement and enhance the user's actual view of the world with virtual objects or symbols. In an effort to steady the gait of individuals with Parkinson's disease, for example, users may sport eye-gear that overlays the visual scene (the walkway) with virtual obstacles (a step), to train them in lifting their legs at each step (Emmett, 1994; see also Jaffe, 1998).

Although their fixed display position and limited display area limit the user's range of interactions, these non-immersive systems have an advantage in that the user is not tethered by glove and helmet and is able to communicate freely with non-VR participants. Desktop virtual reality systems are now < $10 000, and costs will continue to decrease (Blackburn, 1996; Rizzo et al., 1997).

Non-immersive VR is often used to teach knowledge, and immersive VR to teach knowledge, skills, and attitudes (Davies and Helmreich, 1997). This distinction is highlighted in two travel applications for home and professional use, currently under development by the European Union's Collaborative Virtual Environments project (COVEN) (Slater et al., 1998). The Business traveler uses a high-end immersive VR system to enable a small group of individuals to prepare for a coming event by rehearsing possible outcomes in simulations of different situations and environments. For such an application, timing may be vital and interaction with colleagues frequent. Immersion is required so as to maximize the chance of participants learning appropriate behavior that can be transferred to the real-life situation. Still at an experimental stage, the system presently allows travelers to rehearse a simple journey from Heathrow airport to a local institution, experimenting with different modes of transportation.

The Citizen traveler is a virtual marketing and browsing facility which provides a large amount of information (logistics, cultural events, history) on a travel destination as a support to vacation planning. In contrast to the capabilities of the Business traveler, this application uses a non-immersive, desktop approach. It consists of a number of separate virtual environments (zones) displayed on a screen or monitor. Each zone has its own purpose, and users can move easily amongst them. The three-dimensional metaphors are used as a 'natural' and enticing way to provide access to data about a holiday destination, although the application goes beyond just retrieval of information. Users can view the site they wish to visit, seek advice from on-line travel agents and local guides, and communicate with other users, who can offer help, display locations, and accompany them on the excursion. The interactivity and collaboration provided by the Citizen traveler heightens the sense of presence, but does not convey a feeling of actually being at the travel destination. The Business traveler, on the other hand, is intended to provide users with a feeling of being surrounded by the environment, in order to enable rehearsal of and training for real-life situations.

2. Virtual reality and work

The unique features and flexibility of VR give it extraordinary potential for use in work-related applications. It permits users to experience and interact with life-like models or environments, in safety and at convenient times, while providing a degree of control over the simulation that is usually not possible in real life. Workers can use virtual reality to learn to perform routine tasks without pressure, to learn simple components of more complex tasks and to react to infrequently occurring situations such as the preferred response to dangerous events. Exposure to innovations at work, e.g. the retooling of an assembly line, via virtual reality can alleviate worker apprehension by providing an opportunity to practice new techniques prior to their implementation. Workers in need of vocational retraining, particularly those who have sustained major physical or psychological impairment, can be evaluated while trying out highly realistic simulated tasks. They, in turn, have an opportunity to explore whether the new job meets their abilities and interests.

By supplementing traditional training with VR simulation, the cognitive and motor demands of a task can be gradually increased and the trainee's interest and confidence can be enhanced by means of competitive or entertainment elements. VR can thus provide benefits that are not only economic, such as savings in staffing, time, and equipment, but also psychological, since a well-designed VR simulation can be motivating and enjoyable to the trainee (Barfield and Weghorst, 1993, cited in Barfield et al., 1995)

One of the most important applications of VR to the work setting is the analysis of a job site and its component tasks. The representation of a specific work site as a virtual environment enables the ergonomist to view it from a variety of angles and approaches, providing a greater understanding of how the tasks are performed. Moreover, it is easy to make changes in the location and orientation of virtual support surfaces and the placement of virtual work tools and manufactured goods. One can then test the effect these changes will have on both worker performance and on the quality of the finished product. Worker suitability for the task can also be assessed during the initial screening of job candidates. Already regarded by clinical neurologists and psychometrists as the next step in cognitive-perceptual assessment (Rose et al., 1996; Rizzo et al., 1998), VR can be a valuable addition to the screening and interviewing process, enabling the simultaneous, objective measurement of characteristics as diverse as spatial memory, curiosity, ability to stay focused on a goal, learning curves, orientation to unfamiliar settings, reflexes, as well as evaluating the worker performance in simulations of the actual tasks.

The work-related applications that appear to be most promising are those that employ virtual reality for: (1) visualization and representation; (2) distance communication and education; (3) hands-on training; (4) orientation and navigation; and (5) workers with disabilities. Examples of each of these applications will be provided in the following sections.

2.1. A visualization and representation tool

The interactive nature of virtual environments make it a natural extension to the three-dimensional graphics that enable engineers, architects, and designers to visualize real life structures before actually building them. For example, the computer aided design of mechanical tools can be enhanced with a virtual reality interface which allows the designer to navigate within the tool to the part that needs modification, and then use a spaceball (a 6-d.f. joystick-like input device) to stretch, shrink, or change the color of the part, or sketch in a new feature. The designer can then 'switch on' the virtual model and observe the operation of the new feature from different vantage points (Cobb et al., 1995; Trika et al., 1997). Another advantage of the virtual environment over other design tools, including those that are computer-based, is that it enables the user to interact with the simulation to conceptualize relations that are not apparent from a less dynamic representation, and to visualize models that are difficult to understand in other ways. It can therefore be a valuable tool for the radiologist trying to visualize the topology of a tumor (Fenlon et al., 1997; Hussain et al., 1997), the chemist exploring ways that molecules can be combined (Cruz-Neira et al., 1996), or the medical researcher trying to forecast the effects of complex combinations of healing treatments. Furthermore, a virtual environment can be made to respond to actual or hypothetical physical laws. Gravity, for example, can be suspended. Because of this flexibility, the application of VR to industrial and scientific design is one of the fastest growing markets for the new technology.

A significant savings in resources can be realized by testing out virtual reality models prior to physical construction. Wilson (1997) relates how prior simulation of a planned building's layout revealed serious architectural shortcomings such as inadequate access to delivery vehicles. Similarly a, wheelchair VR system (Murphy, 1993) helps to ensure that a proposed building is accessible to people with disabilities. In this fully immersive system, testers wear a dataglove and head-mounted device, sit in an actual wheelchair on rollers, and explore a simulation of the proposed structure to determine its suitability for people with disabilities. The magnitude of door widths, turning radii in small spaces, and even measurements that are not typically listed in building specifications such as faucet heights can all be verified before construction. Although one may argue that such information could be obtained by simpler means, the fact remains that the virtual environment encourages designers and users to interact to construct a truly accessible building (Delaney, 1998).

The use of such 'virtual prototypes' to augment or replace physical prototypes can significantly reduce product development time and costs (Wilson, 1997). Where changes are required, machine components can be readily modified and layouts can be quickly rearranged. Moreover, by allowing users to view the product design in ways that are less ambiguous to non-experts, VR promotes direct collaboration with other industry personnel or customers at an earlier stage in the design or manufacturing process. In the fashion industry, for example, a virtual environment has been developed that allows clothes to be displayed to retailers at their convenience (Stanger, 1997). In an effort to respond more quickly and accurately to market demand, designers create virtual fashion collections which are then modeled to buyers by three-dimensional mannequins who, in response to verbal instructions from the designer, parade the garments in a variety of poses and settings. Although VR prototype garments would not entirely replace the need for the creation of real model collections, they introduce an element of designer–retailer collaboration which, in theory, can enhance the quality and suitability of clothes as well as the speed with which they are available for sale.

Considering its tremendous potential, the commercial application of VR to integrated manufacturing has been proceeding slowly. This relatively slow pace does not appear to be due to limitations in VR itself; rather, it is related to finding efficient ways to merge VR technologies with current manufacturing techniques (Cobb et al., 1995).

2.2. Distance training and communication

With the advances in electronic technology over the past 20 years, the standard training format of having an individual lecture to an audience has been supplemented and, in some cases, replaced by the rapid development and implementation of new training methods. No longer are individuals required to present material in person to trainees as information can be delivered to groups of trainees situated in different locations. Until recently, a significant drawback to distance training was the lack of direct interaction between the instructor and the students, since the ease with which students could ask questions was limited and the instructor was deprived of the opportunity to gauge audience reactions and adjust the presentation accordingly.

One attempted solution to this problem is interactive video teleconferencing. To date, this application has been severely limited by the need to use special transmission lines and equipment capable of handling a large volume of video images in real time. Furthermore, when more than a few users participate simultaneously, the large array of separate video images to which each user must attend can be overwhelming. It is no small feat to try to monitor and teach a group of 20, separately televised, students, even though monitoring and teaching a class of this size is a common practice in real life. Furthermore, participants do not feel that they have achieved a sense of being together in a shared meeting space (Walker and Sheppard, 1997). With virtual reality, however, the potential exists for all remote participants to be together in a shared virtual space, interacting as they would in a real classroom. This could bring a new dimension to long-distance education.

The concept of sharing a virtual environment is fairly straightforward. Separate computers are joined together through the Internet or other computer network. The remote participants share the representation of the same virtual world and interact with one another. The crudest forms of this 'networked virtual reality' are text-based. Each user is presented with a textual representation of a room in which there are various objects and other people with whom he or she may 'talk'. Talking in this context means using the keyboard to communicate with other people in the shared imaginary space and reading their responses on a monitor. Objects in the room, such as virtual blackboards and slide projectors, are interactive and can respond to commands from the users. These virtual environments are currently being used as conferencing tools on the Internet and, despite the crude textual representation, they do give users a sense of 'being there'. Of 53 participants who had attended one such Internet-based conference, partaking in real-time, scheduled scientific discussions over a 4-week period, 74% reported feeling a sense of actually being in the same room with others (Towell and Towell, 1995). Similar results were obtained for two groups of university students who participated in 1-h virtual sessions with their classmates and instructor (Towell and Towell, 1997).

In a more advanced form of networked VR, each participant is presented with an image of all of the other participants, represented by an avatar (an animated graphical representation) seated around a table, with each participant's speech, body movements and gestures tracked and relayed to the other participants (e.g. Pratt et al., 1997). The presence of virtual people and the ability to interact with them in this way promotes user immersion, making the virtual experience more real. This technology obviously holds great promise for collaborative work and teleconferencing.

Sophisticated networked VR technology has been applied to military applications for several years. The Naval Postgraduate School Networked vehicle simulator has brought together several hundred remote participants in an immersive virtual environment consisting of a realistic rendition of a very large area (Pratt et al., 1995). The major goal of this application has been to lower training costs. Even though it is a very costly endeavor to build such a network, it is much cheaper to bring together personnel and blow up virtual vehicles on a computer network than in real-life training exercises.

Although networked VR is expected to become more accessible and affordable, it is not yet available on a wide scale due to the requirement for intensive computing and sophisticated software. More significantly, insufficient bandwidth is still a major limitation despite the major savings in data transmission and speed made possible with the use of avatars instead of actual video pictures. Existing Internet services, characterized by a chronic shortage of bandwidth and lack of quality-of-service, put severe constraints on the complexity of virtual environments and on interaction with other users (Parke, 1997; Schroeder, 1997). More complex environments and forms of interaction require more capacious telephone lines like ISDN (Integrated Services Digital Network) which, until recently, were unavailable or too expensive for most users. More sophisticated multi-user systems have been created for corporate clients on private intranets (Wilcox, 1998). These local networks typically rely on ethernet links which are fast enough to allow multiple participants to interact in the virtual worlds generated by the most powerful VR systems commercially available.

The most advanced commercial systems currently are still at an early stages of development and typically share the resources and expertise of governments and universities. Caterpillar, Inc., designed a system to enable engineers from geographically remote locations to collaborate in designing Caterpillar products. Although intended for use over a trans-Atlantic link, so far the system has only been tested between three VR systems using government supercomputers and a local ethernet. Under those conditions, transmission quality was excellent and participants felt their communication to be quite natural. Even more impressive results were reported in virtual meetings between BT Laboratories and five British universities (Greenhalgh et al., 1997).

The richness of virtual environments, networked or otherwise, is continually being enhanced by complementary technologies under development. Researchers have recently developed a family of computer systems for recognizing faces, expressions, gestures, and speech (Pentland, 1996; Pentland and Bobick, 1998). These systems are attached to 'smart rooms', areas furnished with cameras and microphones which relay information to computers for analysis. This technique allows people in the room to use their actions, voices, and expressions to communicate with the computer, which in turn controls a virtual reality display. A teaching program, for example, could tell if its students are starting to look bored, and modify its virtual reality presentation in response. While such intuitive, multimodal interfaces will probably not be available and affordable in the near future, they will be necessary to take full advantage of the potential of VR distance training and communication.

2.3. Hands-on training

The most common work-related applications of virtual reality are those that utilize its immersive and interactive nature to approximate actual hands-on training. VR is currently used to train operators of various kinds of equipment, where initial training in a virtual environment can avoid the expense, danger, and problems of monitoring and control associated with training in the real life situation. For example, VR can be used to train individuals to tasks in dangerous situations and hostile environments, such as in radioactive emergencies of icy road conditions. In addition to the assurance of safety, the use of a virtual training environment gives the trainer total control over many aspects of the trainee's performance. The virtual environment can be readily modified, either to provide new challenges through adjusting levels of difficulty or to provide training prompts to facilitate learning. It gives an opportunity to pause training for discussion or other means of instruction, and enables the recording of a full history of the trainee's performance. The best-known example of VR hands-on training is flight simulation, but VR training is increasingly being used in the initial training of divers, surgeons (e.g., Hoffman and Vu, 1997), anesthesiologists (Wickens and Baker, 1995), and shipboard fire-fighters (Tate et al., 1998).

A number of highly successful and rapidly developing applications involve the use of VR to train medical personnel. For example, VR provides medical and paramedical students with a dynamic medium for the study of human anatomy and physiology. In contrast to the use of cadavers which can only be dissected once and which are becoming more difficult to procure, VR allows students to access libraries of healthy and pathologic body tissue three-dimensional images at their convenience, and perform the same dissection repeatedly while viewing the various body parts from a variety of angles and perspectives. Particularly helpful in this endeavor are commercial versions of the National Library of Medicine's 'Visible Human' data set (Fasel et al., 1997).

VR also holds great promise in the training of diagnostic skills, particularly when used in conjunction with haptic interfaces which provide force and touch feedback to the hand and digits of the person manipulating the instrumented tool. One application involves the training of young physicians to palpate malignancies, for example, in the liver (Dinsmore et al., 1997) and prostate (Burdea et al., 1998). Preliminary results indicate that tumor detection rates using VR ranged from 50 to 90%.

Some routine medical procedures can be difficult for novice practitioners to learn, causing discomfort and pain to the patient until they are mastered. Hands-on instruction in such procedures using VR has been encouraging. Anesthesiology residents have been trained to inject analgesic drugs into the epidural space by manipulating an instrumented needle on a virtual patient. The trainee 'feels' the different forces associated with puncturing the skin, traversing the intervertebral ligament, and entering the cerebral spinal fluid. Even erroneous contact with bone is sensed as a sudden, large increase in resistance. The haptic feedback is supplemented, when desired, with visual tracking, enabling the physician to observe the needle's exact anatomical location, a feat obviously not possible in real life. In another application, nursing students have been trained for IV needle insertion on a VR system consisting of a haptic interface combined with a graphic simulation of a patient's arm. As in the previous example, trainees feel differences in tissue resistance as the needle is inserted toward the target blood vessel. Students know when they have been successful since a virtual syringe fills with blood upon the accurate insertion of the IV needle.

Finally, VR is now being used to train physicians to carry out intricate surgical procedures such as laparoscopies, arthroscopies, endoscopies and other minimally invasive surgeries (e.g. Lorensen et al., 1998). VR provides a view of the surgical field normally blocked during such procedures and enables trainees to get much needed practice in the left–right motion inversion obligatory for the operation of instruments in minimally invasive surgery.

Virtual environments are being used not only to produce a realistic simulation for training purposes, but also in the actual operation of the equipment itself. Although robotic arms have long been used in combination with remote cameras and other instruments to allow users to operate from a distant location (teleoperation), with recent advances in position and force sensing gloves and other interface technologies (e.g. Yun et al., 1997), VR is seen as offering a more natural and intuitive form of interaction (Mine, 1997). For this reason, applications of VR include not only manipulation of instruments in remote or dangerous environments, but, as seen above, is also particularly suited to the performance of delicate microsurgery.

VR has been suggested for training and education in occupational health and safety. The technology is already used in disaster response training, whether to train airport crews in handling airline crashes using highly realistic simulations (Lavitt, 1996) or to simulate the decontamination process of hazardous radioactive sites (Briggs, 1996). However, the utility of VR extends beyond training appropriate responses to disasters, to assisting in the promotion of prevention efforts. Actual experience with a hazard has been demonstrated as a powerful incentive to adopt mitigation measures (Mitchell, 1997). For example, usually little is done about an earthquake threat until the disaster has occurred at which time there is a flurry of relief activity (Mitchell, 1998). Obviously, it is not feasible to summon hazard events at will where potential victims are exposed to peril, but virtual reality enables a simulation of the hazard where, unlike video (where the participant is a passive viewer), one can interact with phenomena, change them, and then observe the consequences. For example, researchers have developed a VE to train nuclear power plant maintenance workers to disassemble a check valve, which allows trainees to execute tasks even in the wrong order, experience resultant consequence, and perform the appropriate tasks to be done in response to the mistake (Yoshikawa et al., 1997). Such active participation within the hazardous situation can stimulate users to undertake mitigation steps that might otherwise remain undone (Mitchell, 1997).

2.4. Orientation and navigation

Virtual reality is well suited to helping users learn to navigate in unfamiliar or complex surroundings. A number of studies have shown that navigation in virtual reality models of complex buildings generalizes to actual buildings (Goldberg, 1994; Regian et al., unpublished). Other studies have found that military personnel using self-guided virtual terrain environments can learn successfully the actual physical terrain that had been simulated (Johnson, 1994), although the extent of transfer seems to depend on a number of individual factors (Darken and Banker, 1998). Researchers in Japan are developing a system to train guards for power plants in navigating their rounds. In this application, the VR training takes place before workers have been assigned to the site, when the workers are as yet unfamiliar with the look and layout of an actual plant (Umeki and Doi, 1997).

It should be borne in mind that learning to navigate in a virtual environment is still far from equivalent to experience in the actual environment. Therefore VR navigation is currently advocated only as a useful preparation for eventual, real-life exploration within a physical environment. In those instances where experience in the real environment is not feasible, the VR experience will only approximate the real-life experience, and may, in fact, introduce undesirable and unpredictable elements into the learning situation. Although virtual environments are often built to provide exact representations of existing or proposed physical spaces, studies of spatial learning have shown that the user's mental representation of the virtual world is often distorted relative to both the virtual environment and the real environment it is supposed to represent. For example, the user's perception of size and distance based on viewing a virtual simulation is not as accurate as for people who experience the actual environment (Henry and Furness, 1993; Umeki and Doi, 1997). It is hoped that such undesirable byproducts of VR will be reduced as the technology advances and we gain a greater understanding of how people relate to both real and virtual environments.

Learning to navigate and function in unfamiliar environments is one of several applications that are emerging for individuals with disabilities. Using computer simulations, children with severe physical disabilities have accurately learned the layout of buildings, including the location of safety equipment and shortest routes to various exits (Wilson et al., 1996). In the 'Train to Travel' project (Mowafty and Pollack, 1995), people with cognitive impairments are trained in basic travel skills, including the recognition of landmarks, and are then immersed in a simulation of a bus route for as many rides as they need. This training eliminates the need for a teacher to accompany them on real trips, which can require up to 15 h to reach the same degree of mastery/adeptness. VR has also enabled children with severe learning disabilities to develop everyday living skills, whether in virtual homes with interactive kitchens, in virtual stores where they select and pay for groceries, or in virtual city streets for learning traffic safety (Brown and Wilson, 1995). These efforts, which have used relatively inexpensive, non-immersive VR technology with flat screen displays, demonstrated favorable transfer to real life situations compared to control groups engaged in similar, non-VR tasks (e.g. Cromby et al., 1996, but cf. Hall et al., 1998 for more equivocal results).

VR may also be the ideal navigation tool for large or complex databases. Navigating hypertext, for example, is currently a cumbersome process. Web browsers constrain the user to see only one page at a time instead of allowing users to get a sense of where they are currently located within a more general context. Searching is an intellectually demanding task which may involve iteratively comparing the results of many queries in order to home in on useful information. These problems have motivated the development of an interactive VR browser in which one can access specific Web pages while still having a view of the surrounding context (e.g. adjacent pages, the structure of the part of the Web that the user has browsed in the current session, the links the user has followed in the recent past) (Benford et al., 1997). An accompanying search tool allows users to dynamically compare the results of multiple search queries. In a three-dimensional representation of the search space, each query is assigned a position in three-dimensional space and an icon represents each matched page. The spatial position of the icon shows which queries the page matches, while the degree of significance or relevance of each page is shown by the size and shade of its icon. The resulting three-dimensional visualization gives the user a sense of which pages are generally interesting (big and bright ones) and also which pages are most relevant to which specific keywords (spatial position). This search engine allows for many innovative features, such as flying through the three-dimensional scene in order to home in on specific areas.

2.5. VR and workers with disabilities

Individuals with disabilities comprise one of the most under-employed groups of workers. Reasons for their difficulty in obtaining jobs include their limited mobility, reduced manual capabilities and limited access to educational facilities and work settings. VR can help people with disabilities overcome some of these difficulties by facilitating their ability to carry out some of the tasks required in the work setting. VR enhances the accessibility to work by providing the opportunity for individuals to manipulate and explore without requiring physical access, dexterity, and strength (Nemire et al., 1994). Similarly, those with physical limitations can benefit from the flexibility afforded by an increasingly wide range of VR interfaces, thereby minimizing the limitations of the disability, which can be used as prosthetic mechanisms or as alternative access devices. For example, the head-mounted display can be used as a vision enhancement tool for people with low vision.

Another interesting idea involves the use of three-dimensional 'audicons', sounds that surround the participant that can be moved around to control and navigate a computer system. Using a glove interface, users with visual impairments can position the sound in particular places, performing the same 'drag and drop' types of functions that are common with visual icons (Lumbreras et al., 1996). In one of the most promising developments, biological signals such as the electroencephalogram and the electromyogram have been used to allow persons with quadriplegia to manipulate objects in virtual environments (Kuhlen and Dohle, 1995).

3. A realistic appraisal

There has been considerable speculation and enthusiasm among would-be users regarding the potential of VR technology, much of it more wishful thinking than actual applications. The popular media typically make exaggerated claims about the current state of the technology. A more responsible view is that, whereas VR has considerable potential for many applications in industry and commerce, it is neither appropriate nor desirable in all cases (Wilson, 1997).

For training purposes, VR certainly offers a degree of flexibility in presentation greatly exceeding that of that of other forms of computer-assisted tools. A virtual training environment allows for total control of the presentation by the trainer. For the trainee, as well, the ability to customize the virtual environment to the individual opens up a range of new possibilities.

In addition to its versatility, VR offers a number of other features that are thought to make it a particularly effective teaching and training tool. Foremost is the active involvement of the users. Indeed, particularly in immersive VR, participation in the virtual environment is to some extent inescapable (Rose et al., 1997). The participant's movements are tracked by the computer, and produce changes in the environment, to which he or she must adapt. There is speculation that this aspect of VR reduces passivity and learned helplessness, problems commonly found amongst those with physical or cognitive disabilities (Swinth et al., 1993).

The delivery of immediate feedback, in a variety of forms, is also thought to enhance learning. This feedback can include the provision of 'cueing' stimuli or visualization tactics (i.e. selective emphasis) designed to help guide successful performance. Teaching strategies such as errorless learning are easily implemented, and the ability to make mistakes without negative consequences in the benign, forgiving virtual environment, all can have positive implications for learning (Rizzo et al., 1998).

Finally, entertaining, enjoyable, or competitive aspects can be incorporated into the learning situation to increase acceptance and enhance motivation. The most overt use of these features have been in learning tools for children, who have a readier acceptance of, and familiarity with, computers than adults, particularly when the task is made to be like a game (Rose et al., 1997). The sense of presence engendered by VR is itself correlated with enjoyment, which in turn is likely correlated with task performance (Barfield and Weghorst, 1993, cited in Barfield et al., 1995). Additionally, for any trainee, motivation and attention can be enhanced by adjustments to the speed and difficulty of the task, and by incorporation of music and other features suited to the individual's taste.

3.1. Transfer of skills to the real world

Because of its many advantages, VR seems to be an ideal training medium. However, inherent to VR training and education is the assumption that the training that takes place within a virtual environment transfers to the real world. According to Rose et al. (1998), to date, most reports regarding transfer are anecdotal and there has been insufficient effort expended toward demonstrating under what conditions transfer takes place, if at all.

Among the studies that have attempted to examine transfer from computer-generated to real environments, many have focused on flight simulation which, until recently, has been the best known and most sophisticated commercial application of computer-simulated training. In general, simulator training leads to better flight performance, but this depends on the type of task. In terms of spatial learning and navigational rehearsal, for example, Williams and Wickens (1993) concluded that greater realism in navigational rehearsal flights did not lead to better performance in a transfer environment. Thus, if a helicopter pilot rehearsing a dangerous rescue mission wants to learn the specific features of the approaching ground terrain and the rescue site, simply studying a two-dimensional map can lead to retention and performance that is as good or superior to training in a virtual environment (Wickens and Baker, 1995). It may be that the mental effort allocated towards other aspects of on-line performance takes away from the mental effort that is directed solely toward navigational learning (Wickens and Baker, 1995).

The findings from flight simulation research have also been demonstrated in more general studies of spatial learning (Wickens et al., 1994, cited in Wickens and Baker, 1995) examined how well people understood the shape of a complex three-dimensional surface. Previous experience with a highly realistic presentation (three-dimensional, stereo) of aspects of the surface was better than a less realistic presentation (two-dimensional, mono) at helping subjects answer questions about it *as they were viewing it*. However, it didn't help much for *later* memory and understanding of the surface shape. Furthermore, the addition of stereo to the three-dimensional perspective view had no added benefit to later understanding. A more recent study found that passive, monocular viewing of a complex layout of objects from a single vantage point led to greater ability to reproduce the array than active, binocular exploration of a virtual replica (Arthur et al., 1997). Again, these studies demonstrate that VR visualization is not always an advantage, and richer or more complex representations do not necessarily provide any greater benefit for the long-term transfer of learning.

This is not to say that significant transfer of spatial knowledge from a virtual to the real world does not occur. As described earlier, even children with learning disabilities, using modest desktop systems, acquired useful knowledge about the spatial layout of a real building. Rather, results are mixed, appearing to depend on a number of factors, including the veracity of the simulation. More research is needed to determine when transfer to real life situation occurs, and to what extent.

Wickens and Baker (1995) examined the cognitive factors influencing VR learning in relation to the substantial body of research on the psychology of learning (p. 530). They argue that the most successful way to teach concepts is by having VR exposure in conjunction with and related to, alternative, more abstract representations of the same material. Thus, teaching physics concepts by VR alone is better than by lecture, but the best results occur when VR training is complemented with presentations of the same phenomenon in a variety of other forms, including verbal descriptions, graphs, and symbols or equations. They also discuss the detrimental effects of cognitive overload (e.g. if the display is too sophisticated), and the importance of interaction with the virtual environment rather than just passive immersion.

3.2. Presence

The essence of the virtual environment is that participants can interact with it in a way that allows them to relate the experience to the real world. This is the attribute of 'presence', a subjective impression of 'being there' that is presumed to enhance the transfer of knowledge and skills (Stanney et al., 1998). The determinants of presence include the extent of sensory information, the quality of the display, the ease of navigation, the ability to modify the environment, and how comfortable the user feels using a computer (Barfield et al., 1995; Lewis and Griffin, 1997). Given the importance ascribed to achieving presence in virtual environments, it is noteworthy that necessary detail concerning these determinants have yet to be identified and quantified. Indeed, it is not at all clear when presence is a help and when it is, in fact, a distraction (Barfield et al., 1995).

3.3. Rehearsal vs. desensitization

VR is considered a valuable tool for rehearsing critical actions, in preparation for performance in a less forgiving world. It is therefore advocated for training individuals to perform tasks in dangerous situations and under hostile environments, such as in radioactive emergencies. However, rehearsal in a dangerous situation may have unwanted consequences. The user who makes mistakes and only experiences safe, simulated consequences, could become desensitized to, and less fearful of dangerous scenarios. This lessening of anxiety can be an important asset in enabling workers to maintain their cool under duress, but it may also lead to a loss of respect for a real-life danger, particularly where the hazard is experienced in a game format. Similarly, if occupational health and safety efforts present a virtual representation as accurate when, in fact, the simulation is not credible, the participant could leave the experience with the impression that the hazard event is really not of much concern (Mitchell, 1997).

3.4. Side effects

Many users experience physical side effects during and after exposure to virtual environments. Effects noted while using VR include nausea, eyestrain and other ocular disturbances, postural instability, headaches and drowsiness. Effects noted up to 12 h after using VR include disorientation, flashbacks, and disturbances in hand-eye coordination and balance (Wilson, 1996; Kennedy and Stanney, 1996; Kennedy et al., 1997; Lewis and Griffin, 1997). Many effects appear to be caused by incongruity between information received from different sensory modalities, and to the lag time between the user's movement and the resulting change in the virtual display (So and Griffin, 1995; Kennedy and Stanney, 1996). These problems are expected to improve with the development of faster workstations and the modification — or elimination — of headsets in immersive VR systems.

In the meantime, side effects are a health and safety concern (Kennedy and Stanney, 1996; Kennedy et al., 1997), as in the case where an employee operates a vehicle soon after using VR. The danger is magnified by the fact that users' impressions of having adapted to the virtual environment (i.e. they no longer feel ill) may mask an actual worsening of the effects (Kennedy et al., 1995; Kennedy and Stanney, 1996). Measures are currently being developed to ensure that VR users have regained their pre-VR capabilities before returning to the real world (Kennedy and Stanney, 1996; Stanney and Kennedy, 1997). In an interesting twist, VR has been used to reduce the motion sickness that can occur in real life (e.g. in altered-gravity situations) (Kreitenberg et al., 1998).

3.5. Is VR an effective tool?

Clearly, VR is neither for all users nor for all situations. While VR appears to have significant potential in some cases, it is clear that it must accomplish a particular objective in a substantially better way than traditional techniques. Given the cost of even a moderately complex VR application, the technical support required to operate and maintain it, and, in many cases, the lack of evidence demonstrating its effectiveness, it is fair to ask whether virtual reality should be used at all and, if so, under what circumstances and for whom. These are not easy questions to answer. On the one hand, VR may save staff time and money and be a superior way to train staff as compared to accomplishing a goal by more traditional approaches. On the other hand, if the skills do not transfer to the real world and if users get bogged down in technical difficulties or experience detrimental side effects, then VR has failed to live up to its promise.

Rizzo et al. (1998) have proposed using a criterion of 'elegant simplicity' to determine whether VR is warranted for a particular application. That is, can the application's objective be accomplished in an already available, cheaper, and simpler way? If so, then VR is being used, as the skeptics claim, as an elaborate and expensive toy.

However, the evidence gathered thus far indicates that VR is a useful and effective technique for a wide variety of applications. Unfortunately, to date, more effort has been expended on the development of new equipment and software than on the evaluation of whether VR accomplishes its stated goals. The urgency with which this imbalance must be addressed has been identified as one of the most pressing issues to be dealt with by the VR research community (Darken et al., 1998). Standardized methods of evaluation need to be developed and systematic data collection protocols need to be implemented. Specific areas of importance include feasibility in terms of quality and service, cost effectiveness, safety, and the accuracy, speed, and ease of use of new VR applications. It is also necessary to evaluate how the goals could be achieved without VR technology.

The rapid proliferation of VR techniques has prompted the need for considerable research. In particular, it is necessary to characterize the attributes of the various tracking and display devices and simulation software and to determine how these attributes influence user performance and overall effectiveness (Wilson, 1997). For example, how can the design and fit of head mounted displays and other tracking devices be improved in order to provide better feedback and minimize user discomfort and irritation? Cognitive factors, particularly those parameters affecting the interaction between the person and the virtual environment, need to be investigated, and the substantial body of knowledge on human perception, cognition, and performance needs to be incorporated into the design and use of the system. Which sensory modalities (visual, auditory, tactile, vibration, force, vestibular) are most useful to the VR participant, and when is the provision of multiple simultaneous sensory feedback more of a hindrance/nuisance than a help/benefit? Given the wide variety of technologies available with a considerable range in price/cost, we need to know how realistic virtual environments have to be, and to what degree a sense of presence is required, in order to accomplish the objectives of the virtual experience?

4. Conclusion

Considerable hype has accompanied VR since its inception, and in many instances VR is not yet sufficiently developed for economical use in work settings. However, the technology is developing rapidly, and shows considerable potential. The ability of VR to provide realistic simulations of data, objects and environments, with which users can interact and manipulate in an intuitive and

realistic manner, opens up a vast wealth of possibilities for work-related applications. Those responsible for work settings should begin thinking now of ways in which VR might be useful.

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