Virtual Reality Technology: A New Tool for Personnel Selection

Herman Aguinis*, Christine A. Henle and James C. Beaty, Jr.

The purpose of this article is to introduce virtual reality technology as a potential tool for personnel selection in organizations. We describe virtual reality technology, its hardware and software requirements, and some current applications. Then we propose specific types of job knowledge, skills, abilities, and other characteristics (KSAOs) particularly suitable to being assessed using virtual reality technology. We emphasize KSAOs that hold the greatest promise in terms of yielding greater validity than more commonly used selection techniques. We hope the present article will stimulate and guide future empirical research on the potential of virtual reality technology as a personnel selection tool.

Introduction

The task of creating valid predictors of performance has challenged work and organizational (W + O) psychologists for years. We have struggled to develop selection methods that closely resemble the jobs for which they are being used to better predict performance. Imagine having applicants for truck driver positions step into a simulator of a truck to demonstrate their competence or having applicants for lab technicians enter a simulated laboratory and demonstrate their ability to handle various chemicals. Not only would this be highly job related, but it could also be done *without* using real trucks or chemicals. Just a few years ago, this would have only been possible in science fiction movies but today virtual reality technology makes this feasible.

The purpose of this article is to explore the possibility of applying virtual reality technology to personnel selection. First, however, we describe virtual reality technology, its hardware and software requirements, general advantages and disadvantages of using virtual reality technology, and some current applications. Then we propose specific types of job knowledge, skills, abilities, and other characteristics amenable to being assessed using virtual reality. As we will discuss later, virtual reality has been used extensively for training in areas such as the military and medicine. However, we believe that organizations can also benefit from using virtual reality to select applicants with the best chance of successfully performing on the job.

*Address for correspondence: Herman Aguinis, Graduate School of Business Administration, University of Colorado at Denver, Campus Box 165, PO Box 173364, Denver, CO 80217-3364, USA. E-mail: Herman.Aguinis@cudenver.edu

What is Virtual Reality?

Virtual reality, often referred to as virtual environment, is a computer technology that enables users to view or 'immerse' themselves in an alternate world. Through the use of real-time computer graphics, users experience a computer-generated environment as if it is real and they are part of it. Thus, users can walk on the surface of Mars, fly an aircraft, or stroll through the Sistine Chapel without really being there. Virtual reality, although the technology was not labeled as such, began in the 1960s when Morton Heilig invented the Sensorama Simulator. This simulator was a one-person theater with three dimensional (3D) video, stereo sound, aromas, wind, and a vibrating seat (Burdea and Coiffet 1994). Users could take a motorcycle ride through New York that was complete with wind, smell, and vibrations caused by the road. Ivan Sutherland continued this work with the development of the first head-mounted display, which generated wire-framed images over real-world objects and scenes (Wilson 1997). Virtual reality grew as the US military and NASA began to use the technology in flight simulation. In 1989, Jaron Lanier, the Chief Executive Officer of VPL Research, coined the term virtual reality and used it to refer to the multisensory, three-dimensional technology we have today.

According to Vince (1998), there are three characteristics of virtual reality systems: navigation, interaction, and immersion. Users of virtual reality can move about the computer-generated, 3D scene and explore their surroundings. For example, users can walk through the corridors and into the rooms of a virtual museum to view the exhibits. In addition to navigating through the environment, users are

© Blackwell Publishers Ltd 2001, 108 Cowley Road, Oxford OX4 1JF, UK and 350 Main Street, Malden, MA 02148, USA.

able to interact with it. Objects can be touched, lifted, manipulated, and moved (e.g., users could rearrange displays in the museum). Finally, virtual reality systems are often, but not always, immersive. Immersion refers to the perception that the user is fully surrounded by the virtual environment (Pierce and Aguinis 1997; Stuart 1996). The surroundings of the physical environment are blocked out, typically through the use of a head-mounted display, and many senses are captivated through images, sounds, and touch to create a realistic virtual environment.

Although some argue that 'true' virtual reality systems require immersion, nonimmersive and hybrid systems have been acknowledged by many as types of virtual reality. Nonimmersive systems may not be as realistic as immersive because users feel like they are viewing the virtual environment through a window instead of first hand, but they are less expensive. One type of nonimmersive system is desktop virtual reality, which allows users to switch between the real and virtual worlds because complex equipment does not have to be worn by the user. The virtual environment is presented onto a projection screen or onto a computer monitor through personal computer (PC) systems capable of displaying real-time 3D graphics. Users wear special glasses to view the 3D images displayed on the projection screen or computer monitor. A second nonimmersive system is vehicle-based. Three-dimensional scenes are projected onto the windshield of the aircraft, tank, or other vehicle to give the user the illusion that he or she is controlling the vehicle in response to the computer-generated environment (Hawkins 1995). Finally, hybrid virtual reality systems enhance the real world by superimposing computer-generated images over real world images and scenes. These systems also augment realism and users must wear head-mounted displays to view the superimposed environment.

Equipment for Virtual Reality Systems

Virtual reality systems require both hardware and software. Hardware enables users to navigate, interact and immerse into the virtual environment while software creates the virtual environment and integrates the hardware into a working system. Next, we offer a brief overview of the various hardware and software applications that are available. For a more detailed discussion, readers are referred to Stuart (1996), Vince (1995, 1998), and the Websites of virtual reality technology vendors listed in Table 1.

Hardware

Computers. All virtual reality systems require a computer to gather input from the user and modify the virtual environment accordingly. Computers must have sufficient processing speed and power to produce and update high-quality graphic displays. For simple applications (e.g., games), PCs may be sufficient. Although PCs are less expensive and more widely available than other types of computers, they may not generate realistic environments and may have lags in updating the scene because of limited processing power. Graphic workstations are capable of higher quality real-time graphic displays than PCs and they use a UNIX operating system. Supercomputers are usually used for high-end virtual reality applications and image generators are typically used for simulation.

Input devices. Input devices allow the user to interact with, and control, objects in the virtual environment (Denby and Schofield 1999). Commonly used input devices include position trackers, the 3D mouse, and data gloves.

Position trackers. These monitor the position and orientation of the user's head, hand, and/or body. When the user turns his or her head, a tracking device located in a head-mounted display or shutter glasses (discussed later) detects the motion, determines the head's new position, and updates the viewpoint of the 3D environment to create the illusion that the environment is staying still while the user moves. Trackers attached to the back of gloves or located in a 3D mouse detect hand position. In addition, body position can be determined with trackers sewn into a bodysuit or exoskeleton. In the future, eye trackers may be available that will update the view when the user's eyes move. Many types of trackers are available, including mechanical, optical, ultrasonic, and electromagnetic.

3D mouse. The 3D mouse is a hand-held device used to navigate the user through the virtual environment and interact with objects (see Figure 1). To navigate the environment, the user's gaze determines the direction and clicking a button on the mouse moves the user forward. The mouse can also lift and move objects in the virtual environment. When the user collides with an object, a mouse button is pushed to lift it and the object then moves with the user until a button is pushed to drop it. As previously mentioned, position trackers located in the mouse determine the object's and, subsequently, the user's hand position.

© Blackwell Publishers Ltd 2001

Table 1: Examples of virtual reality software and hardware products

Company	Product	Description	Price[a]	Website
Silicon Graphics	320	PC Workstation	$5,104	www.sgi.com
Silicon Graphics	540	PC Workstation	$6,744	www.sgi.com
Ascension Technology	FLOCK	Position Tracker	$2,695	www.ascension-tech.com
Polhemus	ISOTRAK II	Position Tracker	$2,875	www.polhemus.com
Polhemus	FASTRAK	Position Tracker	$6,050	www.polhemus.com
Logitech	Logitech Headtracker	Position Tracker	$1,999	www.logitech.com
Labtec	Spaceball 3003 FLX	3D Mouse	$695	www.labtec.com
Labtec	Spaceball 4000 FLX	3D Mouse	$695	www.labtec.com
Logitech	Magellan 3D Controller	3D Mouse	$495	www.logitech.com
Spacetec	Spaceball	3D Mouse	$3,000	www.spacetec.com
Virtual Technologies	CyberGlove	Glove	$9,800	www.virtex.com
Fakespace Systems	PINCH Gloves	Glove	$2,500	www.fakespacesystems.com
Fifth Dimension Technologies	5DT Glove	Glove	$495	www.5dt.com
Stereographics	CrystalEyes	Shutter Glasses	$795	www.stereographics.com
Stereographics	CrystalEyes Wired	Shutter Glasses	$299	www.stereographics.com
Virtual Research Systems	Window VR	Flat Panel Display	$13,900	www.virtualresearch.com
Stereographics	Zscreen 2000	Flat Panel Display	$1,895	www.stereographics.com
Silicon Graphics	1600SW	Flat Panel Display	$2,393.95	www.sgi.com
Liquid Image Corporation	X3 Full VGA HMD	HMD	$7,900	www.liquidimage.ca
Liquid Image Corporation	MRG2.2	HMD	$3,495	www.liquidimage.ca
Liquid Image Corporation	MRG3c	HMD	$5,500	www.liquidimage.ca
Liquid Image Corporation	MRG4	HMD	$2,195	www.liquidimage.ca
Virtual Research Systems	Ruggedized Glasstron	HMD	$3,600	www.virtualresearch.com
Virtual Research Systems	V6 Head Mount Display	HMD	$5,900	www.virtualresearch.com
Virtual Research Systems	V8 Head Mount Display	HMD	$9,900	www.virtualresearch.com
CyberMind	hi-Res 800	HMD	$6,500	www.vrweb.com
Fakespace Systems	BOOM 3C	Standing BOOM	$60,000	www.fakespacesystems.com
Fakespace Systems	BOOM HF	Sitting BOOM	$95,000	www.fakespacesystems.com
Fakespace Systems	PUSH 640	Desktop BOOM	$13,500	www.fakespacesystems.com
Fakespace Systems	PUSH 1280	Desktop BOOM	$25,000	www.fakespacesystems.com
Fakespace Systems	CAVE C04	CAVE	$305,000	www.fakespacesystems.com
Fakespace Systems	CAVE CS4	CAVE	$370,000	www.fakespacesystems.com
Virtual Technologies	CyberGrasp	Force Feedback Glove	$39,000	www.virtex.com
Virtual Presence	Space Stick	Joystick	$3,000	www.vrweb.com
Virtual Technologies	CyberTouch	Tactile Feedback Glove	$14,800	www.virtex.com
EON Reality	EON Studio	Toolkit	$3,795	www.eonreality.com
EON Reality	EON Immersive	Toolkit	$12,995	www.eonreality.com
EON Reality	EON SDK	Toolkit	$10,995	www.eonreality.com
MultiGen-Paradigm	MultiGen Creator	Toolkit	$10,000[c]	www.multigen.com
Sense8[b]	WorldToolKit	Toolkit		www.sense8.com
Sense8[b]	WorldUp	Toolkit	$5,000	www.sense8.com
Sense8[b]	World2World	Toolkit		www.sense8.com

Note: [a] In US dollars, as of April 2000.
[b] Price of WorldToolKit and World2World range from $6,000 to $12,000 and $7,995 to $27,995, respectively, depending on the type of computer used. All sense8 software requires a maintenance contract, which is 6% of the list price.
[c] Price for MultiGen Creator is an approximation for the basic software package.

© Blackwell Publishers Ltd 2001

Figure 1: Spaceball 4000 FLX (Source: Image courtesy of Labtree)

Data gloves. These indicate the position of the fingers and hand, interact with the virtual environment, and signal commands to the computer through gestures (see Figure 2). Gloves typically have thin fiber optic sensors sewn into the cloth that bend and stretch when the fingers move (Biocca and Delaney 1995), and communicate finger movement to the computer. A position tracker, usually attached to the back of the wrist, monitors the position and orientation of the hand and can be used to create a 3D representation of the user's hand in the virtual environment. When the glove collides with an object, the computer can be signaled to lift it and move it. Gloves can also be designed to provide force and tactile feedback (discussed later). Finally, bodysuits or exoskeletons are available, which function similarly to the glove, but they track movement of the entire body and display a virtual body to which the users can relate.

Figure 2: CyberGlove (Source: Image courtesy of Virtual Technologies)

Figure 3: CrystalEyes (Source: Image courtesy of Stereographics)

Output devices. Output devices convey information from the computer to the user about the virtual environment. There are three groups of output devices: visual displays, haptic devices that convey force and tactile information to the user's body, and audio devices.

Regarding *visual displays*, virtual environments can be displayed and viewed by users in many different ways. Regardless of the display used, it must create realistic scenes that correspond to what the user would see as he or she navigates the virtual environment. Common methods are shutter glasses, head-mounted displays (HMD), binocular omni-orientation monitor (BOOM) systems, and cave automatic virtual environment (CAVE) systems. Shutter glasses create the 3D effect for some desktop virtual reality systems (see Figure 3). A 3D display monitor shows alternate right and left images at a fast rate and the shutter glasses alternately allow light to reach the eyes. When a left image appears on the display monitor, the shutter glasses receive a synchronizing signal from an infrared device placed on top of the monitor to shut the right lens and when a right image appears, the glasses are signaled to shut the left lens. The right and left images are fused together by the brain to produce the 3D image.

HMD present the virtual environment through a device mounted on the user's head that can resemble a helmet with a visor in front of the eyes or a scuba mask (see Figure 4). HMD contain a separate display for each eye so that each eye sees a different view of the same image. As with shutter glasses, these images are fused together by the brain to produce the 3D effect. HMD also have position trackers to signal to the computer the position of the head so that the view of the virtual environment can be updated to match the user's head movements. They may also have sound devices such as headphones or earphones.

© Blackwell Publishers Ltd 2001

Figure 4: HMD 800-35 (Source: Image courtesy of Fifth Dimension Technologies)

BOOM systems have become a popular alternative to HMD because users do not support the image display on their heads. Rather, the BOOM involves a viewer mounted on a stand, which the user holds to his or her face to view the virtual environment. The user can sit or stand, and moves the viewer using handles to observe different aspects of the virtual environment (see Figure 5 and Figure 6). In addition, the user can easily shift between the virtual and real environment because no equipment must be put on and taken off, as with HMD. Although motion may be slightly restricted due to the design of the BOOM, the quality of the graphics display is higher than HMD.

A CAVE system allows one or more users to be completely immersed in the virtual environment. Users enter a small room with large video projection walls, which are used to surround users on all sides with computer-generated images. Users wear shutter glasses to view the environment and a position tracker is mounted on the glasses to determine head position.

Haptic devices provide output from the computer to the user by simulating force and tactile feedback. Users can 'feel' force, tension, friction, pressure, temperature, and speed of

Figure 5: BOOM 3F (Source: Image courtesy of Fakespace Systems)

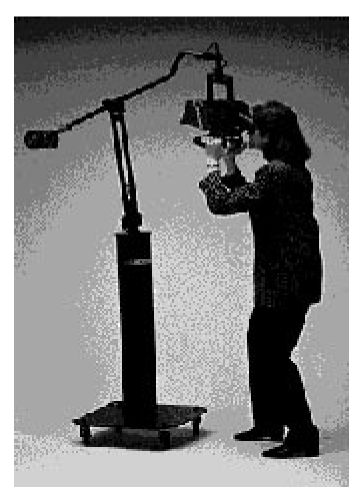

Figure 6: Boom 3C (Source: Image courtesy of Fakespace Systems)

© Blackwell Publishers Ltd 2001

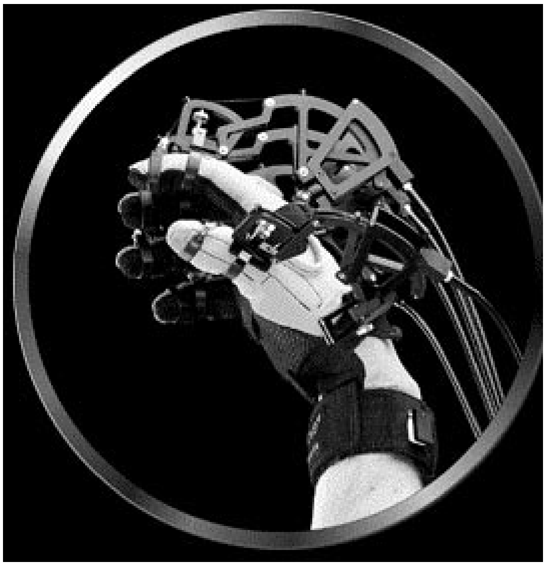

Figure 7: Cyberbrasp (Source: Image courtesy of Virtual Technologies)

Figure 8: CyberTouch (Source: Image courtesy of Virtual Technologies)

objects. Force feedback devices convey information about the resistance of surfaces (e.g., prevents users from walking through walls) and the gravity, weight, and solidity of objects. This feedback is provided through mechanisms such as joysticks, steering wheels, and handgrips. As mentioned earlier, gloves and exoskeletons or bodysuits can be designed to convey force feedback (see Figure 7).

Tactile feedback provides information about the surface and texture of objects in the virtual world. Many types of approaches can be used to communicate touch in the virtual environment. Pneumatic devices simulate touch by inflating and deflating air pockets, air jets, or air rings that are attached to gloves and touch the user's fingers. Vibro-tactile methods signal touch through vibration on the user's skin (see Figure 8). Electrotactile devices send pulses of electricity through electrodes touching the skin. Finally, functional neuromuscular devices directly stimulate the nervous system, but are rarely used because of their invasiveness.

Audio devices are not a necessary component of most virtual reality applications, but they enhance the reality of the experience and help create immersion by replacing sounds from the physical environment with sounds produced in the virtual environment. Headphones are usually built into head-mounted displays. Also, earplugs, which are lighter and less intrusive, can be used. Simple audio systems playback digitally recorded sounds into the user's headphones or through desktop speakers. Higher end systems use spatialization or 3D sound that creates the illusion of sound originating outside the user's head, coming from a particular location away from the user, or moving through the virtual environment (Kramer 1995).

Software

Software is needed to create, display, navigate, and interact with the virtual environment and to coordinate various components of hardware into a functional system. Because software is often application specific, only a general overview of two types of software is provided. For more information on particular software applications, readers are referred to the Websites of vendors listed in Table 1.

There are two types of virtual reality software packages, *toolkits* and *ready to run* or run time (Hitchner 1999). When users desire to customize software for specific applications, they can use toolkits. Toolkits are development tools that programmers can use to create virtual environments. Toolkits, like most software programs, use object-oriented design (OOD). OOD provides self-contained modules with information on how an object should look, behave, and interact with other objects. Toolkits consist of a large library of these object-oriented functions written in programming code (typically C++) and programmers must transform this code into virtual environments. Toolkits also use an Application Programmer's Interface, which enables programmers to prototype, develop, and reconfigure applications. Some toolkits have 3D modelers, which allow programmers to create their own model of the virtual environment while others import models or databases that were created by other applications or from a library provided by the software vendor.

Toolkits require experience with programming, but they give programmers complete control over how the virtual environment is designed and operates. However, if the ability to customize

© Blackwell Publishers Ltd 2001

software is not worth the added expense of hiring programmers to design and implement the software, ready to run software may be an alterative. This software can be used as soon as it is installed onto the computer. It can provide generic applications such as walk-through systems or specific applications like medical simulation. The model of the virtual environment is stored in a database in the software and used to define and describe virtual objects. No programming experience is necessary and ready to run software is usually reliable because vendors have used their expertise and experience to create the software and debug it. Some software packages include programmer's toolkits so that customized extensions can be added to the basic application.

Advantages and Disadvantages of Virtual Reality Technology

Virtual reality technology offers several benefits for users. First, it allows users to view objects in three dimensions versus two as with pictures. This shifts the experience from being on the outside looking in to the feeling of actually being there (Vince 1995). Further, it is difficult to evaluate objects presented in two dimensions because it is hard to determine size, shape, texture, and so forth. Thus, more information about objects is available when they are presented in three dimensions. Virtual reality is also useful for simulating inherently dangerous tasks (e.g., underground mining; Denby and Schofield 1999) or tasks involving expensive equipment (e.g., aircraft; Gunther-Mohr 1997). Users can practice hazardous tasks or simulate rare occurrences in a realistic environment without compromising their safety. Virtual reality is also helpful when objects do not exist (e.g., new products) or are hard to access. In sum, virtual environments enable users to make decisions and perform in a risk-free environment.

However, virtual reality is not without its drawbacks. Being immersed in virtual environments can lead to sopite syndrome, which includes symptoms such as eyestrain, blurred vision, headache, disorientation, balance disturbances, drowsiness, sweating, loss of appetite, nausea, and vomiting (Pierce and Aguinis 1997; Regan and Price 1994). Sopite syndrome is often caused by a delay between head movement and updating of computer-generated images in response to that movement (Wilson 1997). The greater the delay, the more likely it is that the user will experience some physical discomfort. Further, extended time in virtual environments can result in altered visual and visuomotor coordination, which can impair driving and other normal functions (Ellis 1995). These symptoms have not been observed with desktop systems.

Another barrier to the implementation of virtual reality may be its cost and lack of commercial availability. Indeed, virtual reality workstations used to range between US$50,000 and US$60,000, but these figures have recently been cut in half (Lewis 1997). For example, an immersive system, which includes software, data gloves, HMD, PC workstation, and position tracking system, can cost as little as US$31,835 (EON Reality, 2000). Likewise, desktop systems complete with software, shutter glasses, and PC workstation cost US$9,950 (EON Reality, 2000). Further evidence of the affordability of virtual reality is presented in Table 1, which lists prices of various hardware and software used in virtual reality systems.

A final criticism of the technology is its technical limitations. As stated earlier, there is a noticeable lag between the user's movement and the change of scenery in the virtual environment. In addition, graphics, including the virtual representation of the user, may appear cartoon-like. However, as the technology has become more affordable over the years, its quality has also improved, and continues to do so.

Some Virtual Reality Applications

Virtual reality has been used for many different applications in a variety of industries. The technology was originally used to train pilots in the military and is still commonly used for training military personnel. In addition to aircraft simulators for pilots, tank simulators have been developed to practice battle maneuvers (Baxter and Hepplewhite 1999). Virtual environments created for these simulators contain battle scenes complete with enemy fighters and the terrain of several countries. There are even warehouses in Kentucky and Germany housing military tank simulators that can be networked to practice fighting together or against each other (Pimentel and Teixeira 1995).

Virtual reality has also been used in medicine for medical therapy, patient education, disaster planning and casualty care, rehabilitation, and prototyping medical buildings (Zajtchuk and Satava 1997). Virtual reality is particularly useful for teaching and practicing medical procedures. Surgical simulators replicate the patient's body, organs, and bodily reactions to the surgeon's actions. Surgeons can practice a technique without endangering human lives and learn to handle anomalies and emergencies. Simulators can also be used to practice diagnosing patients by presenting a virtual body with particular symptoms. Finally, virtual reality has aided in the creation of new drugs by enabling scientists to work with organic molecules as if they were physically present (Pimentel and Teixeira 1995).

© Blackwell Publishers Ltd 2001

Another common application of virtual reality is design. Architects and engineers use the technology to visualize objects before they are built, which enhances the design process by being able to see how things fit together, thus eliminating physical models and design problems before production begins. With virtual reality, architects can wander through a building and get a feel for space and experiment with lighting, furnishings, and layout before it is constructed.

Finally, virtual reality is used in the entertainment industry to provide users with simulated games and experiences. Virtual reality became available to the public in the late 1980s and generated interest and media attention. The first vehicle-based system, Battletech, appeared in 1990 in Chicago. It enables two teams of seven users to drive separate tanks in a computer-generated, futuristic battlefield with the objective of destroying the other team's tank (Hawkins 1995). Another vehicle-based system, Fightertown, became available in 1992 in California. This system is a military flight simulator that allows six different users to fly separate aircraft over varying terrain (Hawkins 1995). Now, virtual reality systems are popular attractions in the USA at large shopping malls, Las Vegas casinos, and even at Disney World, which has a 40-seat simulator that takes visitors on a realistic space flight (Hawkins 1995).

Virtual Reality Applied to Personnel Selection

As described above, virtual reality has been used by the military to train pilots, by architects to aid in building design, by biochemists in the creation of new drugs, and by the entertainment industry, among other applications. In addition, it has been proposed as a research methodology in organizational behavior and related fields (see Pierce and Aguinis 1997, for a more detailed discussion). However, we conducted an extensive review of the personnel selection literature and application information published by virtual reality equipment vendors, and found practically no indication that virtual reality is used for personnel selection purposes. In fact, we found only one application, which involved a European Union-sponsored project labeled virtual adaptive testing (VAT). The VAT project included samples of applicants for power plant operator, police officer, and high-speed train driver positions in Germany, Italy, Spain, and Switzerland (Pamos 1999).

We argue that the merits of virtual reality for personnel selection should be investigated because virtual reality-based selection procedures may have advantages over more traditional selection techniques (e.g., paper-and-pencil questionnaires, employment interviews).

Reasons for Using Virtual Reality Technology for Personnel Selection Purposes

Applications of virtual reality may prove to be more valid than some traditional selection techniques because of the 'realism' that can be created in the testing procedures. That is, with virtual reality, the work environment stimuli can be presented with high fidelity. The more navigation, interaction and immersion (Vince 1998) that virtual reality applications include, the greater their fidelity. It has been argued that the higher the fidelity of a selection procedure, the more predictive of job performance the selection procedure will be (Asher and Sciarrino 1974; Wernimont and Campbell 1968). This assertion is based on the idea that the more a predictor and a criterion construct overlap, the stronger will be the relationship between the two constructs. In short, the realism that virtual reality can add to selection procedures may lead to higher levels of validity as compared to more traditional selection instruments.

In addition to the above potential advantages over more traditional selection tools, virtual reality technology also provides specific advantages *vis-à-vis* other simulation-based techniques (e.g., role-playing, in-basket exercises). First, virtual reality technology allows for higher levels of standardization and structure. Virtual environments are programmed such that every applicant is presented with a situation that is exactly identical to that presented to all other applicants. Other types of simulations (e.g., role-play) may lack this high degree of standardization. For instance, applicants may recognize non-verbal cues that a role-playing actor/administrator may not intend to convey. Moreover, these non-verbal cues conveyed by the simulation administrator may vary depending on various applicant characteristics (e.g., gender; Aguinis and Adams 1998). Standardization of test administration procedures allows the constructs of interest to be measured with greater precision (i.e., less error), which, in turn, results in greater validity.

Finally, virtual reality offers higher levels of flexibility as compared to other simulation-based assessment tools. In fact, virtual reality technology is limitless in terms of situations that could be simulated. Of course, technology may present some limitations. However, in general, virtual reality technology has the capacity, and greater flexibility, to simulate a greater range of situations and environments as compared to other simulation-based techniques.

In the following section we offer some potential applications of virtual reality to personnel selection. Specifically, we discuss a set of knowledge, skill, abilities, and other

© Blackwell Publishers Ltd 2001

characteristics (KSAOs) that we believe are particularly suitable, and have the greatest promise in terms of increased validity, to being assessed using virtual reality.

Illustrations of Potential Applications of Virtual Reality

As noted earlier, although the cost of virtual reality equipment has declined in recent years, mid- to high-end virtual reality equipment is still rather expensive for many organizations (cf. Table 1). Hence, in many cases, if virtual reality does not have advantages over other selection techniques, its overall utility will be lower because of the cost of equipment. It is important, therefore, that we identify specific areas for which virtual reality may provide advantages over traditional selection techniques designed to assess applicants' job-relevant knowledge, skills, abilities, and other characteristics. Table 2 includes illustrations of KSAOs, and positions for which these KSAOs are critical, as well as some of the traditional selection techniques used to assess them. In addition, Table 2 provides examples of potential virtual reality applications that may have advantages over the more traditional selection techniques.

Assessing Job Knowledge

Job knowledge is usually defined as information (conceptual, factual, or procedural) that is directly applicable to the performance of job-related tasks (Heneman, Heneman, and Judge 1997). For example, a civil building inspector must know what aspects of building design meet or violate codes and standards. Traditional approaches to assessing the job knowledge of an applicant for this position might include a required license or certification listed on a

Table 2: Illustrations of potential use of virtual reality to assess specific KSAOs vis-à-vis traditional techniques

KSAO/Position	Traditional selection technique	Virtual reality selection technique
Job Knowledge/Civil Building Inspector	Paper-and-pencil knowledge test; License or Certification listed on resumé/application	HMD: Move through virtual building and identify code violations
Skills/ Communication and Interpersonal/Manager	Assessment center in-basket	BOOM System: Interact with virtual subordinates
Handling of Hazardous Materials/Hazardous Materials Clean-up Team Member	Situational interview	HMD and Data Glove: Clean up hazardous materials at virtual accident scene
Abilities		
Cognitive: Visual-spatial/ Mechanical Engineer	Paper-and-pencil ability test	Desktop System: Manipulate 3D job relevant designs or models using 3D mouse
Psychomotor: Finger dexterity/Manufacturing Position	Purdue Pegboard	Desktop System and Data Glove: Manipulate small virtual objects
Physical: Strength and Stamina/Firefighter	Simulation/obstacle course	CAVE System: Carry equipment in virtual fire scene
Perceptual: Vision and Depth Perception/Bus Driver	Driving record background check	Seated BOOM or vehicle-based system: Drive bus in a variety of traffic conditions
Other Characteristics		
Conscientiousness and Integrity/Office Administration	Paper-and-pencil conscientiousness or overt integrity test	HMD and Joystick: Perform tasks in a virtual office or play virtual reality game

© Blackwell Publishers Ltd 2001

resumé or application blank, or perhaps the administration of a paper-and-pencil job knowledge test. The test might include pictures that the applicant has to examine to identify potential violations. But what if, instead of answering questions on a paper-and-pencil test or looking at pictures of buildings, the applicant moved through a virtual building and identified potential violations? A similar application has been suggested in testing mining industry workers' knowledge of work environment hazards (Denby and Schofield 1999).

HMD would work well for this application as they allow individuals to navigate in virtual environments. Having applicants actually move through a virtual building and identify code violations provides a sample of their knowledge in a high-fidelity work environment. Hence, we might expect that scores on the virtual reality selection test would be more valid than scores on a paper-and-pencil test. It may even be the case that performance on the virtual reality test would be more predictive of future performance because it would assess not only job knowledge, but also skill in applying knowledge on the job. A substantial increase in validity, relative to the cost of the equipment, would be a distinct advantage for this application of virtual reality over traditional selection techniques, such as a paper-and-pencil job knowledge test.

Assessing Job-relevant Skills

Skills are usually referred to as observable competencies to perform a particular task (Heneman *et al.* 1997). For example, interpersonal interaction is a necessary skill in jobs that have frequent contact with customers and co-workers. Individuals working on hazardous material clean-up teams must possess skills relevant to the careful clean-up and disposal of hazardous materials. It is important that these skills be accurately assessed in job applicants in order to determine whether they are likely to be successful on the job.

Work sample tests are frequently used to assess applicant skills. For example, the in-basket technique is often used in assessment centers to assess job-relevant communication and interpersonal skills. Applicants for a managerial position are presented with a series of written scenarios or videotaped scenes that describe work situations with customers, co-workers, or subordinates. The applicants are then asked to indicate how they would respond in the work situations. But what if applicants were to interact with virtual customers and co-workers in a virtual work setting viewed through a BOOM system? Perhaps the increased reality of the situation, relative to reading a written scenario or watching a video, would provide important information about how applicants are likely to behave in an actual work setting, above and beyond that which can be gained via traditional techniques. In fact, in situations where the virtual reality selection test is highly similar to the work environment, the virtual reality test could be used as a criterion measure. Scores on other predictor measures could then be correlated with the virtual reality test in order to identify valid predictor measures.

Another illustration of the potential use of virtual reality to assess skills is that HMD could be used to present job applicants with a realistic accident scene involving hazardous materials. Rather than asking situational-based interview questions about how an applicant might respond in a given emergency situation, applicants' behavior could be observed in a 'virtual emergency'. Data gloves could be used to manipulate hazardous materials in virtual environments complete with the sights, sounds, smells, and temperature extremes of a real accident scene. The same equipment could be used to present applicants for an emergency medical technician position with a virtual emergency involving injured persons and dangerous, damaged vehicles. These high-fidelity virtual emergencies could be created without incurring the cost of setting-up the scenes multiple times. Individuals' actions in the high-fidelity test situation may provide vital information about job-relevant skills not captured by traditional work sample tests or situation-based interview questions.

In addition to potentially being more valid predictors of performance, we propose that virtual reality applications have another advantage over traditional techniques used to assess job-relevant skills. Work sample data could be gathered in a realistic work setting without the physical dangers inherent in some situations. For example, passing vehicles or broken and dangerous machinery would present a real danger if modeled in a live testing situation. In virtual reality, however, dangerous situations could be presented to test relevant job skills and the danger would only be psychological, in terms of perceived risk or danger. Thus, virtual reality would reduce the risk of physical injury that exists in currently used tests and allow selection tests to be designed for situations that have thus far been considered too dangerous for selection practices. As an illustration, as noted above, the VAT project assessed the skills of applicants for high-risk positions including power plant operator, police officer, and high-speed train conductor.

Assessing Human Abilities

Human abilities are distinct from skills in that they are more stable over time. That is, skills can

© Blackwell Publishers Ltd 2001

be developed but, generally speaking, abilities are enduring individual traits (Heneman *et al.* 1997). Most human abilities can be classified into one of the following four categories: cognitive, psychomotor, physical, and perceptual (Fleishman and Quaintance 1984). We will treat the assessment of each of these abilities separately in examining what advantages virtual reality might offer over traditional instruments.

A variety of *cognitive ability* measures have been shown to be good predictors of future job performance (Pearlman, Schmidt and Hunter 1980). Two specific cognitive abilities that may be assessed well by virtual reality are visualization and spatial orientation. A paper-and-pencil test designed to assess these abilities is sometimes included in the battery of selection tests given to applicants for a mechanical engineer position. But what if, rather than a paper-and-pencil test, applicants were required to manipulate job-relevant designs or models on a virtual reality desktop? Virtual reality tasks involving the manipulation of three-dimensional objects might capture information about visual-spatial abilities not assessed with a paper-and-pencil test. The result, we believe, would be greater validity for the virtual reality application.

Another possible advantage of virtual reality over traditional paper-and-pencil cognitive ability tests is the potential for reduced adverse impact against minority groups. W + O psychologists have proposed several methods of addressing adverse impact in paper-and-pencil cognitive ability testing such as test score banding (e.g., Aguinis, Cortina and Goldberg 1998, 2000; Cascio, Outtz, Zedeck and Goldstein 1991). However, recent work by Chan and Schmitt (1997) suggests that non-paper-and-pencil methods of assessing cognitive abilities may result in smaller racial subgroup score differences. Additionally, they found that racial subgroup differences in face validity perceptions were smallest for a video-based test, as compared to a paper-and-pencil test. If the virtual reality cognitive ability measure reduces emphasis on reading and writing, as in Chan and Schmitt's video-based measure, the reduced racial subgroup difference findings may generalize to virtual reality testing.

Another category of human abilities that is assessed by selection tests includes *psychomotor abilities*. This category includes abilities that involve movement of body limbs and their components, such as reaction time, manual dexterity and finger dexterity. There are several psychomotor tests used in personnel selection to assess these abilities. One such test is the Purdue Pegboard (Tiffin 1968), which assesses, among other things, finger dexterity. The Purdue Pegboard measures finger dexterity by having examinees assemble a number of small metal pins and washers on a wooden board. Scores on the test reflect the number of properly assembled pieces within a time limit. Selection batteries for manufacturing jobs that require fine motor movements sometimes include psychomotor tests like the Purdue Pegboard.

However, using a virtual reality assembly task might increase the validity of a manufacturing selection battery. In a virtual reality test, applicants might complete a few assembly tasks on a virtual reality desktop. The virtual reality test might better assess finger dexterity because it could measure not only what the applicant did right, but also what was done wrong. On a virtual reality desktop, position trackers in a data glove can monitor the position of the hand. Position trackers could be used to indicate when a person touched something that should not have been touched, and could consider those data in the person's score. For example, the applicant might bump objects on the virtual desktop while performing the assembly task. It seems likely that finger dexterity would influence not only the number of objects correctly assembled, but also how precisely they were assembled. This is important information about finger dexterity that, when captured by a virtual reality test, may lead to higher test validity.

Physical abilities are the third group of human abilities. Strength and stamina are examples of physical abilities. Physical ability tests are used frequently when selecting firefighters. Both strength and stamina might be tested by having an applicant carry heavy equipment through an obstacle course. A large CAVE system might include stairs and multiple rooms, much like the obstacle courses used in firefighter physical ability tests. In addition, virtual hazards could be imposed in the CAVE, as well as real stimuli such as heat and the smells of burning materials. Perhaps physical performance under these virtual conditions would yield important predictive information about firefighter performance.

In addition to physical strength and stamina measures taken during a physical abilities test, physiological data could be gathered as well. Before donning firefighter equipment and entering the virtual fire scene, applicants might put on a bodysuit lined with electrodes that record pulse rate, breathing capacity, galvanic skin responses, and brain waves. All these measures, collected in a high-fidelity simulation, could provide additional valuable information about individuals' abilities to perform as firefighters. A final noted advantage is that the proposed virtual reality test, once again, has the advantage of only exposing applicants to 'virtual danger' during the selection tasks.

The fourth category of human abilities is *perceptual abilities*. Generally, this category

© Blackwell Publishers Ltd 2001

includes abilities related to detecting and recognizing environmental stimuli (Heneman *et al*. 1997). Vision and depth perception are examples of perceptual abilities. This classification of human abilities is currently assessed in virtual reality applications in the military, but not for selection purposes (Baxter and Hepplewhite 1999) (the VAT project is a notable exception). Perceptual abilities are very important for performance in flight simulators. As we noted earlier, flight simulators used to train military pilots were some of the earliest virtual reality products. It seems logical that, in addition to training applications, these simulations could be used for selection as well. For example, rather than checking the driving record of individuals applying for bus driver positions, applicants could take a driving test using a seated BOOM or a vehicle-based system. In addition to having applicants drive in heavy traffic or adverse weather conditions, the test could involve frequent stops to test depth perception and unexpected objects entering the roadway to test peripheral vision. Although a background check of applicants' driving record will aid in screening out candidates who are not likely to be successful, the high-fidelity virtual reality driving test would provide additional information about the likelihood that applicants would perform well as bus drivers.

Assessing 'Other Characteristics'

When an individual difference factor is important for job performance, but does not fit into any of the knowledge, skill, or abilities categories, it is often placed in the 'other characteristics' category. Heneman *et al*. (1997) included legal requirements, availability requirements (e.g., employment starting date), and character requirements as broad sub-dimensions of the 'other characteristics' category. Two of the character (i.e., personality) requirements, *conscientiousness* and *integrity*, are among the most frequently discussed 'other characteristics' in the personnel selection literature. Although paper-and-pencil conscientiousness measures have shown success in predicting job performance, virtual reality may be able to improve upon their predictive accuracy. Perhaps observation of behavior in a virtual office environment would provide additional diagnostic information about conscientiousness levels (e.g., handling equipment carelessly). Applicants could also be asked to play virtual reality games that involve opportunities for them to engage in risky activities. Elevated levels of risky behavior or a lack of impulse control in the virtual reality games could be predictive of future job performance or deviant workplace behavior (e.g., stealing or damaging company property). Creative options for assessing job-relevant personality factors will no doubt increase in the future. However, given the success of paper-and-pencil measures of conscientiousness and integrity in predicting job performance, virtual reality tests will need to prove their greater validity in convincing ways in order to provide advantages over the currently used tests.

We have outlined several potential advantages that virtual reality selection tests may have over more traditional selection practices. These advantages include increased validity and physical safety, and reduced racial subgroup differences in cognitive ability scores and face validity perceptions. The cost of virtual reality technology may still be a barrier to conducting widespread research on the application of virtual reality to personnel selection. However, as we noted earlier, the technology is rapidly becoming cost-effective. As the cost of virtual reality software and equipment continues to decline, realization of its potential validity will likely be the driving force behind research on applying this technology to personnel selection.

Potential Drawbacks to Using Virtual Reality for Personnel Selection

Although there seems to be great promise in using virtual reality for personnel selection, there are some potential drawbacks in implementing the technology. First, as previously mentioned, some individuals may experience negative physical effects (i.e., sopite syndrome) when heavily immersed in virtual reality environments. For job applicants, these potential negative effects are obvious barriers to performance in fully immersed environments. Given that many of the negative physical effects are caused by a delay between head movement and the updating of computer-generated images (Wilson 1997), perhaps as virtual reality technology continues to improve, these negative effects will be minimized. Until then, negative physical effects should be a concern in assessing the utility of virtual reality in personnel selection.

A second drawback to applying virtual reality technology to personnel selection is that many applicants will likely need to be familiarized with or even trained in using virtual reality technology. This will require additional investments of resources on the part of organizations because applicants are likely to be unfamiliar with virtual reality equipment. Much like team decision-making studies that first train subjects on how to operate computer simulations (e.g., Hollenbeck, Ilgen, Sego, Hedlund, Major and Phillips 1995), virtual reality

© Blackwell Publishers Ltd 2001

selection tests will likely require an initial exposure period where applicants are familiarized with the test. The initial exposure period would also provide an opportunity to assess whether applicants are likely to experience negative physical effects, as well as their willingness to immerse themselves in a virtual reality environment.

Our final concern is the importance of understanding what constructs will be measured by future virtual reality selection tests. Selection tests are designed to measure job-relevant KSAOs or samples of current performance. However, scores on virtual reality selection tests, regardless of their intended content, may assess the personality construct openness to experience. McCrae and Costa (1987) describe highly open individuals as imaginative, daring, and welcoming of fantasy, new ideas, feelings, and values. Given this description of openness to experience, it seems plausible that highly open individuals are likely to be more comfortable in a virtual reality environment than less open individuals, and thus potentially perform better. As virtual reality selection tests are developed, future research should investigate potential links between openness to experience and performance in virtual reality environments. If found, an empirically validated link between openness and virtual reality selection test scores would not necessarily be a drawback to the use of this technology for selection purposes. Openness to experience has been shown to be a job-relevant 'other characteristic' for certain jobs (e.g., Salgado 1997). In cases where openness is not job-relevant, perhaps the correlations between openness and performance in virtual reality environments would decrease after applicants had ample exposure to the technology. However, if the relationship persists for jobs in which openness is not job-relevant, consideration would need to be given to the possibility that personnel decisions about applicants could be made based on job-irrelevant information.

Conclusion

From its earliest beginnings as a virtual ride through New York, virtual reality has progressed to the point that users can now be fully immersed in virtual worlds and even interact with other individuals in virtual environments. Although high-end virtual reality technology is still rather costly for the average user, prices are becoming increasingly affordable. As the technology becomes even more affordable, it is likely that the use of virtual reality will move beyond training military and medical personnel. We propose that personnel selection is a setting where virtual reality may be successfully applied. In certain settings, virtual reality may indeed have a validity advantage over more traditional selection techniques. In this article, we proposed several virtual reality applications for assessing illustrative KSAOs.

The purpose of our article was to summarize the availability of current technology and highlight some of its potential applications in personnel selection. An overall conclusion is that there is no plausible reason that research on applications of virtual reality to personnel selection cannot move forward. The technology is becoming increasingly affordable and there is high potential for improving selection practices. Forming partnerships between test developers and researchers could lead to immediate advancement of our knowledge in this area.

Finally, we close by emphasizing that we are not providing a blanket endorsement of virtual reality for personnel selection. No selection technique should be used simply because of its novelty, popularity, or availability. However, we do advocate the formulation of research agendas concerning the potential utility of virtual reality personnel selection tests. If research reveals that a virtual reality application is less valid than other selection techniques, then it should not be advocated simply because of its availability. However, because little is known about potential applications, the world of potential connections between virtual reality technology and personnel selection is open to discovery. It is our hope that the present article will be a first step in this direction.

Acknowledgements

We thank Charles A. Pierce (Montana State University) for comments regarding the research reported herein.

References

Aguinis, H. and Adams, S.K.R. (1998) Social-role versus structural models of gender and influence use in organizations: A strong inference approach. *Group and Organization Management*, **23**, 414–446.

Aguinis, H., Cortina, J.M. and Goldberg, E. (1998) A new procedure for computing equivalence bands in personnel selection. *Human Performance*, **11**, 351–365.

Aguinis, H., Cortina, J.M. and Goldberg, E. (2000) A clarifying note on differences between the W.F. Cascio, J. Outtz, S. Zedeck, and I.L. Goldstein (1991) and H. Aguinis, J.M. Cortina, and E. Goldberg (1998) banding procedures. *Human Performance*, **13**, 199–204.

Asher, J.J. and Sciarrino, J.A. (1974) Realistic work

© Blackwell Publishers Ltd 2001

sample tests: A review. *Personnel Psychology*, **27**, 519–553.
Baxter, J. and Hepplewhite, R. (1999) Agents in tank battle simulations. *Communications of the ACM*, **42**, 74–75.
Biocca, F. and Delaney, B. (1995) Immersive virtual reality technology. In F. Biocca and M.R. Levy (eds.), *Communication in the Age of Virtual Reality* (pp. 57–124). Hillsdale, NJ: Lawrence Erlbaum.
Burdea, G. and Coiffet, P. (1994) *Virtual Reality Technology.* New York: John Wiley and Sons.
Cascio, W.F., Outtz, J., Zedeck, S. and Goldstein, I.L. (1991) Statistical implications of six methods of test score use in personnel selection. *Human Performance*, **4**, 233–264.
Chan, D. and Schmitt, N. (1997) Video-based versus paper-and-pencil method of assessment in situational judgment tests: Subgroup differences in test performance and face validity perceptions. *Journal of Applied Psychology*, **82**, 143–159.
Denby, B. and Schofield, D. (1999) Role of virtual reality in safety training of mine personnel. *Mining Engineering*, **51**, 59–64.
Ellis, S. R. (1995) Virtual environments and environmental instruments. In K. Carr and R. England (eds.), *Simulated and Virtual Realities* (pp. 11–51). London: Taylor and Francis.
EON Reality (2000) *Integrated Systems* (On-line). Available: http://www.eonreality.com/products/index_integrated_systems.html.
Fleishman, E.A. and Quaintance, M.A. (1984) *Taxonomies of Human Performance: The Description of Human Tasks*. Bethesda, MD: Management Research Institute.
Gunther-Mohr, C. (1997) Virtual reality training takes off. *Training and Development*, **51**, 47–48.
Hawkins, D.G. (1995) Virtual reality and passive simulators: The future of fun. In F. Biocca and M.R. Levy (eds.), *Communication in the Age of Virtual Reality* (pp. 159–189). Hillsdale, NJ: Lawrence Erlbaum.
Heneman, H.G., Heneman, R.L. and Judge, T.A. (1997*) Staffing Organizations* (2nd edn). Boston: Irwin McGraw-Hill.
Hitchner, L.E. (1999) *The Virtual Reality Software Report: Introduction* (On-line). Available: http://www.csc.calpoly.edu/˜hitchner/hitchner/intro.html.
Hollenbeck, J.R., Ilgen, D.R., Sego, D., Hedlund, J., Major, D.A. and Phillips, J. (1995) The multi-level theory of team decision-making: Decision performance in teams incorporating distributed expertise. *Journal of Applied Psychology*, **80**, 292–316.
Kramer, G. (1995) Sound and communication in virtual reality. In F. Biocca and M.R. Levy (eds.), *Communication in the Age of Virtual Reality* (pp. 259–276). Hillsdale, NJ: Lawrence Erlbaum.
Lewis, D. (1997) Will virtual reality become the standard in safety training? *Safety and Health*, **155**, 38–43.
McCrae, R.R. and Costa, P.T. (1987) Validation of the five-factor model of personality across instruments and observers. *Journal of Personality and Social Psychology*, **53**, 81–90.
Pamos, A. (1999) Virtual reality at a Power plan. In European VAT Consortium (ed.) (TEA Ediciones-Spain, OS-Italy, Hogrefe Verlag-Germany, GM-Italy), *VAT Handbook: Virtual Assisted Testing for High-risk Positions (Technical Report)*. Brussels, Belgium: Esprit Program, European Union.
Pearlman, K., Schmidt, F.L. and Hunter, J.E. (1980) Validity generalization results for tests used to predict job proficiency and training success in clerical occupations. *Journal of Applied Psychology*, **65**, 373–406.
Pierce, C.A. and Aguinis, H. (1997) Using virtual reality technology in organizational behavior research. *Journal of Organizational Behavior*, **18**, 407–410.
Pimentel, K. and Teixeira, K. (1995) *Virtual Reality Through the New Looking Glass* (2nd edn). New York: McGraw-Hill.
Regan, E.C. and Price, K.R. (1994) The frequency of occurrence and severity of side-effects of immersion virtual reality. *Aviation, Space, and Environmental Medicine*, **65**, 527–530.
Salgado, J.F. (1997) The five factor model of personality and job performance in the European community. *Journal of Applied Psychology*, **82**, 30–43.
Stuart, R. (1996) *The Design of Virtual Environments*. New York: McGraw-Hill.
Tiffin, J. (1968) *Purdue Pegboard Examiner's Manual*. Chicago, IL: Science Research Associates.
Vince, J. (1995) *Virtual Reality Systems*. Wokingham: Addison-Wesley.
Vince, J. (1998) *Essential Virtual Reality Fast*. London: Springer.
Wernimont, P.F. and Campbell, J.P. (1968) Signs, samples, and criteria. *Journal of Applied Psychology*, **52**, 372–376.
Wilson, P.N. (1997) Use of virtual reality computing in spatial learning research. In N. Foreman and R. Gillett (eds.), *A Handbook of Spatial Research Paradigms and Methodologies* (pp. 181–206). United Kingdom: Psychology Press.
Zajtchuk, R. and Satava, R.M. (1997) Medical applications of virtual reality. *Communications of the ACM*, **40**, 63–64.

© Blackwell Publishers Ltd 2001